Prospects for District Heating in the United States

District heating can effect a significant reduction in fossil fuel consumption.

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The oil crisis of 1973 made more visible the limits of the U.S. and world oil and gas resources and the political and economical uncertainties inherent in U.S. dependence on foreign oil. Appreciation of these factors has sparked increased research and development in the United States on new and improved technologies for energy supply. However, the cost and difficulty of achieving dramatic gains in energy supplies has resulted in great interest in methods of energy conservation. Energy can be conserved in a number of ways: by reducing demand, by improving the efficiency of end-use devices, and by multipurpose, that is, total energy, use. For example, oil or gas fuel used for home heating can be conserved by: (i) turning down the thermostat in the house; (ii) improving the combustion efficiency of the furnace and the insulation efficiency of the house; or (iii) multipurpose use which, in many cases, can save large amounts of energy without excessive cost or change in life style. For space and water heating systems, energy is only needed at relatively low temperatures—that is, 50° to 100°C. In many situations waste heat from electrical generation plants or industry could be used to meet residential and commercial space and hot water energy demands with resultant large savings in the oil and gas resources now consumed for such purposes.

Space and water heating together currently account for 19 percent of the total U.S. energy demand. Each year 1 billion barrels of oil and 0.2×10^{12} cubic meters of natural gas are consumed in the United States to meet these demands.

In many parts of the world, residential and commercial space and water heat is supplied through large-scale district heating systems. Such systems typically supply hot water at a temperature of about 100°C from a small number of localized sources through a grid of buried transmission and distribution pipes to many thousands of individual consumers. In this article, district heating refers only to space and water heating applications.

District heating systems have not been implemented to any significant degree in the United States. To some extent this has been a result of custom and institutional barriers, but for the most part has reflected the condition that consumers could generally meet their space heat and hot water needs more cheaply with individual heating systems than with district heating systems. The recent large increases in the cost of fossil fuels has made district heating systems much more attractive, however. This trend will continue and the balance will shift even further toward the more efficient district heating systems as energy supplies become scarcer. In addition, demographic projections show the urbanization trend continuing in the United States, with the emergence of new urban areas as well as intensification of population in existing ones. This will also favor a change to district heating.

In studies on the feasibility of district heating systems in the United States (*1*) the focus has been, in general, on the implementation and costs of systems for "new towns," where the district heat system would be constructed as part of a large new residential area. Such applications would be very limited, however, because the vast bulk of the U.S. population will continue to live in existing urban and suburban areas. Additional housing construction will occur in these existing areas but it will represent a relatively modest increase over that already in place, and it will be subject to limitations imposed by existing utilities and roads, for example.

Any significant implementation of district heating in the United States would require the installation of transmission and distribution pipes in existing residential and commercial areas. The laying of pipes under existing pavement will involve costs and public inconvenience substantially greater than those characteristic of systems built in new towns.

World Status of District Heating

Two obstacles to the implementation of district heating systems are mobilization of capital and institutional barriers. Such systems are expensive and usually affect many groups with conflicting interests. Probably only through federal participation could the planning and funding of such large projects be carried out. In fact, district heating systems have been implemented to the greatest extent in countries where the government has played a central role in planning and finance.

District heating systems exist in almost all European countries. Though an old idea, large portions of existing systems were installed during the period of rebuilding after World War II. Since then, district heating has taken a strong hold in Northern Europe and has become a matter of policy in Eastern European countries.

Though precise values for the number of consumers served by district heating systems are not available, approximate values can be estimated by analysis of the heating capacities of existing and proposed district heating systems. A rule of thumb is that the per capita consumption for space and water heat is 3 to 4 kilowatts under peak conditions. On this basis, Sweden is currently meeting the heating needs of about 1.5 to 2 million people or 20 to 25 percent of its population, through district heating systems. This includes several large cities such as Västeras and Malmö in which district heating supplies almost the entire population. Based on growth of its nuclear power program the Swedes project further growth of district heating to an additional 1 million people, including the residents of Stockholm, within the next 10 years. Overall goals call for district heat service to all cities, the waste heat sources being electric power plants and refuse incinerators.

In West Germany, about 3 million people, or 6 percent of the population,

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are now served by district heat systems. However, an extensive 2-year government study, which will soon be completed, assesses the characteristics of a nationwide "super grid" which will involve interconnected service to all cities with populations of 40,000 or more, using waste heat produced by electric generating plants and industrial processes. It is estimated that 94 percent of the space and water heat demand in West Germany can be met through this scheme at a capital investment of $18 billion (*2*). Besides the prime motivation of conservation, large-scale use of district heating also helps to minimize the problem of disposing of waste heat. Alternative uses for waste heat include agriculture, and studies in West Germany indicate that 50 km^2 of arable land could be heated sufficiently well by the heat output from a 1200-Mw nuclear electric plant to extend the spring and fall growing seasons. Two such projects are under way at Neurath and Gundremmingen. Thus, there may be a number of competing markets for "waste" heat.

Denmark has service, at present, to 32 percent of its population, highest in Western Europe, using refuse incinerators, electric plants, and oil-fired boilers as heat sources. For the future, Denmark has indicated the desirability of using waste heat from nuclear electric plants, as have France, Switzerland, and other countries. Finland currently has extensive district heating systems, reaching a total of 14 percent of all homes in the country. The government plans additional connections for a half-million people in Greater Helsinki alone within the next 10 years, using waste heat from nuclear electric plants.

The Eastern European countries have followed the lead of the Soviet Union in establishing a formal government position on the utilization of heat produced in conjunction with electricity. The Soviet Union is the world leader in implementing district heating with waste heat utilization. Seventy percent of the urban heat demand and 54 percent of the entire space and water heat load is met through district heating. Moscow, Leningrad, Kharkov, Kiev, Minsk, Rostov, and other cities have extensive district heating networks. Sixty percent of the district heat is supplied by heat-electric plants, and about one-third of all electric plants operate in this dual mode. This situation has been expedited by the government position that waste heat produced by large power plants should be utilized.

In all of these countries, district heat has been cost competitive with other heating methods. Two further conclusions can be drawn: almost all of the extant and projected district heating systems use hot water as the heat transport medium, and because of cost, environmental, and energy conservation benefits, Europeans project substantial increases in district heating in conjunction with the development of nuclear power.

Institutional Obstacles to District Heating in the United States

That district heating is enjoying success in Europe but not in this country is primarily a reflection of custom and institutional obstacles and not technical considerations. It might be argued that district heating has had the greatest success in countries having cold climates and that the U.S. climate is not suited to district heating. The cost of district heat is determined by system cost and total energy demand, which in turn depend on labor and material cost, population density, total population, climate, and the insulation and floor space characteristics of residential and commercial structures. These last quantities can be reduced to per capita consumption values. Table 1 shows that, on the basis of per capita residential space heat consumption, both the power density and the total energy demand for heating in American cities are comparable to those in European cities in which a substantial part of the demand is met with district heating. This is because American homes are not as well insulated as those in Europe, for example, and have greater per capita living space. Omitted from this table is a comparison of commercial space heat demands and water heat consumption. The former probably parallels the residential comparison, but the latter shows that Americans consume roughly twice as much heat in this sector as do Europeans. It follows that many American cities are as suited to district heating on the basis of energy demand as their European counterparts. Since hourly wage reflects to a degree the materials cost as well as labor expense, it is also apparent that many American cities should be as economically suited to district heating as their European counterparts. That district heating cannot be applied everywhere in this country, because of the pronounced variations in climate, should not diminish its appeal.

Another condition that influences the viability of district heating is availability and cost of alternative energy sources. But, even though oil was plentiful and cheap, worldwide, until a few years ago, district heating still became popular in Europe and not in the United States. Most of the early systems received heat from thermal plants which employed large fossil-fueled furnaces that were considerably more energy efficient and less air polluting than individual home furnaces. Appreciation of these factors helped to provide incentive for the European pioneering efforts in district heating. The following nontechnical considerations demonstrate the primary obstacles for district heating technology in the United States.

One factor contributing to the lack of interest in district heating systems in the United States has been the use of steam as the heat transport medium in U.S. systems. Steam is well suited to the transport of heat over short distances and can effectively meet the high-density demand encountered in the central core of cities. However, steam is inherently difficult and costly to transmit over long distances. Thus, there has been little in-

Table 1. A comparison between several European cities known to have extensive district heating systems and similar American cities; NA, not applicable.

City	Climate*	Total population (thousands)	Population density (people/km^2)	Annual per capita residential space heat consumption (Gj)	Hourly wage (U.S. dollars)†
Stockholm	8100	750	4015	23	7.12
Malmö	6700	254	2340	19	
Helsinki‡	8400	750	600	18	NA
Hamburg	6300	1800	2390	21	6.19
West Berlin	6100	2000	4170	20	
Denver	6300	515	2080	34	
Chicago	6200	3367	5840	33	
Minneapolis	8400	434	3040	45	6.22
Detroit	6200	1511	4230	33	
Buffalo	7100	463	4330	38	
New York	5000	7895	10200	27	

*Calculated as degree-days: cumulative average daily variation below 65°F (18°C). †1975 National hourly wages, including benefits [from (*13*)]. ‡Helsinki metropolitan area.

Table 2. Cost projections for district heat (DH), at point of consumption, for service levels indicated. Data are for cities, except where indicated; DH, district heating.

Urban area	Population encompassed by DH system (%)	Total population served by DH system (thousands)	Average cost for heat supplied (dollar/Gj)	
			From plants sited within the area served	From plants sited 32 to 40 km away from area served
New York	95	7500	0.85	1.09
Chicago	33	1098	0.74	1.10
Philadelphia	79	1543	0.76	1.00
Los Angeles	33	933	1.44	1.73
New Orleans	31	185	1.08	1.53
Baton Rouge	45	74	1.78	2.43
Jersey City*	83	503	0.80	1.08
Newark†	64	481	0.79	1.08
Paterson†	50	173	0.90	1.26

*Data for standard metropolitan statistical area (SMSA). †Data for part of SMSA.

centive for a steam utility to grow with its city. This early experience with district heating established the pattern by which district heating is still viewed today in the United States, where steam supply systems still serve small core areas of cities at a level equivalent to a total population of about 2.5 million (*3*). The European experience has clearly demonstrated that hot water transport is more economical and permits the use of larger systems serving greater populations.

Finally, in the United States, space and water heating systems have generally been in the realm of private enterprise. However, district heating systems are very capital intensive, and though profit margin is there, the primary benefits of such systems would be conservation of scarce energy resources and reduction in balance of payments, and these benefits would be readily perceived only at a national policy level. Thus government involvement appears mandatory for the promotion of district heating, not only for funding but also because it can include national considerations in the decision process. At the same time, government involvement raises complex problems regarding conflict of interest. Financing and administration of heating systems could be handled in like manner to cold water and sewage systems. The fact that the commodity provided by district heating systems has hitherto been supplied by private enterprise means that government operation of district heating systems would put the government in competition with private enterprise. However, there have been similar difficulties abroad that were surmounted without compromising either national or private interests. In view of the substantial national benefits of district heating, it is not unreasonable to expect that similar resolution could be achieved in the United States.

Cost and Implementation Projections

We have examined the potential costs of installing district heating systems in nine urban regions in the United States, and have sought to define the feasibility and economic limits of district heating systems on a national level (*4*).

The nine regions were selected to cover a representative range of existing U.S. population densities, housing profiles, and climates. We analyzed each region demographically, using Census Tract data. Population density was mapped for each region and the most densely populated tracts were aggregated to form large contiguous areas that were judged to be most economically served by district heating (see Fig. 1 for an example). The percentages of the populations in our model district heating areas are shown in Table 2. We could have encompassed greater percentages than those shown, thus the analyses do not represent the optimum implementation level but rather are conservative in approach.

Heating needs for each area were computed on the basis of national average per capita residential and commercial floor space allotments, net regional unit heat demands, and local degree-day data (see Table 1). Model district heating systems were constructed for each region; urethane-insulated pipes constructed of

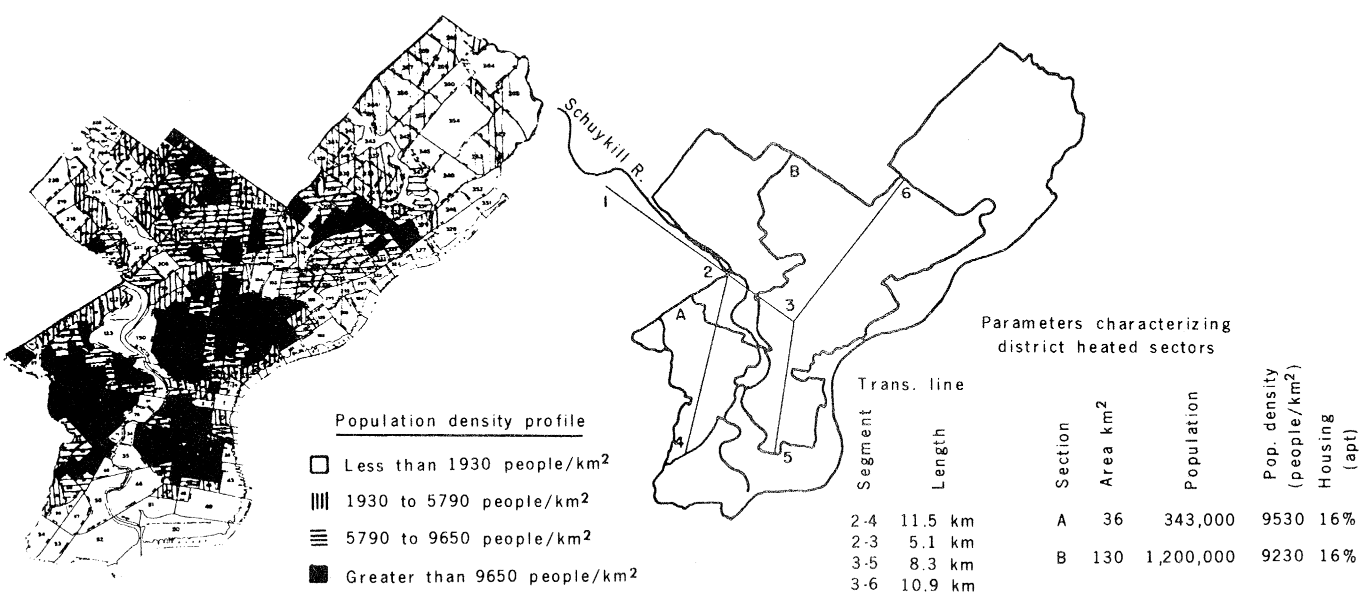


Fig. 1. The left figure shows the profile of population density for Philadelphia, as obtained from an analysis of Census Tract data. Individual contiguous tracts were collected together to form the large heavily populated sections shown in the right figure. Model district heating systems were constructed on the basis of the gross demographic parameters shown. The transmission network shown was designed for a single-site heat source such as the proposed nuclear power complex at Limerick.

polymer concrete and lined with polymer (5) were buried to the specifications of the cold water industry. Both supply and return pipes were buried in the same trench. Estimates of pipe installation costs were based on current costs of installing cold water mains locally, as reported by the various water authorities. These were adjusted to accommodate the insulation cost and greater dimensions of hot water pipes. Finally, the unit heat costs shown in Table 2, which do not include any charge for the waste heat itself, were computed by assuming yearly fixed charges of 10 percent of the capital investment, plus a charge for pumping energy. These costs were apportioned over the projected annual heat demand of the population served. Waste heat costs are discussed in the next section.

Comparison of the last two columns in Table 2 shows that transmission over the distances typical of the separation between fission power plants and large population centers (32 to 40 km) is not a prohibitive cost effect. A brief summary of the details of the Philadelphia district heating system design is given in Table 3. In particular, pumping power is that needed to overcome frictional losses in the transmission and distribution system. Conduction loss reflects the temperature drop of hot water consumed at the extreme end of the system. Overall temperature drop includes supply and return conduction losses and a useful drop of about 42°C in each consumer building. Service connections to houses, apartments, and commercial buildings should be somewhat cheaper than fossil burners sized for these structures. In Philadelphia, the cost of connecting a house to the system was estimated to be $14 per meter of length, and apartment or commercial connections to be $48.25 per meter. Fifteen meters was a typical length requirement. In summary, the regional analyses indicate a favorable economic picture for district heating in American cities, and show that portions of some cities with mild winters could be served by district heating systems.

The second stage of our study was concerned with projections of national levels of implementation of district heating within the economic limits commensurate with alternative energy sources and the accompanying conservation of fossil fuels. For this task we used average values for degree-day data, and installation costs which were computed on the basis of a sample of all cities with populations of 100,000 or more. This sample constituted a total population of 51 million (1970 Census) and yielded a good approximation to national averages. Average heat demand and system capital cost were then computed as a function of density of the population served by a given system. Addition of pumping energy costs and amortization of the capital cost then yielded the profile of unit heat charge (not including waste heat cost) as dependent on population density shown in Fig. 2. We projected levels of implementation by coupling this profile to the population density studies of Haaland and Heath (6). Total population levels that were serviceable at heat costs less than or equal to the effective energy costs (7) of natural gas, imported oil, and electricity appear as points 1, 2, 3 on curve A in Fig. 3. In addition, curve A shows the projected average cost of heat at each level of population served. Since virtually all citizens bear the cost of imported oil to some extent, district heating could probably be implemented at that level with all customers being charged a uniform price. This would permit district heating service to more than half the population (point 4, curve A).

Table 3. Summary of characteristics of the district heating system design for Philadelphia.

Item	Value
1. Population served (thousands)	1543
2. Average density (people/km^2)	9270
3. Annual heat load (10^{15} joules)	62.4
4. Rural transmission line*	
Inside diameter (m)	2.8
Unit cost (dollar/km × 10^6)	2.9
Length (km) and site	35 (Limerick)
5. City transmission system*	
Segment (see Fig. 1)	2 to 4
Inside diameter (m)	1.5
Unit cost (dollar/km × 10^6)	1.8
Length (km)	11.5
Segment	2 to 3
Inside diameter (m)	2.5
Unit cost (dollar/km × 10^6)	4.25
Length (km)	5.1
Segment	3 to 5
Inside diameter (m)	1.6
Unit cost (dollar/km × 10^6)	2.0
Length (km)	8.3
Segment	3 to 6
Inside diameter (m)	2.2
Unit cost (dollar/km × 10^6)	3.25
Length (km)	10.9
6. Distribution system†	
Inside diameter (m)	0.46
Unit cost (dollar/km × 10^6)	0.32
Length (km)	120.00
Inside diameter (m)	0.41
Unit cost (dollar/km × 10^6)	0.28
Length (km)	99.00
Inside diameter (m)	0.25
Unit cost dollar/km × 10^6)	0.153
Length (km)	2015.00
7. Total system cost (items) 4 plus 5 plus 6), (dollars × 10^6)	574
8. Pumping power (percentage of power supplied)	1.1
9. Conduction loss	
Power flow percent	3.7
Temperature drop (°C)	1.8
10. Overall temperature drop (°C)	47

*Allowing for a pressure drop of 1.7×10^4 newton m^{-2} km^{-1}. †Allowing for a pressure drop of 6.4×10^3 newton m^{-2} km^{-1}.

Utilization of waste heat in this manner saves substantial amounts of oil, natural gas, and electricity. The oil equivalent conservation potential (curve B, Fig. 3) is roughly a linear function of population served. This is a direct consequence of the use of population density as the independent variable (Fig. 2). Geographical differentiation, for example, is not evident at this level of description. Consequently, this curve exhibits only average projections.

Capital investment in district heating systems as a function of total population served is summarized in Fig. 4. Also shown is the yearly reduction in balance of payments at current imported oil prices. Though an increase in the cost of foreign oil could permit further penetration of district heating up to the new economic bounds, the benefit to cost ratio (Fig. 4) shows that this effect would be marginal. The primary benefit afforded by district heating in this context would be stability of energy cost. The significance of this for the nation and the consumer cannot be overemphasized.

In summary, we find that between 50 and 55 percent of the U.S. population could be served by district heating at the current economic levels dictated by foreign oil prices. Total investment in district heating systems is estimated at $180 billion; the resultant oil conservation of 1.1×10^9 barrels per year (currently about 55 percent of imports) would translate into a reduction in foreign payments of $13 billion per year. In terms of national benefit, the district heating scheme would pay for itself after 14 full years of operation at maximum implementation, or sooner if imported crude oil were to increase in price. The capital investment corresponds to an average of $5000 per household connected, for a service that can satisfy the entire heat demand of each consumer.

Availability of Waste Heat

For conventional steam-electric plants fired by fossil fuels the average efficiency of conversion of fuel energy to electricity is 33 percent. Fifty-two percent of the fuel energy is discarded through the condenser as waste heat and 15 percent is lost up the stack or within the plant. In existing light water reactor (LWR) nuclear power plants the waste heat is about 62 percent of the input energy, thermal plant losses amount to 5 percent, and electricity is produced at the same efficiency. The annual production of waste heat from existing steam-electric plants is about 8.4×10^{18} joules, an amount greater than the total amount of energy consumed for space and water heating per year in the United States (that is, net consumption, not including conversion losses).

The waste heat from the steam condenser corresponds to the saturation temperature of steam at an absolute pressure of about 0.05 atmosphere, which is normally the outlet pressure from the steam turbine. The waste heat temperature is thus about 40°C and is too low to be used in district heating systems. However, if the outlet steam pressure to the condenser is increased to 1 atm, the steam condenses at 100°C which is sufficiently hot for practical district heat systems. The principal effect of the higher condenser temperature is a reduction in thermal efficiency, that is, in conversion of thermal input to electricity. For each unit of waste heat produced at 100°C, about 0.1 of a unit of electricity is lost, which reduces the conversion efficiency from 33 to about 25 percent. From a total energy standpoint, however, the dual production of electricity and hot water for space heat is much more efficient. For example, the production of 100 units of electricity and 240 units of space heat by separate single-purpose fossil plants requires an input of 300 and 340 units of fuel, respectively, for conversion efficiencies of 33 and 70 percent. The overall average efficiency is then 53 percent to satisfy both demands. A fossil fuel electric plant which operates at the higher condenser temperature, with waste heat being used in a district heating system, will produce the same 100 units of electric and 240 units of usable heat with a fuel input of 400 units, yielding an overall energy conversion efficiency of 85 percent and a fuel savings of 240 units. Nuclear power plants operating in the dual mode offer higher efficiency (95 percent) and greater fuel savings because of the lack of stack gas losses.

Table 4 illustrates the effect of district heating on annual U.S. fuel consumption for three reference years (*8*). The district heat load was assumed to be distributed among steam-electric plants by fuel type in proportion to the projected installed capacities. Large reductions in annual oil and gas consumption and overall energy consumption would be achieved if district heat systems were used at the indicated levels. Increases in total population might open new markets for district heating and allow extension of established systems into suburban areas, thus increasing the oil and gas savings. As new construction with better insulation characteristics becomes significant [in about the year 2000 (*8*)], the net energy savings levels off. At the same time, economic conditions may favor implementation of district heating to levels beyond those assumed in Table 4.

The gas that would be conserved could

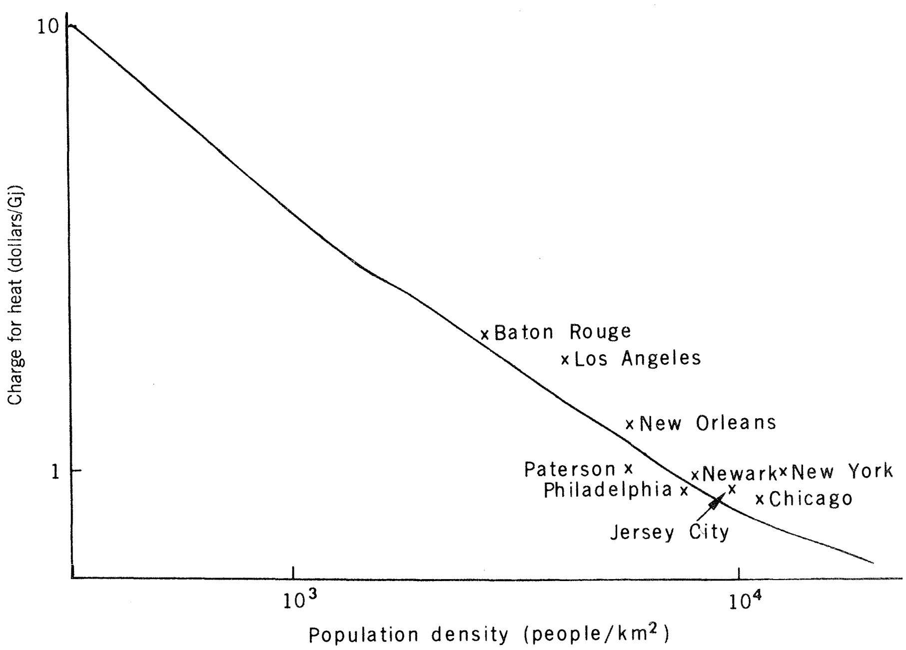
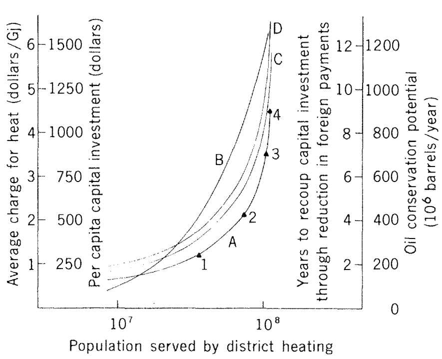


Fig. 2. A curve showing the projected average unit heat cost as a function of gross population density within the area served by each district heating system. Projections are based on nationally averaged per capita space and water heat demand, average labor costs, and 10 percent amortization of capital. Shown for comparison (*X*'s) are the cost projections obtained in our detailed regional analyses. Rural transmission cost and price of waste heat at the source are omitted, but pumping energy cost is included.



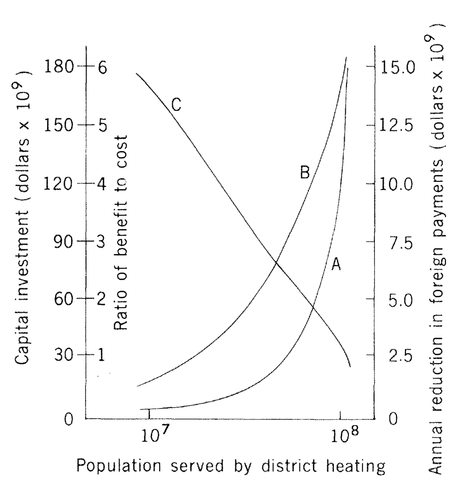


Fig. 3 (left). Curve A shows the projected average cost of heat as a function of total population served by district heating. The sharp rise at about 100,000,000 is due to the disproportionate system expense at low population densities. The points show: 1, population serviceable (38 million) at an average charge of \$1.18 and maximum of \$2 which is the effective energy cost of natural gas; 2, 73 million at an average of \$2 and maximum of \$4.25, the effective energy cost of imported oil; 3, 102 million at an average of \$3.50 and maximum of \$8.50, the average cost of electric energy; and 4, 110 million at an average of \$4.25. Curve B shows the equivalent oil conservation potential, curve C shows the capital investment pay back period, and curve D shows the per capita investment. Fig. 4 (right). Capital projections as a function of implementation level. Curve A, capital investment; curve B, reduction in foreign payments is directly proportional to the cost of imported oil; curve C, benefit to cost ratio is based on 10 percent amortization of capital.

be redirected into applications that would further decrease oil consumption. In all cases the equivalent oil savings would exceed the amount of oil that would be consumed by the space and water heating sectors if district heating were not implemented. Thus, use of district heating could eliminate the use of oil in the space and water heating sectors.

Additional generating capacity would not be necessary in order to maintain electric output at demand levels. The current average steam-electric plant factor of 53 percent (*9*) shows that on the average almost half of all steam-electric capacity is not in use throughout the year. Two factors contribute to this disuse: plant maintenance and temporal variations in demand. The amount of disuse contributed by the latter factor varies with each utility, but total additional capacity needs can still be projected without consideration of the details of operation of each utility.

Upper limits for plant factors are 75 to 80 percent and are readily attained within the electric industry. These should reflect maintenance time requirements and suggest that, on the average, roughly one-quarter of all generating capacity is used intermittently throughout the year. District heating to half of the population using electric plant waste heat would require operation of one-third more generating capacity by those utilities serving the district heated regions. If one assumes that electricity would not be imported by the heat-electric utilities and that half of the intermittently used capacity could be fully mobilized, then the net additional capacity needed would be 4 percent of the current total steam-electric capacity. This requirement would be easily accommodated by the new steam-electric capacity projected to come online within the next decade and which amounts to almost a 100 percent increase in installed capacity.

The amount of extra fuel that would be used by electric utilities that also supply heat is shown in Table 4. One hundred additional units of fossil fuel are required to produce 240 units of usable heat, and for LWR plants the ratio is 1 : 2.8. The cost of additional fuel may be recouped by charging for waste heat in these proportions. Waste heat would cost 14¢ per gigajoule for uranium fuel, 21¢ for natural gas, 32¢ for coal, and 95¢ for imported oil (*10*).

Other waste heat sources exist, though not in the same quantity nor at the same uniform distribution as electric plants. Certain industries, such as steel, produce waste heat that could be used for district heating systems. Some industries now discard heat at temperatures too low to be useful in district heating systems. However, this is often because of equipment design, not thermodynamic necessity, and the temperature could be raised by procedural or equipment modifications without affecting the process efficiency. Finally, refuse incineration could be a source of waste heat as well as a solution to urban waste problems. The garbage produced within a city of average U.S. climate could supply enough heat to meet the full needs of about 7 percent of the city's population. These alternative sources could be used to meet peak demands as well as contribute to the baseload heat supply.

Comparison with Other Technologies

Clearly, district heating is not the only technology option that could significantly reduce oil imports, fossil fuel consumption, and environmental pollution; for example, coal gasification could in principle produce enough synthetic fuel to eliminate oil imports. However, this technology appears to be at least as capital intensive as the district heating scheme with equipment lifetimes (30 years) estimated at half that of the district heating network (at least 60 years). In addition, the cost of synthetic fuels will be strongly affected by the cost of coal, which could rise dramatically in the next few decades. In contrast, waste heat costs are a small part of total district heating costs and should remain so. Once the capital investment in a district heating system is made, the unit charges should remain essentially constant with time. Approximately 80 percent of our present energy end-use devices rely on oil and gas input, so the development of replacement fuels may appear more desirable in the short term than substituting new devices involving less familiar technologies. However, in the long run, new technologies may be more desirable. District heating would appear to be more desirable than coal gasification in the long run, not only because of the necessity to conserve coal resources and reduce environmental pollution, but also because district heating systems should require much less maintenance and repair than equivalent coal gasification plants and fossil fired home heating units.

Solar energy is a more versatile resource than waste heat and in the very long term may be the most important source in the U.S. energy economy, but the nature of its role is not yet defined. With regard to the application to space and water heating, in general, solar heating will not replace conventional heating systems but rather will supplement them. In contrast, district heating systems can replace conventional heating systems, and offer the potential of both larger savings in fossil energy resources,

Table 4. Annual fuel and energy savings projected on the basis of district heating service to half the current U.S. population and, for illustration, to half the projected populations, for three reference years, based on the assumption that waste heat from power plants will be utilized.

Population served (millions)	District heat demand (10^{18} joules)	Steam-electric generation fuel mix (%)				Extra fuel required by power plants in dual mode operation/(10^{18} joules)				Annual savings for U.S. energy system			
		Oil	Coal	Gas	Nuclear	Oil	Coal	Gas	Nuclear	Net (10^{18} joules)	Oil (10^{18} joules)	Gas (10^{18} joules)	Oil equivalent (10^9 barrels)
						Reference year, 1972							
103	3.8	18.8	51.5	25.9	3.8	0.3	0.81	0.41	0.05	5.0	2.6	3.3	1.1
						Reference year, 1985							
103	3.8	8.3	44	9.4	38.3	0.14	0.69	0.15	0.52	5.1	2.7	3.6	1.2
115	4.4	8.3	44	9.4	38.3	0.15	0.8	0.17	0.6	5.5	3.2	3.8	1.3
						Reference year, 2000							
103	3.8	3.3	30	3.2	63.5	0.05	0.47	0.05	0.86	5.2	2.8	3.7	1.2
115	5.4	3.3	30	3.2	63.5	0.07	0.67	0.07	1.21	5.3	3.5	3.7	1.32

*District heat plus electric production.

and lower costs, since dual heating systems are not required.

A third method for space and water heating would require either the direct use of electricity generated in nuclear power plants, or the electrolytic generation of hydrogen during off peak periods (11) for use as fuel in individual heating systems. These methods would exacerbate the waste heat problem, and go counter to the principle of total energy use.

A comparison between the four options in terms of capital investment (current dollars) for a given power capacity appears in Fig. 5. The values shown for the electric plant option are for 1000-Mw baseload plants with a 30-year lifetime. Here, in fact, the district heating option should be substantially more attractive than Fig. 5 indicates, because its operating lifetime should be considerably longer than the assumed 50-year amortization period. Consequently, the district heating scheme should have a substantial advantage over more conventional options which would require more frequent replacement and would probably incur large escalations in capital cost when replaced. Energy cost to the consumer is least sensitive to basic fuel cost in the district heating option. Figure 6 shows that district heat supply to up to 50 percent of the population could provide significant savings. In addition, a rise in the cost of fuel would pass on to the consumer in all cases. The relative scale factors relating the proportional increases in fuel charge for the three heating options are 3 for electricity customers, 1.3 to 1.6 for synthetic fuel customers, and 0.35 to 0.40 for district heat customers.

Economically, district heating would be superior to solar heating for a large segment of the population. From Fig. 3, curve D, capital investment per household in district heating networks with maximal implementation levels will be about $5000 (costs would be lower with smaller implementation levels). The consumer would probably not pay this directly, but instead would pay a service charge which would amortize the cost of the district heating system. He might pay a connection charge of several hundred dollars, however, which would cover the cost of installation of pipe from the street main to his house. For about the same capital expenditure, a house could be outfitted with solar collectors and thermal storage devices that would meet from about 20 percent of the heating needs in the colder parts of the country up to about 100 percent in the warmest parts of the country. In the solar heating

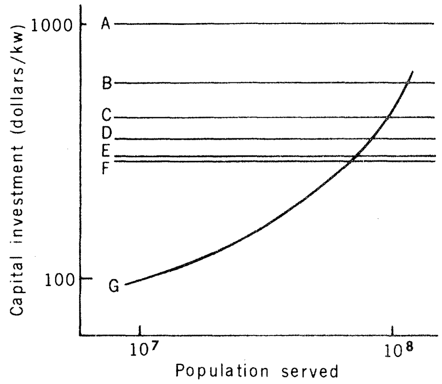


Fig. 5. Comparison of capital investment for several technologies. Plant costs and solar array estimate obtained from (8).

option the consumer might have to lay out capital for both the solar and backup conventional heating systems, though subsidization might be possible, and the consumer might still remain dependent on fossil fuels to a significant degree. There is no single effective heat cost for the combined system since geographical location has a strong bearing on energy mix. At average climate conditions, with half the demand met by solar heat, solar energy cost is estimated at about $14 per gigajoule (12). While this is competitive with electrical energy in some regions, it must be emphasized that conventional structures are not as energy efficient as those certified for electric heating.

Despite the lack of precision of solar cost estimates, it would seem better economically to invest in district heating systems than in solar energy devices for space and water heating in urban and dense suburban areas in the colder parts of the United States. The installation of district heating networks in these areas would also yield a larger cutback in fuel consumption than curve B in Fig. 3 indicates. Solar and district heating should not be viewed as competitors, but as complementary technologies with the former best suited to nonurban areas with relatively mild climates.

District heating has the advantage of being a proved technology in Europe. It requires simple hardware, and is reliable and simple to operate.

District Heating Policy Issues

Any enterprise for reducing the amount of fossil fuel consumed by space and water heating will encounter economic and institutional obstacles, as evidenced by the attempts to improve house insulation. The government must play a central role in the development of a coherent energy program. It will have to establish policies that will overcome obstacles in a manner acceptable to private and public interests while implementing desirable new technologies. Congress has officially recognized this duty in its attempts to allow personal tax deductions for implementation of certain energy conserving measures. These gestures do not constitute a part of an overall national energy policy, however, but indicate some ways government could help effect change in the national interest.

We have shown district heating to be an economically feasible technology for the United States, but its success cannot be guaranteed unless several definitive policy decisions are made. The first is recognition that a particular energy problem might, for technical or economic reasons, optimally have several distinct solutions each of which would best serve a distinct segment of the population. Only with this attitude would the United States be likely to recognize district heating. To provide the greatest benefit to the nation, district heating must be implemented extensively to high levels of population. In many cases, several contiguous cities might be encompassed by a single district heating system being managed by a regional authority. Federal policy would have to provide for several such regional authorities to plan on a local level and solve local problems. That almost all consumers within an area served by district heat use the system is vital. District heating might encounter consumer resistance to change; however, the economics of district heating is attractive in itself and a suitable tax policy could further reward those who use district heat and discourage consumers from using conventional sources. Provision would have to be made for financing the district heating networks and users' equipment where retrofit might be necessary. Long-term government loans could certainly be provided on the basis of it being more beneficial to invest the money internally.

A tax structure that encouraged full use of the energy content of high-grade fuels could make it even more rewarding for an electric utility to use its waste heat in a district heating application. District heating over a large part of any city would certainly eliminate many local home heating fuel businesses, but pipe network construction would produce a net increase in total employment, and operation and maintenance of district heating systems would create new skilled positions. Job dislocation could be minimized by properly scheduling the district heat load buildup.

Finally, federal policy should promulgate the advancement of district heating technology. Since labor would be the dominant cost (about 75 percent in our study) serious consideration should be given to the development of new construction techniques and equipment, such as mechanical moles, that could reduce the labor involved in pipe installation. Pipeline technology could be improved beyond our design. Plastic pipe is undergoing intensive study in Sweden. Extreme durability and the possibility of installation in very long segments might reduce maintenance, replacement, and initial installation costs of plastic pipes to a competitive level. Further development is needed in the technology of plastics to increase their pressure capacity. A composite of materials including plastic inner liner and high-pressure outer jacket such as found on fire hoses might be particularly useful for transmission lines. Reductions in weight and outside diameter decrease all materials and excavation requirements, thus overall cost. Reduction in transmission line cost produces a most pronounced effect in the economics of district heating for isolated cities of low total population (about 25,000 to 100,000).

Conclusions

District heating is a viable technology in many European countries. Many American cities exhibit characteristics similar to those in Europe where district heating now serves a significant portion of the populace and will expand to virtually the entire populace in the near future. In view of the limitations of U.S. oil and gas resources and our increasing dependence on imports, it is necessary for the United States to take definite steps to reduce consumption, and the implementation of district heating would constitute a sizable step in this direction.

The durability of modern materials ensures that district heating would result in very stable heat costs. This is an important feature which must be emphasized in developing consumer confidence in the scheme. To realize the full potential for national benefit, district heating must be implemented on a national scale through a concerted national program.

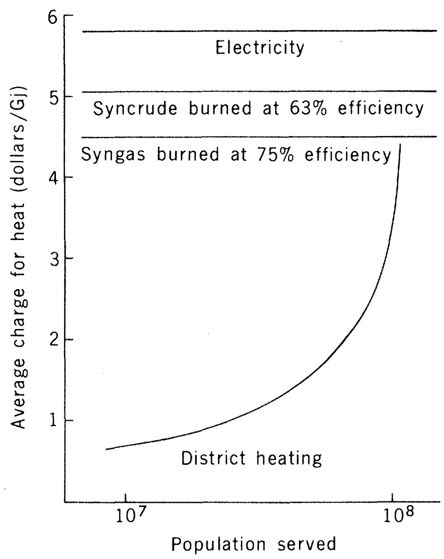


Fig. 6. Comparison of net (after conversion) heat costs (fuel only, excludes capital for end-use devices). The electricity curve reflects current electricity prices adjusted for the higher thermal efficiencies of buildings certified for electric heat.

This will require the involvement of federal agencies in managing finances, producing comprehensive analyses of supply and demand, providing systematic plans and goals for implementing district heating in each urban area, and in furnishing policy measures necessary to ensure acceptance of district heating by the various interest groups. The role which the electric utilities may play in the enactment of such a program should be significant inasmuch as they are a potential source of usable waste heat and have considerable experience in providing reliable utility service.

Though we can undoubtedly borrow heavily from European experience, it is mandatory that several pilot systems be introduced whereby the United States may gain operational experience and develop a procedure for the buildup of very large systems.

District heating is not a universal solution for the space and water heat demand sectors. High costs will prohibit district heating systems from rural and some low-density, warm climate, urban, and suburban areas. Therefore, a complementary technology, such as solar heating, which is suited to these conditions should be developed to reduce fuel consumption within such areas. The point is clear that district heating can and must be seriously considered as an important element in the solutions to our problems of energy supply and demand.

Summary

Large-scale district heating, using waste heat rejected by electric power plants and other sources, is presented as a means of reducing significantly the amount of fossil fuel consumed for residential and commercial space and water heating in the United States. Analysis of the technical and economic aspects of model district heating systems for nine U.S. urban areas shows that district heat service to residential and commercial consumers would be economically attractive. Projections of national service levels show that up to half of the U.S. population could be served by district heating at costs that are competitive with the present costs of imported oil and also with projected costs of new energy forms. An advantage of district heat over the latter is that it is a proved, simple technology.

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