PROSPECTS FOR THE UTILIZATION OF WASTE HEAT IN LARGE SCALE DISTRICT HEATING SYSTEMS

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ABSTRACT

District heating is one potential application for power plant reject heat. In addition to reduction in plant thermal pollution, it offers the potential to conserve over one billion barrels of oil per year. Detailed analyses of model district heating systems for nine U.S. urban areas, including projected heat costs, are presented. In addition, projections of nationwide levels of implementation of district heating systems are discussed. Results show that about half of the current population could be served through district heating at heat cost levels equal to the effective heat cost of imported oil.

INTRODUCTION

Steam-electric generating plants produce waste heat in amounts exceeding the total U.S. space and water heat net demand. The current annual rate of production of about 8×10^{15} BTU will roughly double by the end of the next decade, based on current growth projections of the electric industry.[1] In addition, the geographical distribution of such plants is favorable for transmission of hot water to all but a few urban areas. This hot water could then be used in district heating systems to meet the demands of the residential and commercial sectors for space and water heat. Utilization of this byproduct in this manner offers several incentives. It allows immediate cutback in fossil fuel consumption. It relieves the environment from bearing the burden of huge amounts of excess heat. It opens the supply of fossil fuels to more complex applications where these are used to greater advantage. It raises the energy conversion efficiency of electric plants considerably, and, as we have shown in this study, it can be quite economical.

We pursue these points in the following sections. In particular, in Section II we discuss technical and economic aspects of the adaptation of electric plants to a dual role as heat-electric energy sources. In Section III we discuss the analyses of nine diverse urban regions made for the purpose of estimating unit heat costs under actual conditions. In Section IV we present a generalization of these analyses to the national level where we investigate the maximum degree of implementation of district heating nationwide within the current economic limits imposed by the cost of imported crude. This price ceiling also limits the fossil fuel conservation potential of the district heating scheme. Section V contains concluding remarks.

II. DUAL HEAT-ELECTRIC GENERATION

For conventional fossil fuel fired steam-electric plants the average efficiency of conversion of fuel energy to electricity is 33%. Fifty-two percent of the fuel energy is discarded through the condenser as waste heat and 15% is lost up the stack or within the plant. In existing LWR nuclear power plants the waste heat is about 62% of the input energy, in plant losses amount to 5%, and electricity is produced at the same efficiency.[2] The waste heat from the steam condenser corresponds to the saturation temperature of steam at an absolute pressure of about 0.05 atm., which is normally the outlet pressure from the steam turbine. The waste heat temperature is thus about 100°F, so applications for this low quality heat are extremely limited in scope. Though the quantity of heat is large, the small temperature difference between exhaust conditions and atmospheric ambient or even winter conditions poses technical and economic obstacles for utilization of the heat. For example, use of this heat for space heating of residences and commercial buildings would require the use of very large distribution pipes and huge heat exchangers to effect the transport of sufficient amounts of heat. Additionally, water at 100°F is not suited for such uses as laundering, dishwashing, and personal hygiene. Thus consumers of this low grade heat would have to maintain conventional heating units to meet these demands.

A tradeoff can be instituted to increase the feasibility of this district heating concept. This tradeoff is used in the Soviet Union to very great extent and is gaining wide acceptance in Northern Europe. If the outlet steam pressure to the condenser is increased to 1 atm., the steam condenses at 212°F which is sufficiently hot for economical transport of hot water and for use in both space and water heating applications. The principal effects of this alteration is turbine operating conditions are reduction in electric production efficiency from the normal 33% to about 25%, and production of higher quality reject heat in even greater amounts. This last fact ensures that sufficient heat would be available in the winter.

The overall energy conversion efficiency of heat-electric plants operating at these backpressure conditions ranges from 85% for fossil fueled plants to 95% for LWR's. Roughly 10 units of useable heat are produced for each unit of electric that is lost.[3] On this basis, the lost electric revenue can be recovered by charging for heat at 10% of the electric rate. In today's terms this makes the heat resource worth 77¢ per million BTU.[4] As can be seen from Figure 1, the penalty for backpressuring is not strongly dependent on temperature within a range around 212°F, which we have demonstrated to be suitable for district heat use. On the other hand, the penalty for extracting steam is about twice that for backpressure to 212°F. Backpressuring is a more efficient process than steam extraction because it allows deposition of all heat of condensation at a lower yet useful temperature. The additional heat obtained by extracting steam is small compared to the heat of condensation and does not compensate for the additional loss of electricity. Thus, steam extracted heat is more than twice as expensive at the source. Moreover, direct transport of steam to the consumer, which is the practice in existing district heating systems in this country, is fraught with technical and economic drawbacks not encountered by hot water transport technology.

First, the volume density of heat in hot water at 212°F is greater--by more than a factor of ten--than that in steam at conditions such as those in Figure 1. This means that much greater volumes of steam must be transported to satisfy a given demand. If this transport is over distances of tens of miles, such as may be encountered in distributing over an entire city from a rural power plant site, the pumping energy expenditure for steam transport is ten or more times greater than for hot water at equal heat delivery rates. In addition, steam lines must be carefully graded and expansion joints and manholes provided at frequent intervals, the latter to draw off steam condensate which in turn makes the heat loss from a steam pipe much greater than from a hot water pipe. So it is clear at the outset that steam district heating is considerably less attractive than hot water district heating. The rapid growth of hot water district heating in Europe is sufficient testimony. From this analysis it is obvious that the extraction of useable reject heat from power plants is not the economic obstacle to the implementation of district heating technology in this country since the estimated value of reject heat is considerably less than the effective heat costs of natural gas and imported oil.

III. ANALYSES OF REGIONAL MODEL DISTRICT HEATING SYSTEMS

The feasibility of district heating is controlled by the cost of transporting the heat from the source to the consumer. In view of this, we have developed a methodology for projecting such costs and used actual urban conditions in constructing model district heating systems. We studied nine urban regions that collectively display a wide variation in the parameters that are the primary determinants of unit heat cost. These regions are New York City, Chicago, Philadelphia, Los Angeles, Baton Rouge, New Orleans, Jersey City, Newark, and Paterson. They show great variety in climate, size, population and population density, housing profile, working conditions, and labor costs.

The goal of our analysis is to project heat demand in each region, design appropriate hot water piping systems to distribute this heat, and compute unit heat costs based on district heating system capital and operations costs and yearly heat demand.

Per Capita Heat Demand

Space heat demand is conveniently expressed on a per capita basis assuming the values shown in Table I.[5] Entry A shows that there are 375 ft^2 of residential and 110 ft^2 of commercial floor space per person in this country at this time. These figures hold for the Northeast, North Central, South, and West decomposition of the country and are assumed to hold regionally as well. Entry B shows the geographical breakdown of net heat demand for various structures in terms of floor space. These net values correspond to losses through the surfaces of the structure and are the appropriate figures to use because our system suffers no conversion losses within a structure.

From this Table, it is seen that heat demand depends on the regional housing profile, that is, the proportion of the population residing in apartments, single and multi-family houses. This information is obtained from Census data, but for practical convenience we classed all individuals residing in structures of 5 or more dwelling units as apartment dwellers with an average per capita demand of 10 BTU/ft^2/degree-day, and all other individuals are classed as single family house dwellers at an average per capita demand of 15 BTU/ft^2/degree-day. While these assumptions appear to inflate the projected heat demand, detailed analysis shows that the discrepancies so introduced are small.

In addition, it is seen from entry B that the commercial floor space mix is needed. This is provided in entry C and from these we calculate an average demand of 9.1 BTU/ft^2/degree-day for all commercial structures. Using the per capita floor space allotments, we compute per capita net space heat demands of 5625, 3750, and 1000 BTU/person/degree-day for house residential, apartment residential, and commercial applications respectively.

The hot water supply system design capacity is based on the space heat demand for the coldest month in each region. Climatological data is based on the U.S. Weather Bureau degree-day compolation. We use "climate" to mean the maximum monthly mean degree deviation from the 65^{o}F reference temperature, and "duration of heating season" to be the number of heating days under "climate" conditions to make up the total degree-day compilation. Multiplying the per capita space heat demand figures by "climate" and summing over the populace to be served by district heating yields the system power design capacity.

We propose that a 75^{o}F drop in water temperature within each structure is feasible. This falls within the inlet design temperature of 210^{o}F at the plant and exit temperature of 125^{o}F at each structure and an allowance for conduction losses through the distribution pipes. This translates to an anticipated useful heat transport of 622.5 BTU per gallon of hot water.

In addition to the space heat load, there is a sizeable water heating load. Again, discounting conversion and radiation losses, we consume 6 x 10^{6}BTU and 1.75 x 10^{6}BTU per person through residential and commercial hot water consumption per year. We assume these to be uniform across the country throughout the year and average them over a 16 hour day to construct power demand. We find that this additional power can be supplied without changing the hardware design discussed above by just increasing pumping pressures by easily tolerable amounts. This attractive feature lends a great deal of flexibility to an installed piece of hardware not only in meeting peak power needs but also in supplying outlying areas encompassed in future expansion of the district heating system.

Populace Served

Simple arguments can be given to support the contention that the most densely populated sections of a region are most economically served by district heating. In this light we sought to determine those sections within each region which display the greatest population densities. This was done by analyzing Census Tract data to determine the population density of each tract, which thus yields a fine grained population density profile, and then by aggregating numerous tracts under certain criteria to ensure that the tracts selected are contiguous and that the sections so developed are large in area and encompass the greatest population densities. As an example of this procedure, we show the maps for Philadelphia in Figure 2. At this point we abandon the explicit detail of distributions of population and utilize only gross demographic information, of the type shown in Figure 2, in later calculations. That is, regional cost projections presented here are based on service only to these heavily utilized sections but this should not be construed as our assessment of the extent of applicability of district heating in each region. The results show that our tract selection criteria are too stringent, but no attempt was made in the regional studies to reanalyze toward maximal implementation.

The inaccuracy introduced by erasing the tract detail is studied by constructing distribution systems for the extreme cases of completely random distribution of housing and commercial structures and completely segregated zoning of house, apartment, and commercial structures. Results (Table II, col. A and D) show that such effects are small.

Pipe System

The hot water system consists of four levels of supply lines. Rural transmission lines run from power plants to city limits. City transmission lines are smaller trunk lines which feed into each section as shown in Figure 2. Distribution lines fan out from these through each street and connection is made to each structure from the distribution lines. Polymer lined polymer concrete (PLPC) pipe was chosen for transmission, distribution, and apartment and commercial connection service because of its extreme durability and strength. Chlorinated polyvinylchloride (CPVC) pipe is designated for house connection service also for its durability and ease of installation. Feed lines are insulated with 2 inches of rigid urethane foam to provide very good moisture resistance and highly cost effective suppression of conduction losses. Heat losses over each entire system range from equivalent temperature drops of $2^{o}F$ in New York to $11^{o}F$ in Baton Rouge. When pumping energy expenditure is taken into consideration, these values decrease to $1^{o}F$ in New York and $10^{o}F$ in Baton Rouge. This is so because the pumping energy is expended against friction.

Installed pipe costs are computed for five of the regions based on current installed costs of cold water lines in these regions. These latter are adapted to our purposed by disaggregating labor and materials costs and resumming the costs that accomodate the insulated PLPC pipe and labor and resurfacing costs scaled to the appropriate dimensions for burial of the larger insulated pipe. Since the hot water system is closed, we need to provide return lines which can be buried in the same trench. Figure 3 shows the installed cost curves for a unit length of complete pipe system. The variation between regions is due entirely to variations in working conditions and labor costs. The jump at 50 inches I.D. is due to pressure capacity differences. The smaller pipes are designed for 325 PSI capacity whereas the larger pipes, to be used exclusively for transmission, are designed for 400 PSI capacity. These values provide margins of at least 100% above system operating conditions.

Rural installed costs are constructed in a similar manner using oil pipeline installation costs as a guide. These would lie slightly below the New Orleans curve in Figure 3.

System cost is computed simply on the basis of total length of each diameter of pipe required. Transmission lengths are shown in Figure 2 for Philadelphia. The design envisaged here permits the heat source to be located at a single site roughly 25 Mi distant from the city limits. Pipe diameters are obtained from Figure 4 which shows capacity for different frictional pressure drops. Water capacity translates to heat capacity through the factor 622.5 BTU/gallon. We analyzed the sensitivity to increased transmission pressure drop for the two curves shown and found (Table II,col. B and C) this to be a small effect. Distribution pipe diameters are determined through estimating the number and average length of distribution mains and then correlating these with population served per main to determine power demand, hence diameter. Total distribution length is also obtained from this calculation. These results now yield the total system capital cost. Potential retrofit and connection charges are not included in the system capital cost. Maximum connection charges occur in New York where a house connection with 3/4 inch CPVC pipe costs $261, and an apartment or commercial connection with 4 inch PLPC pipe costs $953. These costs are highly competitive with oil and gas burner costs, but burners have a lifetime that is 25% that of the district heating system and require maintenance. Retrofit to structures that already have piping or air ducts would be minimal, amounting to a heat exchanger. Electrically heated buildings would require extensive retrofitting.

Finally, unit heat costs are computed on the basis of 10% amortization of capital, that is, a mortgage of 50 years, and operations costs consisting of pumping at a charge of $10 per million BTU for pumping energy. The sum of these is divided by the total heat demand for a year. Unit heat charges for several scenarios are shown in Table II. Again, random refers to the case of homogeneous distribution of residential and commercial structures throughout the sections served; and ordered means complete segregation of houses, apartments, and commercial structures. For comparison, imported crude combusted at 60% efficiency has an effective cost of $4.50 per million BTU. The cost of the heat at the plant is omitted here. The analysis given in Section II renders this to be 77¢ per million BTU, but an alternate analysis may be given based on the premise that any given electric utility which also sells heat will meet its electrical demand by operating additional plants and not by importing electricity as the first analysis assumes. Since most utilities peak in the summer, they have intermediate load plants which are not used extensively in the winter months. However, sale of both heat and electrical energy could lead to greater use of these intermediate load plants, and, in effect, greatly increase the energy baseload of the utility. In this case the cost of heat at the plant will be determined by the cost of extra fuel used by the utility. This mode of operation greatly favors coal and nuclear power plants since the value of heat from these is 34¢ and 15¢ per million BTU respectively, but $1 per million BTU from oil fired plants. Siting restrictions on the former plants will influence the cost of heat at the point of use in varying degrees depending on the size of the total district heating load. Figure 5 illustrates the effect that rural siting of power plants has on heat cost ($M=10^6$). It is assumed in each case that the power plants are located at a single site. Remote siting of plants may disfavor the application of district heating to the warmer areas of the country and to small cities. These considerations indicate that the market potential for district heating might temper future power plant siting policies.

Table III contains a summary of the chief characteristics of each region and its model district heating system. The Jersey City, Newark, and Paterson SMSA regions are interesting in themselves because each consists of many small cities, in fact all but the cities of Newark and Jersey City have populations less than 100,000, each of which alone would not be as amenable to district heating.

IV. PROJECTIONS OF NATIONWIDE IMPLEMENTATION OF DISTRICT HEATING

This study sought to define the limits for nationwide implementation of district heating at costs equal to those of currently used energy sources. National projections are based on average values for "climate" (28°F),"heating season duration" (152 days) and unit installed costs (those of Philadelphia). These averages are obtained from a sample of all cities with 100,000 or greater population. At present, these cities contain one-third of the urbanized population of 155 million and constitute a good sample of the regions that can be economically served by district heating.

From the average climate and heating season duration we can project average per capita net power demand and annual per capita heat load and it remains to design proper distribution systems. The parameters relevant to this task are per capita demand, housing profile, population density, size and shape of the region to be served. Since we did not study each city in detail, we instead examined the influence of size and simple shapes on heat cost. We found that a square region, 20 Mi^2 in area, produces average costs. From the detailed regional analyses we were able to establish a relation between housing profile and population density. Thus having fixed the per capita demand and geometry of the regions, national cost projections become a study of the relations between heat cost and population density. Figure 6 shows such a curve based on supply of space and water heat, and including costs for pumping but not heat at the source, to regions with random distribution of structures. Shown for comparison are the cost projections obtained from the detailed regional analyses for the same scenario (Table II, col. A). The close agreement is gratifying since it shows that the curve, which is based on national averages, can be understood to reflect actual regional values.

We projected levels of implementation under various constraints by coupling this cost profile to the population density studies of Haaland and Heath.[6] Table IV gives serviceable population levels at selected ceiling charges, i.e., the marginal cost for adding the last incremental district heating systems. The first three ceiling charges correspond to the effective heat costs of: (1) natural gas, (2) imported oil, and (3) electricity at the point of consumption, including conversion efficiencies.[7] 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. For a nationwide nuclear electric utility this permits district heating service to more than half the 1970 population, i.e., to about 110 million. For an oil electric utility, at current oil prices, half the 1970 population could be served at the same $4.50 per million BTU level, including cost of heat at the plant.

Impact on Utilities and Fossil Fuel Consumption

The impact of district heating on utilities and conservation potential is demonstrated for three reference years[8] in Table V. The district heat load was assumed to be distributed among steam-electric plants by fuel type in proportion to the projected installed capacities. The extra fuel required by utilities is a reflection of the loss in electric production efficiency due to backpressure turbine operation and is independent of whether a heat-electric utility imports electricity or operates additional plants to compensate. The proliferation of nuclear power projected here might not come to pass, but coal fueled plants, a likely alternative, though more efficient than LWR's thus effecting slightly greater energy savings, produce a similar profile. It is important to note that district heating with power plant reject heat is a more efficient, direct, and economical means to replace natural oil and gas heating fuels with coal and nuclear fuel than coal gasification or nuclear powered electrification for up to about 50% of the population.

The population levels in Table V were chosen for illustrative purposes. Increases in total population might open new markets for district heating and allow expansion of established systems into suburban areas. Future economic conditions may also favor higher levels of implementation of district heating. Thus, the conservation potential could be greater than projected here. The gas that would be conserved could be redirected into applications that would further decrease oil consumption. The equivalent oil savings shown in the table reflects this possibility. Thus we project that had district heating service using power plant reject heat been used by 50% of the population in 1972, the savings in fossil fuel would have been equivalent to 1.1 billion barrels of oil per year. At 1975 prices, this would amount to a reduction in balance of payments of $13 billion. The capital investment to install district heating systems to this level of service is estimated at $180 billion, 1975 dollars. This projected oil savings is actually greater than the amount of oil used by the space heating sector in 1972, and the same holds true for the 1985 and 2000 projections. Thus, we anticipate that district heat service could eliminate the use of oil for space and water heating applications. The saturation effect in equivalent oil savings is due to reduction in per capita demand because of better insulation of buildings, projected to become a significant factor about the year 2000.

Comparison With Competing Technologies

Other technology options may effect a reduction in our dependence on imported oil. Coal gasification to produce synthetic oil and gas could feasibly make us energy self-sufficient, and electric heating powered by coal or nuclear plants could produce the same effect. Of course, neither of these technologies result in the utilization of power plant reject heat and the latter exacerbates the problem of waste heat disposal. District heating offers additional economic incentives as well.

Capital investment (1975 dollars) per kilowatt capacity (Figure 7) is more favorable for district heat service to about 70 million people than competitive technologies, and is competitive with electric heat up to 50% of the population. The values shown for the electric plant option are for 1000 MW base load plants with a 30 year planning lifetime. Here, in fact, the district heating option should be substantially more attractive than Figure 7 indicated, because its planning lifetime will be equal to its operating lifetime which should be considerably longer than the assumed 50 year amortization peroid. Consequently, the district heating scheme should have a substantial advantage over more conventional options which would require more frequent augmentation and would probably incur large escalations in capital cost when additions are made.

Energy cost to the consumer is least sensitive to basic fuel cost in the district heating option. Figure 8 shows the average charge for heat at point of consumption, including end use conversion losses but not end use equipment cost. Electricity cost reflects the greater insulation efficiency of buildings certified for electric heating, but takes no account of the cost for this construction. Here again district heat service to 50% of the population is competitive with other "new" technologies. An increase in the cost of fuel would be passed 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.

V. CONCLUDING REMARKS

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. District heating is also a practical means to utilize a large portion of that two-thirds of power plant energy input now rejected as heat. Development of this resource would broaden the energy baseload of electric utilities and provide additional income.

District heating fed by electric plant waste heat is tractable with today's electric generation technology. The prospects for district heating are even brighter when viewed in terms of advanced technology. Both the low fuel cost and the possibility of conjoining useful waste heat production with electric generation in a total energy operating mode serve to enhance the economics of district heating and broaden the base level energy demand. The need for electricity in our economy is certain and its role is expected to expand. Thus, we can rely on the production of useful waste heat in the long term. Hence, this district heating concept transcends the very basic questions about fuel resources and management.

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5. Data in Table I is adapted form "Project Independence Blueprint, Final Task Force Report, Conservation Vol. I: Residential and Commercial Energy Use Patterns, 1970-1990", Federal Energy Administration.

6. C. M. Haaland and M. T. Heath, Demography II (No. 2), 321, May, 1974.

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TABLE I

FLOOR SPACE CHARACTERISTICS

	RESIDENTIAL	COMMERCIAL
TOTAL U.S.	$75{,}600 \times 10^6$ ft.^{2}	$21{,}610 \times 10^6$ ft.^{2}
PER CAPITA	375 ft.^{2}	110 ft.^{2}

A) Floor Space

	Single Family	Multi Family House	Low Rise Apartment	High Rise Apartment	Offices	Retail	Schools	Hospitals	Other Commercial
NORTHEAST	15	12.4	10.4	9.7	12.2	6.7	10.9	13.2	6.7
NORTH CENTRAL	14.5	13.4	10.5	9.6	12.5	6.8	10.9	13.3	6.8
SOUTH	13.5	12	8.5	7.5	14.8	6.3	11	12.8	6.3
WEST	14.4	12.9	8.5	7.3	12.1	6.2	10.8	12.5	6.2

B) Space Heat Demand, Btu/ft^2/degree-day

	Offices	Retail	Schools	Hospitals	Other
NORTHEAST	16.9	20.3	21.5	8	33.3
NORTH CENTRAL	14.1	20.4	23.6	7	34.9
SOUTH	15	18	25.6	6.9	34.6
WEST	17.3	19.4	21.9	5.4	36.1

C) Commercial Floorspace Inventory by Percent

TABLE II

PROJECTIONS OF UNIT HEAT CHARGES (\$ PER 10^6 BTU)

	A	B	C	D	E
New York	.96	----	1.14	.90	1.15
Chicago	.80	1.03	.93	.78	1.16
Philadelphia	.88	1.11	1.03	.80	1.05
Los Angeles	1.74	2.63	2.47	1.51	1.82
New Orleans	1.23	2.46	2.35	1.14	1.61
Baton Rouge	1.98	3.43	3.32	1.87	2.56
Jersey City	.88	1.26	1.05	.84	1.14
Newark	.93	1.14	1.05	.83	1.14
Paterson	.98	1.31	1.19	.95	1.33

A - Random Distribution, Space and Water Heat Service

B - Ordered Distribution, Space Heat Service, Low Pressure Drop Design

C - Ordered Distribution, Space Heat Service, High Pressure Drop Design

D - Ordered Distribution, Space and Water Heat Service

E - Same as D and Includes Rural Transmission Line

TABLE III

SUMMARY OF REGIONAL ANALYSES

	New York	Chicago	Philadelphia	Los Angeles	New Orleans	Baton Rouge	Jersey City SMSA	Newark SMSA (Part)	Paterson SMSA (Part)
POPULATION SERVED BY DISTRICT HEATING (1000's)	7500	1098	1543	933	185	74	503	481	173
PERCENT OF REGIONAL POPULATION SERVED	95	33	79	33	81	45	83	64	50
AVERAGE DENSITY OF POP. SERVED (PEOPLE/MI^2)	40400	35000	24000	13200	18100	8500	30400	25100	18100
HOUSING PROFILE (% APT. DWELLERS)	66	60	16	50	25	13	48	48	33
CLIMATE (^oF)	33	40	32	12	11	13	33	33	33
HEATING SEASON DURATION (DAYS)	150	158	152	168	107	120	150	150	150
DESIGN CAPACITY FOR SPACE HEAT LOAD (MW)	16200	2900	3800	774	148	74	1160	1100	420
ANNUAL HEAT LOAD (10^{12}BTU)	256	46	59	18	2.7	1.3	18	17	6.5
DISTRICT HEATING SYSTEM CAPITAL COST (\$ x 10^6)	2528	457	574	296	41	32	184	177	78

TABLE IV

PROJECTIONS OF NATIONWIDE SERVICE LEVELS

NUMBER OF PEOPLE SERVED (MILLIONS, 1970 CENSUS)	CEILING CHARGE (DOLLARS/10^6BTU)	AVERAGE CHARGE (DOLLARS/10^6BTU)
38	2.10 [=Natural gas]	1.25
73	4.50 [=Imported oil]	2.15
102	9.00 [=Electricity]	3.50
110	11.50	4.50 [=Imported oil]

TABLE V

PROJECTIONS OF ANNUAL FUEL AND ENERGY SAVINGS

		1972	1985		2000	
DISTRICT HEAT SERVICE TO		50% OF THE POPULATION	50% OF THE 1972 POP.	50% OF THE 1985 POP.	50% OF THE 1972 POP.	50% OF THE 2000 POP.
DISTRICT HEAT DEMAND, QUADS (10^{15}BTU = 1mQ = 1 QUAD)		3.6	3.6	4.13	3.6	5.14
STEAM-ELECTRIC GENERATION FUEL MIX-PERCENT	OIL	18.8	8.3		3.3	
	COAL	51.5	44.0		30.0	
	GAS	25.9	9.4		3.2	
	NUCLEAR	3.8	38.3		63.5	
EXTRA FUEL REQUIRED BY POWER PLANTS IN DUAL MODE OPERATION [WITH DISTRICT HEATING], QUADS	OIL	.28	.13	.14	.05	.07
	COAL	.77	.66	.76	.45	.64
	GAS	.39	.14	.16	.05	.07
	NUCLEAR	.05	.49	.57	.82	1.16
ANNUAL SAVINGS FOR U.S. ENERGY SYSTEM [INCLUDING REDUCTION IN OIL AND GAS FOR HEATING]	NET	4.8mQ	4.9mQ	5.2mQ	4.9mQ	5.0mQ
	OIL	2.5mQ	2.6mQ	3.0mQ	2.7mQ	3.3mQ
	GAS	3.1mQ	3.4mQ	3.6mQ	3.5mQ	3.5mQ
	OIL EQUIV.	1.1 x 10^9bbl	1.2 x 10^9bbl	1.3 x 10^9bbl	1.2 x 10^9bbl	1.32 x 10^9bbl

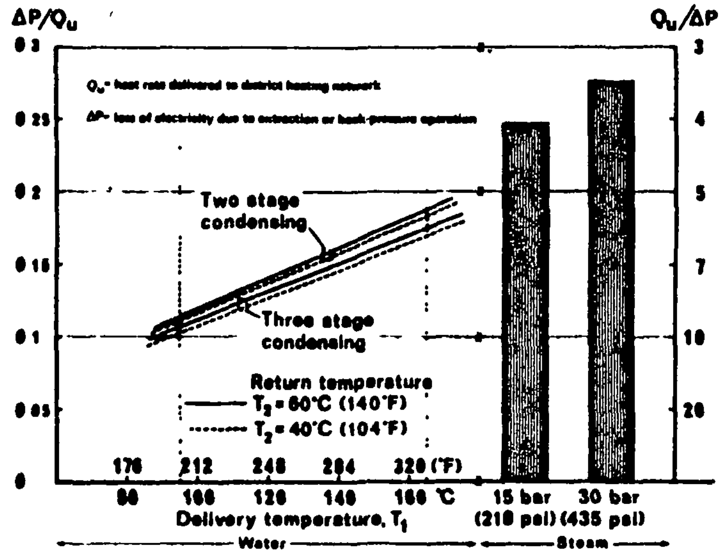
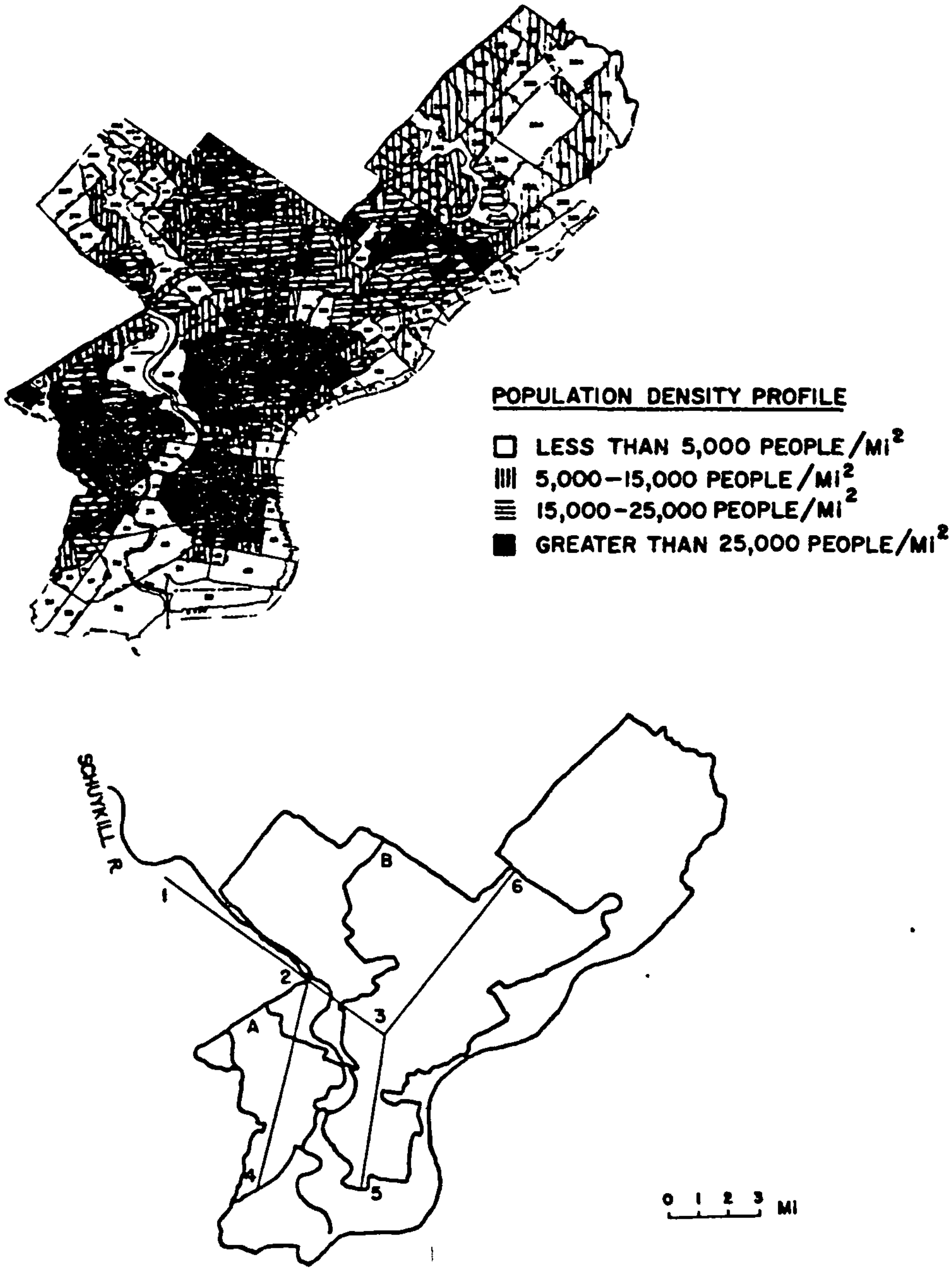


Fig. 1. Electricity Sacrifice (ΔP) to Produce Usable Heat (Qu) (Adapted from Ref. 3.)



PARAMETERS CHARACTERIZING DISTRICT HEATED SECTORS

TRANS. LINE

SEGMENT	LENGTH
2-4	7.2 MI
2-3	3.2 MI
3-5	5.2 MI
3-6	6.8 MI

SECTION	AREA MI²	POPULATION	POP DENSITY PEOPLE/MI²	HOUSING (APT)
A	13.9	343,000	24,600	16 %
B	50.2	1,200,000	24,000	16 %

Fig. 2. City of Philadelphia. Population and Housing Profile, and Model Transmission Line Design

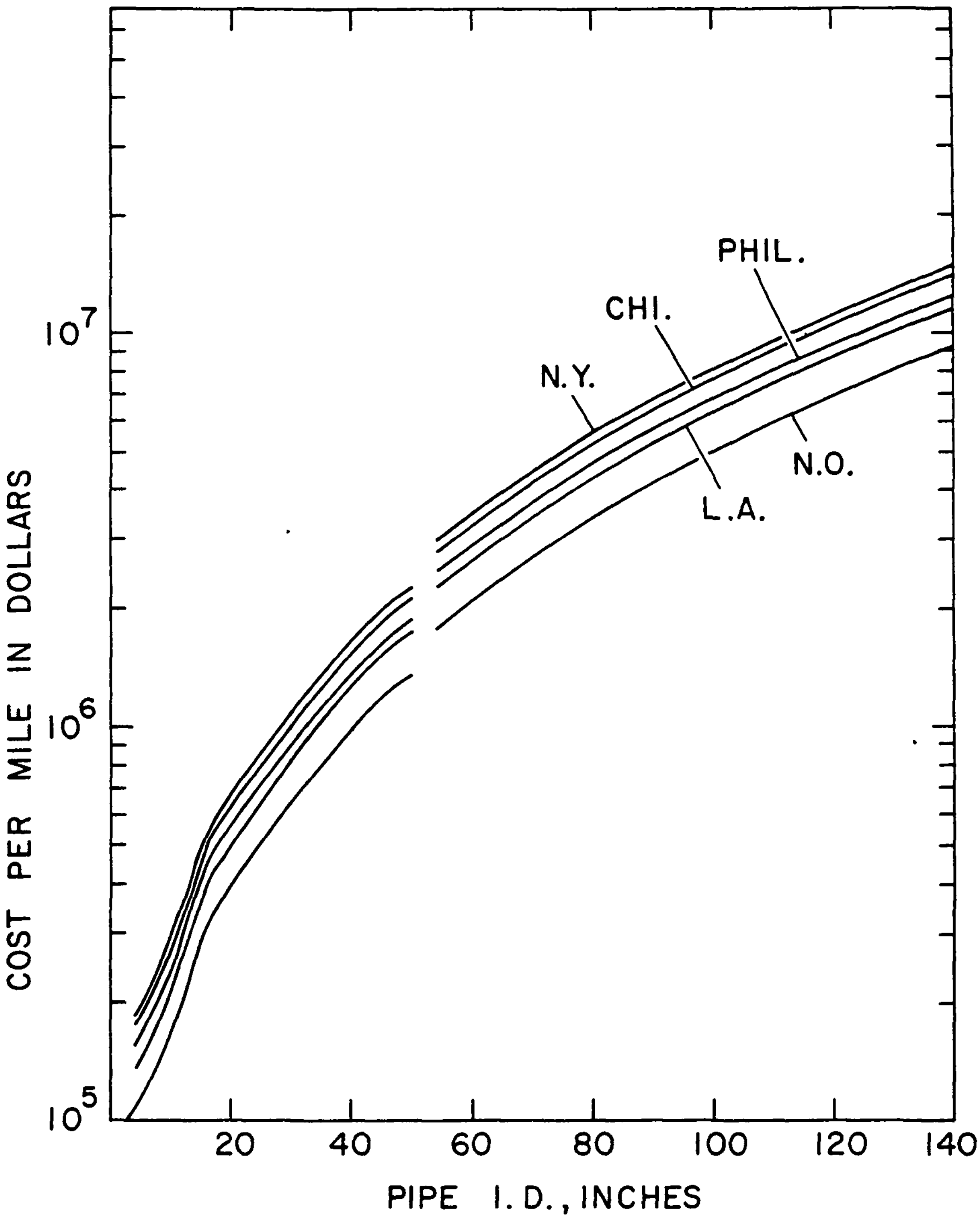


Fig. 3. INSTALLATION COSTS OF HOT WATER PIPE (COMPLETE SYSTEM)

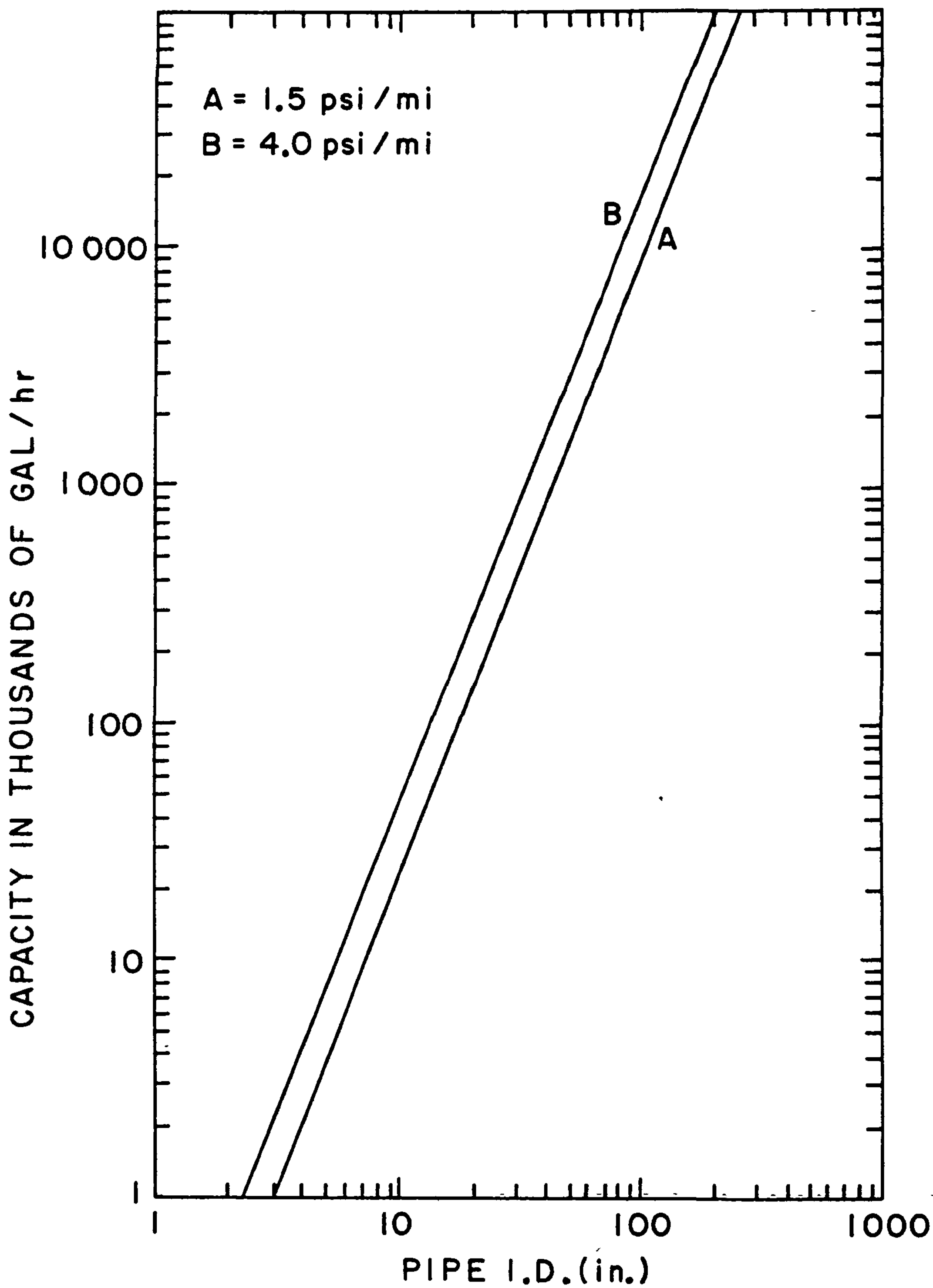


Fig. 4. PIPE DIAMETER VERSUS CAPACITY FOR PRESSURE DROP

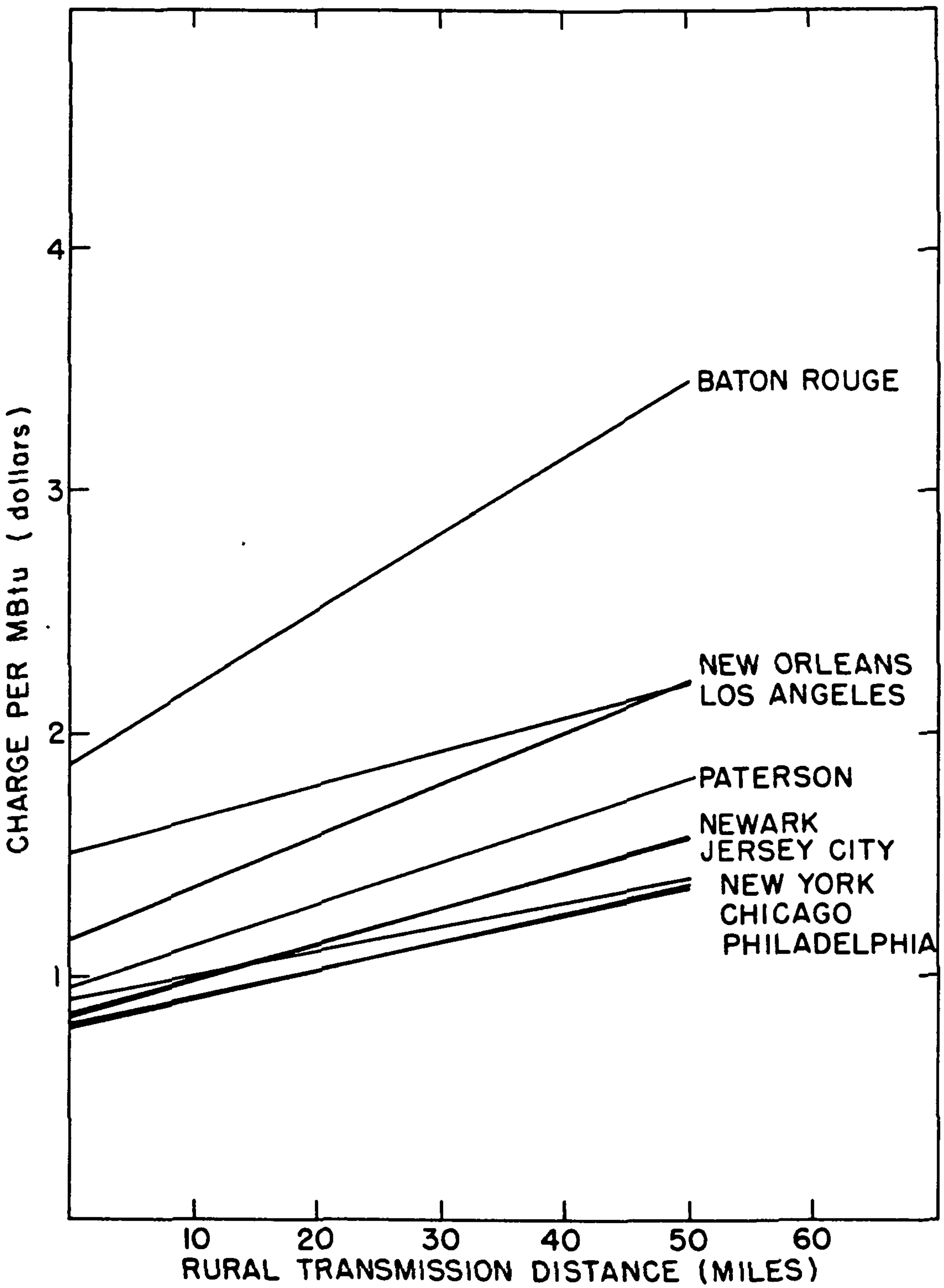


Fig. 5. TOTAL ENERGY CHARGE AT COMBINED SERVICE

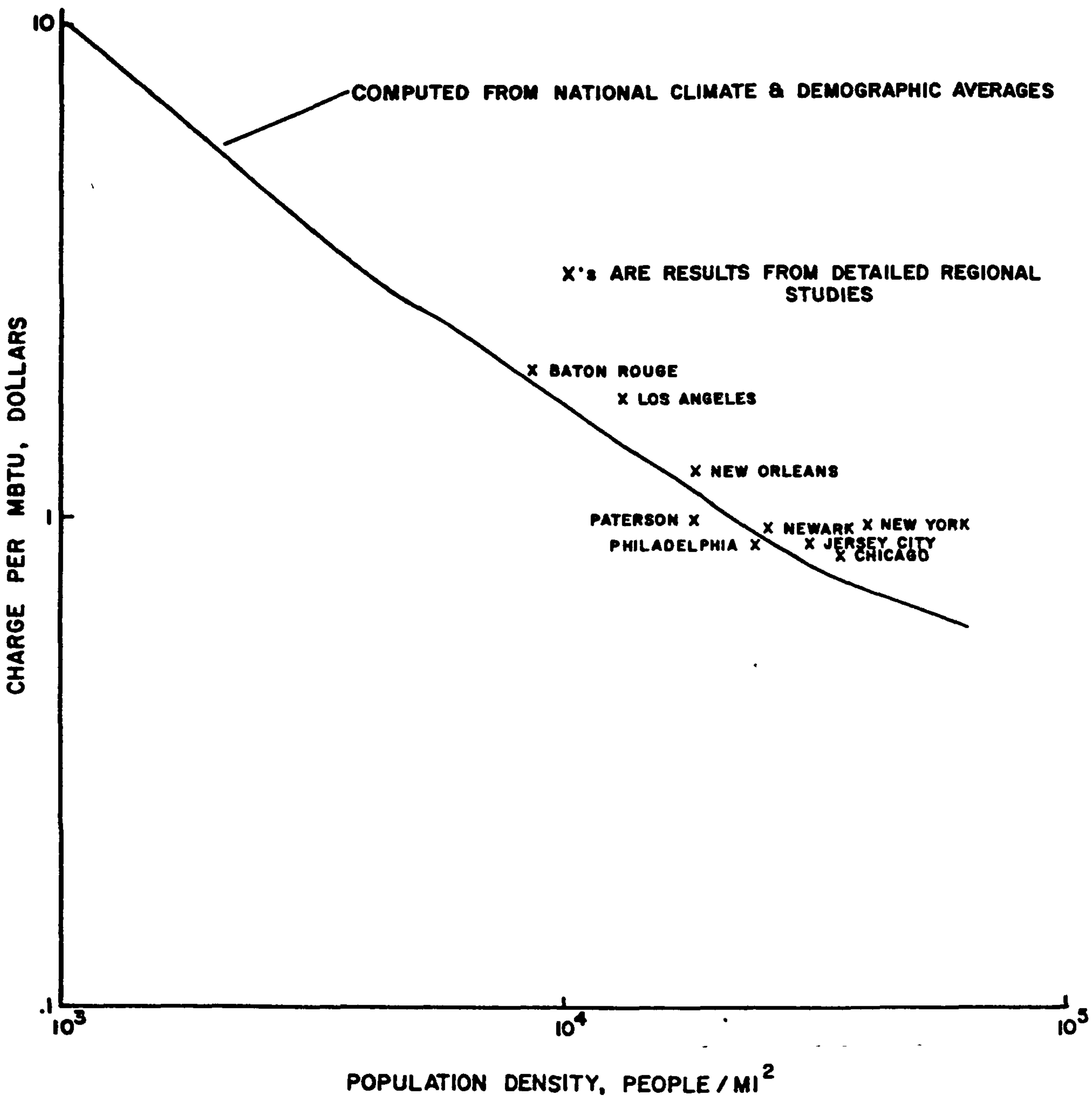


Fig. 6. UNIT HEAT CHARGE FOR SPACE AND WATER HEAT SUPPLY

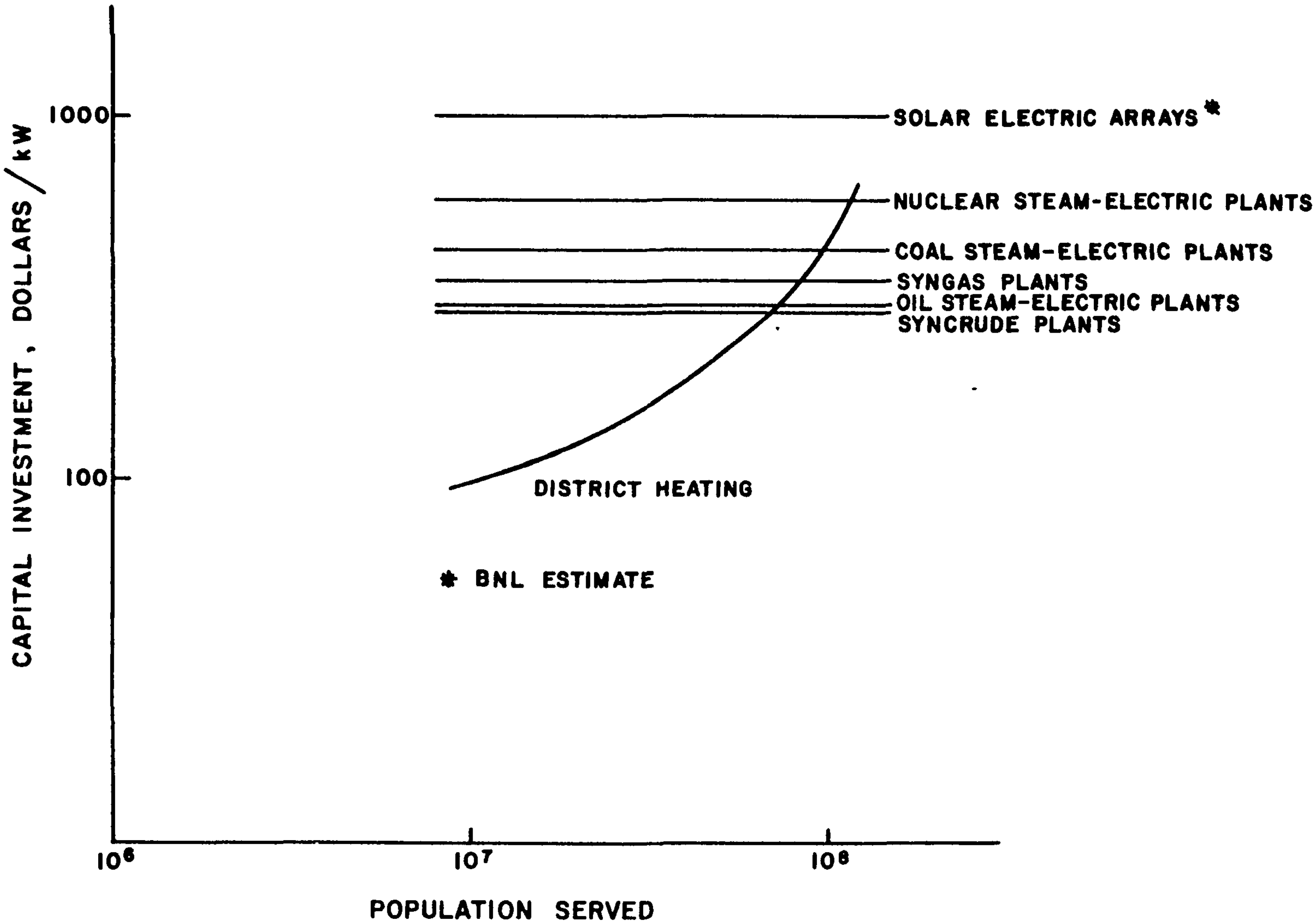


Fig. 7. COMPARISON OF CAPITAL INVESTMENT FOR SEVERAL TECHNOLOGIES

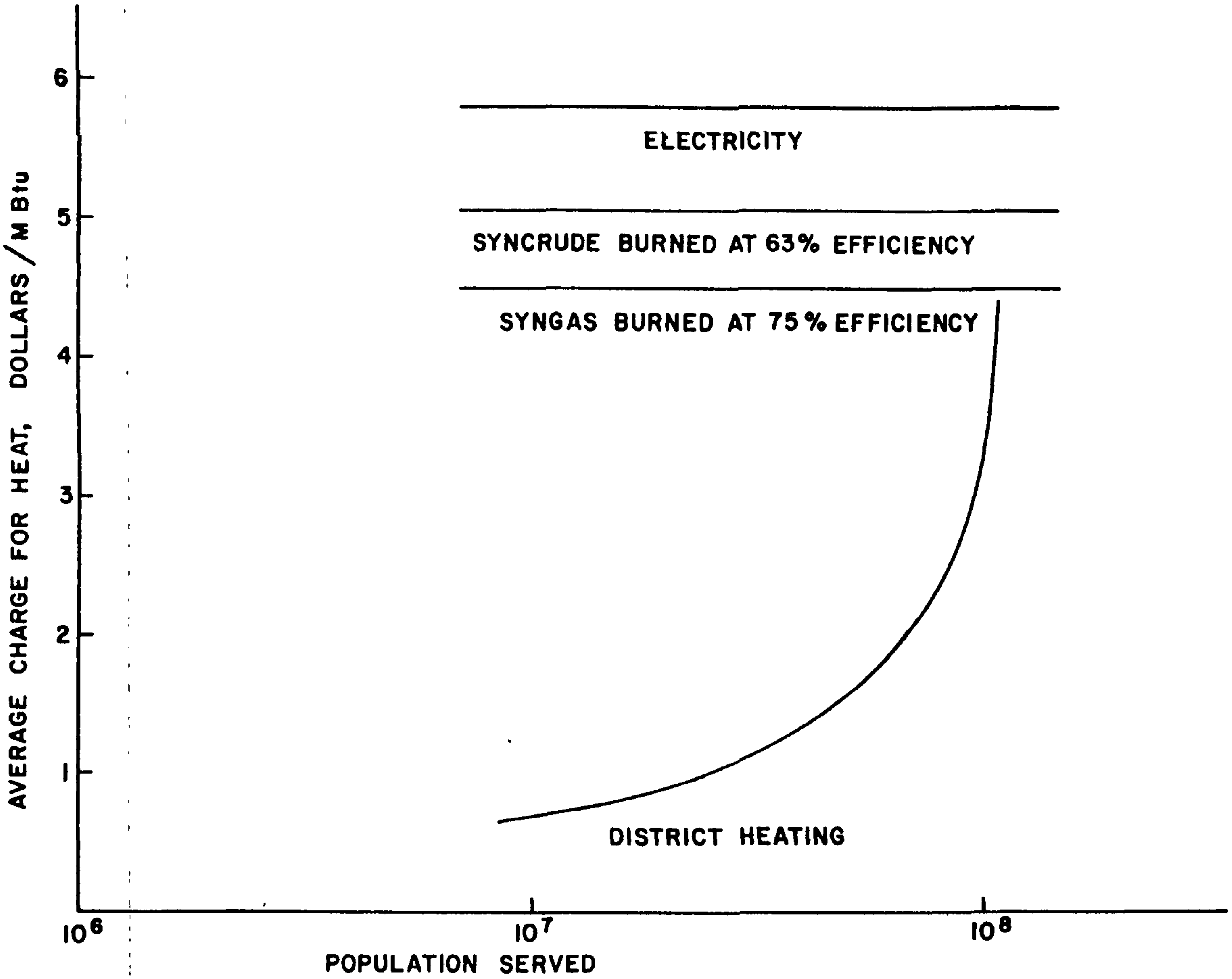


Fig. 8. COMPARISON OF NET HEAT COSTS FOR SEVERAL TECHNOLOGIES