District heating has had a long development of about 50 to 75 years in Germany. What, within the W. German economy today, is meant by district heating, is illustrated by picture 1. A basic distinction is made between public district heating and industrial district heating. The different diagrams in picture 2 show W. Germany's position in district heating among its neighbors and the U.S.A. Comparisons are made in gross national connected load and per capita connected load against different countries of western as well as eastern Europe. In spite of West Germany's highest gross national connected load value in western Europe, this value is relatively small when compared to the U.S.S.R. The per capita values show that the Federal Republic of Germany most probably has a high and not yet developed potential for district heating.

According to the 1975 records of the Association of District Heating Suppliers (A.G.F.W), 112 utility companies were operating 104 heat power plants, and 363 boiler plants with a total of 526 thermal grids. The total connected load in that year was 24 000 MJ/s. District heat is produced in heat power plants and boiler plants where the facilities with larger capacities are usually heat power plants. This paper's main concern will be heat power plants because they are the ones which take over most of the basic heat load, whereas only the peak loads are covered by peak load boiler plants. This situation is best illustrated by picture 3 which can be circumscribed as a graphic representation of the sorted distribution of heat loads over operating hours per year.
picture 1  Public versus Industrial District Heating
picture 2a  Public District Heating in Western Europe (absolute values)
picture 2b  Public and Industrial District Heating: COMECON vs. West Germany (absolute values)
picture 2c  Public District Heating in Western Europe (per capita values)
picture 2d  Public and Industrial District Heating: COMECON vs. West Germany (per capita values)
The interest in district heating in the Federal Republic of Germany has two basic reasons. First of all, district heating, through heat power plants, usually leads to considerable savings in energy. Secondly, district heat, through its centralized efficient combustion process and clean distribution, is friendly to the ecology.

How do we view the way district heating can serve as a major way of saving energy? Picture 4 shows two energy flow diagrams. A modern low-pressure condensation power plant producing only electricity and a modern back pressure unit also producing usable heat are compared. In both cases an output of 100 units of electric energy is assumed. Adding only an expenditure of 51 units to the input of the power plant will yield approximately 162 units of usable heat. This can be viewed as a gain of about 200% of the energy that has been added to the input into the power plant.

The relationship between different methods of central and individual heat producing is shown in picture 5. Here the usable heat output is imagined as being a fixed value of 100 units.

Let us now turn to some aspects concerning the market for heat in the West-German economy. Picture 6 is a simplified energy-flow diagram using data of the year 1974. The situation is still valid today. As opposed to the situation in the U.S.A., the Federal Republic of Germany has to import more energy than it can produce itself. The total prime energy used in Germany is in the process reduced by export, storage, and energy used for chemical processes, leaving an amount of energy which serves as a basis for our subsequent considerations. When analyzing the energy forms consumed by the final user, we find that oil constitutes a larger percentage than among the prime energy usage.
Picture 3: Sorted Distribution of Heat Loads over Operating Hours per Year
picture 4  Energy Balance
( condensation power plant versus back pressure power plant )
basis: equal electricity output
Comparison of Different Heating Methods on the Basis of Equal Usable Heat Output
This is due to the easy handling oil offers for the end producer. Therefore, 56% of the energy used by private residences and small businesses is oil.

When studying picture 7 it becomes evident which large part of the energy consumption falls into the category of room heating and process heat.

Picture 8 indicates how energy saving could be instituted most efficiently to turn energy losses occurring through energy conversion into usable heat for the low temperature heat consumer.

Expedient usage of energy is one important factor in the national economy of a modern industrialized nation. Beyond this, the safety of the national energy supply also has to be given attention. This means that domestic energy sources like coal will have to play a role of increased importance.

As easily comprehensible as these thoughts are, on a macro-economic scale, as difficult seems to be their practical realization. Hesitant, sometimes even unfavorable comments from the press have negatively influenced the district heating discussion in Germany. Also, short term business thinking often prevents the necessary implementation of long term strategies.

A.G.F.W. has conducted an extensive study lasting about 2 1/2 years and involving neutral consultants. The main question to be answered was: to which extent can district heating, through power heat coupling, contribute to energy saving and national energy independence. On the basis of presently available and fully developed technology, it was to be evaluated which parts of West Germany in their current state of development are suitable for district heating and can be further developed to this effect. The underlying period was to be the time until 1990. The prerequisite for a safe statement to this effect was the exact inquiry into the heat demand and
consumption by end users
100% = 244 mill. tons coal equivalent

room heating 40%
process heat 36%
light and power 24%

traffic 0.6%
small business 14.3%
residential 19.8%
industry 5.3%

18.2% traffic
small business 1.1%
residential 0.6%
industry 4.1%

picture 7   End Energy Usage
Total Energy Loss in Energy Conversion and Final Usage

- Energy conversion loss: 93
- Final usage loss: 136
- Miscellaneous (gas production, refineries etc.): 72
- Residential and small business: 57
- Industry: 43
- Traffic: 36

Total energy loss: 229 mio. tons coal equivalent
the establishment of a mathematical model for a precise numerical calculation as to where district heating is most economical and where alternative methods of heat supply would be the better choice.

In parallel to this main study, four urban areas, each of them having quite different characteristics, were researched in order to gain security about the question, where the application limits of district heating for regional supply lie.

Numerous cities already possess an intact and easily extendable gas pipe network. The structure of these gas grids was also analyzed in the study. A system for heat supply via pipe was defined as a long-term goal, mainly in view of the air contamination resulting from individual heating places. The gas supply system (which might have even more importance in the U.S.A.) was chosen as the main criterion for comparing results. Electric heating was not considered a general alternative for district heat. In spite of the gas heat pump's energy efficiency of more than 150%, it was not included in the study because of its presently insufficient state of technology and unsatisfactory economy. Therefore, only the ordinary gas combustion process was chosen as the alternative and as a basis for a comparative calculation.

After all the heat demand data for each areal cell had been entered on magnetic media, fixed and variable costs for gas as well as district heating could be compared through electronic data processing. Each basic areal cell had a certain state of its gas distribution and/or district heating grid which was considered to be 100% if it was fully developed. Beyond this, additional investments like connection of individual buildings and the upgrading of the network to the demanded capacity were regarded. With respect to the gas grid, relatively small additional investments could thus lead to an increased, sometimes even multiple, gas output. For a longterm strategy however, it is necessary to consider
additional influences upon the cost calculations. District heat sometimes has to be led to urban areas which have not yet been included in a heat distribution system and therefore need the full investment.

In the long run, some parts of today's gas grids will become obsolete and need replacement. Obsolete piping systems also tend to cause higher than normal maintenance costs. Other important basic assumptions for the study were the following: a gas price of 7.5 DM/GJ on the basis of 3,000 hours of usage per year was assumed at the entry point to the urban area. A price increase of 1.25 DM/GJ (not counting inflation) was taken into consideration, also. Another 1.25 DM/GJ were added to account for extra cost caused by the previously mentioned obsolescence of the piping. On the other side one must consider the heat generation cost in heat power plants. They were calculated to be in the range of the 2.5 DM/GJ to 12.5 DM/GJ depending on the size and the design.

In view of regional differences in the cost of heat pipe installment, another parameter was introduced. Picture 9 shows two limit curves between which the installment cost could vary. It was assumed that the pipes would be laid in concrete ducts. This method had been proved successful in the past. Areas with high heat density were considered more problematic for pipe installment and therefore associated with extra costs of DM 300 per meter. Reasons for these higher costs are usually the necessity of circumventing objects and established piping and other difficulties. As is well known, the installment costs are usually an essential part of the fixed cost of a district heating system. Therefore, in determining district heating potentials, this cost element turned out to be one of the main parameters. The further development of district heating thus seems to be largely dependent also on research and development in small diameter piping, with the aim of cost reduction. A.G.F.W. has recognized this
picture 9  Pipe Installation Costs (1975)

1 DM \cong 0.5 \$
fact years ago and has promoted new technologies, one of them being full-plastic piping systems.

Picture 10 presents an example of an urban cell (as it was discussed in many similar cases) in which the following assumptions were made: the degree of heat-conducting piping is zero, which means, that there is no district heating system existent. Therefore, also the heat supply is zero. The degree of gas piping is 100%, meaning that a full gas distribution system exists. Through this gas network 30% of a potential market of 100% is supplied with gas. In this example, this is the initial state of an areal cell. It is now to be determined under which conditions the introduction of district heating would be economical. The user of the chart is enabled to determine which maximum capacity in relation to the average individual consumer can be economically supplied in a certain cell, either through gas or through district heat.

To quantify the total potential, 92 cities of the Federal Republic of Germany were subdivided into areal cells, and the most probable heat supply costs were assigned to them. The results were documented in a so-called heat atlas. Picture 11 shows a section of this heat atlas.

For the following evaluations it is now necessary to define some terms. This paper makes a distinction between a technically feasible district heat potential and an economically feasible district heat potential. The technical potential means the total of all houses and buildings that have been changed to a central heating system by the year 1990. To be economically feasible, the criteria illustrated by picture 10 have to be met.

In this long-term consideration, i.e. up to the year 1990, the result for West Germany is illustrated in picture 12. An upper and a lower limit for the district heat potential that is economically feasible by the
initial state of the district
established district heating 0%
established piping for gas supply 100%
gas heat supply 30%

DM/GJ

Decision between Gas and District Heating Supply

picture 10

larger residential buildings 1
commercial buildings 2
single family houses 3

example heat procurement cost 6.7 DM/GJ

area where district heating is economically feasible
area where district heating is not feasible
process heat temperature range 80-200°C

room heating and hot tap water

present district heating

GJ/s 35.4

upper limit (piping cost)

278.5

7.5

68.2

36.1

23.5

23.5

23.5

23.5

district heating
technically feasible
district heating
economically feasible (1990)

picture 12 District Heating Potentials in West Germany
year 1990, has been determined for the total of room
heat, heat for warm tap water, and process heat. Assumed
was, that all technically feasible users are connected
to the district heat grid in those areal cells that
were economically feasible. This is due to the question,
which part of the West German low heat demand could
economically be supplied by district heating systems.
Furthermore, it was stipulated that the final state of
the district heat grid had been established in each cell
without start-up losses.

This introduces into our discussion two main problems
which were significant for district heating in the past.
Firstly, the degree of supply, and secondly, the comple­
tion period. To illustrate these problems, the study
conducted by A.G.F.W. calculated several models.

Picture 13 shows departing from the state of develop­
ment in the year 1975, the possible development, provided
that the economically feasible district heat potential up
to the year 1990 will be consistantly materialized and
starting support will be granted. Without such aids, for
example investment incentives, the development will be
much slower. Federal and local governments already have
allocated about 680 million marks as investment incentives
for district heating for the years 1977 through 1980.

As to the heat procurement it can be expected that
district heat will be best split off from fossil or
perhaps nuclear power plants of higher magnitude which
will have to be built for reasons of electric energy
anyway. Of course, the district heat split-off will
cause a certain reduction in electric energy output
and some other additional investments. Both of these
cost elements will have to be charged as fixed costs
to the district heating. District heat stemming from
heat power plants, which are mainly built for the pur­
pose of heat power coupling, is expected to be more
expensive. The economic evaluation by itself yields
*) study results

picture 13 Development of the District Heat Output
that the provision of heat from heat power plants is only sensible if fresh heat cannot be supplied cheaper, for example, through boiler plants.

The availability of nuclear district heat is no necessary prerequisite for the opening of the evaluated district heat potentials. It is, however, important that fossil heat power plants be erected near the urban areas. Like in the U.S.A. the presently existing and planned nuclear power plants are too distant from the population centers and too remote from dense urban areas.

It seems remarkable that almost 2/3 of the economically feasible district heat potential in 13 to 16 main areas could be supplied by large power plants. The remaining approximately 150 medium and smaller areas again could be covered to 2/3 of their potentials by smaller heat power plants, the rest by large power plants.

Another interesting result is the change in electric power procurement if the district heat supply is developed to the projected extent. Again reference is made to an upper and a lower potential limit (picture 14). It can be seen that the addition of heat power plants has little weight compared to the net power expected for the public supply in 1990. Also, the often overvalued electric power reduction through district heat split-off turns out to have a small order of magnitude, comparatively.

The results can be summarized as follows:

1) With enforced development of district heating trough 1990, a quadrupling of the present district heat output can be achieved. This means that about 25% of the low temperature heat demand (up to 200°C) can be economically covered by district heating.

2) This district heat development will lead to an insignificant change in the electric power balance for 1990.
<table>
<thead>
<tr>
<th>Capacity Reduction</th>
<th>Upper Limit (Piping Cost)</th>
<th>Lower Limit (Piping Cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large power plants</td>
<td>-1400 MW</td>
<td>-800 MW</td>
</tr>
<tr>
<td>through connection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>to district heating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional capacity from power</td>
<td>+2135 MW</td>
<td>+468 MW</td>
</tr>
<tr>
<td>plants with back pressure turbines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional capacity from gas turbines</td>
<td>+5230 MW</td>
<td>+3150 MW</td>
</tr>
<tr>
<td></td>
<td>Ca.6000 MW</td>
<td>Ca.2800 MW</td>
</tr>
</tbody>
</table>

Picture 14: Change of the Total Electric Capacity in West Germany After Increasing District Heating
The development, however, is directly dependent upon the finding of locations for future large power plants and heat power plants.

3) The investment will be in the range of 20 to 30 billion marks within 15 years, depending on the aforementioned upper and lower limits. Another 6 bio. DM will have to be provided by the users to convert from individual central heating.

4) The maximum possible energy saving is estimated to reach about 19 mio. tons of coal equivalent per year in the case of a thorough development to the upper limit of the potential.

5) Compared to the present conditions the emission of harmful substances will be largely reduced with the only exception of nitrogen oxydes.

6) The enforced development of district heating would maintain about 60,000 jobs through the period to 1990.

Some additional conclusions have been drawn by A.G.F.W. from the results of the study:
Raising the capital for enforced development of district heating is not expected to lead to any financial or other difficulties for the national economy of West Germany. In spite of this fact, the investments will reach significant importance for the single utility.

The hesitation prevailing in many utilities with respect to district heating is usually based upon the disappointing usage of the heat distribution systems set up within the last 15 to 20 years. The usage is only in the range of 30 to 50%. Financial assistance, as mentioned before, could enable the utilities to decide for the enforced development. However, this assistance should never assume the character of continued subsidies, but instead only create business incentive.
To initiate the intensive district heat development, local and regional supply concepts have to be established. The consistent development of such concepts could be the key to an integrated planning for all pipe oriented energy carriers. The inclusion of thorough information of the citizenry into all aspects of energy saving seems important. Working out such local and regional supply concepts will become the more necessary as well as difficult, the more comprehensive the heating district is. The main study and especially the additional four regional studies have shown that district heating of a large German urban area is possible under the condition that such areas are supplied with district heating in a straightforward manner and connected to a large power plant as soon as possible.