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Minneapolis District Heating Options

T. K. Stovall
R. J. Borkowski
M. A. Karnitz
Sheldon Strom
Ken Linwick

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MINNEAPOLIS DISTRICT HEATING OPTIONS

T. K. Stovall, R. J. Borkowski, and M. A. Karnitz,
Oak Ridge National Laboratory;
Sheldon Strom, City of Minneapolis;
Ken Linwick, Minnegasco Energy Center

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
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FOREWORD

The Department of Energy and the Department of Housing and Urban Development (HUD) are jointly initiating a program to stimulate the development of district heating systems in a number of U.S. cities. The program is intended to promote district heating in combination with cogeneration and use of domestic fuels to conserve energy and save scarce fuels.

The creditability of modern district heating in this country requires that the steam systems be upgraded and expanded with hot-water systems to demonstrate their utility and economic viability. Prior to initiation of the anticipated program in 1980, HUD instructed the Oak Ridge National Laboratory (ORNL) to provide direct assistance for cities and utilities interested in rescuing their steam district systems. To do this, ORNL has formed a team to provide technical and financial advice for at least four cities with distressed systems. The laboratory will also prepare a written report on each city, which may then be used in applying for an Urban Development Action Grant from HUD, hiring an engineering firm, or taking other actions necessary to revitalize the district heating system.

ACKNOWLEDGMENT

The technical assistance rendered by Michael Barnes, a professional consultant, and Rolf Stoylen, assistant to the city energy office director, is recognized as an essential part of this document.

In appreciation for their gallant efforts, an acknowledgment of the diligent work of the Engineering Technology Division Word Processing Center is in order. Their rapid turnaround and meticulous workmanship permitted the timely completion of this manuscript.

Finally, a tribute goes to Mrs. Jamie Copeland for her secretarial assiduity and patience during this effort.

MINNEAPOLIS DISTRICT HEATING OPTIONS

T. K. Stovall M. A. Karnitz*
R. J. Borkowski Sheldon Strom†
Ken Linwick‡

ABSTRACT

A study was undertaken to determine the feasibility of a large-scale district heating system for the Minneapolis Central City area. The analysis was based on a previous city of St. Paul hot-water district heating study and other studies done by a Swedish engineering firm, Studsvik Energiteknik A.B. Capital costs such as building and heat source conversion, pipeline construction, and equipment were used in comparing the projected expenses of various district heating scenarios. Options such as coal, refuse-derived fuel burning, and cogeneration at the Riverside Power Station were discussed as energy supplies for a cost-effective district heating system.

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1. BACKGROUND

1.1 Executive Summary

1.1.1 Introduction

This study analyzes a number of options for expansion of district heating in Minneapolis and recommends to city decisionmakers those options that most effectively meet the city's short- and long-term needs. The study concludes that Minneapolis can and should play an active role in expanding the use of district heating by assisting in development of a steam line linking the downtown district heating system to the Northern States Power (NSP) Riverside Power Plant. This steam line is regarded as an interim step to the development of a comprehensive hot-water district heating system that could ultimately serve the entire Twin Cities area. By developing a number of "hot-water heat islands" (HWHIs) concurrent with development of the steam line, the city can ultimately

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*Energy Division.

†City of Minneapolis.

‡Minnegasco Energy Center.

achieve the goal of a major hot-water system while minimizing public expense.

District heating began in the United States in the late 1800s and provided low-cost thermal energy for numerous towns and cities for many years. A number of these systems are still in operation, though aged and outdated equipment has led to the decline of most U.S. systems. With the rapid increase in the price of natural gas and fuel oil, and uncertainty about the availability of oil, district heating is once again rising to prominence as a major tool in addressing the energy problem.

In spite of the efficiency and other advantages of district heating, the revitalization of district heating in the United States is complicated by a number of factors, including the following:

1. High capital costs. District heating is very capital intensive. Because many district heating systems have been allowed to deteriorate for many years, the initial capital requirement for system improvements and new construction may be prohibitive in some areas.
2. Steam vs hot-water systems. Most district heating systems in the United States are steam systems. Many of these systems have no condensate return, thus throwing away valuable thermal energy and treated water. In Europe, hot-water systems have been developed since the early 1950s and have two major advantages over steam systems: (1) Hot-water systems can become very widespread, serving entire cities or metropolitan areas, and therefore have the technical flexibility to change as the community changes. Steam systems are limited to relatively small areas of high load densities such as the downtown area. (2) Hot-water systems can be used more effectively in a cogeneration system because they have less impact on electrical power production than steam systems.
3. Building conversion costs. Perhaps the most significant obstacle to the immediate development of hot-water district heating in the Twin Cities is the very high cost of converting building heating systems from steam to hot water. Building conversion costs for a large hot-water heating system in downtown Minneapolis are prohibitive because a large portion of the thermal load consists of buildings with steam distribution systems.

4. <u>Abundance and relative low cost of natural gas</u>. Though natural gas prices have been rising rapidly, natural gas prices in the United States are still relatively low compared with oil and are a real bargain compared with the high cost of imported oil in Europe. District heating is much more cost effective in Europe because the competing fuels are scarce, very costly, and imported. Although everyone acknowledges that natural gas and oil prices will rise rapidly in the United States, uncertainty exists as to the exact rate of this rise. This uncertainty can present real problems to a district heating system in its early stages when cash flows are frequently marginal. For example, if natural gas prices flatten out even for a few years, many customers may not link up to a district heating system, thus leaving fewer customers to share the high capital costs.
5. <u>Institutional barriers</u>. In contrast to Europe, power and authority in U.S. cities are much more fragmented and are shared by a variety of public and private institutions and organizations. To implement a large "European Style" district heating system, these institutions must be brought together to a common focus. This situation presents very complex legal and political problems.

Because of the difficulties imposed by these factors, the feasibility of district heating in a particular city must be carefully and thoroughly analyzed. Minneapolis and St. Paul are fortunate in that a major feasibility study for the Twin Cities was completed in 1979. This study, which was completed under the sponsorship of the Department of Energy (DOE), was done by Studsvik Energiteknik AB, a well-known Swedish firm with extensive experience in hot-water district heating systems. This study indicated that a major hot-water system linking Minneapolis and St. Paul was indeed technically feasible. The Studsvik study estimated that over a period of 20 years or more, a district heating system of ~2600 MW could be developed. This system would save the equivalent of about 31 million barrels of oil during the first 20 years of operation.

For Minneapolis, the Studsvik study recommended retaining the existing downtown steam system and using hot water for all expansion outside the system. It recommended that expansion within the geographic boundaries of the steam system (at that time an 80-MW system) be connected to the existing steam system.

This present study builds on the Studsvik study and examines what specific steps Minneapolis can and should take to expand the use of a district heating system in a manner compatible with the recommendations of the Studsvik report.

Note that two factors have developed since the Studsvik recommendations were made. First, the downtown steam system has doubled in size from 80 to 160 MW. Second, recent detailed analysis shows that the cost of converting building distribution systems from steam to hot water for service by a hot-water district heating system are much higher than those estimated by the original Studsvik study.

1.1.2 Options analyzed

This study examines a variety of options for district heating expansion in Minneapolis. All of these options are related to the basic question of when and how the existing downtown steam system is to be integrated with a hot-water system. The options examined by this study with a summary of each option are as follows:

1. Incremental steam system expansion. The existing downtown district heating system has experienced rapid growth because of the large amount of new development. The system can continue to grow as development occurs without any direction from the city. This growth will be limited by fuel availability and increasing costs and energy losses as steam is piped. Because of this lack of direction, the city will be unable to use the district heating system as a development tool to provide an increase in the tax base and local employment. A district heating system, fueled by a relatively low-cost fuel such as coal, could provide stable prices for abundant energy. This stability could attract development to provide a growing tax base and more jobs for Minneapolis citizens. Without the city's involvement, this fuel substitution will be difficult to achieve.
2. Immediate conversion of the steam system to hot water. This option may appear at first glance to be an obvious first step if the ultimate goal is to develop a hot-water system for the entire metropolitan area. However, this is not the case. Conversion of the existing

steam system to hot water, at a cost of about \$8.7 million, will only work if all buildings with steam distribution in the system are also converted to hot water at an additional cost of about \$20 million. The downtown system would then be converted to hot water but would still be burning natural gas and fuel oil. Because the system already uses condensate return, the efficiency improvement of the hot-water system would be small. If the system were then linked to the Riverside Power Plant (at a cost of about \$20 million), it could then be fueled by coal. This is not a significant advantage over steam, as the same effect could be achieved with a steam line. To truly realize the advantages of hot water, the Riverside Power Plant would have to be adapted to cogeneration at a cost of at least \$9 million. This complete hot-water option would save the equivalent of about 38×10^6 liters (10 million gal) of oil annually, although some additional coal would be burned. At this point, the system could conveniently incorporate all additional *new* buildings, as these buildings would have hot-water heating systems. However, the bulk of additional downtown load is in older buildings that use steam, not hot water. Whereas slightly over 50% of the load on the existing steam district heating system is hot-water buildings, outside the existing system about 80% of the load is steam distribution buildings. Thus, building conversion costs become much more significant for buildings not already served by the existing district heating system.

3. Hot-water heat islands built up around the existing steam system. All major new commercial, residential, and industrial developments (wherever possible) should consider the use of heating systems compatible with hot-water district heating. The city should encourage the remodeling of existing steam building systems and their conversion to hot water. Large groups of hot-water buildings (heat islands) can initially be served by the steam system through centrally located heat exchangers (which transfer heat from steam to hot water) and hot-water distribution systems. The hot-water distribution system can be fueled on an interim basis by gas- and oil-fired boilers. Ultimately, these HWHIs could be linked to the overall district heating system.

The steam line (based on coal) can be used as a tool for the development of hot-water load, which will then expedite the development of a comprehensive hot-water system.

4. <u>Steam line to Riverside Power Plant</u>. This option would initially save the equivalent of almost 38×10^6 liters (10 million gal) of oil annually, although coal burning at Riverside would increase. Initially, under this option interruptible steam, which would serve ~90% of the annual district heating load, would be supplied by NSP. At times of peak electrical use, the existing Minnegasco Energy Center (MEC) gas- and oil-fired boilers would provide the remaining 10% of the annual load. A district heating system fueled by coal could provide abundant energy at relatively stable prices to existing buildings. This stable, secure energy source could serve as a major incentive for additional commercial, industrial, and residential development. As additional hot-water loads are developed, a parallel hot-water line could be run to Riverside making use of the same right-of-way, thus becoming a major element of the metro-area hot-water system as proposed by Studsvik.

5. <u>Solid waste and refuse-derived fuel (RDF)</u>. Because Hennepin County generates an average of 6.35×10^8 kg (700,000 tons) of municipal solid waste per year, this local potential energy source, equivalent to 207×10^6 liters (1.3 million barrels) of oil, is being investigated by Hennepin County. Possibilities for harnessing the energy source could include: (1) the use of processed solid-waste fuel in existing utility boilers as found at the Riverside plant, (2) smaller, modular, self-contained solid-waste fuel combustion plants, and (3) a new solid-waste fired boiler plant downtown. All of these options could supply steam to the district heating system and electricity to NSP. Conservation of nonrenewable oil and gas would not be the only benefit derived from burning refuse. Reclamation of glass, iron, and other salvageable materials could be other economical steps in processing the refuse for fuel. The need for landfill areas would be greatly diminished, and these areas could be more easily managed. Refuse that is potentially valuable, in terms of materials and energy, should not be buried without serious consideration of the alternatives.

1.1.3 Summary of recommendations

Because of the limited scope of this study, more detailed analysis and design work must be completed before any of the study recommendations can be implemented. This extended analysis should include an extensive buildings survey (to determine the existing heating system types and distribution) and an evaluation of life-cycle costs. The study concludes that Minneapolis should play an active role in the development of a steam line linking the downtown district heating system to the Riverside Power Plant and concurrently develop a number of HWHIs. To implement these recommendations, the city should initiate the following activities:

1. Creation of a public/private task force. The city should create a district heating task force with major representation from the private sector. The task force should include, but not be limited to, the following representatives:
   a. user groups,
   b. Building Owners & Managers Association (BOMA),
   c. Downtown Council,
   d. chamber of commerce,
   e. MEC,
   f. NSP,
   g. Hennepin County, and
   h. Minneapolis.

   This task force should develop an implementation plan and timetable for the development of the steam line and HWHIs. Extensive consulting services will probably be required to effectively plan and implement these proposals.
2. Modification of city zoning and building code. Based on direction from the task force, the city should modify its zoning and building code or other appropriate regulations to encourage the use of heat systems compatible with hot-water district heating.
3. Development of a UDAG. In spite of recent cutbacks in the federal budget, the city should submit an Urban Development Action Grant (UDAG) application for assistance in funding the steam line and HWHIs. Minneapolis can be in an excellent position for a UDAG, if extensive

involvement can be obtained from the private sector. In applying for a UDAG, special emphasis should be placed on the HWHIs, especially those that benefit low- and moderate-income people such as those who live in Elliot Park.

4. Solicitation of other funding sources. Because district heating is so capital intensive, funding must be obtained at the lowest possible interest rate. Based on direction from the task force, the city should attempt to obtain funding from state bonds, city revenue bonds, and a variety of other funding sources.

1.2 General Introduction to District Heating

1.2.1 District heating background and current status

Our society places a high priority on the heating of buildings and homes and demands that space-heating energy be available at a stable price. Currently, space and water heating combined account for about 20% of the total U.S. demand. Over 90% of these requirements are supplied by oil and natural gas, fuels that are subject to rapid price escalation. In addition, our increasing dependence on foreign oil threatens our national security and economic stability and adds significantly to the U.S. international trade deficit. District heating, which can use alternate domestic fuels, can result in stabler prices and greater national self-sufficiency.

District heating is a process in which thermal energy from a central source is distributed to commercial, industrial, and residential consumers for space heating and domestic hot-water needs. The heat energy is distributed from a central plant to individual buildings by either steam or hot-water pipelines. Buildings connected to the district heating system extract thermal energy from the system rather than use fuel directly in boilers or furnaces located in each building. Plants can be built for a district heating system that can use a variety of available domestic fuels including coal, nuclear energy, and refuse. Thermal energy can also be supplied by industrial waste heat, solar energy, and geothermal sources.

The Department of Housing and Urban Development (HUD) and DOE are jointly initiating a program to stimulate the development of district heating systems in a number of U.S. cities. Both departments recognize that modern forms of district heating can bring about major social, economic, environmental, and energy benefits to many U.S. cities. Analytical investigations indicate that district heating is a viable concept capable of serving the thermal energy needs of a significant portion of the country. From a national energy perspective, district heating appears to be the most practical alternative for converting the existing heating systems of a vast number of urban based buildings to more plentiful domestic fuels and renewable energy resources.

Recognizing the need to conserve scarce fuels, reduce the importation of foreign oil, and provide a means for upgrading and assisting in the restoration of existing cities, HUD has instructed the Oak Ridge National Laboratory (ORNL) to provide direct assistance to cities and utilities interested in rescuing their existing district heating systems. The restoration of district heating systems is viewed by HUD as a strategy for revitalizing many distressed urban areas. District heating offers long-range potential for supplying the energy needs of commercial and retail establishments, thus maintaining the value and desirability of existing buildings in metropolitan areas. District heating also offers the advantages of providing the urban business community with a competitive edge of space-heating utility rates. With the expectation of ever increasing energy costs and uncertain fuel supplies, a viable and economically competitive district heating system could draw commercial businesses back to urban core areas with a minimum of physical disruption and change to the central cities. Cheap oil and gas helped to displace district heating, but rapidly increasing oil and gas prices may bring it back into favor.

U.S. district heating history. District heating is not a new technology. The concept was first used in Lockport, New York, over 100 years ago. The first systems were designed around heat-only boilers that supplied steam for space heating. During the early part of the 20th century, the first small cogeneration district heating plants came into existence. These systems used the exhaust steam from small dual-purpose power plants to heat buildings in nearby business districts. As a result, district heating combined with cogeneration was widely accepted. During the late

1940s, however, the introduction of inexpensive oil and natural gas for space heating reduced the rapid growth of district heating. At about the same time, utilities were introducing large condensing electric power plants located remote from the urban areas. It was not economical to transport steam over such long distances. As the smaller, older cogeneration units were retired, sources for the district heating system steam were eliminated and the costs of supplying steam escalated, making district heating even less attractive.

Many U.S. steam district heating businesses were not profitable because of such factors as inadequate rates or the lack of proper metering devices. For example, as the costs increased during the transition from the use of exhaust steam to prime steam, rates were kept low by regulation. As a result, utilities shut down many small district heating systems because they were not profitable. Current statistics from the International District Heating Association show total annual utility steam sales of 8.44×10^7 GJ (80×10^{12} Btu). It is estimated that nonutility district heating systems (government institutions and college campuses) use a total quantity of steam about equal to that of utilities. District heating thus satisfies less than 1% of the demand for heating in the United States.

In addition to the MEC in Minneapolis, one of the remaining successful U.S. steam district heating businesses is in Milwaukee, Wisconsin, where Wisconsin Electric owns and operates a steam system that dates back to the turn of the century. The company has continually made investments to maintain and improve the system. The Wisconsin Electric system is profitable and at the same time sells thermal energy 20 to 25% lower than the most competitive space heating options (natural gas). Steam energy is presently being sold to consumers in the range of \$3.80 to \$4.70/GJ (\$4 to \$5/10^6 Btu).

The Milwaukee system serves an area of ~5.2 km^2 (~2 mi^2) in the heart of the city. Of three cogeneration units that supply thermal energy to the system, the largest is a coal-fired unit. It was completed in 1968 and has a capacity of 280 MW(e) and 470 MW(t) (1.6×10^9 Btu/h). This fuel flexibility feature is the single most important advantage of the concept of district heating. It allows the opportunity for competitive space-heating energy prices. The Milwaukee system is a good example of how the United States can utilize its more plentiful fuels (in this case coal) for space heating.

European district heating history. The history of district heating in Europe is somewhat different from that in the United States. The development of district heating networks in northern and eastern Europe started in the late 1940s. Hot water, rather than steam, was used as a transport medium, and for large systems hot water has proved to be the more economical of the two. European systems tend to have larger service areas than those in the United States. They serve lower heat-load density regions and use remotely located cogeneration power plants. The aggregated annual growth rate of district heating in these countries is about 20%/year.

The dramatic surge in the use of district heating in Europe has occurred in the last 25 years. Figures 1 and 2 show this growth from 1960 to 1975. As can be seen, the district heating capacity of the Federal Republic of Germany has more than quadrupled between 1960 and 1975 from 5,000 to over 20,000 MW. In eastern Europe, the Czechoslovakian district heating capacity rose from less than 5,000 MW in 1965 to ~35,000 MW in 1975.

Sweden, a country with a population of 8.1 million, has been one of the leaders in the development of modern district heating systems. Approximately 3 million Swedes live or work in premises served by district heating. About 40% of the total energy consumed in Sweden is for space heating, and at present more than 25% of the heat demand is supplied by district heating. The country has an installed capacity of 12,000 MW(t) and by the year 2000 expects an installed capacity of 30,000 MW(t). A rough estimate of the potential for district heating in the United States can be made by multiplying the Swedish numbers by a factor of 10. This factor is based on segmenting our northern tier areas into 10 regions roughly the size of Sweden. All of the larger Swedish systems used cogeneration (producing both heat and electricity) power stations that operate at high thermal efficiencies and contribute to the country's fuel conservation effort.

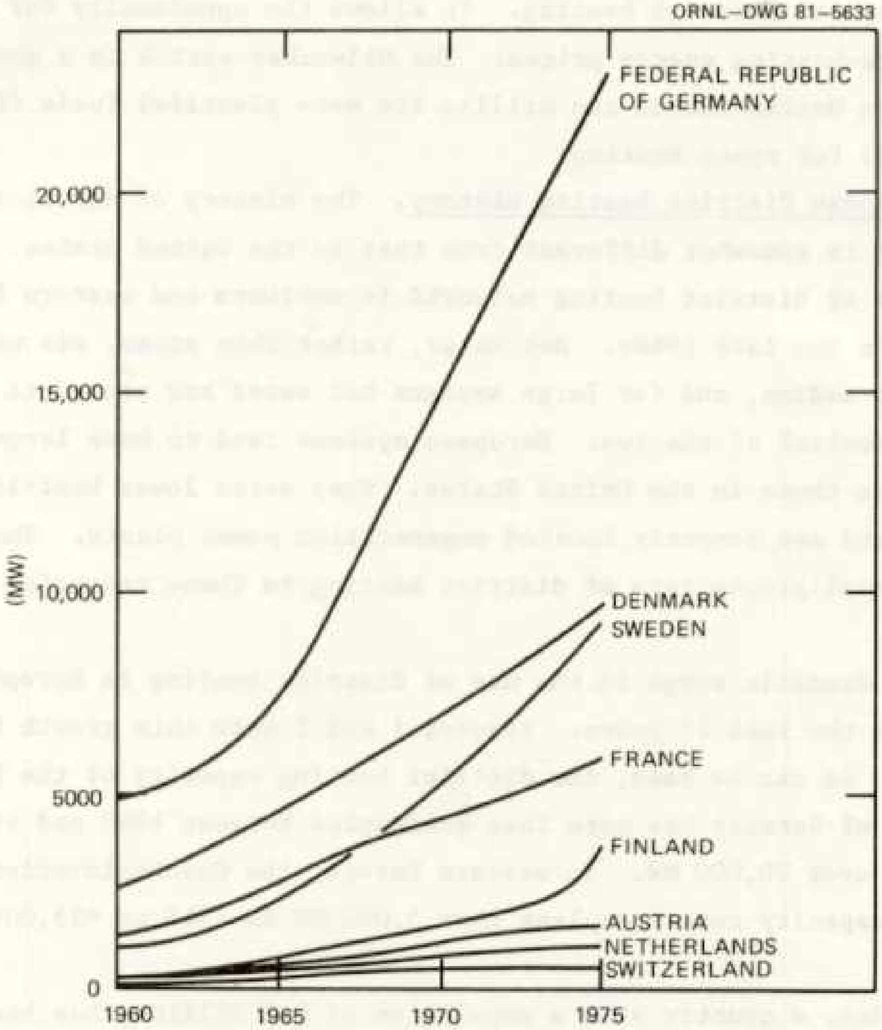

Fig. 1. Development of connected thermal capacity (western Europe). Source: Volker Scholten and Manfred Timm, "Survey of Existing District Heating," *Nuclear Technology* 38 (Mid-April 1978):179. Used with the permission of *Nuclear Technology*.

An example of a modern hot-water district heating system is the city of Uppsala, which has a population of 110,000. Uppsala, a university city 40 miles north of Stockholm, started district heating in the beginning of the 1960s. The city dates back to the 12th century, and many problems had to be solved before introducing district heating in such an old city. A parliamentary committee of politicians and technicians studied the system feasibility for Uppsala. The study results showed that during the next 10 years Uppsala would have a large heating load with a heating density even

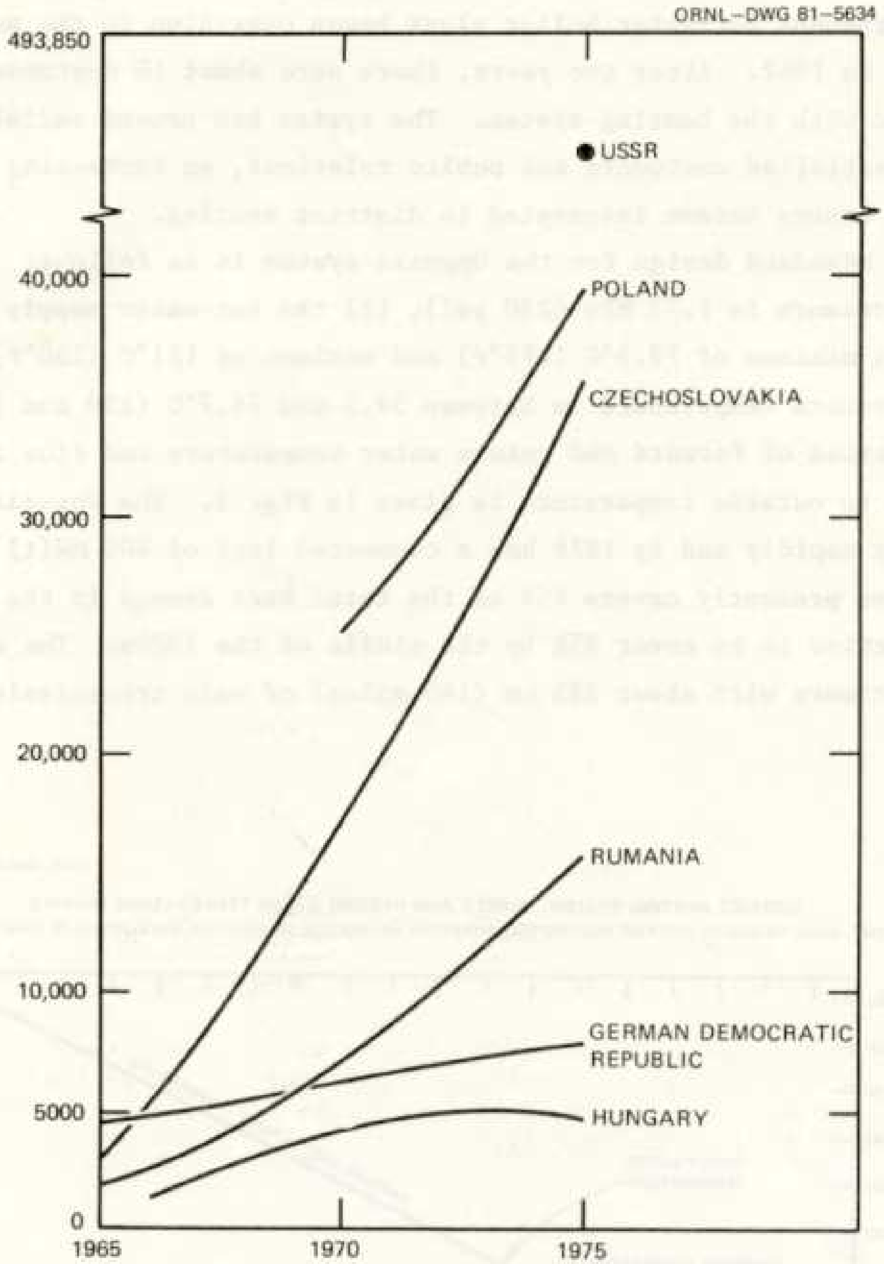

Fig. 2. Development of connected thermal capacity (eastern Europe). Source: Volker Scholten and Manfred Timm, "Survey of Existing District Heating," *Nuclear Technology* 38 (Mid-April 1978):180. Used with the permission of *Nuclear Technology*.

higher than other Swedish towns that had successful district heating systems.

In 1961, the first district heating service (made from transportable boilers) was initiated for a new building in the middle of Uppsala. The first permanent hot-water boiler plant began operation in the new part of the city in 1962. After two years, there were about 10 customers, all satisfied with the heating system. The system had proved reliable, and through satisfied customers and public relations, an increasing number of building owners became interested in district heating.

The standard design for the Uppsala system is as follows: (1) the system pressure is 1.72 MPa (250 psi), (2) the hot-water supply temperature is a minimum of 79.5°C (175°F) and maximum of 121°C (250°F), and (3) the return temperature is between 54.5 and 76.7°C (130 and 170°F). The variation of forward and return water temperature and flow in relationship to outside temperature is given in Fig. 3. The Uppsala system grew very rapidly and by 1978 had a connected load of 800 MW(t) (Fig. 4). The system presently covers 75% of the total heat demand in the area, and the objective is to cover 95% by the middle of the 1980s. The system has 4000 customers with about 225 km (140 miles) of main transmission line.

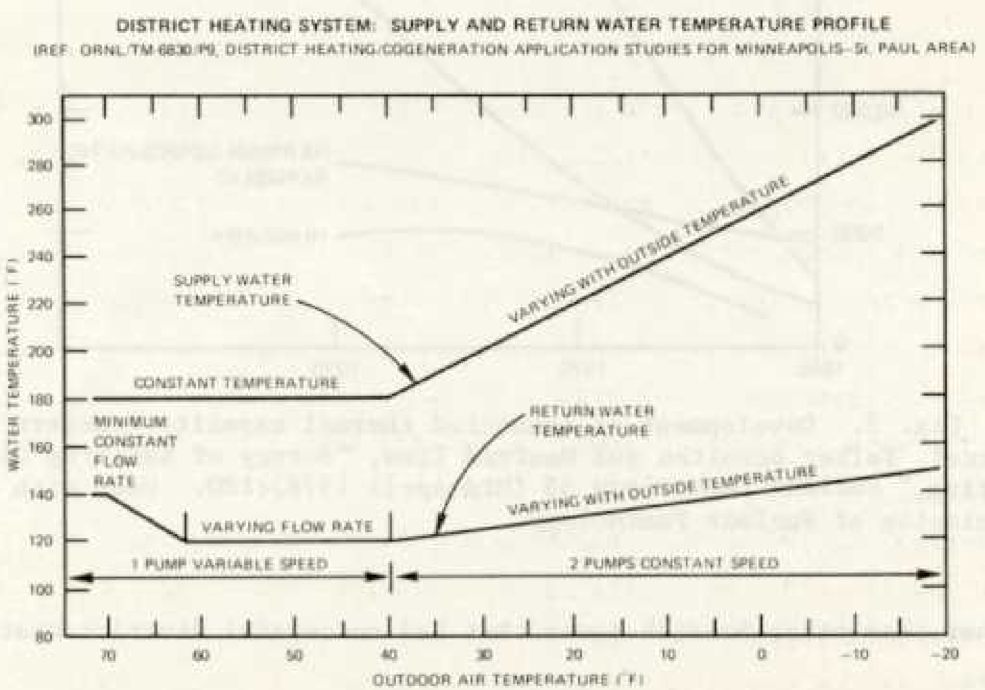

Fig. 3. Relation of temperature to flow rate of district heating system.

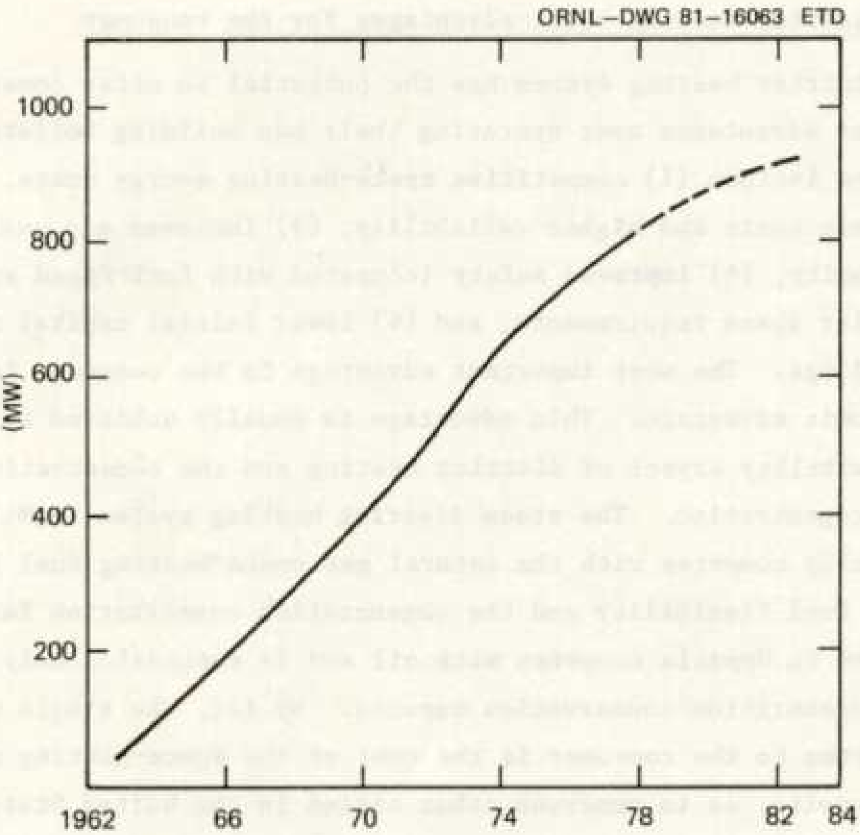

Fig. 4. Connected heat-load growth for Uppsala.

In 1974, a cogeneration plant was put into operation. The plant can deliver 200 MW(t) of electricity and 340 MW(t) of hot-water energy simultaneously. The Uppsala cogeneration plant uses oil. However, the Uppsala system is a modern efficient distribution system (~90% efficient), and the consumer's main alternative is also imported oil. The conservation effect (due to cogeneration) of the district heating systems allows the utility to sell the space-heating energy at a much lower price than the price at which the consumer could produce the energy through an individual boiler-only plant.

A total of $95 million had been spent on the district heating system by the end of 1978. The system's main problem is its dependence on oil. To lessen this dependence, the feasibility of burning wood in a new hot-water boiler and using heat from a nuclear plant 44 miles north of Uppsala is being investigated. The fuel flexibility advantage of district heating allows these options to be considered.

1.2.2 District heating — the advantages for the consumer

A district heating system has the potential to offer consumers many major advantages over operating their own building boilers. The advantages include (1) competitive space-heating energy costs, (2) lower maintenance costs and higher reliability, (3) improved air quality in the community, (4) improved safety (compared with fuel-fired systems), (5) smaller space requirements, and (6) lower initial capital costs for new buildings. The most important advantage to the consumer is clearly the economic advantage. This advantage is usually achieved through the fuel flexibility aspect of district heating and the conservation potential of cogeneration. The steam district heating system in Milwaukee successfully competes with the natural gas space-heating fuel by using both the fuel flexibility and the cogeneration conservation features. The system in Uppsala competes with oil and is successful only because of the cogeneration conservation aspects. By far, the single most important item to the consumer is the cost of the space-heating energy. In Minneapolis, as in numerous other cities in the United States, natural gas is the only alternative to district heating. The only way that a district heating system can compete is through the fuel flexibility feature available to district heating systems, which implies the need to use a relatively inexpensive fuel such as coal.

Another consumer advantage is the lower maintenance cost and high reliability. These advantages are a result of the simplicity of the consumer's equipment. The main component of this equipment is a series of heat exchangers that are similar to car radiators. The heat exchangers seldom need maintenance and in addition, no boiler operator is needed. Therefore, the simplicity of the building equipment results in higher reliability and lower consumer maintenance costs.

The district heating system also has the potential for improving air quality in a community. Emissions from one stack at a central power plant replace emissions from many low-level space-heating stacks, and more effective controls can be put on the central stack than on the many low-level stacks. However, the overall effect of district heating on air quality depends to a large extent on the type of fuels being replaced in the individual units.

The developers of new buildings that connect directly to a district heating system have lower capital costs because the cost of a heat exchanger is much lower than that of a boiler. Also, additional floor space results, because a boiler room is not required. Consumer advantages are summarized below:

1. competitive space-heating energy costs,
   a. fuel flexibility,
   b. cogeneration/conservation;
2. lower maintenance costs and higher reliability for consumers;
3. improved air quality in the community; and
4. lower capital costs for new buildings.

1.2.3 Steam vs hot-water district heating

A hot-water district heating system has many advantages over a steam system. A hot-water system has lower energy transport costs that result in more economical distribution over large distances than is typical for steam systems. Thermal energy transported by steam is limited to a maximum distance of about 8 km (5 miles), whereas a hot-water system can transport energy economically and with low energy losses for up to 80 km (50 miles). Another significant advantage is that in a cogeneration system hot water can be produced more cheaply than steam. A modified or new cogeneration plant does not sacrifice as much electricity when producing hot water as when producing steam for a district heating system. The hot water temperatures range from 82 to 150°C (180 to 300°F). The lower electricity sacrifice means lower thermal energy costs. Also, a hot-water distribution system is more flexible than a steam system. Hot water from various sources can be used, and new pumping stations can be added to extend the system. As a result, a hot-water system is more adaptable to meeting the changing needs of a community.

The majority of modern buildings are now constructed with internal hot-water or hydronic distribution systems. These systems allow for more effective control of the heating system and do so with considerably less noise. The most modern heating and ventilation systems are compatible with the hot-water district heating system. Of course these buildings could also be heated with a steam district heating system, but energy losses are incurred in the use of pressure-reducing equipment.

For these reasons a hot-water district heating system should be considered whenever an existing steam system is due for replacement or when an existing steam district heating system is being expanded beyond the current system boundaries.

1.2.4 UDAG

The UDAG program was created by the Housing and Community Development Act of 1977 (P.L.95–128) to provide grants for "severely distressed cities and urban counties to help alleviate physical and economic deterioration." The UDAG program was designed to improve the physical condition of cities by (1) assisting in the redevelopment of underused property; (2) building or rehabilitating housing, factories, offices, and stores; and (3) building access roads, sewers, and utility facilities.

A significant difference between the action grant and earlier federal urban redevelopment programs is the necessity for firm financial commitments from the private sector. The program is not intended to supplant private capital but rather to make otherwise economically unattractive projects desirable for private investment. An underlying goal of the program is to support projects that improve the economic climate in order to favor further private investment in an area.

Major advantages of the UDAG program are inherent flexibility and an expeditious review process. Funds are awarded to local governments, which can then lend or grant them to private or municipal developers. Flexibility in management of funds is designed to promote stronger working relationships between the local government, the commercial and industrial sectors, and the public in overcoming development problems.

The assurance of a rapid review process is the other positive aspect of the program. Applicants can reasonably expect a decision on their proposal within two months of its submission. The review process is further enhanced by having four separate dates each year for filing applications. The annual schedule for the application process is presented in Table 1 for metropolitan and small cities.

Table 1. Calendar of the application process for UDAG programs (1981)

Submission dates[a]	Application period	Review period	Decision date
Metropolitan cities			
Nov. 30	Jan. 1–31	Feb. 1–Mar. 31	Mar. 31
Feb. 28	Apr. 1–30	May 1–June 30	June 30
May 31	July 1–31	Aug. 1–Sept. 30	Sept. 30
Aug. 31	Oct. 1–31	Nov. 1–Dec. 31	Dec. 31
Small cities			
Dec. 31	Feb. 1–28	Mar. 1–Apr. 30	Apr. 30
Mar. 31	May 1–31	June 1–July 31	July 31
June 30	Aug. 1–31	Sept. 1–Oct. 31	Oct. 31
Sept. 30	Nov. 1–30	Dec. 1–Jan. 31	Jan. 31

[a]Preapplication SF-424 must be submitted by this date for determination of eligibility.

Applicant eligibility requirements. Projects in the UDAG program are selected on the basis of a national competition. Selection criteria are based on regulations established by the action grant program (Title 24, *Code of Federal Regulations*, Part 570.459). The first major eligibility criterion is the necessity to acquire firm financial commitments from the private sector. The program is meant to catalyze increased investment in distressed communities by private sector involvement, so such investments must be firm before a grant can be approved. An appropriate measure of economic viability necessary to attract the minimum private investment required for UDAG projects is in the range of $2.50 private for each $1.00 of UDAG funding.

The second major requirement is determination of the level of economic and physical distress in the community. Periodically HUD publishes minimum standards of distress that metropolitan cities, urban counties, small cities, and unique locations (pockets of poverty) must meet. Factors such as age and condition of housing stock (including residential abandonment), per capita income, population out-migration, unemployment, and others are used to indicate distress.

In addition to the appropriate distress factors, applicants are judged based on 16 other factors delineated in the regulations. Some of these factors are impact on employment in the community, effect on the tax base, likelihood that the proposed project will be completed on schedule and within budget, applicant's housing and development record, relocation needs, and participation by and benefits to various groups within the community. The final criterion is intended to demonstrate the applicant's history of providing housing for persons of low and moderate income and in providing equal opportunity for low- and moderate-income persons and minority groups.

Energy UDAG. Recently, HUD has proposed an amendment to the UDAG program that would give more favorable consideration in the selection of applicants for energy conservation and alternative energy supply projects. The purpose of the Energy UDAG is to improve the physical and economic viability of urban areas by supporting projects that are designed to conserve scarce fuels and result in direct energy cost savings to the public, municipal governments, and commerce and industry. This department recognizes that many proven and valuable energy conservation practices and alternative supply technologies may have difficulty obtaining 100% private financing. Even projects with the potential for conserving significant amounts of energy or scarce fuels may have difficulty attracting private investment because of an insufficient rate of return. Energy UDAGs are intended to be used to make otherwise infeasible projects desirable for private developers. It is not, however, the purpose of the program to fund research, development, or demonstration projects that lack commercial viability.

The current set of energy conservation and alternative supply technologies that HUD has defined as appropriate for Energy UDAG consideration include the following:

1. district heating,
2. geothermal systems,
3. small-scale hydroelectric dams,

4. cogeneration systems (industrial, commercial, municipal),
5. modular integrated utility systems,
6. alcohol fuels production systems,
7. wind power systems,
8. energy conversion from wastes,
9. solar parabolic troughs,
10. low- and medium-Btu gasification processes, and
11. building energy conversion.

The application, processing, and eligibility requirements for participation in an Energy UDAG are essentially those necessary to compete for another UDAG project. Energy projects, however, are favored to the extent that they conserve scarce fuels or increase energy efficiency. In comparisons among Energy UDAG applicants, those from communities that have adopted plans or programs to conserve energy or provide alternative sources of supply on a community-wide basis will be favored over communities making no effort in this regard, all other factors being equal.

Energy UDAG applicants are required to submit some additional information to become eligible for funds. The following information should accompany the Energy UDAG application:

1. a technical and economic feasibility study;
2. evidence that the project does not provide an undue energy subsidy to any customer or class of customers;
3. the ratio of scarce fuels saved to the amount of UDAG funds requested; and
4. a description of any community-wide energy conservation plan or program undertaken by the applicant, and the relationship, if any, of the project to such plan or program.

The recent origin of the Energy UDAG program provides little indication of the time that may be required to review each application. The two-month rapid review process characteristic of the conventional UDAG program could be extended to accommodate the additional engineering and economic reviews required for an energy project.

2. DESCRIPTION OF MINNEAPOLIS, MINNESOTA

2.1 Population Characteristics

2.1.1 Population

Minneapolis's population (as of 1979) is estimated to be 372,000. The city's population has declined by nearly 150,000 from a high of 521,718 reported in 1950. Annual loss, however, has undergone substantial moderation since 1975 and is estimated to be less than one-third of that occurring during the early 1970s.

Annual net population loss since 1975 is estimated to be less than 3,000 persons per year, or less than one-third the estimated 10,000 persons-per-year losses experienced during the early 1970s. (The Metropolitan Council estimates Minneapolis lost only 1,100 persons between 1978 and 1979.)

Continued population loss is attributable to (1) decline in household size resulting from out-migration of families with children (primarily preschoolers and elementary-age children), (2) decreasing birth rates during the 1970s combined with a general trend toward later marriages and smaller families, (3) generally increased divorce rates, and (4) substantial in-migration of young single adults. The average size of Minneapolis households has declined substantially over the last 30 years, falling from 3.08 persons in 1950 to an estimated 2.24 persons in 1979.

A recent survey of Minneapolis homeowners (*Homeowners in Minneapolis: A 1979 Survey*, published July 1979) indicated that 92% want to live within the city for at least the next five years. In addition, the survey indicated that recent in-migration of homeowners (particularly of young adults) exceeds planned exodus from the city, indicating that Minneapolis can expect an increase in its homeowner population over the next several years.

The trend toward a less family-oriented population is reflected in comparative age profiles for the city in 1970 and 1979. These profiles are shown in Table 2. Estimates of 1979 proportions of children and middle-aged adults reflect a decline from 1970 levels, while proportions of younger adults and senior citizens reflect an increase.

Table 2. Minneapolis population comparative age profiles, 1970 and 1979

Age	1970		1979 (estimate)	
	Number	Percent	Number	Percent
Preschool (1–4)	32,294	7.4	24,200	6.5
School age (5–19)	103,567	23.8	75,800	20.4
Young adult (20–29)	87,134	20.1	86,300	23.2
Adult (30–49)	78,082	18.0	74,300	20.0
Middle-aged (50–64)	68,062	15.7	52,700	14.1
Senior (65+)	65,261	15.0	58,700	15.8

2.1.2 Race

The minority population in Minneapolis grew by 14% between 1978 and 1979. Minority persons now make up 12.2% of the city's population. This growth continues patterns of increase witnessed in the city since 1950 and is consistent with the 40% change witnessed during the 1950s and 1960s and predicted for the 1970s.

The Black population is estimated to be 28,850. This shows an increase of 1,850 persons from the 1978 estimate. The data suggest that Black families are immigrating to Minneapolis.

The American Indian population in Minneapolis is estimated to be 9,700 in 1979, ~1,000 more than in 1978. However, the process of estimating Indian population is complicated by movement to and from the reservations. An estimate may be more valid at different times of the year when traditional Indian movement occurs.

The Asian and Hispanic populations are estimated at 6,875 in 1979. This represents a substantial increase from 1978. However, precise statistical data are not available for estimating certain household characteristics for this subpopulation, and the estimate should be considered subject to change.

2.1.3 Labor and employment

The Minneapolis work force in March 1979 totaled 269,600, a slight decrease from the total of 1978. The work force total includes all those working within the city, as estimated by the Minnesota Department of Economic Security. Those employed individuals include both Minneapolis residents and nonresidents.

The March 1979 Minneapolis labor force total of 198,600 may be compared to 196,300 for March 1978, indicated in *State of the City 1978*. The labor force is composed of those city residents who are working, as well as those seeking employment. The March 1979 labor force estimate is composed of 191,700 employed residents (96.5% of the labor force) and 6,900 unemployed (3.5% of the labor force). The current year data thus show a larger Minneapolis labor force, more residents employed, and fewer unemployed than in March 1978:

Date	Labor force	Number employed	Number unemployed
Mar. 1978	196,300	188,900	7,400
Mar. 1979	198,600	191,700	6,900

The professional-technical occupations continued their decade-long rise, according to the most recent Minneapolis resident employment information.

The 1977 occupational distribution of employed Minneapolis residents is derived from the information provided by those who reported their job type on state tax returns. For 1977, the distribution is based on the responses of 130,855 workers.

Current data suggest that the post-1970 trend of an increased share for professional-technical occupations has continued. In 1977, this share reached 22.8% (up from 22.4% in 1976), a level exceeded only by the percent of clerical workers, at 22.9. Note that the clerical worker share in 1977 was down slightly from 1976, while those of all other categories remained generally at their 1976 levels.

2.2 Residential Sector

A great variety exists within the city's housing inventory. The housing choices available to Minneapolis residents are as numerous as any offered in the metropolitan area. Although single family and duplex housing predominate in a majority of the city's neighborhoods, nearly 40% of the city's 165,000 housing units are apartments. The mix of housing types varies considerably within Minneapolis, as shown in Table 3. Forty-two outlying neighborhoods have, on the average, less than 1.49 dwelling units per structure, reflecting the dominance of single family housing with scattered duplex and multi-unit structures. The average number of units per structure increases with proximity to the Central Business District (CBD). The significant number of multi-unit structures to the southwest of downtown and to the east surrounding the University of Minnesota is reflected in average-units-per-structure ranges in excess of 3.00. Relatively high averages in neighborhoods whose land area is largely devoted to single family and duplex structures result from small clusters of multi-unit structures — in Powderhorn Park and Windom, for example.

The single family structure (detached structure) is still dominant in the city's housing supply, accounting for 45% of the city's 165,000 housing units. Single units (condominiums, cooperatives, and townhouses) account for only 1% of the city's housing supply.

Table 3. Distribution, age, and condition of Minneapolis housing by type of structure (September 1979)

Structure type	Median age	Average condition[a]	Number of structures	Number of units
Single family structures	56	3.01	75,006	75,006
Single units[b]	20	2.06	1,592	1,592
Duplex	71	3.15	13,548	27,096
3–4 units	70	3.36	2,153	7,962
5+ units	53	3.02	2,839	53,332
Total city	58	3.04	95,138	164,988

[a]3.00 equals average condition. The scale on which this figure is based runs from 1–5 with 1 indicating the best condition and 5 indicating the poorest.

[b]Single units include those in townhouses, condominiums, and cooperatives.

As of July 1979, 1600 units in cooperatives, condominiums, and owner-occupied townhouses had been registered in the assessor's office. According to permit records, however, as many as 700 additional units are in the process of conversion or construction. Single units are found primarily in the Central, Calhoun-Isles, Powderhorn, and university communities.

Although the definition of single units includes townhouses, cooperatives, and condominiums, most of the identified units are cooperatives or condominiums. Only 18% of the single units are identified as townhouses. For all practical purposes, then, a single unit is likely to be located in a multi-unit structure.

The five-or-more (5+) unit structure follows single family structures as the most important element in the city's housing supply. More than 53,000 rental housing units are located in 5+ unit structures.

Unit counts in the 5+ unit structures are virtually unchanged overall from 1978. There are 53,332 units in 5+ unit structures in the city, compared with 53,337 in 1978. This number does not include cooperative or condominium units, which are recorded as single units. All of the units in the 5+ structures are therefore rental units.

These structures are most often found in the northeast community and in a general southwesterly direction from the downtown area. Although the western tracts of the Powderhorn community have several 5+ unit structures, in other parts of the city the type is relatively rare.

The most significant change since 1978 in the tenure of Minneapolis housing has been the conversion of ~1000 rental units to condominiums or cooperatives. The proportion of single family and duplex structures that are owner-occupied remained stable. Approximately 52% of the city's housing units are rental units, and 48% are owner-occupied.

Citywide, 69,232 (92%) of 75,006 single family structures are owner-occupied. Significantly low rates of owner occupancy — below 79% — are found in only six inner-city neighborhoods.

The condition of Minneapolis housing has improved. In September 1979, 943 fewer dwelling units were in substandard condition than were substandard a year earlier. Of all units in 1- and 2-unit structures, 17.3%, or 17,644, were substandard. Of all units in 3+ unit structures, 14.7% or 9,016 units were substandard. The geographic distribution of substandard units remained unchanged.

2.3 Commercial and Industrial Sectors

2.3.1 Economic activity

Economic activity in Minneapolis increased from $6.8 billion in 1967 to an estimated $10.6 billion in 1977. "Economic activity" represents the sum of retail sales, service receipts, wholesale sales, and value of manufacturing shipments. This sum was derived from data gathered through the Department of Commerce's *Economic Census*.

Minneapolis economic activity increased only slightly, from $6.8 billion to $7.4 billion, in the five-year period 1967 to 1972. A 43% increase has been estimated for the 1972 to 1977 period through use of the advance economic census reports.

It should be mentioned, however, that although the 43% growth between 1973 and 1977 seems impressive, it relates to current dollars over a period that experienced higher inflation rates than in the immediately preceding period. For example, the consumer price index in the Minneapolis-St. Paul area increased nearly 46% from 1972 through 1977 (and less than 26% from 1967 to 1972), in contrast to that 9% increase in the 1967 to 1972 period.

2.3.2 Commercial-industrial inventory

Data resulting from an R. L. Polk Company survey indicate that the CBD contained 4,100 commercial-industrial units, or over 27% of the total of 15,083 units identified within Minneapolis in 1978.

The net unit loss found in the CBD between 1977 and 1978 totaled 156, or just under a 3.7% net decline over the year. The net loss in the CBD accounted for about one-third of the city's net loss of 467 commercial-industrial units.

The term "commercial-industrial units" relates here to the quarters occupied (or vacated) by firms engaged in such activities as manufacturing, retail and wholesale trade, services, and finance-insurance-real estate operations. Therefore, even though a considerable amount of construction (particularly office) is under way downtown, it has not yet been completed and occupied to any degree by firms that might fall within this commercial-industrial category. Furthermore, some units were removed from the inventory to make room for new construction. This point may explain the seeming incongruity between the visible mass of potential new commercial-industrial quarters going up and survey results showing a considerable 1977 to 1978 net decline of commercial-industrial units.

Minneapolis building permit values reached nearly \$216 million in 1978, the highest recorded total in the city's history, and nearly double the 1977 values. Office construction in 1978 was valued at \$69.5 million, a level nearly nine times that of the previous year.

Identified industrial investment, principally manufacturing and associated warehousing, added nearly 92,900 m^2 (1×10^6 ft^2) to the city's inventory. New and expanding firms also provided at least 372 new jobs in Minneapolis.

2.3.3 Industrial investment

In 1978, new and expanding industry in Minneapolis invested an identified \$16.7 million in nearly 92,900 m^2 (1×10^6 ft^2) of plant and warehouse facilities. The year 1978 was one of proportionately high industrial investment in Minneapolis. The \$16.7 million invested during 1978 represents over 21% of the nearly \$78.8 million invested from 1972 to 1978 (Table 4). The nearly 92,900 m^2 (1×10^6 ft^2) addition accounts for more than 24% of the 380,000 m^2 (4.083×10^6 ft^2) of new area identified as added by the investment over the seven years.

In 1978, Minneapolis warehouse investment totaled over \$8.2 million, an amount equivalent to ~34% of the total warehouse investment identified for the 1972 to 1978 period. Warehouse investment thus continued to significantly lead all other identified categories, not only in 1978, but over the entire seven-year period tabulated in Table 4.

Table 4. Minneapolis new and expanding industry, 1972–1978; investment and square footage by category[a]

	Category							
	Warehousing	Food manufacturing	Nonelectric machine manufacturing	Nonmetals manufacturing	Rubber/plastic manufacturing	Electric machine manufacturing	Other[b]	Total
				Investment ($ millions)				
1972–1977	16,039	7,703	4,613	5,322	2,060		26,381	62,118
1978	8,240	475	2,610	1,192	190	1,590	2,375	16,672
Total	24,279	8,178	7,223	6,514	2,250	1,590	28,756	78,790
Share, %	30.8	10.4	9.2	8.3	2.8	2.0	36.5	100.0
				Square footage [1000 m^2 (1000 ft^2) rounded]				
1972–1977	124.6 (1,341)	12.4 (134)	48.9 (526)	28.2 (304)	4.9 (53)		68.4 (736)	287.4 (3,094)
1978	38.9 (419)	1.3 (14)	8.7 (94)	5.0 (54)	0.7 (7)	4.8 (52)	32.4 (349)	91.9 (989)
Total	163.5 (1,759)	13.7 (149)	57.6 (619)	33.2 (359)	5.6 (60)	4.8 (52)	100.8 (1,085)	379.3 (4,083)
Share, %	43.1	3.6	15.2	8.8	1.4	1.3	26.6	100.0

[a]In some individual data listings by year, information on square footage was not available.

[b]High totals in this category reflect a few major investments over the period, including from 1972–1977 a utility, Research and Development facility, speculative buildings, a power plant, a chemical plant, and in 1978, two printing and publishing plants.

Sources: Minnesota Dept. of Economic Development; Minneapolis Industrial Development Commission.

2.4 Minneapolis Urban Redevelopment Plan

The Mississippi central riverfront played an important role in the early days of the lumber and flour milling industries and continues to be of primary importance in today's redevelopment efforts. Numerous groups have been actively planning for redevelopment in the central riverfront for over a decade. These groups include the City Planning Department; the Riverfront Development Coordination Board (RDCB), which has representatives from the Minneapolis City Council; the Minneapolis Park and Recreation Board; the Minneapolis Housing and Redevelopment Authority (MHRA); and the Mayor's Planning Department office. Other groups active in the area include the Heritage Preservation Commission (HPC), the Metropolitan Council, and neighborhood and community groups. The planning reports that have been produced by these groups address a broad range of concerns. Some examples are: Metro Center '85; Minneapolis Metro Center '90; Mississippi/Minneapolis; RDCB Central Riverfront Open Space Master Plan; RDCB Goals, Objectives and Area Development Guide Policies; Minneapolis Plan for the 1980s; HPC Regulations and Guidelines; and consultant studies on a variety of issues.

The Mississippi Central Riverfront is also important, because it is part of the state designation of the Mississippi River corridor as a Critical Area. The Critical Area designation requires the development and coordination of municipal plans and regulations that ensure the protection of the river and its corridor. Critical Areas Plan requirements include specific guidelines addressing land use, natural resources, visual quality, heritage preservation, open space, and transportation concerns.

In the Critical Area, the Central Riverfront is located in an Urban Diversified District that is one of three districts used for the river corridor. The Urban Diversified District allows a diversity of commercial, industrial, residential, transportation, and public uses to be continued in the river corridor. New development is permitted if historical sites and areas and natural, scenic, and environmental resources are protected, and if public use of the river is increased.

Within the central riverfront are located a number of MHRA redevelopment districts. These redevelopment districts include St. Anthony West, Holmes, North Loop, Gateway, and Industry Square. Some development is currently under way and more is under contract. However, much more development is anticipated over the next decade, because the city has given high priority to accomplishing the objectives in the Minneapolis Plan for the 1980s, which calls for redevelopment of the central riverfront area.

2.5 Energy Status

2.5.1 Climate

The cold Minnesota weather is a major factor affecting energy use in Minneapolis. The effect of climate on energy use is measured by "degree days." A degree day is an index of the heating or cooling that is required to maintain a building at 18°C (65°F). The Minneapolis weather year is characterized by 8159 heating degree days — near the top of the range from 206 degree days in Miami to 9750 in Duluth.

Minneapolis also averages 585 cooling degree days. Summer heat is costly for energy use. Air conditioners, fans, and dehumidifiers added to already heavy electric demand between the hours of 9:00 AM and 9:00 PM can lead to times when existing base-load power plants cannot produce enough electricity to meet customer needs. Then the electric utility uses standby generating equipment, which burns expensive fuel oil. This peak generating period is the most expensive part of electrical costs to the utility and is affected by seasonal variations in summer heat.

2.5.2 Energy sources

Minneapolis is less fortunate than the majority of other large cities in the nation because Minnesota contains none of the fossil fuels that account for over 99% of the city's energy consumption.

The city is dependent on the three traditional energy sources: petroleum, natural gas, and electricity. Electricity, in turn, is generated by coal combustion and uranium fission. All of these fuels are imported from outside Minnesota.

Petroleum is imported from the oil fields of Alberta, Canada, the south central United States, and the Middle East. Over 90% is brought into the state through pipelines — 65% as crude oil brought to four state refineries, and the remaining 35% as refined products brought to terminals. Thirteen terminals are located in the Twin Cities area including two based at refineries. Gasoline, engine oil, and fuel oil are trucked by licensed distributors from the terminals to fuel oil users and gas stations in the city. Petroleum supply to the state and city is dependent on the negotiations of a variety of private corporations. These corporations act as prime suppliers, regionally or nationally, and contend with (1) national allocation policies, (2) changing regulations in oil-producing states, (3) changing Canadian export policies, and (4) the competitive market defined by Middle Eastern politics.

Natural gas is imported from underground wells in Kansas, Oklahoma, and Texas. It also is shipped through pipelines, but the distribution system is considerably simpler than for petroleum because (1) the gas pipeline system runs directly from the source to the ultimate user and (2) the Minneapolis import system is controlled by one supplier and distributed regionally by one public utility.

Coal, which is a primary source of electrical generation in Minneapolis, comes from U.S. mines both east and west of the Mississippi River. Western state mines, in Montana, Wyoming, and North Dakota supply three-quarters of the coal while eastern state mines in Illinois, Kentucky, Tennessee, West Virginia, and Ohio supply one-quarter. Coal is brought in by train or by barge to two local purchasers: NSP accounts for 94% and the University of Minnesota for over 5%.

The nuclear fuel used to produce ~40% of the region's electrical energy is uranium. It is mined in the southwestern United States where it is enriched and fabricated into small fuel pellets which, in turn, are sealed in rods. Nuclear fuel assemblies of rods are purchased by NSP and transported via surface transportation for use at the Prairie Island and Monticello nuclear fission power plants.

2.5.3 Energy use

Based on 1977 estimates, Minneapolis uses 105.5 PJ (100×10^{12} Btu) of energy annually. About 56% of this energy is derived from consumption of petroleum, 35% from natural gas, and 8% from the electricity generated by using coal and nuclear fuel.

Table 5 details the city use of each of the resources. Nearly two-thirds of the most extensively used resource, petroleum, is used as gasoline and engine oil for transportation by planes, trains, buses, trucks, and by the largest user, automobiles. Almost three-quarters of natural gas use is for heating — half for heating homes and the other half for heating stores, offices, industries, and institutions. Most of the coal and all of the nuclear fuel is used to generate electricity, and approximately three-quarters of that electricity is used to meet commercial-industrial-institutional demand for lighting, air conditioning, and operation of other machines or appliances; the other one-quarter is used for similar needs in homes.

The breakdown shows that transportation takes about the same amount of energy as space heating. The table also shows, however, that the heaviest demand for energy overall stems from commercial-industrial-institutional users in the city, with transportation users in second place and residential users in third place.

2.5.4 Natural gas use

In 1978 Minneapolis gas users consumed 1×10^9 m^3 (35.5×10^9 ft^3) of natural gas. Almost 75% was used for heating. Residential gas users accounted for roughly 50% of this consumption, commercial users 17%, and industrial users slightly over 5%. Table 6 shows total natural gas use for Minneapolis from 1969 to 1978. The table includes data on "interruptible" users (i.e., users shut off in cold weather).

In 1978 natural gas consumption by small industrial and commercial users totaled slightly over 226 million m^3 (8 billion ft^3). Large users in the interruptible category consumed almost 283 million m^3 (10 billion ft^3) of gas.

Interruptible gas users (businesses, institutions, and industries) must have alternative heating systems (i.e., fuel oil systems) available in the event that a cut-off occurs. Interruptible users are classified according to consumption. The largest category and the consumer most likely to be cut off will use over 5,660 m^3 (200,000 ft^3) of gas in a maximum-usage day. Smaller interruptible users, while susceptible to having their gas supply interrupted, are more assured of their supplies.

Table 5. Minneapolis energy use estimates, 1978

Fuel type and disposition	Functional area: Residential	Commercial, industrial, institutional	Transportation	Other[a]	Total
Petroleum[b]					
Functional share, %	5	32	63		100
Usage, 10^6 L (10^6 gal)	77.2 (20.4)	493.2 (130.3)	969.0 (256.0)		1,541.8 (407.3)
Usage, GJ (10^9 Btu)	2,975.2 (2,820.0)	19,041.7 (18,048.0)	37,488.2 (35,532.0)		59,505.2 (56,400.0)
Natural gas[c]					
Functional share, %	50	50			100
Usage, 10^6 m^3 (10^6 ft^3)	500.26 (17,666.5)	500.26 (17,666.5)			1,000.52 (35,333.0)
Usage, GJ (10^9 Btu)	18,639.1 (17,666.5)	18,639.1 (17,666.5)			37,278.2 (35,333.0)
Electricity[d]					
Functional share, %	24	74		2	100
Usage, MWh	613,314	1,937,710		54,957	2,605,981
Usage, GWh	613.3	1,937.7		55.0	2,606.0
Usage, GJ (10^9 Btu)	2,208.4 (2,093.2)	6,977.5 (6,613.4)		198.0 (187.7)	9,383.9 (8,894.3)
Total, GJ (Btu)	23,822.8 (22,579.7)	44,658.3 (42,327.9)	37,488.2 (35,532.0)	198.0 (187.7)	106,167.4 (100,627.3)
Percent of total	22	42	35	1	
Activity distribution by functional area usage[e] [GJ (10^9 Btu)]					
Space heat	16,676.0 (15,805.8)	22,329.2 (21,164.0)		9.9 (9.4)	39,015.1 (36,979.2)
Water heat	3,335.2 (3,161.2)	893.1 (846.5)		9.9 (9.4)	4,238.3 (4,017.1)
Machines, appliance, other[f]	3,811.6 (3,612.7)	21,435.0 (20,317.4)	37,488.2 (35,532.0)	178.2 (168.9)	62,914.0 (59,631.0)
Total	23,822.8 (22,579.7)	44,658.3 (42,327.9)	37,488.2 (35,532.0)	198.0 (187.7)	106,167.4 (100,627.3)

[a]"Other" in the case of electricity refers to water-sewage pumping, street lighting, and traffic signals.

[b]See Report, *Energy Policy and Conservation Report*, Minnesota Energy Agency, 1978, p. 24, Mpls. Share at 10% of state's projected 1978 Btu estimate (564 trillion, as interpolated). Functional shares based on p. 24 table, with residential adjusted downward based on industry data gallon age derived from Btu (1 million gallons at 138.5 billion Btu).

[c]Data source is Minnegasco. Functional share from data breakdown. 1 million ft^3 = 1 billion Btu.

[d]Data source is NSP shares from data breakdown. 1 million kWh = 3.413 billion Btu. Note that primary energy used to generate electricity is about three times the amount of electrical energy produced.

[e]Based to a considerable degree on MEA Report, cited above.

[f]Includes, for example, air conditioning units, lighting, engine operation.

Table 6. Natural gas consumption in Minneapolis, 1969–78 (million m^3)

Year	Residential commercial, and industrial	Interruptible	Total
1969	815.44	597.76	1413.21
1970	838.94	642.72	1481.66
1971	826.72	542.84	1369.56
1972	870.65	503.86	1374.50
1973	745.39	608.05	1353.44
1974	768.90	515.94	1284.83
1975	767.22	436.62	1203.84
1976	760.31	364.85	1125.16
1977	712.51	291.03	1003.54
1978	731.86	275.07	1006.93

The number of interruptible users has decreased to less than 1,200 customers in 1978; they are no longer sought as gas customers.

Gas use by small industrial and commercial users has not been consistent through the past few years, and no clear conservation trend is apparent. Table 7 shows that average consumption in 1976 fell from the 1975 level and that average consumption remained relatively low in 1977 and

Table 7. Natural gas consumption by small industrial and commercial users, 1969–1978 (10^6 m^3)

Year	Commercial	Industrial	Total
1969	168.62	64.44	233.06
1970	181.52	64.39	245.81
1971	182.34	63.08	245.42
1972	198.14	59.11	257.25
1973	171.03	56.78	227.81
1974	175.14	63.11	238.25
1975	179.72	64.76	244.48
1976	179.67	56.03	235.70
1977	169.30	51.15	220.45
1978	176.18	53.95	230.13

1978. Even in an analysis that ignores the interruptible user, small industrial and commercial users still account for nearly one-third of the city's gas use. Table 8 shows actual residential gas consumption from 1969 to 1978.

Table 8. Residential gas consumption in Minneapolis, 1969–1978

Year	Residential consumption [10^6 m^3 (10^3 ft^3)]
1969	582.381 (20,566,600)
1970	593.127 (20,946,100)
1971	581.577 (20,538,200)
1972	613.411 (21,662,400)
1973	517.584 (18,278,300)
1974	530.652 (18,739,800)
1975	522.740 (18,460,400)
1976	524.578 (18,525,300)
1977	492.051 (17,376,600)
1978	501.709 (17,717,700)

2.5.5 Energy costs

The trends in predicted price increases show an increasing gap between petroleum prices and those for natural gas and electricity. Electricity costs will rise at the lowest rate of the three energy sources, but natural gas will continue as the best bargain for energy output.

The bite of increased energy costs on an average Minneapolis household income will rise from 7.5% in 1979 to 12.8% in 1983 (assuming the same rate of consumption), even though income is expected to rise at an annual rate of 6 to 7%.

2.6 Financial Status

2.6.1 City expenditures

The city's 1979 budget appropriation of $501.7 million is nearly 61% above the 1978 level. A rise in capital expenditures accounts for over half the increase.

Total municipal expenditures in Minneapolis climbed from $69.9 million in 1967 to nearly $312.1 million in 1978. This increase is more than 346% over the ten-year period. Note for comparison, however, that the consumer price index, whose base year was also 1967, increased nearly 100% over the same period in the Twin Cities area. This illustrates the fact that a substantial portion of the expenditure increase can be attributed to price inflation. As Table 9 shows, the 1979 level is represented by an appropriation of about $501.7 million, a level that is 60.8% above the 1978 expenditure total of $312.1 million.

Expenditures have been distributed by program in Table 9. The table includes the 1977 and 1978 actual expenditures and the 1979 appropriations. It can be seen that the total net operating expenditures for 1979 have increased by about 37% over the previous year, due principally to expansion of activities in housing and economic development programs. Total capital expenditures led by major increases in economic development commitments have risen by over 259%. (Economic Development capital projects are generally carried out by the MIDC, the MHRA, and the City Coordinator.) Capital expenditures have varied from 15 to 30% of the total budget during the 1977 to 1979 period. Table 9 shows 1978 actual and 1979 appropriation data for several operating departments.

The city's general obligation debt is secured by the "full faith and credit" of the city of Minneapolis. Payment of interest to bondholders is therefore borne by the taxpayer. General obligation debt increased from nearly $72.4 million in 1967 to $254.5 million in 1978, an increase of over 251% over the ten years. Debt service, at $51.4 million, represented nearly 16.5% of the total municipal expenditure for 1978.

Note that $53.3 million of the debt is applicable to the debt limit. The limit on December 31, 1978, was $166.4 million (3-1/3% of just under $5.0 billion, the city's total market value). Applicable debt was therefore at about 32% of its possible maximum legal limit.

2.6.2 City revenues

Minneapolis's taxable assessed value increased by over $48 million relative to taxes payable in 1979. The city's tax rate declined relative to taxes payable in 1978 and 1979 and will again be lowered for 1980.

Table 9. Minneapolis expenditures by program

Program	1977 actual	1978 actual	1979	
			Appropriation	Estimate
Economic development: net operating	7,488,631	7,562,500	21,238,647	12,136,307
Debt service	5,541,675	9,752,007	10,233,582	9,272,194
Capital	7,290,318	5,823,754	84,913,252	57,649,628
Total	20,320,624	23,138,261	116,385,481	79,058,129
Total expenditures, %	7	7	23	15
Government management: net operating	10,887,514	12,892,144	13,992,099	13,484,276
Debt service	12,138,613	13,335,781	13,832,031	13,832,031
Capital	649,327	643,094	846,465	846,465
Total	23,638,253	26,871,019	28,670,595	28,162,772
Total expenditures, %	9	9	6	6
Health and safety: net operating	51,017,952	56,258,402	64,432,781	59,763,865
Debt service	37,200	36,000	0	34,800
Capital	0	0	0	0
Total	51,055,152	56,294,402	64,432,781	59,798,655
Total expenditures, %	19	18	13	12
Housing: net operating	19,920,725	45,682,717	100,320,872	157,066,473
Debt service	2,750,392	3,386,016	5,317,325	4,222,950
Capital	7,929,885	5,498,202	13,205,942	8,640,415
Total	40,601,002	54,566,935	118,844,139	169,929,838
Total expenditures, %	15	18	24	33
Human development: net operating	30,620,558	38,683,254	35,811,705	34,052,821
Debt service	2,684,011	5,266,587	3,501,550	3,501,550
Capital	3,570,254	2,564,537	3,736,868	3,736,868
Total	36,874,823	46,514,378	43,050,123	41,291,239
Total expenditures, %	14	15	9	8
Physical environment: net operating	9,458,609	10,276,855	11,074,968	9,451,801
Debt service	1,903,400	1,510,000	687,000	884,560
Capital	76,992	0	0	0
Total	11,439,001	11,786,855	11,761,968	10,336,361
Total expenditures, %	4	4	2	2
Property services: net operating	26,484,462	28,608,279	30,883,842	31,109,642
Debt service	4,303,470	4,270,252	4,663,640	4,663,640
Capital	8,507,817	9,182,203	15,088,287	15,088,287
Total	39,295,749	42,060,734	50,635,769	50,861,569
Total expenditures, %	14	13	10	10
Transportation: net operating	17,285,358	18,298,340	21,104,761	19,593,543
Debt service	12,554,453	13,859,037	12,248,415	12,248,416
Capital	17,157,733	18,694,011	34,544,290	37,651,744
Total	47,997,544	51,201,388	67,897,467	69,403,703
Total expenditures, %	18	16	13	14
Total net operating	183,089,407	218,262,491	298,859,675	336,658,728
Total debt service	42,913,214	51,415,680	50,483,544	48,660,141
Total capital	45,182,326	42,405,801	152,335,104	123,613,407
Total	271,184,947	312,083,972	501,678,323	508,932,276

Table 10 shows data related to total property taxes payable in the years 1977 to 1979. The table shows that while tax rates fixed to levy municipal funds have been reduced each year since 1977, a slight rate increase by other taxing jurisdictions (school district, county, and other districts) resulted in a total tax rate increase in 1978. Both rates decreased in 1979. The total tax amount payable by Minneapolis property owners in 1979 dropped, with the tax rate drop, to just over $193.1 million (Table 10).

Table 10. Property valuation, tax rate, total tax amount, 1977–1979

Year payable	Taxable assessed valuations[a] (million $)	City tax rate (mills)	Total tax rate (mills)	Total tax amount payable[b] (million $)
1977	1,483.3	48.571	129.888	192,620,200
1978	1,488.3	48.564	130.092	193,660,200
1979	1,536.8	43.421	125.362	193,100,200

[a]Excludes tax-increment values.

[b]Derived by multiplying total tax rate and taxable assessed value. This is therefore the total dollar amount of tax levied against the total of Minneapolis' taxable property value. Approximately 98–99% of the amount levied is actually collected.

It is estimated that the city's taxable assessed valuation will rise in 1980 to at least $1.7 billion. The tax rate will again be lowered, to a level of 37.85 mills, in 1980. The lowering of the rate applicable to taxes payable in 1980 will be the third consecutive decrease.

Revenue sources for 1979 and projected 1980 are shown in Table 11. Property taxes produced an estimated 13% of the city's revenues in 1979 and will account for an estimated 14% in 1980. Also in 1980, the share of revenue produced by state aids and bond proceeds is expected to rise, while that produced by federal grants and other sources will decline.

Table 11. City revenue sources (%)

Source	1979	1980
Bond proceeds	18	22
Federal grants	16	14
Property taxes	13	14
State aids	9	10
Service charges	6	7
Other[a]	38	33

[a]Includes such sources as franchise fees, fines and forfeits, and interest earnings.

"Other" revenue sources include moneys received from such areas as franchise fees, fines and forfeits, interest earnings, property use revenue, interagency revenue, and miscellaneous revenue.

3. MINNEAPOLIS DISTRICT HEATING SYSTEM

3.1 Development of the System

The Minneapolis District Heating System is a moderate-sized system in downtown Minneapolis and was the outgrowth of a system owned by Baker Properties.

Baker Properties was a major property owner in downtown Minneapolis and developed its steam system in what is now called the Baker Block to serve buildings owned primarily by Baker Properties. As other buildings were acquired by Baker Properties in downtown Minneapolis, their boiler plants were usually shut down and a steam line was run from the Baker Block to serve these buildings. Later these buildings were put under actual contract as they were sold to new owners, and a small very compact distribution system developed, which primarily passed on the economies of scale to those on the system. Gradually, a few other properties located adjacent to distribution lines were added to the system under long-term contracts. The heating demand of the buildings on the system was approximately 24 MW (80,000 lb/h) in 1972 when the Third Avenue Development Company was formed.

On January 2, 1968, Baker Properties (including Central Heating Company) was sold to IDS Properties, a wholly owned subsidiary of Investors Diversified Services. IDS Properties proceeded to develop the concept of the IDS Center, a 223×10^3 m^2 (2.4×10^6 ft^2) development between 7th and 8th Streets and Marquette and Nicollet Avenues. At the same time, Hennepin County was proposing to construct a new facility. These two major additions, coupled with the Metro Center '85 Plan (developed by the Minneapolis Planning Department) encouraged IDS Properties and Minnegasco to form a partnership called the Third Avenue Development Company to promote district heating. The present energy center was constructed in 1971 and went into service on approximately January 1, 1972. The original equipment consisted of two 25-kg/s (200,000-lb/h) boilers with room for four additional boilers. The original construction also included 34.7 MW (9880 tons) of refrigeration.

Steam and chilled water distribution lines were run up 8th Street to serve the existing facilities and the new IDS Center and were also routed down 3rd Avenue to supply the Hennepin County Government Center.

The low cost of energy in the early 1970s and the high first cost of a new plant resulted in somewhat slow development at first. However, as the cost of energy started to rise after the first OPEC oil shortage in 1973–74, the purchase of steam and chilled water from an outside source seemed more desirable. New construction in downtown Minneapolis of more than $600 million helped assure the future of the downtown district heating system. For a new building to tie into the energy center on a long-term contract was less costly than putting up the capital necessary for boiler and refrigeration equipment. Gradually, older buildings were also added to the system as the cost of alternative energy supplies (gas and oil) increased.

By January 1, 1979, contracts totaling 102 MW (346,000 lb) of steam demand were in force. By January 1, 1980, commitments for an additional 81,600 kg (180,000 lb) of steam had been realized, and this total is anticipated to approach 90,700 kg (200,000 lb) of steam for a total contract demand of 248,000 kg (546,000 lb) of steam (160.6 MW). Fig. 5 shows the MEC service area under contract for 1985. Future development depends on obtaining permits from DOE to put in additional firm capacity in boilers that can burn gas or oil. Permits from the Minnesota Pollution Control Agency are also necessary to operate additional boilers in downtown Minneapolis.

3.2 Description of the System

The MEC, at its primary location between 3rd and 4th Avenues, currently has two 90,700-kg/h, 1.72-MPa (200,000-lb/h, 250-psig) gas oil boilers installed. The plant was designed for an ultimate capacity of 90,700 kg/h (200,000 lb/h). The plant was also originally equipped with 34.7 MW (9,880 tons) of refrigeration, which has now been increased to 47.5 MW (13,500 tons) with the addition of a turbine-driven condensing centrifugal machine with a capacity of 12.3 MW (3,500 tons). Major distribution facilities run up 8th Street and tie the main plant into the standby plant located in the Baker Block between 7th and 8th Streets and

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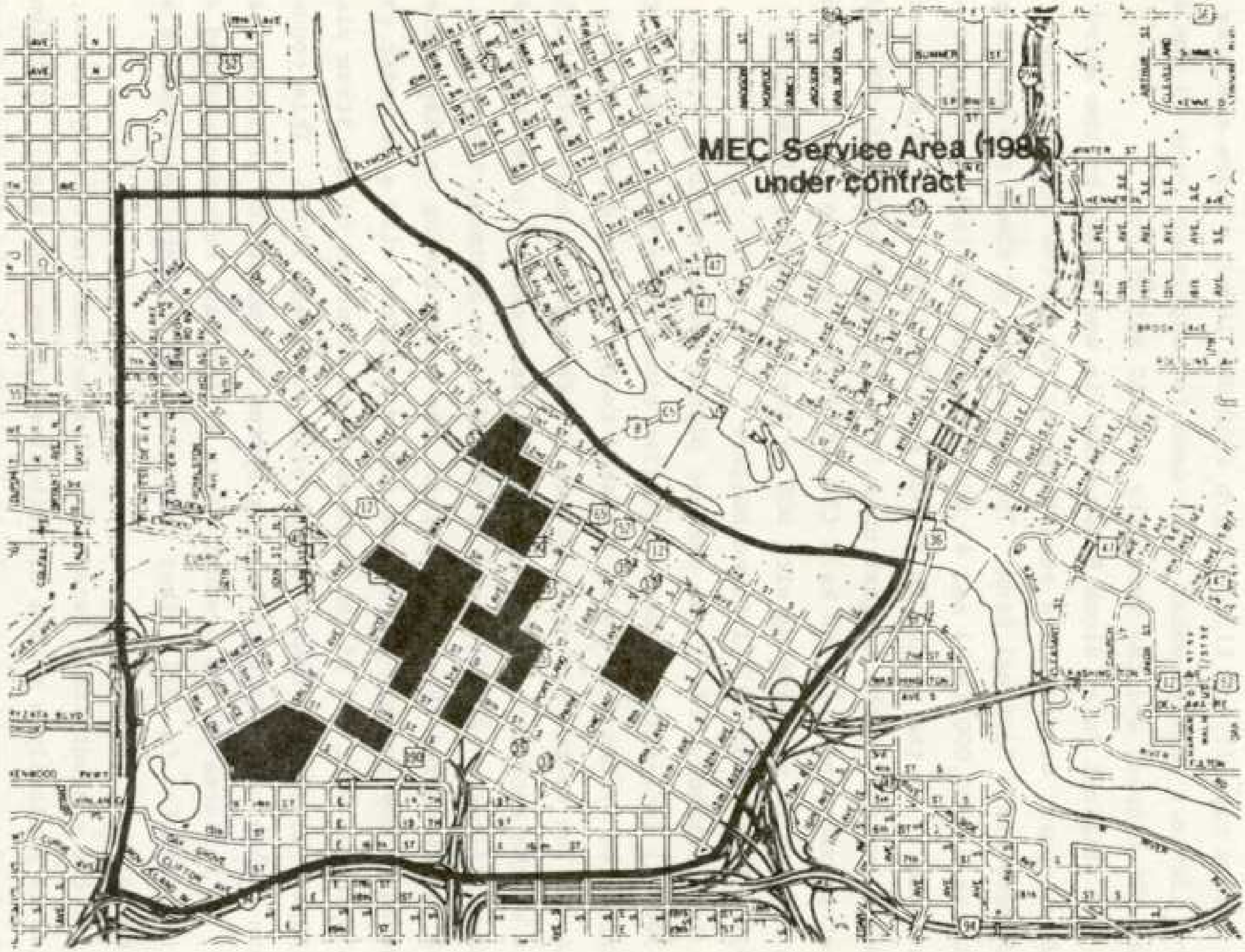

Fig. 5. MEC service area (1985) under contract.

2nd Avenue and Marquette. The distribution system in 8th Street consists of a 0.46-m, 1.7-MPa (18-in., 250-psig) steam line with a capacity of 272,000 kg/h (600,000 lb/h) and a 0.3-m, 1.72-MPa (12- in., 250-psig) line with a capacity of 113,000 kg/h (250,000 lb/h). There are also two 0.76-m (30-in.) chilled water lines used for supplying loads in the Baker Block, IDS Center, and the Twin City Federal Building.

The original Baker Block Steam Plant is now leased by the Third Avenue Development Company as a standby plant, as is the original plant of the Northwestern National Bank. The capacities of these two plants are 91,000 kg/h (200,000 lb/h) and 45,000 kg/h (100,000 lb/h), respectively. Firm capacity of the system is 91,000 kg/h (450,000 lb/h) of contract demand allowing for the largest unit [i.e., 204,000 kg/h (200,000 lb/h)] out of service and a 22,700 kg/h (50,000 lb/h) in-house load. An exemption request is now pending with DOE to install another 91,000-kg/h (200,000-lb/h) gas- or oil-fired boiler.

Approximately 95% of the present piping system totaling 4,100 m (13,500 ft) in length has been installed since January 1, 1971. If this distribution system were to be replaced today, it would cost roughly $6 million. The system piping is either run through the customers' buildings or is of the conduit-type design using a steam carrier pipe insulated with calcium silicate. An air space is provided for draining the system, and a steel conduit forms the outer casing. The outer casing is also protected by either epoxy or coal tar enamel and is equipped with a cathodic protection system. Over 97% of the condensate is returned to the steam plant via pipes placed in a common trench with the steam lines. This condensate return enables the district heating system to operate at efficiencies near 80%. No failures of the present steam system have been encountered since its installation in 1971, other than minor maintenance requirements within the manholes.

At the present time, except for ties between the standby plants, the system is basically a radial distribution system with single distribution lines piped to remote areas. It is hoped that in the immediate future new distribution lines running down parallel streets to serve new loads will be possible. This would tie together the system extremities and improve the integrity of the system.

3.3 Status of Steam District Heating Business

The MEC is one of the few district heating companies in the United States that is showing sizable growth. This growth is possibly a result of the MEC rate structure. The Energy Center's rates are based on the competitive costs of in-house gas or oil systems and these do not necessarily return sufficient income to MEC to provide an adequate return on its investment. The Energy Center, which was constructed in 1972, has not yet operated in the black. This is primarily a result of the high original capital costs for the oversized system. It is anticipated, however, that by 1882 the first profits for MEC will be realized.

4. ANALYSIS OF DISTRICT HEATING POTENTIAL

4.1 Heating Loads

Heating loads in downtown Minneapolis were surveyed by Studsvik in 1978 (Ref. 1). Two areas were defined and are shown in Fig. 6. The M1 area consisted of those areas served by the existing downtown steam system. The M3 area is the downtown area excluding the M1 area. In 1978, there was a load of ~80 MW in M1 and ~347 MW in M3. The building heating system distribution in 1978 was ~79% steam, 8% hot water, and 13% hot air on a peak-load energy consumption basis.[2] The M1 area has added 22 MW of steam load and 58 MW of hot-water load since 1978 (Ref. 3). As no firm information on load growth in M3 is available, this analysis assumes that the load in M3 has remained constant because little construction has been done in this area in the past two years. Recent experience in M1 shows that the majority of new buildings will have hot-water systems that will be compatible with a hot-water district heating system.

There are several different types of steam heating systems. The MEC provided a breakdown on the types of steam systems used in M1 (Ref. 3). This breakdown was used to calculate the average building conversion costs given in Sect. 4.4. A St. Paul building survey that gives a breakdown of steam system types was used to identify these systems within the overall steam classification for M3.

Four new development areas are considered in this evaluation: Burlington Northern, Industry Square, East Bank, and Elliot Park. The heat loads in these areas were estimated by using city building size projections and a correlation for energy loads as a function of building size (Table 12). This correlation was developed by MEC for new buildings based on their recent experience. The assumption was made that all buildings within these new development areas would have heating systems compatible with a hot-water district heating energy source.

4.2 Energy Production Plants

District heating systems require thermal energy that can be supplied by almost any energy source including coal, oil, nuclear, natural gas,

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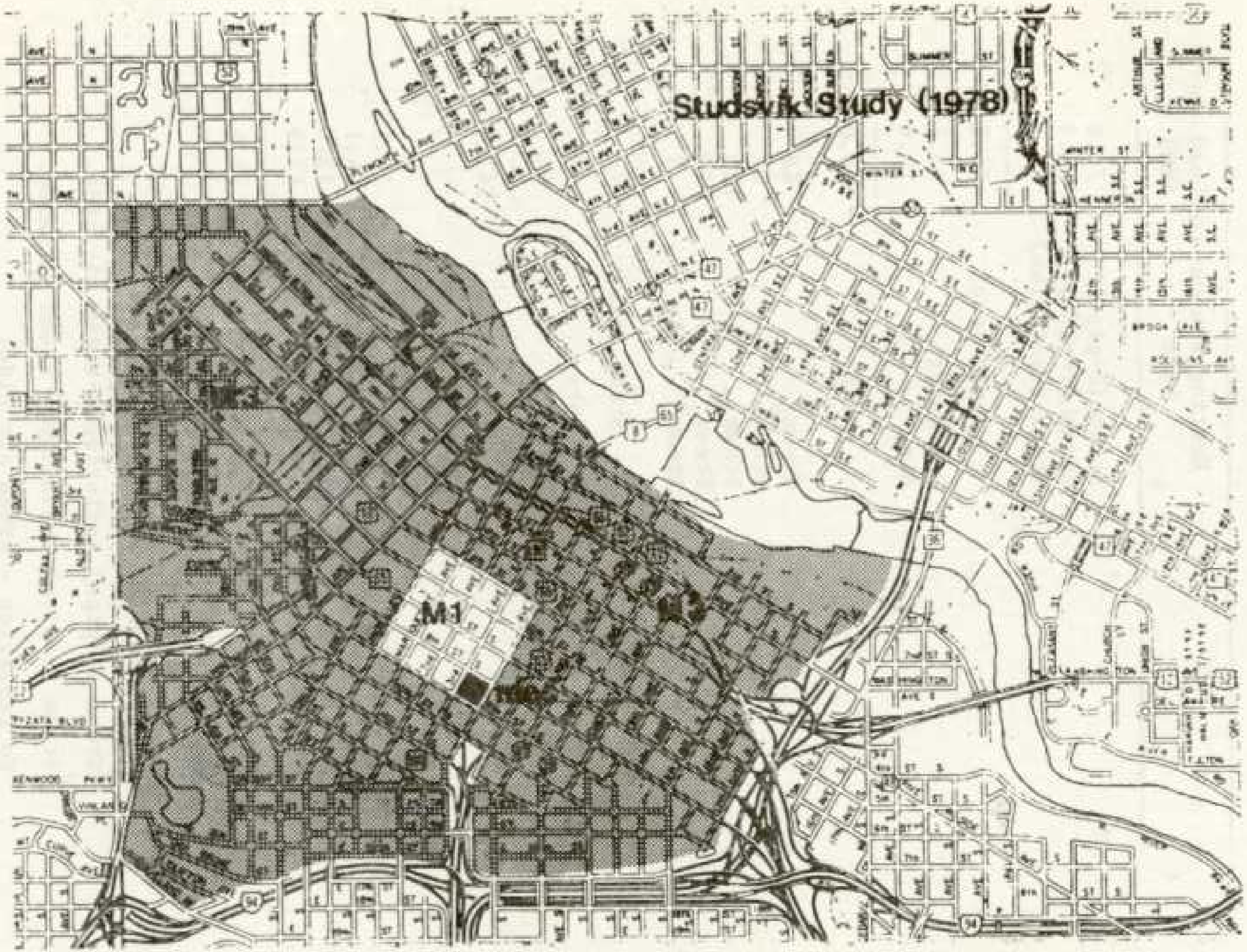

Fig. 6. M1 and M3 areas defined in 1978 Studsvik Study.

Table 12. Minneapolis heat loads

Area	Heating system type	Load (MW)
M1	Steam (2-pipe)	79.6
	Steam (1-pipe)	4.5
	Steam (radiation)	1.1
	Steam total	85.2
	Hot water	64.4
	Air	10.4
	Total	160.0
M3	Steam[a]	66
	Steam[b]	22
	Steam[c]	153
	Steam[d]	30
	Steam[e]	3
	Steam total	274
	Hot water	28
	Air	45
	Total	347
Heat islands		
Burlington Northern	Hot water	14.7
Industry Square	Hot water	34.1
East Bank	Hot water	12.9
Elliot Park	Hot water	12.9
	Total	74.6

[a] Steam (2-pipe) radiation — no air side.

[b] Steam (1-pipe) radiation — no air side.

[c] Steam (2-pipe) radiation — steam air side.

[d] Steam (1-pipe) radiation — steam air side.

[e] No radiation — steam air side.

solar energy, RDF, and geothermal energy. Discussed in Sect. 5.5, RDF is under serious consideration in Hennepin County. Solar and geothermal energy sources are not abundant in the area, especially during the cold winter months. Oil and gas are costly, and their supply may be interrupted by international events. Coal and uranium are resources available within the United States and are available in Minnesota at a moderate cost.

The energy production plant for the existing district heating system burns oil or natural gas and is described in Sect. 3. If the existing system were replaced with a hot-water system, necessary modifications to this steam plant would cost ~$2 million.

The thermal energy source must be located relatively close to the district heating distribution system. However, some thermal energy transmission mediums, such as hot water, allow long distance [~65 km (40 miles)] transport between the source and the delivery point. This distance limitation has focused attention on the Riverside Power Plant as a possible energy source (for steam and hot water) for the Minneapolis District Heating System.

Because the Riverside plant was built over a long period of time, it has boilers and turbine generators of varying types and capacities. All of these boilers burn western coal transported to Riverside on unit trains.[4] These boilers range from a set of small, old, low-pressure units to a large, modern, high-pressure unit.

The water quality is determined by the requirements of the highest-pressure boiler. This water must be very pure, and water treatment is relatively expensive. To conserve this costly water at the power plant, heat exchangers would be used to transfer thermal energy from the power-cycle steam to less pure, and less costly, water. This heat exchanger is called a reboiler and would transform the less expensive water into steam for transport to the Minneapolis District Heating System.

A cogeneration power cycle produces both thermal and electrical energy. Any power cycle must dissipate (or waste) a significant portion of the energy provided by the fuel. A cogeneration cycle, however, wastes less energy than a power cycle that produces only electricity. This leads to a cost benefit for cogenerated thermal energy vs boiler steam produced without cogeneration.

United Engineers[5] has estimated the cost of thermal energy from a cogeneration plant at ~\$1/GJ (~\$1/10^6 Btu) using a calculation methodology appropriate for retrofits. They estimate the cost of thermal energy without cogeneration to be approximately twice this amount, or ~\$2/GJ (~\$2/10^6 Btu). These costs are in 1979 dollars and do not account for significant cogeneration indirect costs including: (1) impact of electrical derate on system operations and system costs, (2) electrical derate capacity charge during peaking periods, and (3) a significant replacement energy charge.

Accounting for these indirect costs at the Riverside Power Plant has led to estimates that cogeneration will only produce savings of ~15% (Ref. 5). Cost estimates supplied by NSP (Ref. 6) quote a price of ~\$3.3/GJ (~\$3.3/10^6 Btu) for interruptible steam. Application of the 15% savings factor for cogeneration gives a price of ~\$2.8/GJ (~\$2.8/10^6 Btu) for cogenerated energy. These costs include the necessary capital charges for connection at the Riverside plant. These cost savings are very dependent on the accounting methodology used. No guidelines for cogeneration cost accounting have been approved by the Public Utility Commission. Until such approved guidelines are available, the cost estimate must be open to question.

None of the present Riverside units are cogeneration units. Noncogeneration units may sometimes be retrofitted for cogeneration, but none of the Riverside units seem appropriate for this type of change. The older units present physical obstacles that make retrofit very expensive and technically difficult. The newest unit presents few physical retrofit problems, but the replacement power costs would be high because it is a base-loaded unit. This, in turn, raises the cost of the cogenerated energy to a level where no cost saving is attributable to cogeneration. This cost savings calculation depends on fuel price projections. Any extreme variation in these prices would affect the viability of cogenerated energy.

Space is available at the Riverside plant for the addition of a new cogeneration turbine. At the present time, no excess boiler capacity is available to provide steam to another turbine. Unless boiler capacity is added, such as the RDF adaptations (Sect. 5.5), NSP would not invest in an additional turbine. However, this possibility should be kept in mind for long-term applications. If such a turbine were added during the late 1980s or early 1990s, it could coincide with the expansion of the district heating system and the addition of a hot-water line from Riverside to Minneapolis. This new cogeneration turbine has been estimated by NSP to cost ~\$15 million (Ref. 7).

4.3 Distribution System Costs

Distribution system costs are affected by the energy density and average consumer size (in terms of energy demand) within the area under consideration. Studsvik gives hot-water distribution costs based on empirical data from Swedish installations in the Stockholm area for a wide range of energy densities and consumer sizes.[1] Argonne collected cost data from nine cities in the United States and gives high- and low-cost correlations as a function of heat density.[8] These costs are significantly higher than the Swedish costs as shown in Fig. 7. These higher costs may be due to a number of factors including: (1) immature district heating technology in the United States, (2) different construction practices, and (3) lack of experience.

The median distribution system costs used in this report fall between the high and low limits given by Argonne.[8] A detailed cost estimate prepared for St. Paul falls very near this median line shown on Fig. 7 (Ref. 9).

Distribution costs within the center city area (M1) were derived from information received from the MEC showing that ~5,090 m (16,700 ft) of pipe were installed for ~\$6,680,000. The M1 area has a load of ~160 MW in an area of ~0.5 km^2, which establishes a heat-load density of ~320 MW/km^2. The MEC distribution system costs on an energy basis are ~\$21/kW. This cost is relatively low, due to both the high heat-load density and large unit sizes.

Table 13 shows heat-load densities and distribution costs for the areas near downtown Minneapolis considered in this evaluation. Because

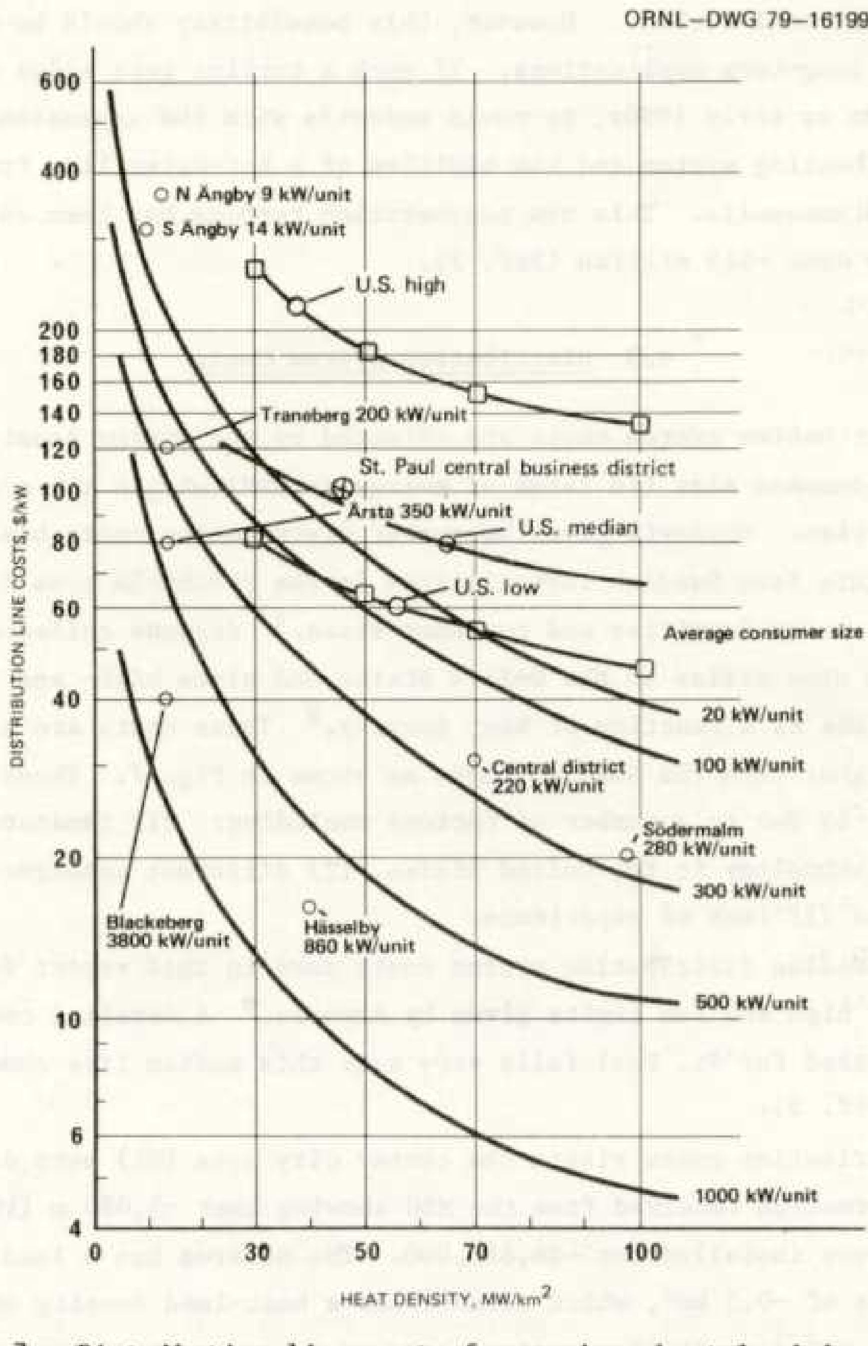

Fig. 7. Distribution line costs for various heat-load densities and consumer sizes.[1,8]

Table 13. Hot-water distribution system costs

Area	Heat-load density (MW/km^2)	Hot-water distribution system cost (1980 $)
M1	320	6,680,000
M3	53	29,495,000
Part of M3[a]	49	26,280,000
Part of M3[b]	24	15,960,000
HWHIs		
Burlington Northern	53	1,250,000
Industry Square	53	2,898,000
East Bank	27	1,509,000
Elliot Park	53	1,096,000
Total HWHI		6,753,000

[a]Serves 84% of M3.
[b]Serves 40% of M3.

M3 has a group of buildings with extremely high conversion costs, an option to connect only those with low to moderate conversion costs was considered. These options are called "Part of M3" in Table 13.

Steam distribution costs are higher than hot-water distribution costs because steam traps and additional insulation are required. Costs are assumed to be 10% higher for a steam system in M3 than for a similar hot-water system. This gives a steam distribution system cost of $32,444,000 (1980 dollars).

4.4 Building Conversion Costs

The buildings that make up downtown Minneapolis are heated by a wide variety of systems. Their fuel is usually natural gas or oil. The heating systems within each building distribute heat via steam, hot water, hot air, or some combination of these three mediums.

The costs of connecting buildings to a steam or hot-water district heating system vary with the type of heating system within each building.

Some buildings will require only the addition of a heat exchanger to connect their systems to a district heating system. Other buildings, such as those with dilapidated steam systems, will require completely new piping systems to justify connecting them to a district heating energy source.

For this study, we assumed that the district heating transport fluid (steam or hot water) would never circulate through a customer's building. Such circulation can lead to contamination (dirt or chemicals) of the transport fluid. In turn, this contamination could lead to serious pipe erosion or equipment fouling.

An alternative method allows the transport fluid to circulate through the user's building and controls possible contamination with a variety of methods including improved monitoring, filtration, chemical treatment, or contractual obligations that place penalties on any customer who contaminates the fluid. This alternative may lead to increased operation and maintenance costs but it does not require a heat exchanger between the transport fluid and the building circulation fluid. Because the heat exchanger is a major cost item, the building conversion costs for this alternate method are much lower. In the buildings where the existing Minneapolis district heating system uses this approach, building conversion costs as low as \$10 to \$20/kW have been experienced. Conversion costs for hot-water system connections could also be as low as ~\$20/kW for hydronic buildings. This method and its lower conversion costs were not evaluated in this feasibility study but should be considered in any future detailed system design work.

It is important to distinguish between district heating conversion costs and heating system renovation costs. In many old buildings, the heating systems are in disrepair and need either replacement or a major overhaul. It is incorrect to assign these building maintenance charges to a district heating conversion. In many cases, the connection of a district heating source will call attention to such existing problems and precipitate large renovation expenditures. These costs, however, would have occurred without the intervention of a district heating system.

Conversion costs for steam buildings are usually less for a steam district heating system than for a hot-water district heating system. A steam system seldom requires alterations other than the addition or conversion of a central heat exchanger. A hot-water system sometimes requires new piping within steam buildings, usually the return line that carries condensate from the steam radiators.

The conversion costs used for this report were derived from a survey of 94 buildings in the St. Paul area.[10] These buildings were divided into ten heating system types and detailed hot-water conversion cost estimates were prepared for each building. These cost estimates were used to derive a typical hot-water conversion cost for each type of building on a $/kW basis. The distribution of building types and related costs was used to derive weighted cost averages for conversion of steam-, hot-water-, and air-heated buildings to a 120°C (250°F) hot-water district heating source. These costs are given in Table 14.

Table 14. Building conversion costs for a 120°C (250°F) hot-water district heating system

Building heating system type	Conversion cost ($/kW)
Steam, average	174
Steam, type 2[a]	140
Steam, type 5[b]	181
Hot water	62
Air	110

[a] 2-pipe radiation, no air side.

[b] 2-pipe radiation, steam air side.

These costs were then applied to the areas of downtown Minneapolis considered by this study. The distribution of building types for areas M1 and M3 was taken from a Studsvik study performed in 1978 (Ref. 2). The energy loads were identified by this same survey. Load growth since 1978 in the M1 area was given by MEC. For the purpose of this study, the assumption was made that M3 has not changed since 1978. The projected loads for new development areas were calculated using city estimates of projected building sizes and MEC correlations for energy consumption as a function of building size for new buildings. All new buildings were assumed to have hot-water heating systems compatible with 120°C (250°F) hot-water district heating source. Table 15 gives the estimated loads

Table 15. Building hot-water conversion costs by area

Area	Building system type	Load (MW)	Conversion cost (1980 $)
M1	Steam	85.2	14,825,000
	Hot water	64.4	3,993,000
	Air	10.4	1,144,000
	Total	160.0	19,962,000
M3	Steam	274	47,676,000
	Hot water	28	1,736,000
	Air	45	4,950,000
	Total	347	54,362,000
Part of M3	Hot water	28	1,736,000
	Air	45	4,550,000
	Steam, type 2[a]	66	9,240,000
	Steam, type 5[b]	153	27,693,000
	Total	292	43,219,000
Part of M3	Hot water	28	1,736,000
	Air	45	4,550,000
	Steam, type 2[a]	66	9,240,000
	Total	139	15,526,000
Heat islands			
Burlington Northern	Hot water	14.7	907,000
Industry Square	Hot water	34.1	2,104,000
East Bank	Hot water	12.9	796,000
Elliot Park	Hot water	12.9	796,000
	Total	74.6	4,603,000

[a]2-pipe radiation, no air side.

[b]2-pipe radiation, steam air side.

and conversion costs for adapting distinct portions of Minneapolis to a hot-water district heating system.

As M3 has a group of buildings with extremely high conversion costs, options were considered to convert only those buildings with low to moderate conversion costs. These options are called "Part of M3" in Table 15 and would not serve 16% and 60% of the load but would save 21% and 71% in conversion costs, respectively.

The conversion of buildings for a steam district heating system was also considered. This study assumed that connecting a steam system to any type of building would cost approximately as much as connecting a hot-water system to a hot-water building. This cost is given in Table 14 as $62/kW and does not include costs for system improvement. The total building conversion cost for placing M3 on steam is estimated at $21,514,000.

4.5 Hot-Water Heat Islands

4.5.1 Description

The heat islands associated with the Minneapolis district heating system would receive hot water from large heat transfer stations that allow steam energy to be transferred to a water distribution system serving many customers. In effect, these islands are small hot-water district heating systems; they permit the use of the more energy-efficient and cost-effective hot-water distribution technology.

These islands can initially be served by gas- or oil-fired boilers and later connected to a comprehensive district heating system. The heat islands could also be served initially by a steam system through heat exchangers and later connected to a major hot-water system. Through use of heat islands an adequate hot-water load can be gradually developed so that ultimately the costs of a distribution system can be justified by amortization of line costs over a larger total load.

For Minneapolis, HWHIs represent a low-cost way of starting a large, comprehensive hot-water district heating system. Because of the high costs of converting older buildings from steam to hot water, the opportunities for HWHIs lie in new development.

Four areas near downtown or the riverfront (Fig. 8) appear to have significant potential for the development of HWHIs. While the exact size or timing of these developments is unclear, these areas will certainly experience significant development in future years. Development plans for these four areas follow:

1. Burlington Northern — This area offers great potential for a combined commercial and residential development. It is estimated that the development will include ~1000 m^2 (1.25 million ft^2) of housing and 1000 m^2 (1.25 million ft^2) of commercial or office space.

2. Industry Square — It is estimated that this develoment will include ~4200 m^2 (4.8 million ft^2) of housing and 870 m^2 (1 million ft^2) of commercial or office space.

3. East Bank — Development in the East Bank is estimated as 870 m^2 (1 million ft^2) of housing, 350 m^2 (400,000 ft^2) of commercial or office space, and 790 m^2 (900,000 ft^2) of manufacturing.

4. Elliot Park — Elliot Park is a low-income area on the perimeter of downtown. It is estimated that 1900 m^2 (2.2 million ft^2) of housing will be developed in Elliot Park.

4.5.2 Heat island costs

Projected distribution system costs of the heat islands are calculated based on the St. Paul study and are shown in Table 13.

Building conversion costs were estimated by evaluating the heat loads of the various heat island areas and assuming that these new development areas would have a conversion cost factor approximately equal to the average hot-water conversion cost of \$62/kW (Table 15).

The heat exchanger loads were calculated assuming a 10% distribution loss from the central heat exchanger to the consumer. These loads are given in Table 16.

The total equipment cost[9] of the 3rd Street Station in the St. Paul study is used to estimate the equipment cost of the heat islands.* Included in the total are costs for: (1) structures; (2) heat exchanger;

*These costs were scaled using a scaling factor of 0.6; cost = cost for 3rd Street $\left(\frac{\text{heat island size}}{\text{3rd Street size}}\right)^{0.6}$.

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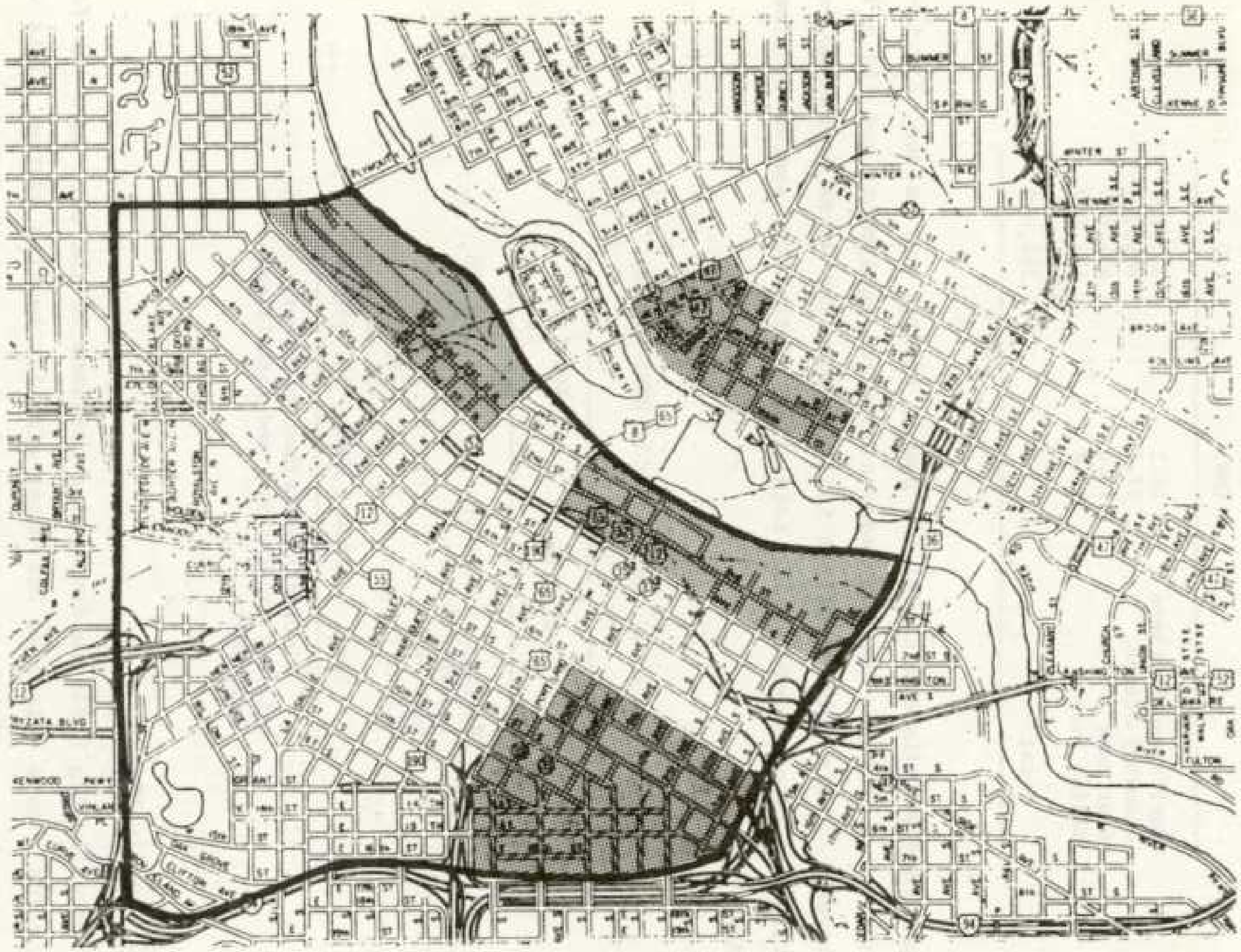

Fig. 8. Potential HWHIs.

Table 16. HWHI loads and total equipment costs

District	Heat exchange load (MW)	Total equipment cost ($)
Burlington Northern	16.2	532,000
Industry Square	37.5	880,000
East Bank	14.2	491,000
Elliot Park	14.2	491,000
Total		2,394,000

(3) pressure vessels and tanks; (4) pumps, piping, and valves; (5) instrumentation controls and accessory electrical equipment; and (6) a 15% contingency. This total does not include costs for water treatment facilities for make-up water. The total cost of the HWHI system is given in Table 17.

Table 17. Total cost of HWHI system

District	Total cost[a] ($)
Burlington Northern	2,688,000
Industry Square	5,882,000
East Bank	2,796,000
Elliot Park	2,303,000
Total equipment HWHI	13,669,000

[a]Includes distribution network, building conversions, and heat island equipment.

4.5.3 Implication

Establishing HWHIs in developing sections of the city lays the foundation for a more extensive hot-water district heating system. This would encourage the use of building heating systems compatible with a hot-water distribution system in both new and renovated buildings. If a total hot-water district heating system becomes a reality, then cogeneration from Riverside could be more effectively implemented.

5. OPTIONS FOR SYSTEM EXPANSION

5.1 Introduction

Chapter 5 is a description of the various district heating options available to Minneapolis. The existing steam district heating system is in good condition and is relatively new.

Options exist for extending or replacing this system and/or improving the fuel mix for the system. An important set of options involves running a large steam or hot-water line from the Riverside plant to provide steam or hot water to the Minneapolis District Heating System. This steam or hot water would be based on coal rather than oil or natural gas. Municipal refuse may also be burned to raise steam.

The options evaluated are: (1) steam line to serve M1 (the area served by the existing district heating system), (2) steam line to serve M1 and four HWHIs, (3) steam line to serve M1 and M3 (M3 is the central business district except for the M1 area), (4) hot-water line to serve M1, (5) hot-water line to serve M1 and four HWHIs, (6) hot-water line to serve M1 and M3, (7) RDF and mass burning, and (8) do nothing. Other options included providing service to only those parts of M3 with relatively lower building conversion costs, serving industrial customers, and providing very high-temperature water. These alternatives were not included in the final summary of options because they require detailed study beyond the scope of this evaluation. Options (1) through (3) are discussed in Sect. 5.4, (4) through (6) in Sect. 5.3, (7) in Sect. 5.5, and (8) in Sect. 5.2.

If hot-water distribution is used, the existing steam distribution system in M1 must be replaced. Distribution networks in M3 and the heat island areas will be new for both steam and hot-water systems. Building conversion costs for a 120°C (250°F) hot-water system are higher than for a steam system because many of the buildings were originally designed for steam heat.

The HWHIs can provide a foundation for future expansion of a hot-water system throughout the M3 area. This phased approach allows the gradual conversion of buildings to hot-water systems according to normal renovation and rehabilitation schedules. These converted buildings will then form a growing market for a future hot-water line. When a hot-water line is added to serve this market and the original HWHIs, excess steam line capacity will become available. This could be used to serve industrial customers with high load factors.

Hot water could also be piped from Riverside at temperatures high enough to produce low-pressure steam for use in steam-heated buildings. This energy source would be appropriate for the downtown area outside the existing district heating system. If it were also used for the existing system, a new hot-water distribution network would be required. However, this type of hot-water system has a very serious technical drawback. The hot water experiences a very small drop in temperature when it is used to produce steam, so more water must be circulated to deliver a given quantity of heat. The water leaving the building is still at a relatively high temperature and contains a significant amount of unused energy. The energy costs to the consumer would likely be very high to account for the consumption of large amounts of hot water and the rejection of this unused energy.

A final option is to do nothing. This choice would limit the size of the existing steam system and require the continued use of oil and natural gas. It is preferable, however, to provide heat to the residents of Minneapolis based on either coal or RDF rather than oil or gas. This leads to the consideration of a hot-water district heating system and the local RDF options. A Riverside hot-water line will be able to serve new customers but will be unable to serve the existing steam customers without extensive capital investments in their systems.

As noted in previous ORNL studies, hot-water district heating systems are generally preferable to steam district heating systems, especially for distribution distances that exceed ~8 km (5 miles). This fact is especially true when planning a new system or replacing an old system that is no longer in good operating condition. This generalization is not applicable to Minneapolis because the existing steam district heating system is new, has a condensate return line, and is relatively efficient. Therefore, it is more appropriate in the Minneapolis situation to consider hot-water distribution systems for future expansion rather than for replacement of the existing system.

Ultimately, the choice must be based on cost and energy conservation considerations. The cost considerations must consider both the short- and the long-term implications of any decision. Energy considerations should include not only the cost of the energy form, but also the security of the energy supply under consideration.

5.2 Incremental Expansion (Do Nothing)

The first option considered for the expansion of district heating is for Minneapolis to play no direct role and simply let the system grow incrementally in response to continued development downtown. The existing downtown district heating system has grown rapidly in recent years and has attracted almost all new downtown buildings to its system. The system could continue to grow as development occurs but is constrained by the high fuel cost of natural gas and oil, possible boiler capacity limitations, and the inefficiencies and costs of a large steam distribution system.

The present downtown system is fueled by interruptible natural gas and fuel oil. The new, large boilers of the MEC are more efficient than smaller, less sophisticated boilers used in individual buildings. In addition, the district heating system is more convenient for building owners and reduces their initial capital costs as well as maintenance costs. Though the present system offers its customers this added convenience at reasonable cost, it is operating on a very fragile profit margin because it must pay high fuel costs that will continue to increase in the near future.

The MEC has secured future commitments for steam sales that it cannot supply with its existing boilers. While there is additional space in their facility to add four more boilers, thus tripling their production capacity, they may be constrained by environmental and Fuel Use Act regulations. Though the necessary permits will likely be obtained for the additional boilers, additional expansion could be constrained by environmental regulations.

The costs per megawatt of load of the distribution lines for the present district heating system are low because of the very high thermal load density in the center of downtown. As the system expands to lower density areas to serve new buildings that use significantly less heating energy, the distribution costs will become much more significant. In addition, the longer distribution lines will incur greater energy losses, thus reducing the effect of the efficiency advantage of the MEC boilers over individual building boilers.

When one combines the impacts of high fuel costs with increasing distribution costs and distribution lines losses, the potential for significant expansion of the existing district heating system appears limited. However, even if significant expansion does occur, it offers no real advantages to the city if natural gas and fuel oil are used to fuel the system. As long as scarce and costly fuels are used, we will continue to export tens of millions of dollars each year for fuel.

District heating provides significant economic advantages only when fueled by inexpensive abundant fuels such as coal, solid waste, or either of these fuels used in a cogeneration system. Without the assistance of the city, this is unlikely to occur until the late 1980s, if at all. Therefore, this option is not in the city's best interest.

5.3 Hot-Water Line to Riverside

5.3.1 Energy savings

Cogeneration turbines may be either back-pressure turbines or extraction turbines. Back-pressure turbines are used for stable, continuous operation, and extraction turbines are used where seasonal load change is a factor. In a back-pressure turbine, all of the steam is removed at a chosen pressure and used for industrial process purposes or district heating. This type of turbine system does not have turbine stages below the chosen back pressure and cannot generate electricity with steam at conditions below this chosen pressure. Back-pressure turbines may be chosen by winter-peaking utilities with high winter steam demands. These utilities meet their simultaneous peak demands for steam and electricity with reduced capital equipment costs.

In an extraction turbine, steam is removed between turbine stages. A portion of the steam flow remains in the turbine cycle and is used to produce electricity at lower pressures. The extraction point is usually controllable so that only the required steam flow is extracted, and the remainder is used to produce electricity. This type of cogeneration cycle is usually chosen by utilities with winter-peaking steam loads and summer-peaking electrical loads. Most utilities in the United States have summer-peaking electrical loads and therefore choose extraction turbines for cogeneration.

A hot-water district heating system requires a very low extraction pressure, ~0.1 to 0.2 MPa (15 to 30 psia). Steam systems require much higher extraction pressures. As the extraction pressure increases, the electrical output decreases. Figure 9 shows this trade-off and was generated using a computer model of a turbine cycle.[11] This decrease in electrical output decreases the overall efficiency of the system. A decreased efficiency means that more fuel must be consumed to provide the same energy services.

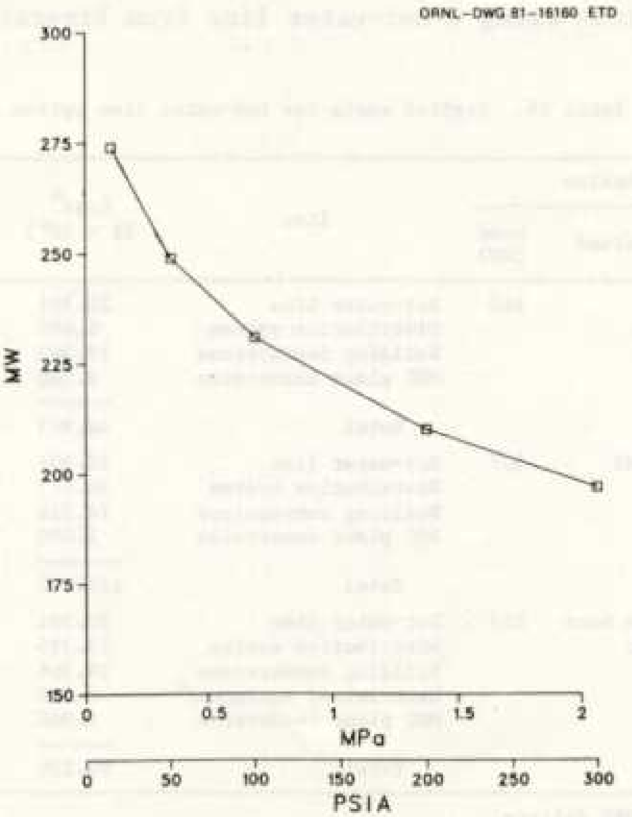

Fig. 9. Electrical output vs extraction steam pressure for a 358-MVA generator with a 125-kg/s (1×10^6 lb/h) steam extraction.

5.3.2 Cost considerations

Studsvik has calculated the cost of installing large hot-water lines for energy transmission.[1] This cost is given as a function of pipe diameter for various soil types and installation conditions. An installed two-way pipe cost of $20,301,000 was calculated for a line connecting Riverside and M1 using these correlations and escalating the costs to 1980 dollars. This is close to an HDR estimate[12] of $21,230,000 for the same size pipeline designed to carry steam along the same route.

The Riverside plant is described in Sect. 4.1. The addition of a cogeneration turbine will not be considered until the late 1980s. The near-term cost of the energy carried by a hot-water line will therefore be approximately the same as if it were carried by a steam line. The Riverside plant modifications are included in the energy cost charged by NSP.

Building conversion and distribution system costs are given in Sects. 4.4 and 4.3, respectively. Table 18 shows the total capital costs for various options using a hot-water line from Riverside.

Table 18. Capital costs for hot-water line option

Option: Area served	Option: Load (MW)	Item	Cost[a] ($ × 10^6)	$/MW
M1	160	Hot-water line	20.301	
		Distribution system	6.680	
		Building conversions	19.962	
		MEC plant conversion	2.000	
		Total	48.943	305,900
M1 and M3	507	Hot-water line	20.301	
		Distribution system	36.175	
		Building conversions	74.324	
		MEC plant conversion	2.000	
		Total	132.800	261,900
M1 and 4 heat islands	235	Hot-water line	20.301	
		Distribution system	13.355	
		Building conversions	24.564	
		Heat island equipment[b]	0.000	
		MEC plant conversion	2.000	
		Total	60.220	256,300

[a] 1980 dollars.

[b] HWHI equipment is unnecessary with this distribution system.

5.3.3 Implications

The high building conversion costs make this alternative difficult at the present time. A hot-water line will be more appropriate after a hot-water market has been established by the expansion of HWHIs.

5.4 Steam Line to Riverside

5.4.1 Energy savings

Nearly all of the potential energy users on the receiving end of the energy transmission line from Riverside now burn natural gas, fuel oil, propane, residuals, or a combination of these fuels. The large industrial users primarily burn fuel oil, and only the large utility generating stations use coal.

The energy savings, in terms of imported oil, could approach ~885,000 bbl/year on full implementation of the district heating system.

Ultimately, a fuel oil savings by the energy supplier generates a cost savings for the energy consumer. Most predictions show a rapid escalation of the cost of oil compared with that of coal or processed solid waste, therefore magnifying future savings. Also, having a single large energy source rather than several smaller plants enhances the overall cost-effectiveness of this project.

5.4.2 Cost considerations[12]

Three alternative energy transmission lines were studied by HDR before recommendation of a steam line. The alternative transmission lines included: (1) initial operation with hot water; (2) initial operation using steam at 2.07 MPa (300 psig), with future conversion to hot water; and (3) use of 2.07-MPa (300-psig) saturated steam. This pressure was chosen because the existing steam system uses 1.72-MPa (250-psig) steam, and MEC has requested that steam be delivered at this pressure. The 2.07 MPa (300 psig) allows for pressure losses in the line from Riverside to the downtown area.

These alternatives were evaluated for several different routings and pipe sizes:

1. Plan A — Under this plan, energy would be transmitted along the most direct route from NSP's Riverside plant to the MEC via a 0.76-m-diam (30-in.) steam line and a 0.3-m-diam (12-in.) condensate return.

2. Plan B — This plan is the same as Plan A, except that it incorporates a 0.6-m (24-in.) steam pipe rather than a 0.76-m (30-in.) pipe.

3. Plan C — This plan provides for initial operation with steam (Plan A) and future conversion to hot water with two 0.6-m (24-in.) pipes. These pipes are designed for the initial steam conditions.

4. Plan D — This plan is the same as Plan A, except that the steam line is routed north from the Riverside plant to a railroad bridge for crossing to the west bank.

The construction costs of each plan were estimated assuming contactor's overhead and profit of 8% with engineering fees and contingencies of 15%. Labor rates and cost data in 1980 dollars were supplied by the vendors and contractors for the analysis. The costs included $1,842,000 for reboiler and auxiliaries at the Riverside plant. The construction costs were determined to be as follows:

1. Plan A — $20,477,000
2. Plan B — $19,235,000
3. Plan C — $23,072,000
4. Plan D — $24,473,000

The construction costs of Plans C and D are prohibitive, being 12.7 and 19.5%, higher than Plan A respectively. Plan B is the least expensive but does not permit as great a future expansion of the steam transmission capacity as would Plan A. Both A and B could, at some future date, be retrofit for a hot-water system by retrenching and adding another 0.6-m (24-in.) pipe. Plan A is the preferred piping system because of its flexibility for increased steam capacity, its potential for conversion to hot water, and its moderate cost.

The Plan A proposed thermal transmission line location is shown in Fig. 10. The cost breakdown of this plan is shown in Table 19.

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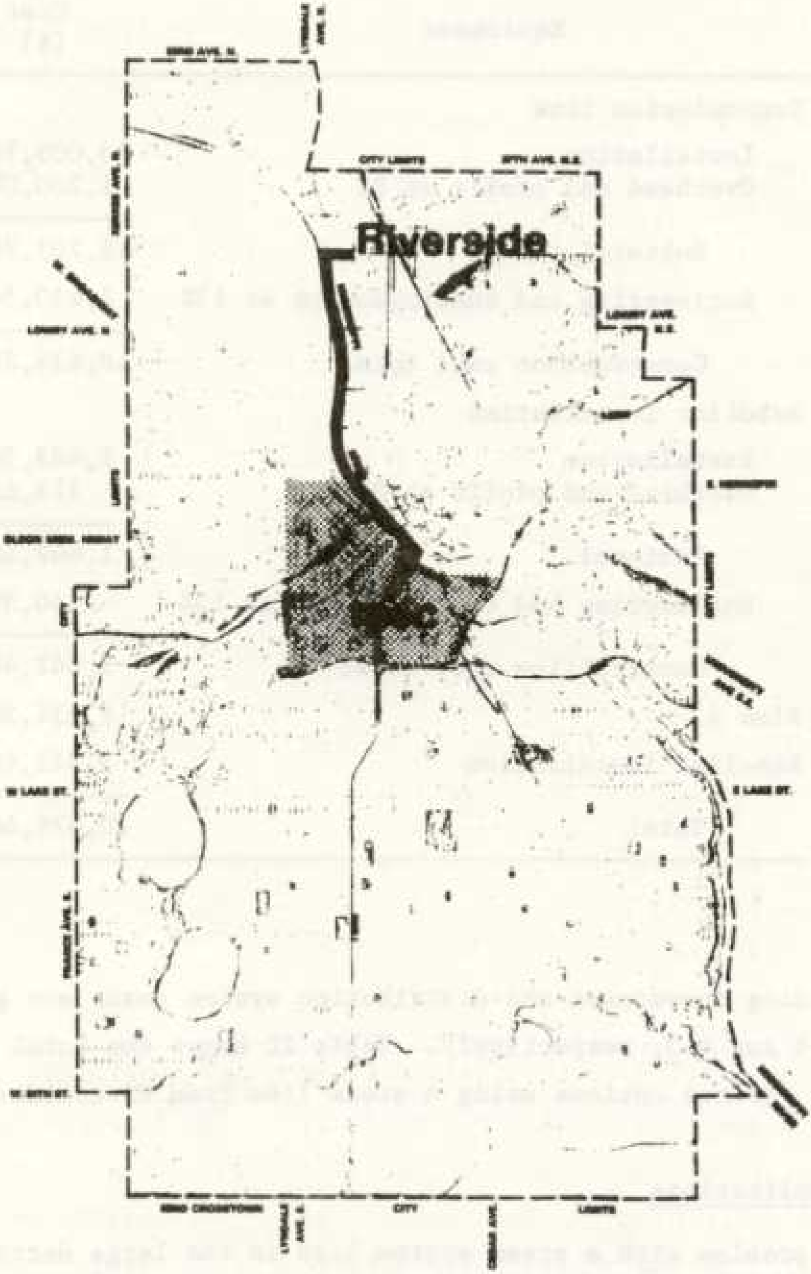

Fig. 10. Possible steam transmission line route from Riverside to MEC.

Table 19. Cost summaries for Plan A

Equipment	Cost ($)
Transmission line	
Installation	15,003,700
Overhead and profit at 8%	1,200,000
Subtotal	16,203,700
Engineering and contingencies at 15%	2,430,500
Construction cost total	18,634,200
Reboiler installation	
Installation	1,483,500
Overhead and profit at 8%	118,600
Subtotal	1,602,100
Engineering and contingencies at 15%	240,300
Construction cost total	1,842,400
Plan A	18,634,200
Reboiler installation	1,842,400
Total	20,476,600

Building conversion and distribution system costs are given in Sects. 4.4 and 4.3, respectively. Table 20 shows the total capital costs for various options using a steam line from Riverside.

5.4.3 Implications

One problem with a steam system lies in the large decrease in the peak electrical generation capacity when cogenerating. With a hot-water system, the overall energy recovery from the fuel burned can be increased more by using cogeneration than with steam cogeneration. This increased efficiency contributes to cost savings of at least 15% for cogenerated hot water. Steam, on the other hand, can be used for some industrial processes incapable of using hot water.

Table 20. Steam option capital cost

Option: Area served	Option: Load (MW)	Item	Cost[a] ($ × 10^6)	$/MW
M1	160	Steam line	20.477	
		Distribution system	0.0	
		Building conversion	0.0	
		Total	20.477	128,000
M1 and heat islands	235	Steam line	20.477	
		Distribution system	6.754	
		Building conversion	4.603	
		HWHI total equipment costs	2.394	
		Total	34.228	150,000
M1 and M3	507	Steam line	20.477	
		Distribution system	32.444	
		Building conversion	21.514	
		Total	74.435	147,000

[a]1980 dollars.

5.5 RDF and Mass Burn of Municipal Waste

5.5.1 The Riverside option

Since the metropolitan area landfills are expected to be filled by 1983 and the Hennepin County landfills by 1985, an urgency is developing for alternative waste management in the area. The recoverable energy reserve found in the waste generated by the county is equivalent to ~206 million liters per year (1.3 million bbl) of oil. Most of this energy could be recovered, and the amount of waste to be buried could be reduced by burning.

The process of converting raw municipal solid waste into RDF involves the following seven fundamental steps (Fig. 11) similar to the

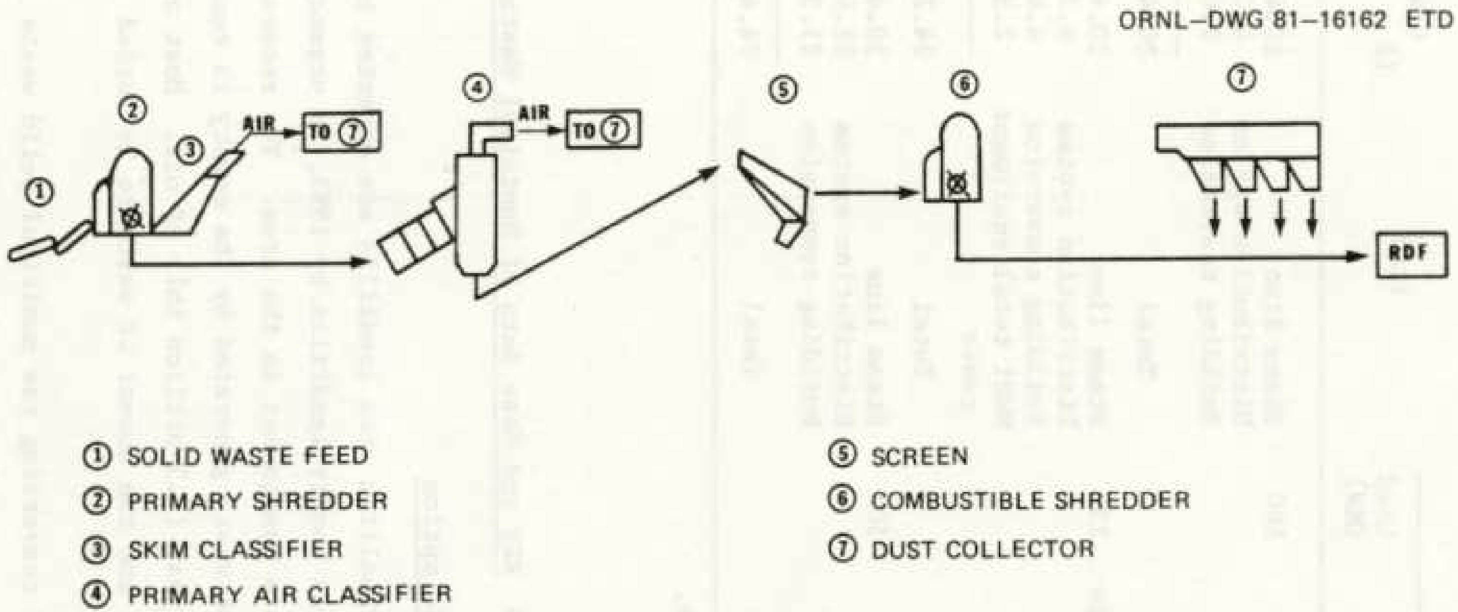

Fig. 11. Process for producing RDF from municipal solid waste.[14]

process developed by the St. Louis resource recovery facility:

1. solid waste feed;
2. primary shredder — reduces the incoming waste to <0.3 m (12 in.) in size;
3. skim classifier — removes the initial small quantity (15%) of light combustible materials (paper, plastic, and dust) from the coarse-shredded refuse and controls dust from the primary shredder;
4. primary air classifier — separates shredded feed material into light and heavy fraction;
5. screen — removes the fine glass, grit, and dirt from the light fraction of the air classifiers;
6. combustible shredder — fine shreds the refuse and discharges RDF for storage and loading; and
7. dust collector — removes dust from the processed air. Dust is added to light combustibles, becoming part of the RDF fraction.

Recent studies indicate specifications for the RDF. Although all of these specifications are not directly applicable to the Riverside option, the significant specifications for RDF include:

Heating value, MJ/kg (Btu/lb)	~12.8 (~5500)
RDF yield from municipal solid waste, wt %	71
Ash, %	12
Maximum diameter size for Riverside boilers 1 through 5, m (in.)	<0.15 (6)
Percentage of glass, dirt, and ferrous metals removed, %	85 to 95

The three resource recovery options under investigation include: (1) the sale of RDF to NSP for steam and/or electricity production, (2) the production of steam and/or electicity at a centrally located facility, and (3) the conversion of solid waste to steam at numerous industrial plants or other small markets using modular combustion plants. Each of these options could potentially supply the district heating system with steam and NSP with electricity.

The RDF sold to NSP could be used in the existing Riverside power station. NSP has examined the feasibility of burning RDF in the boilers at Riverside. The favored approach is to refurbish the retired Riverside boilers 1 through 5 at an estimated cost of $43 million (1980 dollars). This cost compares favorably with the estimated $76 million cost for new boilers of the same capacity installed at Riverside.

The specific modifications necessary to supply district heating steam from RDF at Riverside include a temperature and pressure control station, a reboiler, and renovation of the five boilers. The cost of the reboiler is included in the district heating system costs rather than in the plant costs.

5.5.2 Modular incineration[13]

Currently, a number of municipalities are investigating the possibility of employing municipal RDF in modular incineration to supply industrial customers. The Minneapolis district heating load is very large, predictable, and capable of accepting all the steam produced from modular incinerators. Supplying a portion of the district system's baseload with this type of incinerator would make the project more economically attractive because steam sales would constitute a source of revenue.

Modular incineration has received increasing attention from municipal governments as a means of acceptably reducing their volume of solid waste while simultaneously producing marketable energy products — steam or hot water. The modular design allows increased flexibility over conventional municipal incinerators in siting, pollution control, and operation requirements. The capability to expand incineration capacity by integrating additional modules permits the system to accommodate future growth in the solid waste supply. Factory fabrication permits cost savings and increases system reliability.

Most modular incinerators used for municipal solid waste employ a multichamber design. Multichamber incinerators consist of a primary burning chamber, a low-velocity settling section, and a reaction chamber (Fig. 12). The municipal waste is placed and burned in the primary chamber, frequently with the assistance of an auxiliary burner and with a

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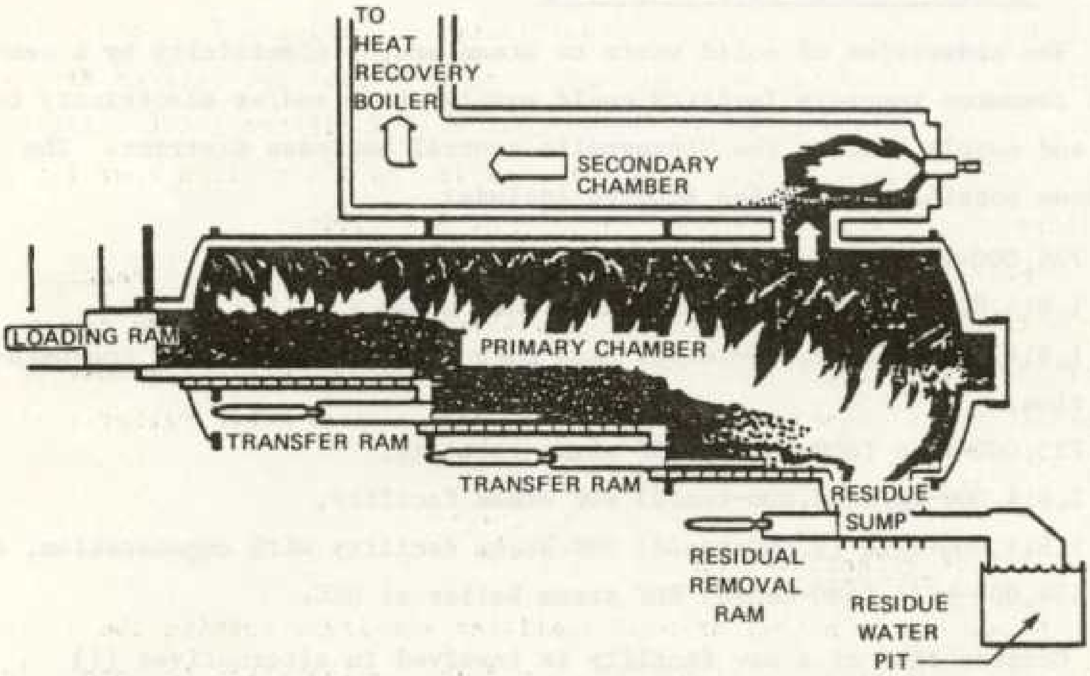

Fig. 12. Typical multichamber type incinerator.[14]

minimum amount of air. The floor and the primary chamber may be cast-iron grates or a refractory hearth. The hearth is claimed to be less susceptible to fouling by noncombustibles. Gases and particulates from the primary combustion chamber pass to a low-velocity transmission section where particulates are allowed to settle out by gravity. In the reaction section, the gases are completely oxidized by (1) maintaining the temperature at 870°C (~1600°F) using an auxiliary burner and (2) adding excess air for combustion.

Marketable steam (or hot water) is produced by heat exchangers located in the secondary combustion chamber (Fig. 12). During steam production, feedwater is pumped into the heat exchanger tubes, converted into steam, and passed into the steam separator drum. The steam pressure available for delivery is a function of steam generation rate and the system pressure.

A potential advantage of modular incineration is the cost differential between oil and RDF-supplied steam as oil prices escalate.

5.5.3 Central resource recovery study

The conversion of solid waste to steam and/or electricity by a central resource recovery facility could supply steam and/or electricity to NSP and supply heat to the Minneapolis central business district. The various possible facilities studied include:

1. 725,000-kg/d (800-ton/d) mass-burn steam facility,
2. 1,814,000-kg/d (2,000-ton/d) mass-burn steam facility,
3. 1,814,000-kg/d (2,000-ton/d) mass-burn steam facility with cogeneration,
4. 725,000-kg/d (800-ton/d) RDF steam facility,
5. 1,814,000-kg/d (2,000-ton/d) RDF steam facility,
6. 1,814,000-kg/d (2,000-ton/d) RDF steam facility with cogeneration, and
7. 454,000-kg/d (500-ton/d) RDF steam boiler at MEC.

Construction of a new facility is involved in alternatives (1) through (6), whereas (7) deals with installation of a new RDF-fired boiler in the existing MEC. The proposed capacities were chosen by a project team as most appropriate for the county based on the quantities of refuse, energy load characteristics, and other potential means of disposal. Alternatives (4) through (7) require processed RDF, which necessitates the building of a refuse preparation facility.

The potential market for steam and electricity can be found in Table 21. These three significant markets have indicated an interest in energy purchases and have provided information on the current conditions of energy value and delivery. Note that the energy values are current estimates and that the final market price is yet to be established. The values of steam to MEC and the Metropolitan Medical Center (MMC) are the current fuel replacement values for steam delivered to their respective distribution system. The value of steam to NSP assumes sufficient delivery to operate the low-pressure turbine generators. The full capacity of a 1,814,000-kg/d (2,000-ton/d) refuse-fired plant is required for operation.

The 725,000-kg/d (800-ton/d) mass-burn and RDF plants could be used to provide steam to the MEC and MMC. To meet the peak demands of these

Table 21. Potential market for steam and electricity

Potential market	Energy available			Energy value	
	Form	Quantity			
		Demand	Annual	Usable ($/unit)	Refuse [$/tonne ($/ton)]
NSP	Electricity	Unlimited	Unlimited	17.00/MWh	15.17 (13.76)
NSP	Steam, 2.76 MPa at 399°C (400 psig at 750°F)	450,000 kg/h (1×10^6 lb/h)	4.0×10^9 kg/year (8.8×10^9 lb/year)	1.63/GJ ($1.72/10^6$ Btu)	10.92 (9.90)
MEC	Steam, 1.72 MPa at 208°C (250 psig at 406°F)	135 MW (460×10^6 Btu/h)	1.23×10^6 GJ/year (1170×10^9 Btu/year)	3.79/GJ ($4.00/10^6$ Btu)	25.40 (23.04)
MMC and County Hospital	Steam, 0.93 MPa at 181°C (135 psig at 358°F)	29 MW (100×10^6 Btu/h)	6.75×10^5 GJ/year (640×10^9 Btu/year)	3.79/GJ ($4.00/10^6$ Btu)	25.40 (23.04)

loads, the existing gas or oil boilers will be used. The 725,000-kg/d (800-ton/d) plants could supply 67% of these total annual loads.

Two energy market situations could be serviced by the 1,814,000-kg/d (2,000-ton/d) plants. In one instance, NSP could use the steam produced to drive their existing turbines for electricity generation. The total capacity of the 1,814,000-kg/d (2,000-ton/d) plants could be used. In the second situation, these plants could supply electricity to NSP and steam to MEC and MMC with cogeneration. The heating loads would be supplied up to the limit of extraction of a new extraction turbine because of the higher efficiency of a cogeneration cycle. This cogeneration plant is the most expensive to build and produces the largest revenue.

The most attractive revenue-to-cost ratio occurs with the steam plant option at MEC. However, the downtown location poses environmental and transportation problems. The delivery of RDF and removal of ash in the congested downtown area are serious objections to the downtown site. The emission of flue gas near the tall office buildings must also be considered.

The estimated cost comparison is not the only factor that should be used to decide between an RDF and a mass-burn facility. The availability of the materials, their reliability, and the maintenance cost must be weighed. Mass-burn plants have been used in Europe for decades, and their operation and technology have been studied and proven successful. RDF is a rather new technology being advanced by major U.S. boiler companies. The history of RDF has been too short to permit a solid documentation of its merits and shortcomings compared with mass burn. The ultimate selection should be based on all information available, but on final analysis the selection may necessarily be based on costs and information unrelated to their technological differences.

RDF can also be coburned with coal, which may be attractive to NSP at Riverside or other power plant locations.

5.6 Industrial Steam Users

This study does not consider the application of a district heating system to industry. This omission is due to time constraints and not because the industrial sector is unimportant.

The addition of 24-h/d, 365-d/year customers would definitely improve the economics of a steam line from Riverside to Minneapolis. These customers would increase the annual load factor and therefore decrease the capital charge for each unit of delivered energy.

Any future evaluations of a steam line should survey potential industrial customers. Some of these customers may be able to use energy supplied by a hot-water line.

6. RECOMMENDED ACTIONS

6.1 Best Combination of Options

Because of the limited scope of this study, more detailed analysis and design work must be completed before any of the study recommendations can be implemented. This study concludes that Minneapolis should play an active role in the development of a steam line that links the downtown district heating system to the Riverside Power Plant and should concurrently develop a number of HWHIs.

When the steam line tunnels and culverts are sized, the option of making them large enough to allow the addition of a hot-water line at some future time should be considered.

The scope of this study was affected by limited time and resources. Capital cost evaluations cannot accurately portray the cost-effectiveness of many district heating systems. More accurate data about the existing buildings and their heating systems would be helpful but could require an extensive survey of the downtown area. Future studies should also consider life-cycle costs for the options.

6.2 Funding Sources

In spite of recent cutbacks in the federal budget, the city should submit a UDAG application for assistance in funding the steam line and HWHIs. Minneapolis can be in an excellent position for a UDAG if extensive involvement can be obtained from the private sector. In applying for a UDAG, special emphasis should be placed on the HWHIs, especially those that benefit low- and moderate-income people, such as those who live in Elliot Park.

Because district heating is so capital intensive, funding must be obtained at the lowest possible interest rate. Based on direction from the task force, the city should attempt to obtain funding from state bonds, city revenue bonds, and a variety of other funding sources.

6.3 Institutional Implications

A district heating system, fueled by a low-cost fuel such as coal, could provide stable prices for abundant energy that could attract development to provide a growing tax base and more jobs for Minneapolis citizens. Without the city's involvement, this fuel substitution will be difficult to achieve.

The city should create a district heating task force with major representation from the private sector. The task force should include, but not be limited to, the following representatives: user groups, BOMA, Downtown Council, Chamber of Commerce, MEC, NSP, Hennepin County, and the city of Minneapolis. This task force should develop an implementation plan and timetable for development of the steam line and HWHIs. Extensive consulting services will probably be required to effectively plan and implement these proposals.

Based on direction from the task force, the city should modify its zoning and buildings codes or other appropriate regulations to encourage the use of heat systems that are compatible with hot-water district heating.

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