ORNL/TM-6830/P2

District Heating/Cogeneration Application Studies for the Minneapolis-St. Paul Area

Executive Summary: Overall Feasibility and Economic Viability for a District Heating/New Cogeneration System in Minneapolis-St. Paul

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Lars-Åke Cronholm
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ABSTRACT

A study was undertaken to determine the feasibility of introducing a large-scale, hot water, district heating system for the Minneapolis-St. Paul area. The analysis was based on modern European hot water district heating concepts in which cogeneration power plants supply the base-load thermal energy. Heat would be supplied from converted turbines of existing coal-fired power plants in Minneapolis and St. Paul. Toward the end of the 20-year development period, one or two new cogeneration units would be required. Thus, the district heating system could use low-grade heat from either coal-fired or nuclear cogeneration power stations to replace the space heating fuels currently used — natural gas and distillate oil.

The following conclusions can be drawn: the concept is technically feasible, it has great value for fuel conservation, and with appropriate financing the system is economically viable.

1. BACKGROUND

Contacts between Studsvik,* the U.S. Department of Energy (DOE), and Oak Ridge National Laboratory (ORNL) in 1977 resulted in a proposal for studying the technique of introducing district heating on a large regional scale in a suitable metropolitan area in the United States. The district heating system would replace fuels in limited supply — gas and oil — by using thermal energy from coal or nuclear cogeneration power plants. After further contacts with key personnel in several cities and states, the Twin Cities area — Minneapolis and St. Paul, Minnesota — was selected as the location for the study.

The overall study contract was awarded to Studsvik, and ORNL was to serve as coordinator of the various activities. The Minnesota Energy Agency (MEA), local utilities, and local consultants became deeply involved. This report is an executive summary of work completed under the contract. Several phases of the study are being pursued in more detail by the electric utility, Northern States Power Company (NSP); MEA; and local consultants. Although the study is site specific, the general methodology is considered to be applicable for other cities in the northern area of the United States.

2. THE TWIN CITIES AREA

The Twin Cities area encompasses two concentrated municipalities about 7 miles apart — one in Minneapolis and one in St. Paul (Fig. 1). These areas are surrounded by a region of industrial sites and residential housing that links the areas into one continuous metropolitan region. The total metropolitan population of over 1 million includes 0.8 million within the two city boundaries. This dense population, coupled with the cold climate (>8000 Fahrenheit degree-days), creates a large heat demand.

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*Studsvik Energiteknik AB, formerly AB Atomenergi.

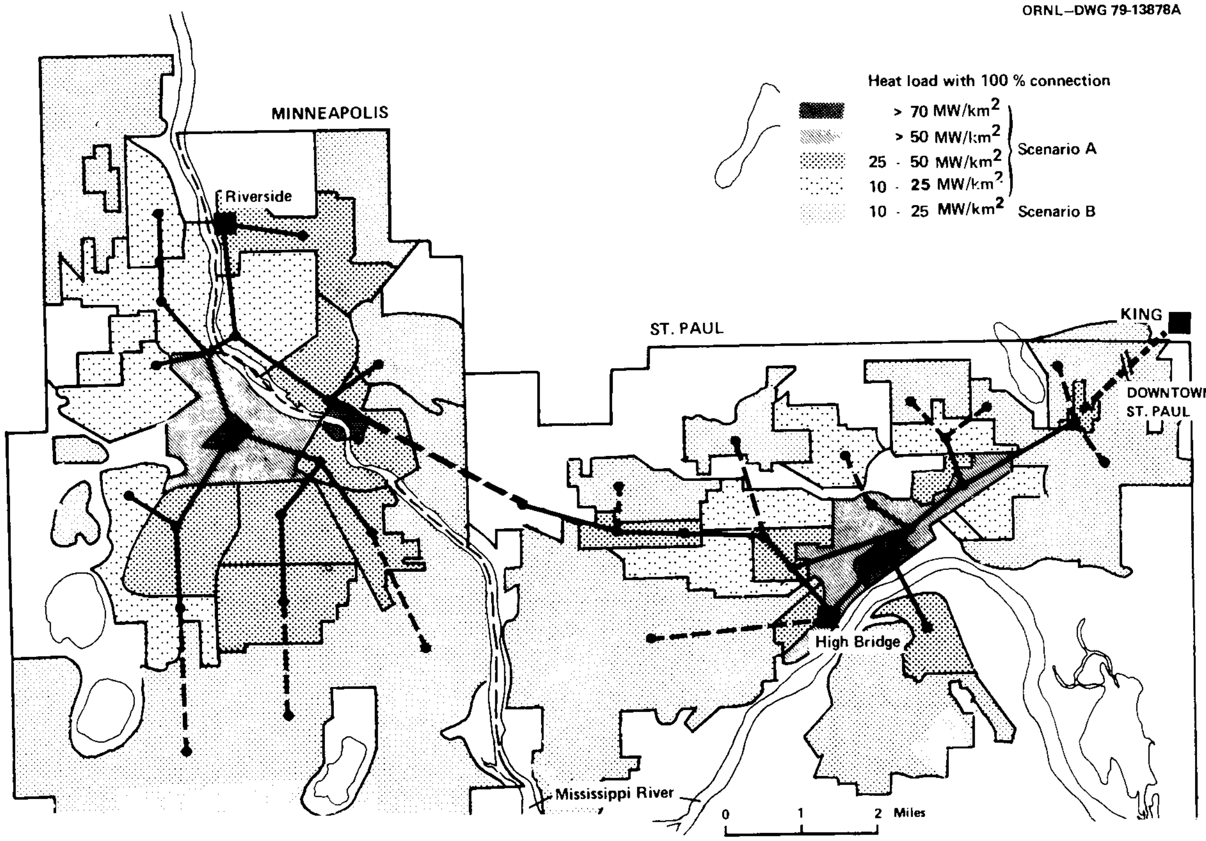

Fig. 1. Heat load densities in the Twin Cities area and possible regional piping systems.

Most of the heat demand is presently supplied by natural gas; however, gas supplies for the larger customers are interrupted during winter and replaced by oil. There are three small steam-based district heating systems in the area — an old one in downtown St. Paul [60 MW(t)], a fairly new one in downtown Minneapolis [about 80 MW(t), including also some district cooling], and one at the University of Minnesota [about 125 MW(t) also including some cooling]. These systems all use steam as the distribution medium and none uses cogeneration; however, a cogeneration plant has been proposed for the University. Thus, gas and oil have been the main fuels for district heating, with some conversion to coal at St. Paul and the University.

There are two fairly large coal-fired electric generating stations within the city boundaries — High Bridge for St. Paul and Riverside for Minneapolis — as shown in Fig. 1. A third station, Black Dog, is located about 10 miles south of Minneapolis, and there are several newer coal-fired and nuclear plants outside the metropolitan area. The closest of these is King, 17 miles from downtown St. Paul. King is also a possible site for another new unit.

This brief account indicates that the Twin Cities area is a prime candidate for a regional district heating system because of the following attributes:

1. a cold climate and a city structure well adapted to district heating and with a large potential heat load;
2. the present use of fuels that will become increasingly expensive and scarce (natural gas and oil);
3. the existence of coal-fired generating stations near the city with units suitable for conversion to cogeneration;
4. some tradition of district heating and yet not so much that the current steam distribution technology should strongly influence the technology to be used in the future; and
5. interested and cooperative local authorities and utilities with a desire to improve fuel usage and reduce air pollution.

3. SCOPE OF STUDY

Two levels of district heating implementation are discussed: Scenario A, which restricts district heating to the downtown and industrial commercial areas and nearby residential districts, and Scenario B, which also covers medium-density residential districts with one- and two-family houses outside the central parts of the cities. Over a 20-year period, these scenarios are estimated to involve a thermal load of around 2600 and 4000 MW(t), respectively, for the two scenarios (Fig. 2).

The 2600 MW(t) for Scenario A excludes the loads of the existing district heating systems in Minneapolis and at the University of

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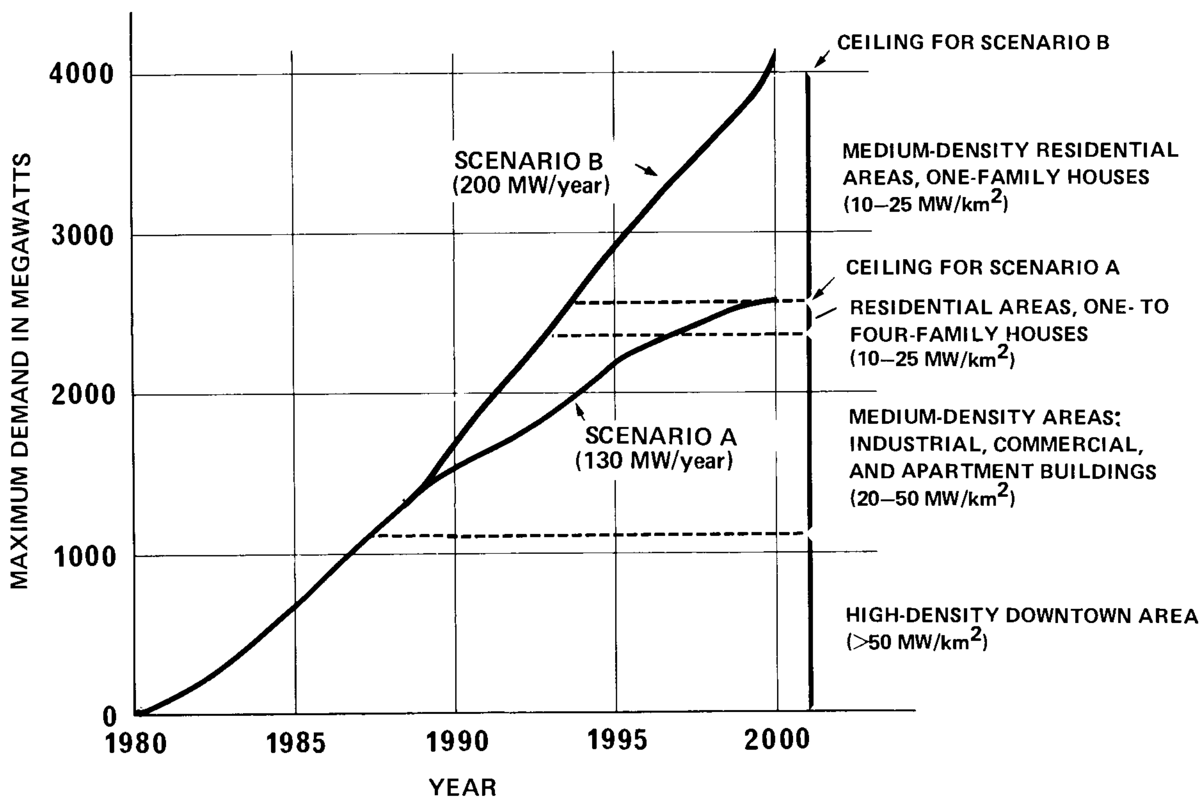

Fig. 2. Assumed load connection rates for Scenarios A and B.

Minnesota because more detailed studies on integration of these schemes into the overall scheme are necessary. It also excludes the loads of some large industries that require more study and all loads for future establishments within the area. To compensate for the conservatism of these assumptions, it was assumed in the base case that all remaining consumers within the area would subscribe to the service. The influence of a lower effective subscription rate was evaluated separately. For Scenario B, 70% of the potential additional consumers over and above those of Scenario A were assumed to use the service.

Although the assumed starting date for the development is 1980, practical questions may delay the date by one or more years. The basic technology assumed is that used in modern Swedish systems, which now supply an increasingly large part of the national demand for space heating and domestic hot water by hot water distribution systems. About 3 million people in a population of 8 million are now served by district heating at home or at work.

3.1 Principal Features of Proposed Concept

The proposed district heating concept functions as follows:

1. The base load is supplied by cogeneration plants that provide about half the total peak-load capacity but nearly 90% of the annual heat energy (Fig. 3). Most of the thermal energy from cogeneration units is provided by converting turbogenerators to pass-out machines at two existing power stations — Riverside in Minneapolis and High Bridge in St. Paul. As illustrated in Fig. 4, this greatly improves fuel utilization. Toward the end of the period, these units would be complemented by new units. A new unit at Riverside is assumed for Scenario A. For Scenario B, two larger units about 17 miles from the center of the city area are proposed because it seems impracticable to use the city power plants exclusively. The cogeneration plants replace large quantities of oil and gas by small quantities of coal.

2. The peak load and reserve capacity requirements are supplied by oil-fired, heat-only boilers. These have a large total capacity but supply only a small percentage of the annual heat energy. They are located at various points of the supply area, thus reducing the size of pipes necessary between the central cogeneration plant sites and the supply areas.

3. The heat is transported from the production plants to the various parts of the supply area by hot water mains in accordance with modern European district heating technology. Large pipes run through tunnels for the parts of the area having adequate rock structure. Elsewhere underground pipes protected by concrete culverts are used. The transport systems are built up separately in Minneapolis and St. Paul initially and then interconnected during the second half of the period.

4. The heat is distributed from the regional system to individual buildings and houses by a hot water distribution system that runs under pavements, under streets, or, where possible, through cellars.

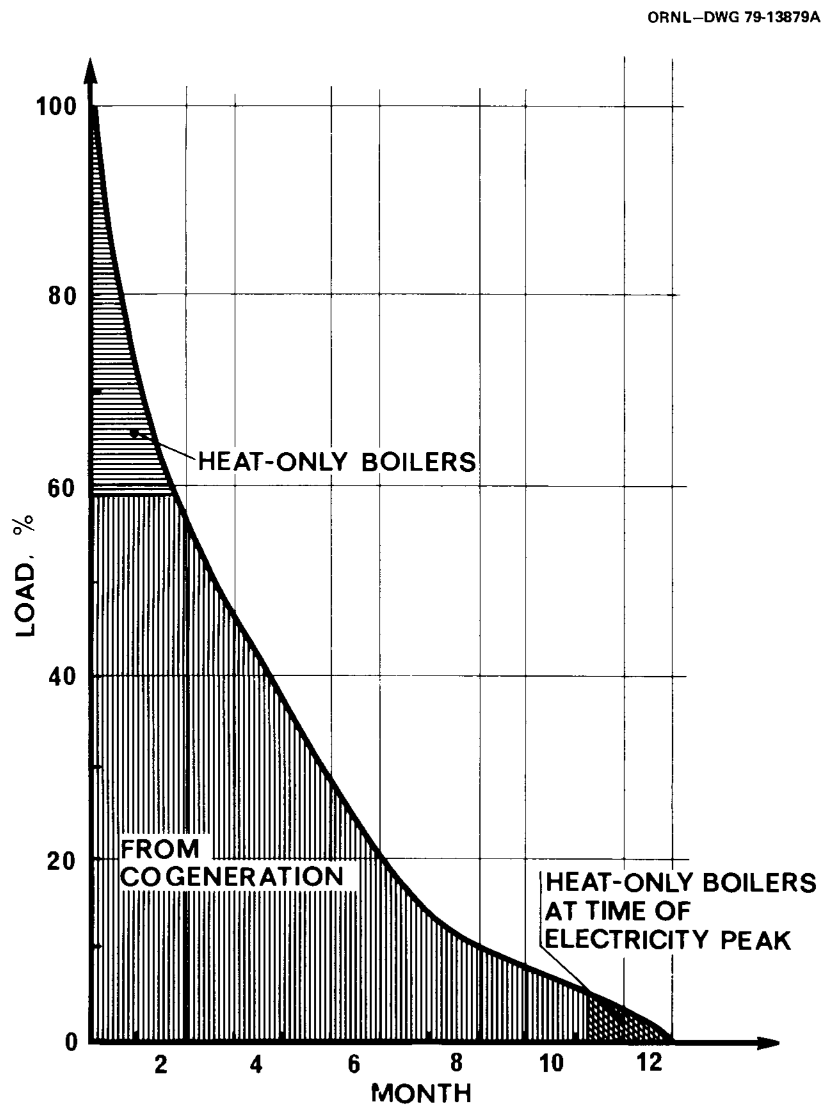

Fig. 3. Heat load duration curve and load distribution.

Prefabricated pipes complete with insulation and protection ducts are used. For Scenario B, in addition to conventional current piping systems, a newer type of piping distribution system for low-heat-density residential areas has been examined.

5. The heating systems of existing buildings are adapted so that they can be connected to the district heating system through heat exchangers. Different conversions are used for buildings and houses currently supplied by hot water, steam, or hot air.

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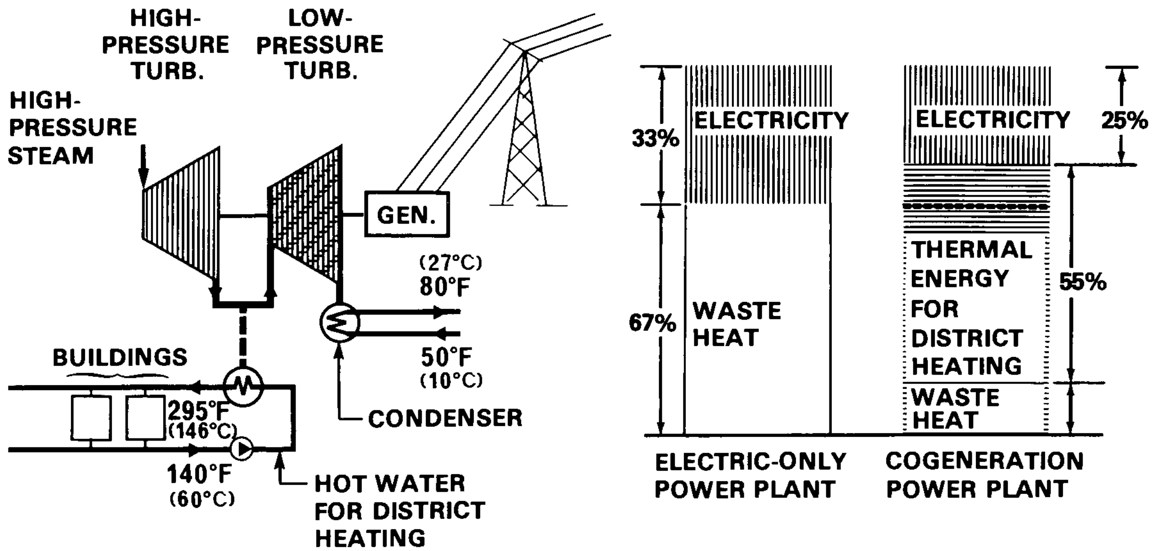

Fig. 4. Comparison of overall thermal efficiency of electric-only and cogeneration power plants.

6. The cooling loads were ignored in the analysis. However, in principle, existing absorption chillers could be converted to operate on hot water and could be supplied from the district heating system if certain restrictions are placed on the lowest permissible temperatures for hot water in the summer. The total capacity of such coolers is presently small, so that the impact on the overall economics would be minimal.

The system is built up progressively, starting with the densest heat load areas so as to start generating maximum revenues as soon as possible. The heat loads of the two existing district heating systems in central Minneapolis as well as the heat loads of some large industries have been ignored because more detailed studies are required before these loads can be integrated into the overall scheme.

3.2 Method for Calculations and Cost Estimates

Heat loads were calculated from data of actual gas consumption in the various subdistricts, corrected for curtailments and other factors.

Investments for the turbogenerator conversions were based on Swedish experience for similar conversions. Subsequent studies by NSP confirmed these estimates. Specific costs for the regional transport pipes were based both on available local data and on Swedish cost data for similar pipes in the Stockholm area — a congested area with higher specific costs than for other parts of Sweden. For the regional piping cost used in this analysis, an additional increment was added to the Stockholm rate. Local Minnesota data on tunneling costs were used for tunnels. The costs of the distribution systems for the individual subareas were estimated without going to the detail of drawing up a road-by-road network. The costs were estimated from data on Stockholm districts with similar ground conditions, densities, and building sizes. Even in this case, Stockholm has higher specific costs than other Swedish cities due to congestion and labor costs.

The regional piping system was designed using a computer program. The impact of the operation of the cogeneration plants on the electricity system was studied by comparing costs for all electric generating units in the NSP utility system without and with cogeneration.

The cost estimate for converting the heating systems of existing buildings for connection to a district heating system of the type proposed was based on a preliminary study carried out by MEA with the help of local consultants and advice from a Swedish consultant.

4. FUEL SAVINGS

The study shows that the district heating system would replace oil and natural gas equivalent to 49 and 61 million barrels of oil for Scenarios A and B, respectively, over the 20-year period studied (Fig. 5). Without district heating, the amount of fuels used for space heating with respect to the areas for Scenarios A and B is 57 and 72 million barrels. After correction for extra coal consumption at the power plants, the net fuel savings are 31 and 39 million barrels of oil, respectively. Thus, very substantial contributions to conservation of fuel — particularly the scarce fuels — are made. It should be pointed out that since the

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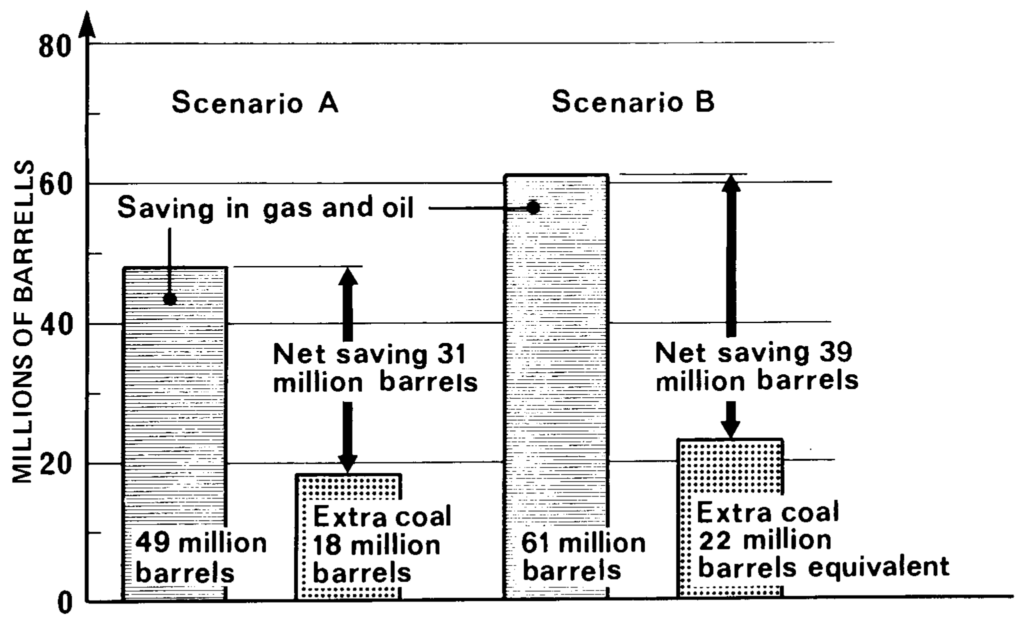

Fig. 5. Fuel savings realized with district heating, 1980-2000, Scenarios A and B.

system is developing from "ground zero" during this 20-year period, the fuel savings in the following years will be even greater. Almost as much fuel will be saved in the subsequent 10 years as in the first 20 years.

5. REQUIRED INVESTMENTS

The total additional investment for the utilities and buildings is estimated at 625 million 1978 dollars for Scenario A. The total investment for Scenario B is $1235 million with conventional distribution technology and $1136 million with newer technology (see Table 1).

6. ECONOMICS

Whereas, in practice, the cost of consumer heat system connections and conversions could be borne by the consumers or the utility (or both), it was assumed in the study that the utility would finance these investments. As a result, the rate charged for heat can be compared directly

Table 1. Total investments for Scenarios A and B

	Investment ($\$ \times 10^6$)		Investment per simultaneous maximum demand[a] ($/kW)	
Scenario A				
Cogeneration plants	55		21	
Peak load boilers	66		25	
Total production	121		46	
Hot water transport	104		40	
Hot water distribution	274		105	
Transport and distribution	378		145	
Production, transport, distribution	499		191	
Building conversion	126		48	
Grand total	625		239	
Scenario B				
Cogeneration plants	98		24	
Peak load boilers	114		28	
Total production	212		52	
Hot water transport	221		54	
Hot water distribution	601	502[b]	149	124[b]
Transport and distribution	822	723	203	178
Production, transport, distribution	1034	935	255	230
Building conversion	201	201	50	50
Grand total	1235	1136	305	280

[a]2621 MW, Scenario A; 4042 MW, Scenario B.

[b]New technology.

with the value of the fuel replaced by the elimination of individual boilers. The rate was set 10% below the cost of the fuel consumed by the cheapest alternative using individual boilers. Capital and operation and maintenance costs of individual boilers were not included in determining the cost of heat of the district heating alternatives.

The cheapest fuel, natural gas or oil, was used to assess these alternative costs, based on fuel price projections prepared by the utility (NSP). Initially the cheapest fuel is gas, but from the mid-1980s on it is oil. Swedish experience is that most consumers prefer district heating even if the cost is higher than that for alternative supplies because of the greater convenience.

If the cost of consumer system connections and conversions is borne by the consumers, the utility can offer a lower rate for the heat. This gives the consumer an additional saving that can be used to pay the capital charges on the investments.

The difference between the utility's income from sales of heat and the utility's annual operating costs and capital charges (including taxes) has been termed the "net saving."

6.1 Inflation and Fuel Costs

For the base cases, predictions by NSP on future inflation rates and development trends for fuel costs were used. These represent an inflation rate of 5 to 6%/year at the beginning of the period which will decrease to 4%/year by the year 2000. The cost projections are illustrated in Fig. 6. The inflation factor is applied in calculating investments and fuel costs in current dollars.

Coal costs are assumed to increase by about 1.3%/year in terms of 1978 dollars throughout the period. Electricity costs for auxiliaries such as pumps also increase only slightly in terms of 1978 dollars because the influence of some fuel price increases is counteracted by cost reductions due to the growth of the overall system.

Oil costs are assumed to reach world market prices of $16 per barrel of building heating oil by 1981* and to increase thereafter at about 2%/year

*Significant increases in world market prices have occurred since the beginning of the study.

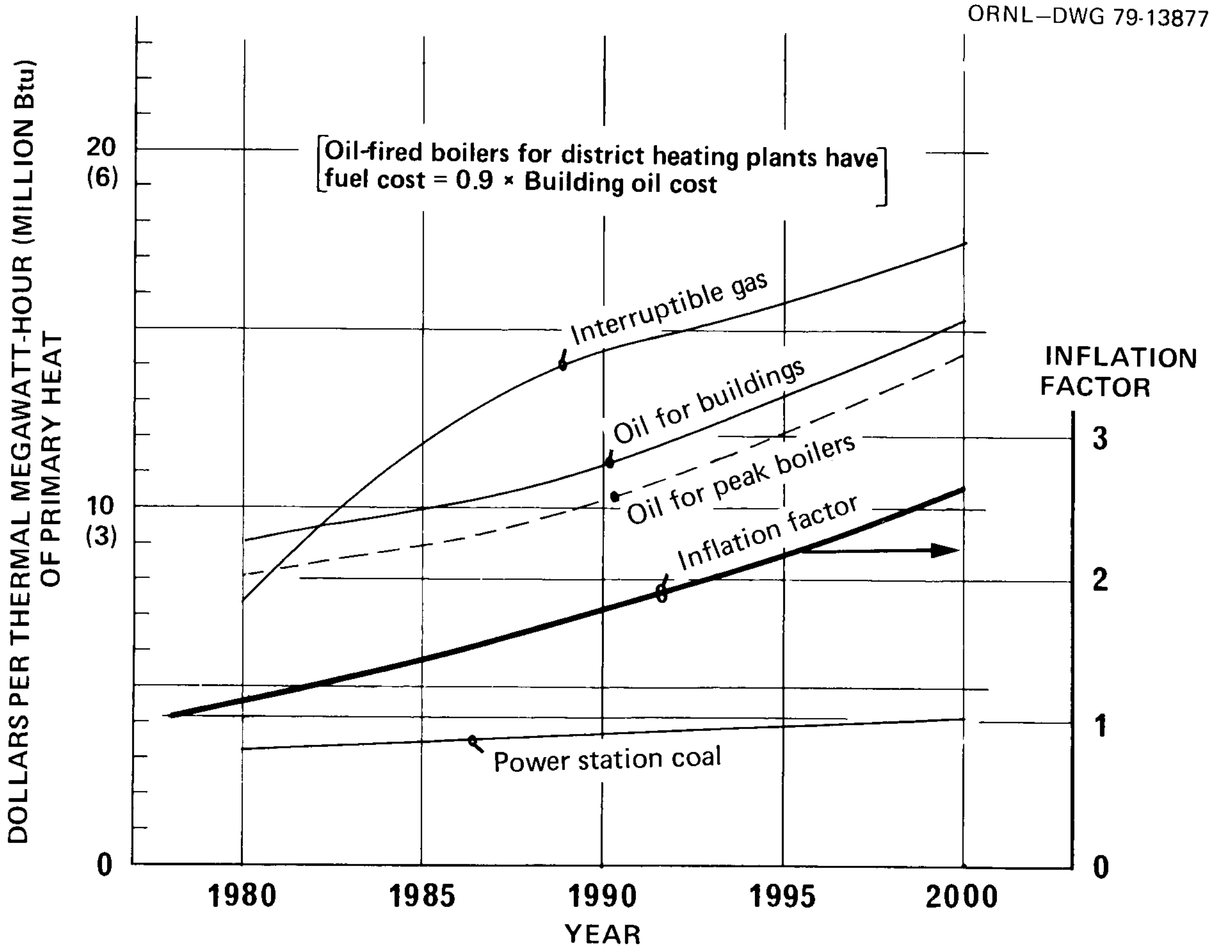

Fig. 6. Assumed costs of primary fuels over the period 1980–2000 in 1978 dollars (higher calorific value of fuel).

in terms of 1978 dollars (i.e., slightly more rapidly than inflation). The mean individual boiler efficiency is 70%, and efficiency for large heat-only district heating boilers is 90%. The additional residential load for Scenario B is assumed to have a mean individual boiler efficiency of 58%.

Gas prices are assumed to increase by a factor of 2.4 over the 20-year period. By the mid-1980s the gas prices to consumers begin to exceed those for light oil (houses) and medium-grade oil (buildings). The NSP estimators state that their oil price projections are on the low side for the long-term view. To compensate for this, an alternative case has been covered by the calculations in which gas and oil prices increase by an additional 1%/year.

6.2 Capital Charges

The capital charges (Table 2) for the district heating utility have been calculated on two bases: (1) with municipal utility financing and (2) with private utility financing including taxes.

Table 2. Capital charges and book depreciation periods[a]

Base	Capital (%)		Capital charges (%)		
	Debt	Equity	Interest on debt	Interest on equity	Tax
Private utility	50	50	8.4	13.36	51.95
Municipal utility	100		6.5		

[a]Book depreciation periods (years): transport and distribution lines (35), new cogeneration plants (30), conversion of existing turbines (20), heat-only boilers (25), consumer substations (15).

6.3 Results

The economic calculations for Scenario A and municipal financing show that the net savings are negative in the initial years but soon become positive (see Fig. 7). Over the entire period, there is an accumulated present worth net saving equivalent to 183 million 1978 dollars (Fig. 8).* With private utility financing, capital charges are higher and the accumulated present worth net saving therefore becomes negative — $77 million over the period studied. The sensitivity of the result to changes in assumptions (e.g., fuel cost projections) is also illustrated. With an intermediate financing system — private utility for the production plant and municipal financing for piping systems — the net accumulated savings would be about $132 million.

For Scenario B, municipal financing gives accumulated net annual savings of $238 million and $274 million for conventional and for newer distribution technology in the outer residential areas,

*All monetary figures in this section are in terms of 1978 dollars.

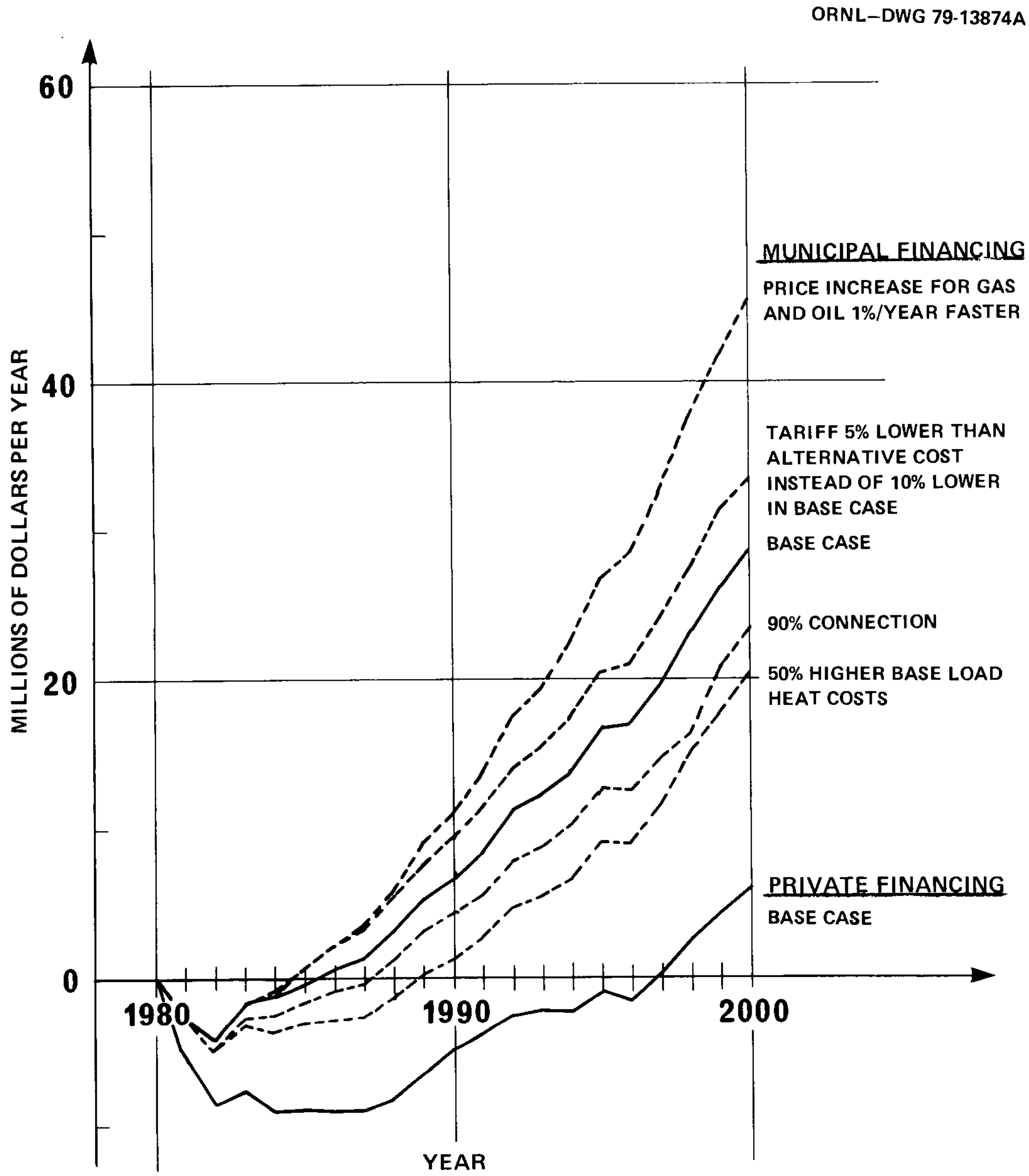

Fig. 7. Annual net savings in 1978 dollars, Scenario A.

respectively (Fig. 9). The savings are -\$151 million and -\$118 million for private utility financing and +\$171 million and +\$201 million for the intermediate case of private utility financing for production plants and municipal utility financing for distribution systems. Any significant positive net savings could be used to lower the rate charged for heat, thereby making the district heating system even more attractive to the customer when compared with the oil and gas alternative.

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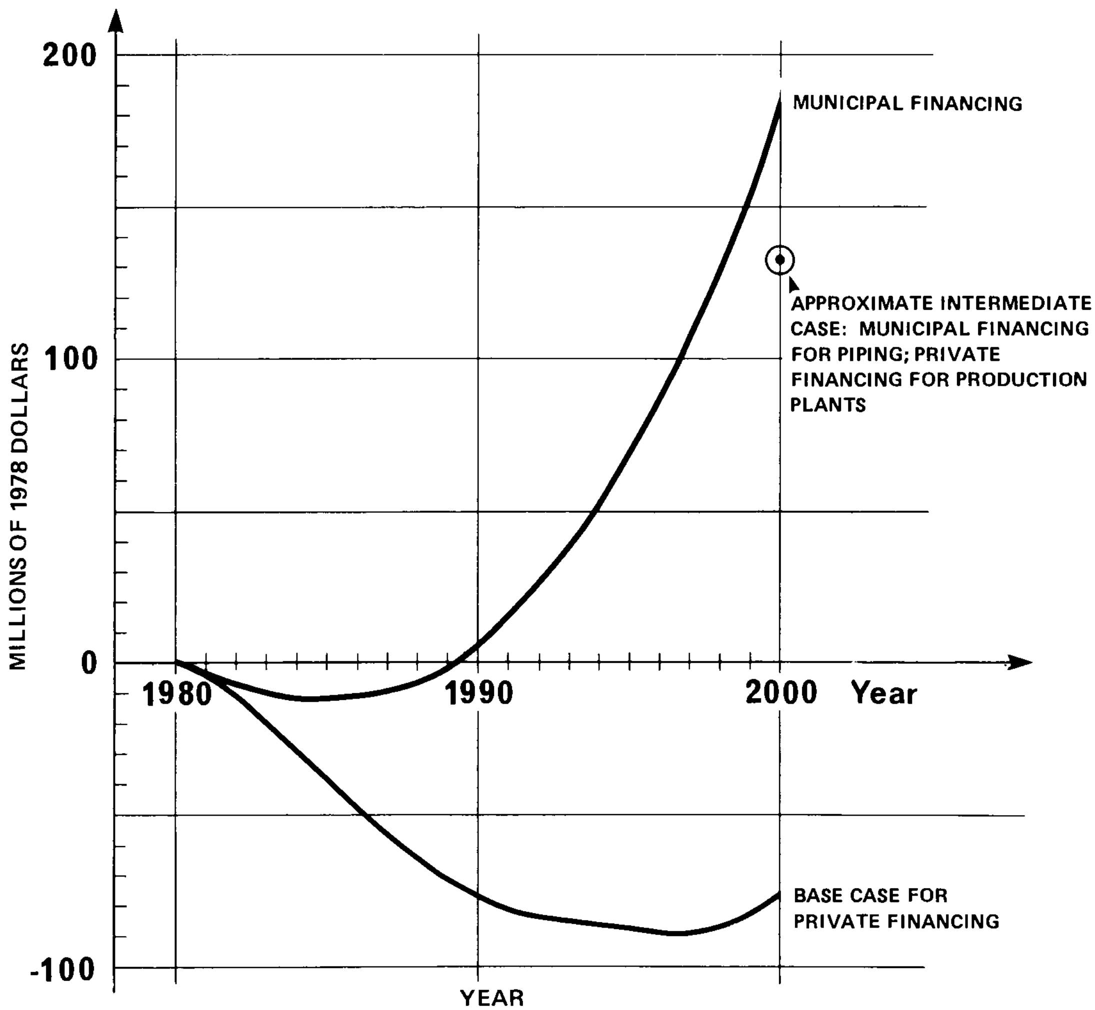

Fig. 8. Accumulated present worth of net savings for base case, Scenario A.

6.4 Sensitivity to Variations in Assumptions

The influence of different assumptions in the economic calculations has been evaluated (Table 3). For example, it is assumed that piping costs have been evaluated conservatively compared with the costs that would result if European experience were fully utilized. A 20% reduction in this cost would increase the accumulated net saving by about $44 million, and a 1%/year faster rise in fuel costs would increase the accumulated net savings by $125 million.

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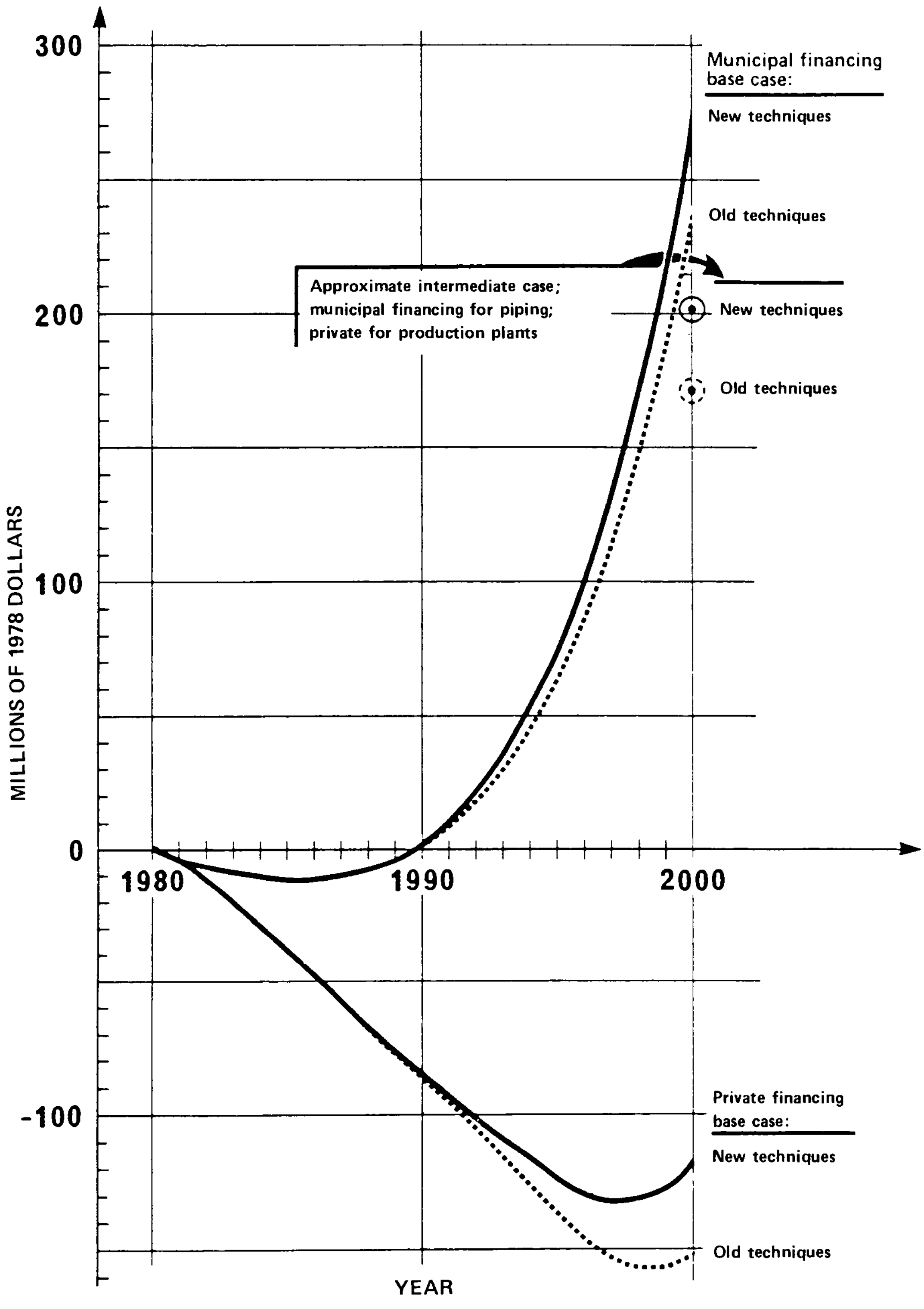

Fig. 9. Accumulated present worth of net savings for Scenario B.

Table 3. Sensitivity of net accumulated savings (millions of 1978 dollars) to changes in assumption, Scenario A

	Net accumulated saving		Change from base case	
	Municipal finance	Private utility finance	Municipal finance	Private utility finance
Base case	182.8	-76.5		
20% lower transmission and distribution costs	227.2	-32.5	+44.4	+44.0
90% connection without change in transmission and distribution costs[a]	127.2	-103.1	-55.6	-26.6
50% of building conversion costs charged to district heating system (instead of 60%)	189.6	-62.2	+6.8	+14.3
1%/year faster oil and gas cost increases	308.1	-13.7	+125.3	+62.8
50% higher base-load energy costs (coal)	81.3	-131.8	-101.5	-55.3
District heating rate at 5% below alternative fuel cost (instead of 10%)	234.3	-48.7	+51.5	+27.8
Includes the effect of property taxes (4.5% for the private utility finance)		-133.3		-56.8
Extends the economic analysis another 10 years for a total of 30 years	501.0	11.88	+318.2	+88.4

[a]Pessimistic assumption because transmission and distribution systems would be cheaper with 90% connection.

One of the potential benefits excluded in the analysis is the influence of a deferment of investments. This could be realized by connecting the low-pressure part of the existing steam district heating system in St. Paul to a hot water system via a heat exchanger producing low-pressure steam and then converting the system to water as the existing system becomes obsolete.

The variations in assumptions produce increases or reductions in the calculated accumulated net savings compared with the base cases. However, the base cases are assumed to represent a reasonable assessment with some conservatism of what really can be achieved (Table 4).

Table 4. Simplified assumptions that tend to give conservative (+) or optimistic (-) results compared with expectations, Scenario A

Assumption	Conservative assumptions	Optimistic assumptions
Heat-only boilers		
Neglect to use existing boilers at 3rd Street plant in St. Paul, at larger industries, and in larger buildings	+	
Assumption that sites can be found for new oil-fired boilers at all major line junctions		-
Heat storage		
Neglect of use of heat accumulators to cut daily load peaks and improve flexibility of cogeneration plants	+	
Existing low-pressure steam system		
Neglect to connect St. Paul 8-psi steam system load (about 40 MW) by heat exchanger to delay conversion and new mains	+	

More detailed studies are under way for the cost of converting the existing turbogenerators, for pipe design and cost estimates related to specified districts, and for building conversions that will allow the economic calculations to be refined successively during 1979.

7. ENVIRONMENT

Environmental effects are being studied separately, but some general observations may be made.

Experience from Swedish cities using mainly oil for heating indicates that district heating greatly improves air quality, particularly sulfur dioxide, at street levels. This improvement is partly due to elimination of low-level emissions and partly due to more complete combustion. In some cases, sulfur dioxide content at street level has been reduced by an order of magnitude. According to the assumptions made in the economic analysis for this study, without district heating, individual buildings would use the cheapest fuel available, which would be oil from the mid-1980s on. If the actual practice is in accordance with this assumption, a major increase in air pollution will occur in the Twin Cities area. However, district heating would restrict this pollution to limited amounts from high power station stacks, thus greatly improving air quality. If gas is used extensively for individual heating, even after the mid-1980s, the impact of district heating on air quality would be reduced, but the economics of district heating would be improved because gas prices are projected to be higher than oil prices.

8. INSTITUTIONAL ISSUES

Institutional issues are also being addressed separately. The present report emphasizes the importance of defining ownership at an early date, establishing favorable financing methods, at least for the piping systems, and the following:

1. clarifying at an early date permission to continue operation of converted cogeneration plants, bearing in mind the net beneficial effects on environment despite continued emission from these plants;
2. arranging forms of reasonably long-term loans for consumer connection and conversion investments; and
3. devising a rate structure for the sale of heat and other incentives to ensure that practically all consumers will connect to a distribution line once it is available (state and federal measures could help fulfill this goal).

9. CONCLUSIONS

The overall conclusion of the study is that district heating on a regional basis in the Twin Cities area is technically feasible, that large quantities of the potentially scarce and expensive fuels (natural gas and oil) can be saved, and that air quality can be improved. The economics are judged to be viable provided a suitable method of financing is used for the transmission and distribution systems.

The study should be complemented by more detailed engineering designs before the scheme can be implemented.

Much of the information and the methodology used is applicable also to other cities in the United States, though individual studies are necessary to establish the economics in each case.

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