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IEA District Heating

Programme of research, Development and Demonstration on District Heating and Cooling

THE ENVIRONMENTAL BENEFITS OF DISTRICT HEATING AND COOLING

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REPORT ON THE
ENVIRONMENTAL BENEFITS OF
DISTRICT HEATING AND COOLING

Prepared for

The International Energy Agency

by

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1.0 INTRODUCTION

Near the end of 1983, the International Energy Agency (IEA) implemented its Program of Research, Development and Demonstration on District Heating Systems. The program has since been expanded in scope to include district cooling systems. The program continuously monitors ten participating IEA countries ongoing research, development and demonstration district heating and cooling projects.

This report examines the environmental benefits of district heating and cooling, and is one of several summary reports on particularly relevant topics. This report has been prepared on behalf of the IEA for information and education exchange.

District heating and cooling is the distribution of heating (hot water, steam) and cooling (cold water) energy transfer mediums from a central energy production source, to meet the diverse thermal energy needs of residential, commercial and industrial users. Thermal energy needs or demands include space heating and cooling systems for maintaining human comfort, domestic hot water requirements, manufacturing plant process heating and cooling system requirements, etc. In many of the systems that have been established around the world, both district heating and district cooling have not been provided. For example in Europe, where moderate summer temperatures prevail, most district thermal energy systems provide heating capability only. District cooling has only recently become more widespread, with the most prevalent application being in North America, where summer temperatures can, over extended periods, reach extremes of 30°C to 40°C.

There are a number of factors which must be weighed when determining whether or not a district heating (DH) or district heating and cooling (DHC) system should be implemented in a particular community. These factors include local economic and climatic conditions, viability of competing alternative energy supply systems, local energy production and utilization efficiency considerations, local environmental benefits, and differing producer and user perspectives on the significance of benefits of district systems.

The subject of this report, environmental benefits of DHC, must be considered pre-eminent on this list of district energy system assessment factors, considering the industrialized countries increasing emphasis on reducing and avoiding the negative impacts that various human activities, including technological developments have had, and continue to have, on the global environment.

This report is broken down into the following major sections:

- Section 2.0 discusses the environmental impacts that are associated with the various heating and cooling systems in use today. Impacts discussed include global climate change, ozone depletion and low level environmental impacts such as acid rain and local air quality.

- Section 3.0 examines specific aspects of district heating and cooling systems, outlining the components associated with these operations and the environmental benefits that can result when such systems are adopted.

- Section 4.0 illustrates, through actual case studies, the environmental benefits which are experienced through the use of district heating and cooling systems. The benefits discussed in this report relate primarily to the environmental impacts identified in Section 2.0.

2.0 ENVIRONMENTAL IMPACTS ASSOCIATED WITH HEATING AND COOLING SYSTEMS

2.1 GENERAL

With the exception of electric heating and cooling systems that utilize only power produced by hydro or thermonuclear power generation facilities, the thermal energy required for heating and cooling purposes is produced by systems that require the combustion of fossil fuels. The combustion process creates "products of combustion" (POCs) which are emitted to the atmosphere at elevated levels via stacks. POCs associated with thermal energy production, include among others, particulate matter and oxides of sulphur, nitrogen and carbon. Such emissions contribute both locally and globally, to the background level concentrations that result from all the air emission sources, and together result in negative environmental impacts such as global warming, acid rain and poor local air quality. In addition, chilled or cooling water production systems, in most applications to date use electrically driven compressor chilled water production systems that require refrigerants such as chlorofluorocarbons (CFCs). These chemicals are thought to be the primary contributor to ozone layer depletion in the upper atmosphere. The environmental impacts associated with POCs and refrigerants are discussed in more detail below.

With heating and/or cooling systems, some electric power is required to operate fans, pumps, cooling system compressors, and in some cases, heating coils. Such power is typically generated by hydro, nuclear, fossil fuel fired power generating plants, or a combination of all three. In the case of the fossil fuel fired power plants, the combustion process results in POC's and impacts as described previously. In the case of nuclear power plants, disposal of radioactive wastes and releases of radioactive material to the air and water systems during process upsets are a major source of concern. Even hydro-electric power plants are being identified as possible sources of pollution problems, and negative environmental impacts, that result from the loss of agricultural, wildlife habitat, and forest lands and flooding and impacts that result from the build-up of the concentration of mercury in the environment upstream of hydro dams. Thermal power generation plants (nuclear and fossil fuel fired) also discharge large quantities of waste heat to the environment (via air and/or water) from the steam turbine condensing system portion of the plant.

With the above, it is apparent that heating and cooling systems that minimize the quantity of fuel and electrical power required to meet the users needs will result in reduced negative impacts on the environment. It should be noted that the combustion process and CFC refrigerant based thermal energy systems represent the most prevalent systems used throughout the industrial world, from the household level up to major power production plants. While DHC plants are not immune to the production of pollution causing emissions, as discussed in Sections 3.0 and 4.0, the nature of operation of these plants is such that significant reductions in the pollutants emitted can be realized, compared to the other widely utilized alternatives.

2.2 GLOBAL CLIMATE CHANGE

In general, considering the many factors that can significantly influence climatic conditions at a particular location from day to day, year to year, the earth's climate on the whole has been relatively predictable over the years. For many places on earth, normal day-to-day and seasonal average conditions and typical variations in temperature, precipitation, cloud cover, wind and other atmospheric conditions have been charted and for the most part, provide reasonable expectations regarding that place's climate. As a result, we expect that the climate at certain times of the year in any particular location, remains relatively constant from year to year, although we recognize that from time to time, we do experience conditions that deviate from the "norm". Trends and indicators have been observed in recent years however which suggest that the earth's climate is undergoing abnormal changes. The term "global warming" is now commonly used to describe the trend that global average temperatures appear to be on the rise. Global warming and the potential impacts on the earth's climate and inhabitants are of concern to many scientists and lay persons. Many believe global warming is occurring and is largely attributable to human activity.

The global climate system is a complex phenomenon. In simple terms, as energy from the sun reaches the earth, it warms the land and surrounding air, in turn causing atmospheric winds and ocean currants to be set in motion, driving the evaporation/precipitation processes. The movement and relative position of the sun, moon and earth result in continuing changes to these conditions. Other factors that affect climate include topographical features of an area, the residual effects of forest fires and volcanic eruptions, the presence of densely populated areas and the related structures. All these factors, and others, combined result in our constantly changing weather patterns.

The overall climate system, despite the variations, is generally in a state of equilibrium. That is, the rate of solar energy input from the sun is balanced by an equal amount of energy released (as infrared radiation) back to space. As long as the factors that maintain this equilibrium remain constant, global temperatures are expected to, on average, remain relatively constant. The observed global warming trend is therefore thought to be caused by a shifting of the equilibrium conditions of the past, as a result of the build-up of certain gases in the atmosphere (some naturally occurring, others not). Such gases inhibit the release of infrared radiation, causing the "greenhouse effect". These "greenhouse gases" include carbon dioxide, methane, nitrous oxide, ozone and chloroflurocarbons (CFCs). Their presence in increasing or decreasing concentrations changes the equilibrium point and impacts our environment.

When considering the impact each of the greenhouse gases has on global warming "potential", three factors must be considered; the heat absorbing effectiveness, the amount in the atmosphere, and the atmospheric lifetime of each gas (period before being transferred to a harmless state by natural chemical reactions). These factors are substantially different for each gas. When collectively considered, carbon dioxide is estimated to account for 55% of the global warming potential, CFCs - 24%, methane - 15%, and nitrous oxide - 6%. The significance of the impact of low level ozone from a global warming perspective, is not yet completely clear since the effect of the build-up of low level ozone may be offset by the ozone layer depletion that is occurring in the upper atmosphere (see Section 2.3).

Carbon dioxide (CO_2) is produced by both natural and human activities. It is estimated that human activities (primarily related to vehicle exhausts and, to a lesser degree, fossil fuel combustion) account for only 4% of the CO_2 found in the atmosphere, however, this amount is not only in addition to an already balanced naturally occurring carbon cycle, but is cumulative with time. The human related production of CO_2 is now approximately 10 times greater than at the turn of the century. Concentrations in the atmosphere are reportedly at their highest levels in more than 135,000 years (corresponding roughly with the end of the second last ice age). Human activity also includes deforestation which may also have an impact on the environment since loss of our forests reduces the potential for CO_2 absorption into the natural carbon cycle.

Methane (CH_4) is produced naturally by the decay of organic matter in the absence of oxygen. The increase of CH_4 in the atmosphere, estimated to be about 1% per year, is thought to be related primarily to changes in land use stemming from a rapid worldwide population growth.

The impact of CH_4 will not be reviewed further in this report since its production is for the most part unrelated to the character of the emissions associated with most thermal energy production systems. In some instances, potential does exist to harness the energy associated with methane generation sites. Such applications could indirectly be integrated with district heating or cooling systems. One such example involves power and/or heat energy production from the methane gas generated at organic waste landfill sites.

Nitrous oxide (N_2O) concentration levels in the atmosphere are increasing, albeit at a relatively slow pace. Still, the global warming potential of N_2O is not insignificant. N_2O production is believed to result primarily from ammonia-based fertilizers and fossil fuel combustion processes.

Low level O_3 (ozone) formation is partly due to a migration of O_3 from the upper atmosphere and partly through chemical manufacturing and combustion processes that result in the formation of gases such as nitrogen dioxide (NO_2) and carbon monoxide (CO). Both these gases result from combustion of fossil fuels. Ground level O_3, which is estimated to be increasing at a rate of 1% annually, has also been linked to air pollution problems in the form of smog (see Section 2.4).

Molecule-for-molecule, chlorofluorocarbons (CFCs) are the most potent of the greenhouse gases. A CFC molecule absorbs approximately 15,000 times more heat than a CO_2 molecule and has a much longer atmospheric lifetime. CFCs, as indicated previously, have less than ½ the impact CO_2 has on the global warming problem. However, this lower impact is simply because so much more CO_2 is emitted to the atmosphere. CFCs are man-made chemicals used as refrigerants in air and water chilling systems, solvents, foaming agents and spray-can propellants. The significance of CFCs contribution to global warming problem, as well as upper level ozone destruction (see Section 2.3), has been recognized and many nations have committed to phase out CFC manufacturer and use. More environmentally benign alternatives have been, and are being, developed including hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs). Such alternatives have much reduced ozone depletion characteristics. HFCs and HCFCs have only about half the heat absorbing capacity of CFCs and a much shorter lifetime. Consequently their overall global warming potential is about ten times lower than CFCs. A discussion, with respect to ozone depletion, of CFCs and the replacements HFCs and HCFCs is found in Section 2.3.

Although most people studying global warming do not dispute that greenhouse gases trap radiated heat causing a warming effect in the lower atmosphere, considerable debate does exist within the scientific community as to the significance or overall impact this warming trend will have on our environment. Some believe that, as a result of global warming conditions, the earth's average temperature could increase anywhere from 1.5°C to 4.5°C in less than fifty years. Such an increase could cause ocean levels to rise considerably causing flooding of coastal inhabited areas; lake levels could drop creating a shortage of fresh water and a degradation of water quality; storms, floods, erosion, droughts could all be more severe and frequent; and plant and wildlife inability to adapt to these relatively sudden changes to their habitat, and possibly major climate changes, may imperil many species. Skeptics of global warming theories point out that the environmental impacts suggested are based on estimated average temperature rises derived from computer models; models which have been shown to poorly predict global temperature changes observed in the past. Still most agree that intensifying conservation efforts and reducing emissions to the atmosphere makes good sense, whether or not global climate change ever becomes a reality or is the driving force behind such initiatives.

2.3 OZONE DEPLETION

Ozone (O_3) occupies only a very small fraction of the earth's atmosphere and yet the existence of the ozone layer is of vital importance to life on earth. Ozone is the only atmospheric gas which absorbs and reduces to reasonably safe levels the especially harmful portion of the UV spectrum known as UV-B. Without such UV protection most life forms, including plants and animals, can experience living cell damage with serious consequences including, for example, a decrease in photosynthesis activity in plants, and cancer in humans.

Generally, the destruction of ozone in the atmosphere results from a series of cycling chemical reactions between an O_3 compound and a catalyst such as chlorine, bromine, hydrogen or nitrogen. The catalyst breaks down the O_3 compound by stealing one oxygen molecule, creating a stable oxygen compound O_2 and a new catalyst/oxygen compound. In the case of some catalysts such as chlorine, the catalyst/oxygen compound can then easily break apart leaving a solitary oxygen molecule. The oxygen molecule can then combine with another single oxygen molecule, forming O_2. More importantly, the catalyst becomes available again to destroy other O_3 compounds. This chain reaction can result in the destruction of hundreds of thousands of O_3 compounds before the catalyst eventually forms a stable compound that is no longer available to destroy ozone.

Since the discovery in the mid-1980's of an ozone "hole" over Antarctica and with subsequent discoveries of ozone depletion over other areas of the earth, most notably over the Arctic, considerable research has been conducted to determine the specific forces behind ozone destruction. Evidence now suggests that ozone depletion is primarily caused by man-made chlorofluorocarbons (CFCs) which contain the all-important ozone-destroying catalyst, in this case, chlorine. CFCs have a particularly stable chemical structure which results in their being highly effective transporters of the chlorine. In fact, CFCs will not normally break down and release the chlorine molecule until they become exposed to the upper atmosphere's intense radiation, coinciding unfortunately with the very location of the highest concentrations of ozone.

CFCs have been used worldwide for over 60 years as refrigerants, solvents, foaming agents and spray can propellants. The level of free chlorine in the atmosphere, believed to be primarily attributable to the extensive use of CFCs, is estimated to be about six times higher now than at the turn of the century. Recently, substitute products having comparable performance to CFCs but imparting much less impact on the ozone layer have been developed. These include hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs). HFCs contain no chlorine or other readily available catalyst thus they have an ozone depletion potential (ODP) of zero. HCFCs, although containing chlorine, break down in the lower atmosphere thus they do not provide a catalyst near the concentrated ozone layer (upper atmosphere). The ODP of HCFCs ranges from 10 to 50 times lower than that of CFCs.

Although the development of HFCs and HCFCs appears quite promising in terms of minimizing ozone depletion, the substitution of these refrigerants into the countless refrigeration systems currently using CFCs is not as easily accomplished as might first be assumed. The replacement refrigerants exhibit slightly different properties than CFCs resulting in reduced system efficiency and cooling capacity, and increased operation and maintenance costs. Losses in efficiency and capacity may require that additional equipment be purchased and put on line to meet the current loads, for which there may be no readily available space. Certain HCFCs are more corrosive than the CFC refrigerant, necessitating modifications to ensure equipment is suitable for operation on the new refrigerant. Depending on the class of equipment and the equipment's operating conditions, such as temperature and pressure, some replacement refrigerants may not be operationally suitable, requiring implementation of less desirable replacements. Indeed, factors may favour and result in selection of HCFCs over HFCs, even though HCFCs have a non-zero ODP and have recently been attributed with possible toxicity effects. Actually HCFCs are now intended to be phased out themselves, between the years 2020 and 2030, or possibly sooner. Major retrofitting efforts to accommodate an HCFC, only to have it phased out during the new equipments' lifetime, is forcing decision-makers to carefully examine their options.

Nitrogen, in the form of the relatively stable compound, nitrous oxide, is another ozone-destroying catalysts carried to the upper atmosphere. This compound is available in part as a result of fossil fuel combustion, thus both fuel combustion and refrigerant use aspects of thermal energy production schemes play a role in contributing to the depletion of the ozone layer problem.

2.4 LOW LEVEL ENVIRONMENTAL IMPACTS

This section discusses low level (i.e. near the earth's surface) environmental impacts that are associated with thermal energy production. Such low level impacts include acid rain, particulate matter deposition and local air quality concerns such as urban smog.

Acid Rain is created through the process of acidification of natural precipitation by oxides of sulphur (SO_x) and nitrogen (NO_x), both POCs of fossil fuel combustion.

SO_x is formed during combustion through the oxidation of sulphur and sulphur compounds present in the fuel. SO_x formation depends almost exclusively on the amount of sulphur in the fuel, as opposed to such factors as burner design or combustor capacity. Commonly used fuels, coal and oil, contain small but significant percentages of sulphur, while natural gas contains only trace levels. Historically, 90% or more of the sulphur present in these fuels has been released to the atmosphere during combustion. Thus, even though the weight percentage of sulphur in coal and oil fuels is relatively small (normally less than 2.5% and often below 0.5%), the total emissions are significant because of the significant quantities of coal and oil that are burned throughout the world to produce power and heat energy.

NO_x is formed during the combustion process through the oxidation of both atmospheric nitrogen (the combustion air is 80% nitrogen) and nitrogen contained in the fuel used. The rate of formation of NO_x during combustion depends on many factors including combustion chamber temperatures and oxygen levels, the degree of turbulence and/or the extent of stratification of the combustion air, fuel and combustion products in the combustion chamber, and the combustion products cooling rate within, and downstream of, the combustion chamber. Each of these factors are affected by, or resulted from, specific system characteristics such as the type and size of combustor, the fuel being burned, and the actual operating conditions at the time. NO_x emissions are formed during combustion of coal, oil and natural gas.

Once released to the atmosphere, the SO_x and NO_x emissions chemically react with moisture in the air and can then return to earth as acidified precipitation. This precipitation may be in the form of rain, snow, fog or mist. The acidified precipitation is not restricted to the proximity of the emission sources. These emissions can be carried a considerable distance by prevailing winds before reacting with moisture laden air and before the precipitation event is experienced.

The impacts associated with acid rain are significant, affecting flora and fauna. Acid rain has resulted in major ecological damage to, and even the "death" (with the destruction of life form habitats) of, thousands of lakes around the world. Forests and crops have also been extensively damaged and their continued existence threatened by acid rain effects. In addition, acid rain causes damage to man-made materials, modern and historical buildings, monuments, etc. Evidence also indicates that acid forming air pollutants can contribute to respiratory problems in children and other susceptible groups.

Important steps have recently been initiated by many of the industrialized nations to minimize the emission of acid rain causing air pollutants. These initiatives take the form of commitments to reduce and/or avoid any further increase of SO_x and NO_x emissions considering both existing and new sources.

Although the depletion of ozone in the upper atmosphere has been linked to negative environmental impacts, as discussed in Section 2.3, **elevated low level ozone levels** (i.e. occurring normally in the lower atmosphere), have also been identified as a pollution problem. Ground level ozone is a major component of what is commonly referred to as smog. Smog describes conditions that negatively impact the local air quality and are of concern to public health in many densely populated areas. Ozone related smog is normally associated with the urban environment with the increased concentration of both mobile and fixed emission sources and is therefore often termed urban smog. However, since the pollutants necessary to the formation of ozone can be transported downwind to rural areas, rural smog is also a concern, albeit in most parts of the world, to a lesser degree.

Low level ozone is primarily formed by photochemical reactions with two pollutants; volatile organic compounds (VOCs) and oxides of nitrogen (NO_x).

VOCs are emitted from both human related and natural sources with the latter being the major contributor in rural and open spaces. The former predominates in the urban environment. Human related sources of VOCs include, among others, combustion of fossil fuels, although thermal energy production facilities are not significant contributors.

Elevated ozone levels, and hence smog levels, are known to have adverse effects on human health, vegetation and materials. Human health concerns centre around respiratory ailments such as coughing, decreased lung function and premature aging of the lungs. Impacts on vegetation usually occur as damage to foliage, resulting in problems with plant growth and productivity. Observed man-made material damage associated with low level ozone include hardening of rubber materials and bleaching of paints.

Control and reduction of low level ozone concentrations is being pursued by some industrialized nations, through the establishment of VOC and NO_x emission reduction targets.

3.0 BASICS OF DISTRICT HEATING AND COOLING SYSTEMS

3.1 GENERAL

This section describes the basic elements of district heating and cooling (DHC) systems and compares the environmental benefits of DHC systems with conventional (i.e. non-district) systems.

In general terms, DHC systems can be defined as the production of heating (hot water or steam) and cooling (chilled water) energy at one or more sources, and subsequent distribution of the thermal energy via pipelines to "district" users. A typical DHC system is therefore comprised of three subsystems:

1) thermal energy generation; where steam or hot water in the case of district heating, and chilled or cold water in the case of district cooling, are produced,
2) thermal energy distribution; where the thermal energy medium (steam or water) is distributed via pipelines from the production source(s) to the network of users, and
3) incorporation of the thermal energy at the user's (customer's) location.

The concept of DHC is similar to potable water distribution or electric power generation and distribution systems. A combination of residential, commercial and industrial users may be involved with varying uses of the thermal energy including space heating and cooling, domestic hot water heating, plant process heating and cooling, etc.

A district heating and/or cooling system differs fundamentally from a conventional system in that, in the case of the latter, thermal energy is produced and distributed at the location of use. Examples of conventional systems include home heating and cooling with, respectively, furnaces and air conditioners, electric heating of offices, package boilers/chillers providing heating/cooling of apartment complexes, and a dedicated boiler plant providing heat to an industrial facility.

There are many factors regarding DHC systems which must be considered in determining whether or not implementation of a particular system is preferred. These include economic criteria, viability of competing systems, local climatic conditions, user characteristics such as load density, total load requirements, characteristics of the heating and cooling systems currently in place, developer's perspectives, local utility considerations, local and global environmental impacts, and others. All of these factors will likely have a bearing on decisions made regarding the viability of a particular DHC system.

The description which follows provides a conceptual overview of DHC systems, with emphasis on those components which have an environmental impact. Other components, (i.e., do not have significant environmental impact) which would have to be considered in an overall system analysis, such as types and costs of equipment used, heat distribution medium proposed (water, steam), operating temperatures and pressures, system control characteristics, user prerequisites, etc., are only briefly discussed, as these aspects are not the focus of this report.

Section 3.2 provides a discussion of the basic equipment that is associated with DHC systems.

Section 3.3 identifies potential environmental benefits of DHC systems compared to conventional systems. These benefits are illustrated through actual case studies and examples in Section 4.0.

3.2 DISTRICT HEATING AND COOLING SYSTEM COMPONENTS

3.2.1 System Prerequisites

Although varying from country to country and city to city, certain conditions must generally prevail in order for a DHC system to be viable compared to conventional systems.

Heating and cooling load densities, that is the heating/cooling requirements per unit area, should be relatively high. The very nature of a DHC system dictates this criterion since it becomes uneconomical to distribute energy to sparsely populated areas where distribution piping costs and thermal "losses" become comparatively high.

Generally speaking, a relatively high total heating/cooling load is preferred since improved operating efficiencies can be realized at larger facilities, and since economies of scale favour larger installations.

Apartment complexes, hospitals, universities, groups of office buildings, and factories are all energy user candidates which meet the above prerequisites well. Many major cities around the world meet much of their heating requirements through district heating. DHC systems that service areas of the City beyond the high density building zones typically result when adjacent housing densities are fairly high and/or several inexpensive sources of thermal energy are available. Examples of relatively inexpensive thermal energy include waste heat recovery from energy-from-waste facilities, from large power generation plants, and from gas turbine combined cycle cogeneration plants. Without such local opportunities for DHC supply and utilization, city-wide applications become borderline candidates at best.

A partial list of cities with well developed district heating systems would include Paris, Helsinki, Stockholm, Copenhagen, Moscow, New York, Boston, San Francisco, Toronto and Tokyo. In Sweden, Finland and Denmark, district heating supplies 30, 39 and 42 percent, respectively, of the entire countries heating demand serving downtown core areas to urban and suburban residential areas.

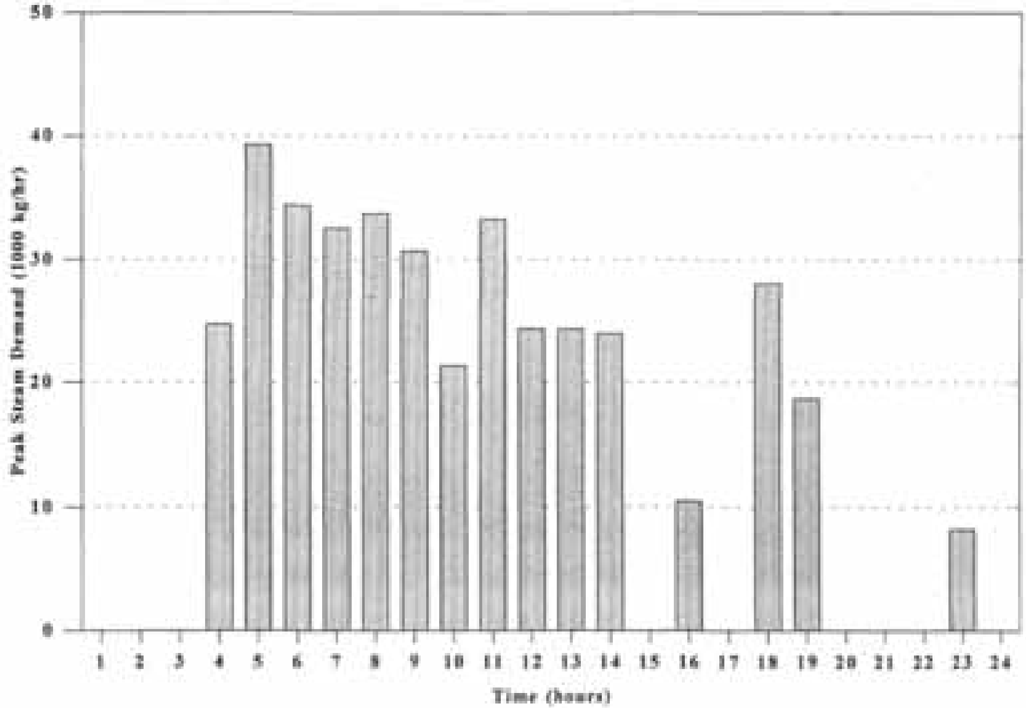
3.2.2 Thermal Energy Generation

DHC systems, owing to the fact that they are usually connected to a diverse group of customers with varying load requirements, must typically accommodate a relatively large total heating/cooling load with potentially wide variations from season to season. Since individual customers often experience their peak loads at different times of the day, the central production plant's daily characteristic load curve tends to be smoothed out, with the peak demand reduced, compared to the sum of all the individual peak loads. Thus, the installed total capacity of a DHC system can be less than that of conventional decentralized systems - a distinct advantage of a district system.

Figures 1 and 2 show actual hourly demand profiles for two large buildings in Toronto, one in a commercial office tower and the other a large hotel. Both buildings demonstrate significant demand during normal daytime hours and minimal off hour demand. Figure 3 shows the demand profile of the Toronto District Heating Corporation's major customer and demonstrates the flattening effect on peak demand when used by a variety of customer types.

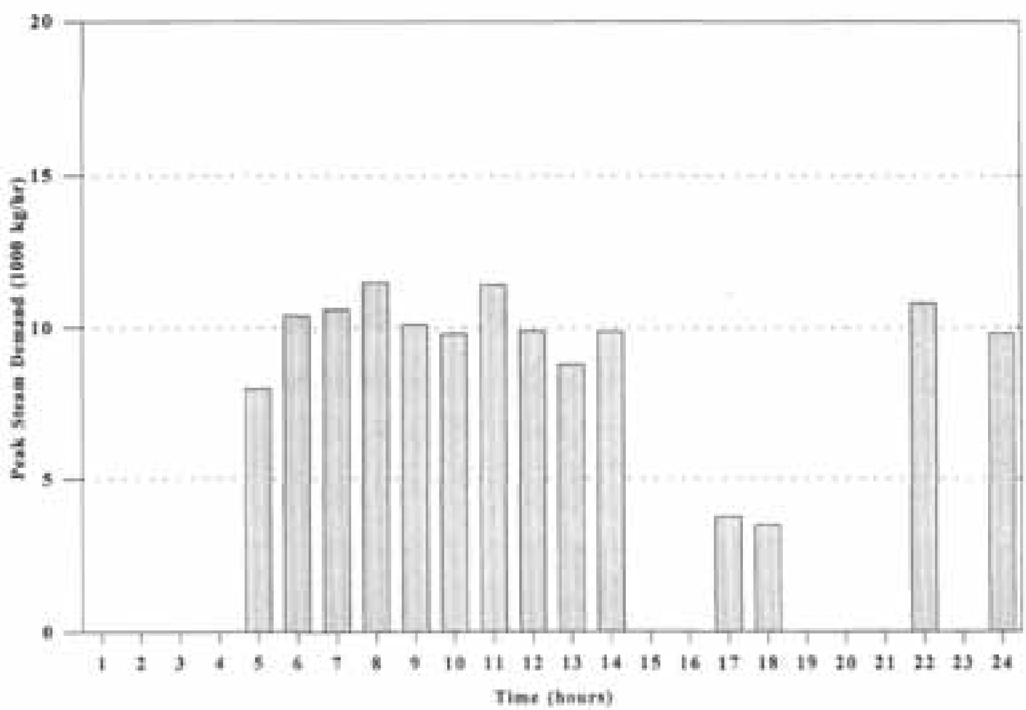
Depending on total system peak and average load requirements and the load variations from day-to-day and season-to-season, DHC plants of varying complexity can and have been developed. A relatively simple DHC system might utilize a single energy production facility, comprising for example an oil or gas fired boiler (heating) and an electrically driven centrifugal chiller

Figure 1
Peak Steam Demand Profile (Dec/90 - Feb/91)
Multi-Storey Office Tower



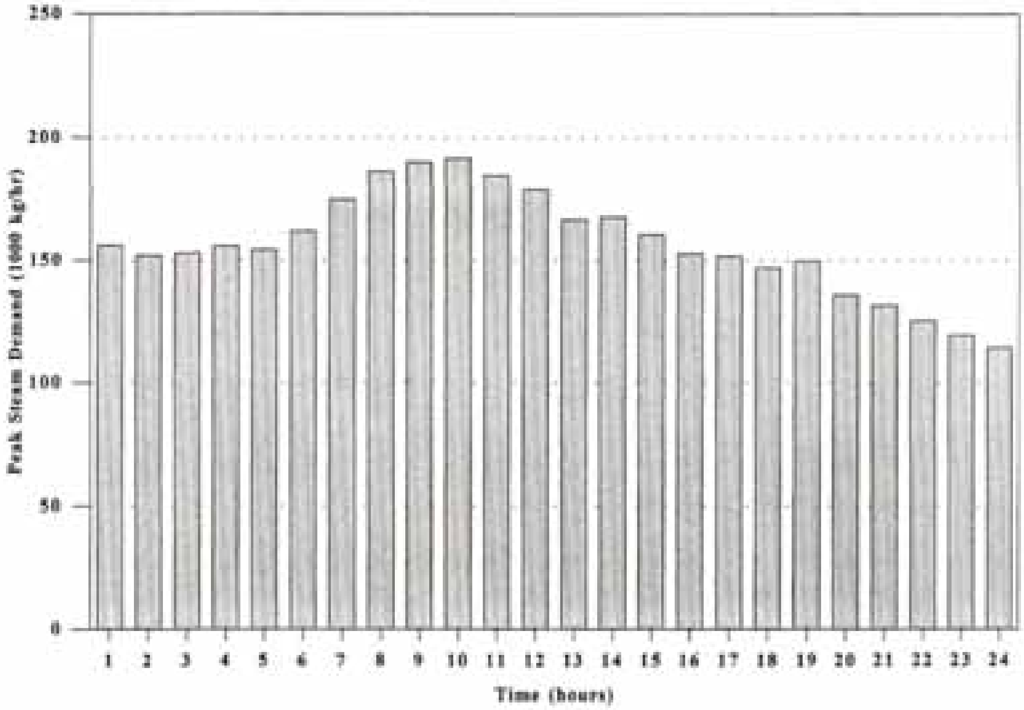
Data courtesy of Toronto District Heating Corporation

Figure 2
Peak Steam Demand Profile (Dec/90 - Feb/91)
Multi-Storey Hotel



Data courtesy of Toronto District Heating Corporation

Figure 3
Peak Steam Demand Profile (Dec/90 - Feb/91)
Major TDHC Customers



Data courtesy of Toronto District Heating Corporation (cooling). Multiple units may also be selected to more efficiently meet base, intermediate and peak loads, as well as providing standby capacity and increased system reliability. More complicated DHC systems might utilize several different energy production facilities such as EFW (energy-from-waste - normally from municipal, commercial and industrial waste incineration), waste heat from manufacturing plant processes, absorption chillers, heat pumps, coal fired boilers. Other sources of heat for DH system include geothermal, cement kilns, biomass (burning of woodpulp, peat, straw, etc.) and solar collectors. In the case of these more complicated thermal energy production systems, the energy sources selected and the manner in which they are used depend on local fuel prices, availability of such alternatives, proximity of the load to such sources, environmental sensitivities, and other factors.

Promising Energy Production Alternatives

A very promising thermal energy source being used more and more is combined heat and power (CHP), or cogeneration. Energy from a cogeneration plant is normally extracted in one of two ways; heat is produced and used in a process while exhaust heat from the process is utilized to drive a turbine and produce electric power, or conversely electric power is first produced and exhaust heat from this production is then recovered for other uses. Although system efficiencies depend on the overall energy production capacity and the type, capacity and efficiency of the individual cogeneration components, typical cogeneration energy conversion efficiencies can be as high as 85-90%. This compares favourably with typical electric power generation facility efficiencies of 30-35%. The efficiency of the cogeneration plant is only this high if all of the waste heat associated with the electrical power production facility is utilized. This can be the case with DHC facilities utilizing heat from cogeneration plants for heating purposes and/or when absorption cooling systems are used for cooling purposes. Absorption systems utilize steam or hot water to pressurize and vaporize the refrigerant and the refrigerant, after condensation and expansion, chills the cooling system recirculating water (i.e., heat from space or equipment transferred to chilled water and ultimately to the refrigerant).

DHC systems need not confine themselves to heat utilization from central heating plants. Indeed district systems, because of their centralized and arterial nature, are well suited to becoming energy "brokers", collecting thermal energy from whatever sources have waste heat or unused capacity are available, and distributing the thermal energy to wherever it is needed.

A promising concept for a district heating and cooling system, acting in an energy broker capacity and enabling waste heat to be utilized, is through the extraction of heat from wastewater using a heat pump system. Possible applications include municipal waste treatment plant effluents and industrial waste treatment plant effluents. With such applications, during heating periods, heat would be extracted from the wastewater using heat pumps. The heat pump converts the low temperature heat extracted to a temperature that can be used in heating applications. During cooling periods, these same heat pumps, operating in reverse, extract heat from the space and/or equipment being cooled and transfer the heat collected into the wastewater.

Another promising concept that is receiving attention for district cooling applications is the utilization of, as a thermal energy source, cold lake water. Depending on the capacity of the source and depth at which the cold water is extracted, the temperature of the water remains at a relatively constant "cold" temperature. Such a system, requiring only pumping through the distribution and heat exchanger systems, use as little as 5% of the electricity used by electrically driven chillers. This concept is currently being studied in Toronto, Canada and is referred to as the Deep Lake Water Cooling (DLWC) project. At the present time, studies are underway to determine if any environmental impacts can be expected from the use of this potentially renewable thermal energy source, to establish the viability of the scheme, and to identify how the scheme should be developed.

Peak Shaving Thermal Energy Storage Concept

Thermal Energy Storage (TES) is another developing concept. TES offers the potential for economic and indirect environmental benefits. TES was developed in response to the very nature of typical cooling and heating load demands experienced by district energy production systems. Most systems, regardless of scale, are characterized by periods during the day when demand is quite low and other "peak" periods when demand rises considerably. The energy production required to meet the sum of the (more or less) coincidental peaks requires additional installed thermal energy production capacity with the resulting increases in capital and operating costs and may stress the local utility's resources, discouraging expansion of existing DHC systems. Because the daily peak demand is short-term and the thermal energy production equipment that is provided to meet such demands is used infrequently, utility rates are often considerably higher for peak loads to provide incentive to the users to reduce their short-term peak loads.

The principle behind TES is to produce surplus quantities and store thermal energy during periods of low demand and subsequently utilize, when necessary, the stored energy to meet peak demands. The thermal energy storage medium may simply be hot water or cold water and ice. With adoption of TES, the daily peaks of the typical DHC demand curve can be reduced so that the hourly energy production varies less. This means that the energy production equipment can be reduced in size, still be capable of meeting the lower maximum capacity, and can operate closer to a peak efficiency point throughout the day.

DHC systems are well suited to incorporating TES. In general, compared to individual building systems, DHC systems have more flexibility to reduce installed capacity by using TES, without losing system reliability, and are more capable of covering the higher capital costs involved and distributing the recovery of such costs over longer periods. In addition, because district systems normally cater to a diverse group of users with varying peak load requirements, the DHC system's characteristic load curve tends to be smoothed out, with the result that the total TES capacity requirements are proportionately lower than if TES was considered at the individual building level.

With large TES systems in place, DHC systems that utilize waste heat from power generation plants can also implement load-management, supplying TES based heat during peak power production periods. This reduces the demand for waste heat at extraction plants, permitting production of more power, thereby reducing the peak power demand of the power generation utility.

On the district cooling load side, thermal storage systems using ice formation and storage technology can be utilized to reduce chiller capacity and meet peak short term demands. As with the heat storage system, during low demands, ice is made in the storage system, with the ice subsequently melted and cooling capacity released when demands peak.

Emission Considerations

A wide variety of fuels are used at DHC plants including various grades of oil and coal, natural gas, refuse and other biofuels such as wood chips, peat and straw. The combustion of these fuels may, as indicated in Section 2.0, produce environmentally hazardous products of combustion (POCs) thus flue gas cleaning devices and other emission reduction measures are often incorporated. Such measures are usually required under increasingly strict legislation, before approval to operate a facility is granted. Examples of pollution control equipment used at DHC plants include acid gas scrubbers. These systems typically utilize hydrated lime to react with the moisture, SO_2 and other acid gases in the flue gases discharged from the combustion system. With such systems, the lime-acid gas-water vapour reaction products are efficiently collected by electrostatic precipitators as particulate matter. Bag filters are also utilized in many applications to capture the particulate matter as well as the acid gas scrubbing reaction products. Conventional oil/gas fired boilers utilizing low NO_x burners to dramatically reduce NO_x emissions are also becoming more common. Flue gas recirculation to reduce NO_x emissions has also been proven to be effective. Other emission control or reduction techniques can be introduced with DHC systems, including optimization of combustion efficiency (i.e., reduces CO_2, CO and hydrocarbon emissions) through the use of modern computerized combustion control systems, and utilization of higher quality, lower emission producing fuels.

Decentralized Energy Production

Energy production at conventional or non-district heating facilities differs from DHC plants in several respects.

With the exception of some large boiler plants, most conventional facilities are usually too small to permit staged energy production (through use of multiple units or different energy sources). For systems having multiple boiler and/or chiller units, staged energy production can be utilized to meet base, intermediate and peak loads, allowing the energy production equipment to operate at or near maximum efficiency. Such capability is of course typical of DHC systems. Conventional systems that utilize a single piece of equipment (must be rated for peak loads) operate most of the time at partial loads. Depending on the class of equipment used, this may result in dramatic reductions in operating efficiency.

Conventional systems are faced with high costs if pollution control equipment is utilized or required, due to a general lack of suitable low cost pollution control technologies being available for smaller applications. This creates disincentives to incorporate such equipment. Indeed, in the case of households and small commercial establishments, it is completely impractical to incorporate pollution control equipment that could achieve the low emission levels experienced by DHC systems.

The potential environmental benefits of DHC systems attributable in part to the above differences between district systems and conventional systems, as well as to other features of district systems, are discussed in further detail in Section 3.3.

3.2.3 Thermal Energy Distribution

In district systems, the thermal energy medium, whether it be hot water, steam or cold water, is delivered to customers via a system of arterial and branch supply pipelines. Having exhausted its energy transfer potential to the user, the medium is then normally returned to the production plant via a return pipeline system. While hot or chilled water is pumped to the users and back to the generation plant(s) through the distribution piping network, steam is delivered to the users under its own pressure. Steam, having given up the usable portion of heat at the user's location, is typically pumped back to the thermal energy production source as condensate. (Note: When cooled, steam condenses to hot water.) In some cases, such as when steam is supplied to a plant to meet process needs, the user's process may dictate that the steam be discharged directly into the process, in which case condensate is not returned to the production source. In other instances, where pipeline installation and maintenance costs are excessive, condensate is not returned to the production facility for reuse, but is wasted. In either case, additional energy and chemicals are required to replace the heat energy that is lost when the condensate is not returned.

The piping used in the distribution network is typically buried although it can be supported above ground for industrial applications or run within building basements when owners and costs permit. Depending on the pipe size various common materials of construction can be used. To minimize thermal losses the pipes are normally insulated.

Four types of distribution piping systems are generally in use today:

- Single Pipe System: This system is only used for steam supply applications with no condensate return. While it features low pipeline costs, this type of system results in comparatively low energy production efficiency and therefore higher costs and emissions.

- Two Pipe System: This system is utilized where water or steam is distributed to users in the supply pipe, and returned to the thermal energy production source via the return pipe. Two pipe systems provide capability for transferring heating or cooling energy (not both) at one time. Thus between heating and cooling seasons, a distinct "switch-over" of the energy production source must be made if chilled water and heat energy is to be delivered from a remote source. Such systems are practical for residential or apartment complexes serviced by DHC, or any other application where heating and cooling are not required in the same season.

For applications requiring heating only, no such switchover is required. Also, note that steam can be utilized for both heating and cooling demands if absorption chillers are installed at each customer's location. A two pipe system utilizing the pipes for cold water during the cooling season, requires users to have their own means of heating water for domestic hot water (DHW) use.

- Three Pipe System: This system's capability is similar to that of a two pipe system, but the additional supply pipe is provided for, and dedicated to, meeting the domestic hot water (DHW) requirements. The three pipe system has therefore been developed in recognition of the fact that DHW is required during both heating and cooling seasons, and that in some applications, local DHW production is not adopted.

- Four Pipe System: Although the most expensive system, this approach provides the greatest flexibility since two pipes are dedicated to hot water or steam (supply and return), and two are dedicated to cold water (supply and return). This system is necessary for applications where both heating and cooling are provided from the central source and are required during either the heating or cooling season.

There are no direct environmental benefits associated with DHC distribution systems when compared to a conventional or non-district system. In fact, because of the extensive burying of pipe that is required with a district system (a mostly non-existent requirement of a conventional system), there are disadvantages. These disadvantages include, during excavation for burying or pipe repair and maintenance when leaks develop in the distribution piping, potential for localized traffic congestion and tie-ups, and general inconvenience to pedestrians and motorists. These factors in most instances are outweighed by the potential benefits of a district heating and cooling system.

3.2.4 System Components at the User's Location

Basically, with DHC systems, the integration of the generation and end use thermal energy transfer functions can utilize indirect and/or direct connected distribution systems.

Direct systems do not have isolated subsystems. Rather, hot or chilled water, or steam from the production source, is distributed directly through the customer's radiators or air handling equipment.

Indirect systems, on the other hand, incorporate heat exchangers at both the energy production location and at the user's location, thus the generation, distribution, and energy utilization subsystems are effectively isolated from each other. Another indirect system option utilizes heat exchangers at the user end only, thereby isolating the generation and distribution systems from the user subsystem. This arrangement is common for steam generation and distribution systems.

In the case of a fully isolated indirect district heating system, hot water (or steam) can be produced by suitable means and circulated through a heat exchanger at the production facility where the hot water (or steam) transfers its heat to the hot water in the distribution network. The water in the distribution network, which has now been heated, is in turn circulated through the end user's heat exchangers where the hot water transfers its heat to the user's distribution system at the rate required to meet the various heating needs of the user. The water in the distribution network is then circulated back to the heat exchanger at the thermal energy production source where it is re-heated for continuing use. In fairly small systems (less than, say, 15 MW), or as noted previously, with steam generation and distribution, the heat exchanger between the production source and the distribution network is omitted. In the case of the latter, this enables users that require steam to be serviced directly from the district heating system while users that have hot water heating systems can utilize isolating heat exchangers.

The same basic principles described above apply for a district cooling applications.

Domestic Hot Water (DHW) is either generated independently from the district heating system, on the user's site, or is passed through a heat exchanger to acquire its heat in both direct and indirect DHC systems.

Although direct systems were at one time the more prevalent of the two systems, indirect systems are now becoming the preferred approach. This is due primarily to several inherent advantages associated with indirect systems including:

- greater protection against surge induced radiator damage (bursting radiators) at the customer's end, due to surge protection provided for the distribution system and by the pressure isolating heat exchangers;

- lower make-up water treatment costs due to much less likelihood for extensive leakage in indirect systems (customer radiators may leak due to age and lack of maintenance which becomes a major problem in direct systems);

- greater flexibility, as indirect systems can accommodate to a much higher degree users of various sizes and having varying pressure requirements;

- ease of control since the two basic operating points (at the production plant and the at the user's location) are essentially independent in an indirect system;

- ownership of generation and distribution systems can be separated when necessary and/or desirable.

The thermal energy users in a DHC system can vary from individual householders to large complexes such as hospitals, hotels, blocks of offices, high rise buildings, manufacturing facilities, universities, etc. The equipment requirements for these various users, if they are considering retrofitting from a conventional system to a DHC system, are not substantially different than that for the conventional system, assuming the user's climate control systems are compatible with hot water or steam heating and cold water cooling (i.e. a conventional system utilizing electric heating or direct gas fired heating, and decentralized air conditioning units, for example, would require significant equipment upgrades if connected to a DHC system).

Two references which discuss the possibilities of retrofitting existing heating and cooling systems are the IEA publication, "Guidelines For Converting Building Heating Systems For Hot Water District Heating", publication No. 1990 R8 and the Washington State Energy Office's "District Heating Development Guide - Legal, Institutional and Marketing Issues".

Typically, facilities utilizing hot water radiators and/or fan coil units (suitable for hot and cold water) for conventional space heating and cooling are ideal candidates for DHC systems. Larger facilities utilizing direct gas make-up air heaters can also be converted to DHC, although distribution system piping and heat exchangers have to be installed. Ideally, in retrofitting a conventional system to a DHC system, the only appreciable equipment changes required are in the boiler room. Here the "conventional" hot water or steam source, the boilers, is replaced with heat exchangers which tie-in the customer's piping network with the DHC distribution piping. The "conventional" cooling source, normally centrally located chillers producing cold water, is also replaced with heat exchangers which may or may not be the same units as exchanged for the boilers. The potential for utilizing a common heat exchanger depends on the system operating temperatures and the DHC pipe system used (two or four pipe). Cooling towers commonly used to affect heat rejection in the condenser loop of the chillers can be eliminated with conversion to district cooling.

Other important equipment items at the customer's location such as circulation pumps, control valves, the water treatment package, DHW storage tanks, metering devices, etc. are essentially common to both conventional and DHC systems, and are not associated with significant environmental impacts, either positive or negative. Thus, although their importance should not be underestimated, since they are critical to the proper operation of any heating and cooling system, these items will not be considered further with regard to environmental benefits.

The potential environmental benefits associated with this subsystem are closely tied to those of the thermal energy production subsystem described earlier. The benefits relate primarily to the limiting of the number of emission sources (boilers, make-up air heaters) and refrigerant use (chillers) installations in the community to a few efficiently run, well monitored thermal energy production plants. A detailed review of the potential environmental benefits associated with this subsystem compared to conventional heating and cooling of individual buildings is presented in Section 3.3.

3.3 POTENTIAL ENVIRONMENTAL BENEFITS ASSOCIATED WITH DHC SYSTEMS

In Section 3.2, the basic components of DHC systems were discussed. In this section, the potential environmental benefits of DHC systems, compared to conventional or non-district systems, are identified considering the negative environmental impacts identified in Section 2.0. These benefits are derived, partly due to the difference between district and conventional systems and, partly due to stand-alone features of DHC systems.

Partial Load Efficiency

In general, DHC plants operate at higher efficiencies under partial thermal load conditions, compared to conventional systems. This is because conventional systems typically employ only one boiler and chiller unit. While such units must be rated for peak seasonal and hourly loads, they actually operate most of the time at much lower partial loads. Operation at these lower loads can, depending on the class of equipment used, result in much lower operating efficiencies. District systems on the other hand, with multiple units can optimize overall plant efficiency by selectively operating fewer units at or near maximum efficiency during partial load conditions. Further, DHC systems that comprise several different types of thermal energy generation plants can optimize plant and system efficiency by utilizing, whenever possible, the thermal energy sources with the highest energy conversion efficiencies for base and other partial load conditions. The sources with the poorer conversion efficiencies can then be utilized only to meet peak loads. Ultimately, improved efficiency means use of less fuel for the same amount of energy produced which in turn results in the conservation of fossil fuels, reduced emissions of POCs (products of combustion) such as those described in Section 2.0, improved air quality, and reduced use of refrigerants (CFCs or replacements HCFCs or HFCs) in cooling applications.

DHC Integration with Power Generation

District systems are well suited to combine with electric power production facilities forming what are known as combined heat and power (CHP) plants or cogeneration plants. As discussed in Section 3.2, the amalgamation of these two energy production/utilization schemes results in a substantial improvement in overall energy conversion efficiency since district heating systems can effectively utilize the otherwise wasted heat associated with the electric power production process. A district system meeting much or all of its load requirements with waste heat from power generation facilities will have a positive environmental impact as fuel consumption within the community is reduced considerably. Conservation of fossil fuels and a reduction of combustion-related emissions are resultant direct benefits of such DHC system.

Biomass Combustion

Biomass combustion is considered by many as a means of zero production of CO_2 when combined with reforestation. The underlying principle is that by burning biomass, CO_2 is released but with reforestation the CO_2 is absorbed in the new growth provided the rates of each activity are balanced. Case Study No.8 regarding the Prince Edward Island DH system discusses this approach.

Limited Number of Emission Sources

The centralized nature of DHC energy production plants results in a reduced number of emissions sources in a community. This introduces the potential for several direct benefits.

Firstly, large facilities are much more capable of, and likely to, incorporate sophisticated state-of-the-art pollution control technologies than individual buildings (particularly households, commercial establishments and small industrial complexes). To incorporate such equipment on a small scale basis, due to the general lack of low cost effective pollution control equipment, is normally impractical. In comparison, therefore, large scale district systems, which in many cases have included best available control technology (BACT) are capable of significantly reducing the emissions to the environment on an equivalent energy production basis.

Secondly, the exhaust stacks, characteristic of large energy production facilities, are relatively high and therefore the exhaust gases that are discharged from the stack are well mixed with large volumes of the ambient air before the pollutants can reach the surrounding population, structures or plant life. The resultant improved dispersion introduces the benefit of minimizing low level pollutant concentrations and deposition in the immediate zone of greatest potential pollutant fall out (i.e. near the source), compared to the numerous lower stacks required of a non-district system. While local air quality can benefit significantly from DHC, it should be noted that long-range pollutant transport is a subject of continuing debate. While high stacks are an effective means of discharging pollutants so that high concentrations are not experienced locally, they do permit the pollutants to migrate long distances. However, the problems associated with these dispersed pollutants are still related more to the total quantity of pollutants that are emitted to the atmosphere, regardless of stack height.

Superior Operating and Maintenance

Large, centralized plants, such as DHC facilities, typically use better operating and maintenance practices than do small individual building systems. Large facilities have trained staff, as well as sophisticated computerized monitoring equipment available to continuously monitor system operations, ensuring performance specifications are being met on a long-term basis. When such specifications are not met, prompt maintenance can be administered, or operating changes or upgrades introduced, as necessary. Regularly scheduled maintenance is a normal function of facilities of this scale.

With large DHC systems, the incentives to maintain a high level of operability, with little downtime or drop in operating efficiency, are economically based and are often critical to maintain the overall viability of a plant. Individual building systems, on the other hand, can not always afford sophisticated and continuous monitoring equipment (or to upgrade existing obsolete equipment), or permanent maintenance staff. The result is many such operations deteriorate because of the poor maintenance, with operating efficiencies subsequently dropping well below optimum levels. The higher operating efficiency afforded larger, well maintained, facilities translates directly to reduced fuel consumption which in turn results in conservation of fossil fuels and reduced emissions. Higher operating efficiency of the combustion process (where parameters such as temperature, combustion air and fuel input levels, residence time, etc. are closely monitored) also impacts emission production in that the concentration of certain pollutants produced, particularly CO_2 and NO_x, is reduced.

Technical Upgrades

Centralized DHC facilities permit developing thermal energy production and emission reduction technologies to be adopted at the earliest possible date. Such technology improvements usually have significant positive environmental impacts. Examples of such developments include:

- retrofitting boilers with low NO_x burners, flue gas recirculation or selective catalytic reduction techniques to reduce NO_x levels,

- flue gas heat recovery scrubber systems to minimize SO_2 emissions, while at the same time improving the thermal efficiency of the system (further reduces emissions),

- plume abatement techniques to reduce the vapour plumes associated with cooling towers, and

- implementation of CFC refrigerant substitutes (with lower or no ozone depletion potential) in chillers.

With DHC systems, new technologies can be implemented at much reduced cost and much more practically, even when compared to the same emission reduction effort being achieved at an equivalent number of conventional facilities.

With the ability to implement new technologies on older existing DHC systems, a great opportunity is available to system operators in areas of emission-related "non-attainment". Such facilities can continue to achieve the most recent regulatory based emission levels, as quickly as possible, after such regulations are enacted.

In comparison, implementing such techniques on the multitude of smaller sources that exist when DHC is not adopted is not a realistic alternative. Thus, the emissions from existing decentralized system sources cannot be reduced effectively over time.

Higher Design Efficiencies

In many cases, the relatively high capacity equipment associated with DHC facilities inherently operates at higher efficiencies than similar lower capacity units. This is particularly true of large centrifugal chillers which have coefficients of performance (COPs) of more than 5.0. This compares with the smaller units, such as those installed in individual buildings, which have COPs in the range of 3.0 to 4.0. The COP is the ratio of the refrigerating effect or cooling capability of the unit to the power input required to achieve this capability. COP provides a means of comparing the performance of various chiller types.

Other Environmental Benefits

There are many indirect environmental benefits of DHC plants which may not have as much impact as the benefits described above but which are worth noting.

The noise associated with the operation of heating and cooling equipment is concentrated at a single source with a centralized facility. Sophisticated noise control measures to minimize noise impacts on the surrounding neighbourhood can be applied more practically and cost effectively at a central facility than at numerous individual buildings, With the concentration of fuel oil storage at central facilities, the potential risks associated with leakage are reduced since centralization implies elimination of multiple smaller oil storage vessels which deteriorate with time and lack of supervisory care. Storage vessels at centralized facilities are more likely to be regularly inspected for leaks or deterioration.

For liquid and solid fuels associated with DHC systems, the reductions in fuel use identified above will indirectly reduce vehicle emissions associated with fuel shipment as the requirement for delivering such fuels will also be reduced.

Where local air quality is a significant problem, the type of fuel burned can be upgraded in many DHC applications, with significant environmental benefits. For example, a plant burning coal or even relatively clean burning fuel oil can reduce its emissions simply by converting the operation to natural gas firing. Without DHC alternative fuel options are impractical in most communities.

Finally, considering cooling systems, with DHC, the conversion from CFCs is simplified and a practical option. Also, the use of cooling water from local rivers or lakes in lieu of cooling towers is a realistic alternative with DHC systems. The flexibility, offered by DHC systems, to pursue such environmentally beneficial alternatives is virtually non-existent with decentralized systems with their multitude of small units and owners.

3.4 DETECT, HEATMAP COMPUTER MODELLING SYSTEMS

There are a number of computer models available for studying the feasibility of DHC available. Two of these are DETECT and HEATMAP.

DETECT was developed in an information project carried out by the IEA's Executive Committee for DHC. The objective of the DETECT program is to demonstrate the environmental and economic benefits possible by introducing DHC and combined heat and power (CHP) projects. It does not provide a detailed design or analysis of a system but is intended for preliminary planning purposes.

DETECT is available by mailing a cheque for US$70 payable to NOVEM from the following locations:

NOVEM P.O. Box 17 NL - 6130 AA Sittard The Netherlands	Washington State Energy Office 809 Legion Way S.E. P.O. Box 43165 Olympia, WA 98504-3165, USA

HEATMAP was developed by the Washington State Energy Office (WSEO) and is intended to provide a means of modelling and analyzing a DHC system. The model can map the entire DHC including the distribution system, customers load information, production plant information and may be used to study the economic feasibility of DHC and demonstrate the benefits in reduction of air emissions.

Along with the software provided by WSEO, the user will need to purchase and install AutoCAD on their system.

HEATMAP is available from:

Washington State Energy Office
809 Legion Way S.E.
P.O. Box 43165
Olympia, WA 98504-3165, USA

The cost for HEATMAP software and manual are US$2,000 for the public sector and US$3,000 for private sector.

4.0 CASE STUDIES

4.1 GENERAL

This section provides, through actual case studies, specific examples of the environmental benefits which can be obtained through the use of DHC systems. In most cases, the case study presented hereafter is a summary of a more comprehensive report on the subject. The more comprehensive source is referenced should the reader desire to investigate more specific details regarding each study.

Each case study is broken down into four parts as follows:

- Case Study Significance (where the particular reference to the environmental benefits discussed in Section 3.0 is identified),
- Project Background,
- Measures Taken to Achieve Environmental Benefits, and
- Summary of Environmental Benefits.

4.2 COGENERATION EMPLOYED AT THE INDIANA UNIVERSITY OF PENNSYLVANIA - CASE STUDY NO.1

4.2.1 Case Study Significance

This study examines the positive environmental impact realized since cogeneration technology was integrated into an existing DH system at the Indiana University of Pennsylvania (IUP). The environmental benefits, primarily related to the reduction of combustion-related emissions, are consistent with Section 3.0 discussion which pointed out that the increase in fuel conversion efficiency associated with cogeneration should result in a corresponding reduction in total emissions. A quantitative summary of the emissions of SO_2 and NO_x before and after cogeneration was implemented is presented.

This case study is a summary of a report entitled, "Cogeneration: The Environmental Benefits", authored by Geletka and Crumm.

4.2.2 Project Background

Electric, steam and hot water utility systems serving the Indiana University of Pennsylvania (IUP) support a campus community comprising 81 hectares, 66 major buildings, 1550 faculty and staff and nearly 15,000 full-time students. Approximately 4,000 of those students reside on campus. Cogeneration was installed at the IUP in 1988. Prior to this, four bituminous coal-fired boilers were used to provide all the steam requirements for the campus. Electricity, purchased from the local (coal fired) electric utility, was received at a central substation owned and operated by the university from which electrical energy to the campus was distributed.

In 1988, the IUP commenced operation of a 24.3 megawatt cogeneration plant designed to meet the average annual thermal energy requirements of the campus while exceeding total electrical energy needs. Excess electricity is sold to provide revenue for debt service and other operating costs. The prime movers in the cogeneration system are four (4) dual-fuelled, internal combustion engines which burn natural gas as the primary fuel. The waste heat recovery system can develop approximately 20,000 kg per hour of saturated steam at 18 kPa. Steam load requirements during sustained ambient temperatures below 2°C are met by supplemental coal fired boilers.

The University's annual steam consumption is approximately 164 million kg while annual electrical needs amount to 30 million kWh.

4.2.3 Measures Taken to Achieve Environmental Benefits

The construction of the cogeneration plant in March of 1988 required only a few minor changes to the district heating system. An additional district hot water system was designed and employed to heat two dormitories housing 800 students, the university printing center, the university post office and one dining hall. The hot water is generated by the prime movers in the cogeneration system. The electrical distribution and district steam heating systems remained essentially the same as pre-cogeneration era design.

The facility utilizes its prime movers, the four dual-fuelled engines, to produce electricity and exhaust gas flow from this process is used to produce steam. The facility was sized to meet the campus steam requirements which results in an excess of electric power produced. This excess is sold to the local utility for revenue.

The annual fuel efficiency of the IUP cogeneration plant is reported to average 59%. Although the efficiency of energy conversion prior to the cogeneration facility is not reported, the University does save more than $1.5 million US annually in displaced utility costs; a benefit primarily derived from the increased plant efficiency associated with waste heat utilization.

The following table summarizes the average operating parameters at the IUP and is used in developing the pre-cogeneration and cogeneration emissions comparison in the next section.

Table 4.2.1 - Production and Consumption Figures - Pre-cogeneration and Cogeneration Periods

Campus Steam Requirement:	164,000,000 kg/yr
Campus Electricity Requirement:	30,000,000 kWh/yr
Steam Production Under Cogeneration:	164,000,000 kg/yr
Electricity Production Under Cogeneration:	202,000,000 kWh/yr
Pre-cogeneration Coal Consumption:	14,550 tonnes
Cogeneration Coal Consumption:	3,000 tonnes
Cogeneration Natural Gas Consumption:	51,000 Mm^3
Cogeneration Diesel Fuel Consumption:	2,952,000 L
Annual Operating Availability of Cogeneration Plant:	93%

4.2.4 Summary of Environmental Benefits

Table 4.2.2 provides a summary of the emissions of SO_2 and NO_x for the pre-cogeneration and cogeneration periods. In each case the same steam and electricity production (164,000,000 kg/yr and 202,000,000 kWh/yr respectively, as shown in Table 1) were used, however, the sources of production are somewhat different depending on which production mode, pre-cogeneration or cogeneration, is used. Reference is made to Table 4.2.1 which identifies the quantity of fuel used in each case.

Table 4.2.2 - Summary of SO_2 and NO_x Emissions at IUP - Pre-Cogen and Cogen Periods

Emission Source	Pre-Cogen SO_2 (tonnes)	Pre-Cogen NO_x (tonnes)	Cogen SO_2 (tonnes)	Cogen NO_x (tonnes)
Steam Production at IUP	465 (1)	69 (2)	93 (1)	14 (2)
Electrical Production (3)	1127 (4)	611 (5)	7 (6)	1232 (6)
Total Emissions Both Sources	1592	680	100	1246

Notes:

(1) Sulphur content of coal: 1.6% by weight as S. Stoichiometrically twice as much SO_2 is produced as S.

(2) Typical NOx emission rate for vibra-grate stoker boiler of 0.16 kg/MM BTU used.

(3) Pre-cogen electricity produced at local utility, cogen electricity produced at IUP.

(4) Local utility reports sulphur emission rate (as SO_2) of 0.545 kg/MM BTU of fuel input; 6136 BTU/kg coal heating value; average fuel conversion efficiency of 33%.

(5) Local utility reports NO_x emission rate of 0.295 kg/MM BTU of fuel input.

(6) Based on actual stack gas testing of 0.91 kg/hr SO_2 and 151 kg/hr NO_x.

A comparison of the pre-cogen and cogen emissions indicates a very positive 16-fold decrease in SO_2 emissions. At the same time NO_x emissions actually increased by a factor of about 2. The predominantly natural gas fired cogen plant is primarily responsible for the NO_x increase which might be expected since the IUP produces, in total, much more energy under the cogeneration scheme than in pre-cogen days.

The total mass of SO_2 and NO_x emissions has decreased by 41% although the report authors point out that mass representation of these two pollutants does not completely describe the impact of each upon the environment. In terms of each pollutant's acid equivalent weight (higher for SO_2 than NO_x), the authors show that a 51% reduction in acidity is realized when cogeneration is utilized. Furthermore it is noted that the cogeneration facility is well suited to adopting recently developed emission control technology which will potentially reduce NO_x levels by 80%.

Other environmental benefits associated with the implementation of cogeneration noted include:

a) the elimination of large on-site coal stockpiles and associated acid run-off;

b) the elimination of the need to upgrade the emission control equipment for coal firing to meet requirements under the Clean Air Act Amendment of 1990;

c) an assumed reduction of particulate emissions, due to natural gas firing as opposed to coal firing, of about 80%.

4.3 ENERGY-EFFICIENT TECHNOLOGIES COMBINED WITH MODERN DHC CONCEPTS EMPLOYED AT CALIFORNIA STATE UNIVERSITY, FULLERTON - CASE STUDY NO.2

4.3.1 Case Study Significance

This study examines the environmental benefits associated with the upgrading of an existing DHC plant at California State University, Fullerton. These benefits, which include dramatic reductions in plant emissions particularly NO_x, elimination of the use of refrigerants having non-zero ozone depletion potential, and substantial energy savings, are all indirectly a result of the centralized plant being readily and cost-effectively capable of implementing developing technologies and modern operating concepts. This study is a summary of a report entitled, "Thermal Energy Storage, Energy Conservation and DHC at California State University, Fullerton" authored by Henrikson.

4.3.2 Project Background

The California State University, Fullerton campus was initially built during 1961-63 and consists of twelve major buildings of approximately 150,000 m². Ten additional buildings are scheduled to be constructed between the present time and the year 2000, giving the campus a total operational building area of 230,000 m². A single central plant serves, and will continue to serve, all campus buildings with chilled water for space cooling and hot water for space heating and domestic hot water heating.

The Cal State Fullerton central plant generates high temperature hot water (HTHW) for campus space heating and cooling needs. Three HTHW generators produce 177°C water at 41 kPa, of which the majority is used to drive single-stage absorption chillers that generate 7°C chilled water. Hot water is also distributed to campus where the temperature of the hot water is stepped down to 82°C in building heat exchangers. This hot water is then delivered to heat exchange coils to maintain 35°C air for space heating and 60°C domestic hot water.

Presently there are three 8.8 MW HTHW boilers, each capable of firing either natural gas or No.2 fuel oil. All three boilers are the watertube type with thermal efficiencies of 75-80% when firing natural gas.

The central plant has a total of three chillers consisting of one 2,638 kW and one 4,045 kW, HTHW, absorption chillers; and one 2,638 electrical centrifugal chiller in conjunction with a eutectic salt thermal energy storage (TES) system. The Cal State Fullerton central plant utilizes four cooling towers for condenser loop heat rejection. There are three 175 L/s cooling towers and one 265 L/s cooling tower utilizing respectively three 30 kW and one 60 kW cooling tower fans. The cooling towers were built in the early 1960's and are considered beyond their useful life.

When compared to modern DHC plants, the nearly 30 year old Cal State plant is relatively inefficient. In terms of achieving high energy efficiency, to create the 177°C HTHW is inherently wasteful, considering the ultimate use of the energy is to produce 35°C water for space heating and 60°C water for DHW. Also, there is no capability in the present system to reallocate available waste heat energy and in fact the chillers operate around the clock to get rid of this heat. With the existing plant beginning to exceed its useful life and with the campus poised for a major expansion, the University decided to upgrade the central plant into a more energy efficient and environmentally friendly facility.

4.3.3 Measures Taken to Achieve Environmental Benefits

Upgrading of the Cal State DHC system, which is currently underway, incorporates both energy-efficient technologies and modern operational concepts to improve overall efficiency. These are summarized below.

The new distribution systems at Cal State will distribute hot water and chilled water to the campus, and will be variable flow distribution systems. Unlike a constant flow system, where the distribution system pumping capacity is selected for, and often operates continuously, at a rate corresponding to a peak hour condition, a variable flow system tracks the demand, delivering only enough flow to satisfy the short-term cooling and heating demands. The savings in pumping horsepower are substantial since horsepower is reduced as the cube of the reduction in flow. In addition, the existing 5.6°C delta T chilled water system is being converted to a high delta T chilled water distribution system, with a delta T of 13.3°C. This has the effect of reducing the flow by almost 60% since every litre of chilled water carries almost 150% more cooling energy.

The original relatively insufficient single-stage absorption chillers, arranged in parallel, are being replaced with more efficient electric motor driven centrifugal chillers arranged in series. The series arrangement is the most efficient since, unlike a parallel arrangement, only one of the three chillers must produce the cold 4.4°C chilled water output required of this system. The other two chillers operate at higher output temperatures and consume less energy.

The heat generated through normal activity in campus buildings, which would normally require rejection through chiller/cooling tower packages, is under the new system captured for space heating at other needy locations on campus. To accomplish this, the first chiller in the series line-up is a heat recovery chiller. This unit is used to extract the available heat from 18°C chilled water return. At the same time, this same unit, without increasing its electricity demand, produces chilled water supply for space cooling and low temperature hot water supply (recovered from elevated condenser heat) for space heating and DHW heating.

Furthermore, all chillers at the plant will operate on R-134a refrigerant (an HFC) which has an ozone depletion potential of zero.

With time-of-use electrical rates, generating chilled water for space cooling in the middle of the day is an expensive proposition. Chilled water thermal energy storage (TES) was identified as a key central plant component to alleviate this concern. The centrepiece of this system is a 10,000 m^3, above-ground, chilled water TES tank. This tank is sized with sufficient storage so that the electric driven chillers will be completely off-line during on-peak electrical rate periods. As a result, there will be almost no central plant electrical demand contribution to the campus peak electrical demand. Other benefits fall out of this TES strategy. With TES in place, chiller and cooling tower operation can be regulated to cooler periods of the day, thus their operation becomes more energy-efficient. Chiller operation also occurs during the higher heating demand periods of the day thereby maximizing the prospect of useful heat recovery.

In that space heating and domestic hot water heating are to be accomplished with recovered chiller condenser heat, creating a coincidence of chiller operation and the heating demand is important. Also, with only one heat recovery chiller, the ability to store heat for later use is important. Therefore, 1,140 m^3 of hot water TES is also being implemented.

With both chilled water TES and hot water TES, the campus has an excellent level of flexibility in the use and reuse of its energy resources. This flexibility translates into cost-effectiveness and energy-efficiency of the DHC system.

4.3.4 Summary of Environmental Benefits

The now under construction all electric central plant involves a drastic reduction in air pollution emissions - 97% NO_x reduction over that of current emissions attributable to the Cal State Fullerton central plant. This is accomplished by removing the combustion processes from the local site and instead using electricity generated at the utility power plant where efficient, large-scale, industrial grade Best Available Control Technology is used.

Several central plant development scenarios are presented below to illustrate the NO_x emissions associated with each scenario. Scenario 1 represents the central plant as it was before any upgrading began. Scenarios 2, 3 and 4 represent possible alternative upgrades that could have been considered at different time frames. Finally, Scenario 5 represents the central plant now under construction at Cal State, Fullerton.

	Central Plant Development Scenario	NO_x Emissions (kg/yr)
1.	Year 1990 central plant with 90 ppm NO_x HTHW generators and single-stage absorption chillers	7,270
2.	Year 1992 central plant with 40 ppm NO_x HTHW generators and single-stage absorption chillers (after installation of low NO_x burners and flue gas recirculation)	3,230
3.	Year 2000 central plant (expanded campus) with 40 ppm NO_x HTHW generators and single-stage absorption chillers (after installation of low NO_x burners and flue gas recirculation)	4,820
4.	Year 2000 central plant with 40 ppm NO_x HTHW generators, electrical centrifugal chillers, and TES (after installation of low NO_x burners and flue gas recirculation)	2,180
5.	Year 2000 all-electric central plant with electrical centrifugal chillers, TES, and a heat recovery chiller (excludes off-campus power generation - local utility's contribution to NO_x emissions)	190

The source report for this case study does not quantitatively report the magnitude of energy savings expected due to the upgrades discussed.

4.4 STUDY OF UPGRADES TO A 25 YEAR OLD DISTRICT HEATING PLANT IN THE CITY OF TORONTO, CANADA - CASE STUDY NO.3

4.4.1 Case Study Significance

This study presents an example of the technological upgrades which can be implemented with a 25 year old central DH plant and which, if incorporated, will enable the plant to meet the local regulatory requirements applicable to new facilities. The study presents estimated maximum contaminant concentrations at critical receptors (dispersed stack emission impingement locations), both under present operating conditions and with the upgrades in place. Relevant regulatory standards are also presented.

The scope of the source study entitled, "Toronto District Heating System Upgrade and Expansion Study" with respect to this plant, was to establish the upgrades necessary to allow the facility to comply with the most recent regulatory requirements. The study did not, therefore, establish a comparative cost to achieve the same end at an equivalent number of individual plants as this was not a realistic alternative. It is considered, however, that such upgrading at numerous individual plants would be considerably more costly and, given the number of decision-making sources that would have to be motivated to do so, unlikely to ever be carried out.

4.4.2 Project Background

District heating in the downtown core of Toronto is presently being provided to approximately 80 commercial and institutional customers by the Toronto District Heating Corporation (TDHC). TDHC delivers approximately 900 million kilograms of steam to their customers annually. The TDHC system presently consists of two gas/oil fired steam generation plants. The Walton Street Plant, owned by TDHC, operates as the base load plant. The Pearl Street Plant, the subject of this review, is owned by Toronto Hydro and is operated by TDHC. The Pearl Street Plant operates primarily only when required to meet peak system demands.

Adjacent to the TDHC service area, the University of Toronto operates a DH system, independently of TDHC. This second district heating system services buildings on the U of T campus. The U of T system delivers approximately 320 million kilograms of steam annually to buildings within their system. The City installed, in the early 1980's, steam and condensate return piping systems to interconnect these three central steam plants, increasing system capacity and reliability. No agreement was ever signed between TDHC and U of T to consummate the integration of the two district heating systems in part, because expansion of the TDHC service has not materialized and therefore TDHC service has not needed the U of T plant's additional capacity.

With the proposed extensive new development in the City of Toronto, known as the Railway Lands development, the City identified the potential for expansion of the existing TDHC system. A study was subsequently conducted with emphasis placed on developing alternatives that would ensure sufficient capacity was available to serve the immediate needs of existing and future downtown core customers, and the new customers on the Railway Lands. These alternatives included integration of U of T's plant and upgrading the existing Walton and Pearl Street steam plants. The Pearl Street Plant upgrading was proposed to enable the facility to meet the local air quality standards and thus to introduce the flexibility of the plant to operate at capacities other than strictly a peaking plant. At the present time, the Pearl Street Plant, because of its marginal air emission characteristics, is used only to meet peak demands.

The Pearl Street Steam Plant is located in the downtown core and currently contains eight packaged steam boilers, each rated at 45,400 kg/hr. The boilers are fuelled by interruptible natural gas with No.2 distillate oil as back-up. Each boiler unit generates approximately 21.5 m^3/s of flue gas at 260°C with the combined flows discharged from a single 83.8 m high stack having an exit diameter of 2.7 m.

Atmospheric emissions from the Pearl Street Plant include oxides of nitrogen, sulphur and carbon as well as particulate matter and unburned hydrocarbons. Dispersion modelling of the emissions discharged from the existing facility has been conducted. The results indicate that with the existing burner systems and stack, local NO_2 air quality standards can be exceeded, using "point of impingement" criteria, when one or more boilers are operating on gas or No.2 distillate oil; with or without the use of low NO_x burners. Total Suspended Particulate (TSP) and SO_2 air quality standards can also be exceeded when the boilers are operating on No.2 distillate oil. The exceedances are primarily due to the encroachment of new high-rise buildings (built much higher than the Pearl Street Plant's 25 year old plus stack) which have become new critical receptors of emissions. As a result of the above, the study concluded that the Pearl Street plant could not comply with emissions regulations applicable to new facilities.

To reduce impingement concentrations, two new stack alternatives were reviewed, in conjunction with retrofitting the existing boilers with state-of-the-art low NO_x burners and eliminating the burning of No.2 fuel oil. Developing technologies were also considered to establish whether any further reductions in emissions released to the atmosphere could be possible.

4.4.3 Measures Taken to Achieve Environmental Benefits

The constructing of a higher exhaust stack, integrated into a planned new SunLife Building (i.e., proposed to be constructed across the street from the central DH plant) during its construction, was identified as being a possible alternative to the continued use or replacement on-site of the existing stack. With this approach, an interconnecting tunnel between the Pearl Street Plant and the SunLife Building would be required, together with a vertical shaft up through the centre of the new building to the roof. The new stack height would be 135 m above-grade, being an additional 20 m above the SunLife Building height, as required by local regulations (Regulation 308 of the Environmental Protection Act or EPA).

Dispersion modelling using the higher stack at the SunLife Building was conducted. This modelling suggests that six gas fired boilers, equipped with state-of-the-art low NO_x burners, could be operated in compliance with the local EPA air quality standards. Operation of a seventh boiler results in a 10% exceedance of the NO_x standard. Under oil-fired conditions, the SO_2 standard would be exceeded for any number of boilers operating, even when low sulphur fuel is used. The analysis verified un-interruptible gas supply would be necessary to avoid exceedances.

This attractive stack option was reviewed with the SunLife Building representatives who indicated they were not receptive to the concept, thus the alternative of constructing a new free-standing stack to replace the shorter existing stack at the Pearl Street plant was reviewed.

Dispersion modelling was undertaken to establish the height the new stack at the Pearl Street plant would have to meet Regulation 308 air quality standards. The results indicated that seven boilers (eighth retained as standby only) could be operated on natural gas or No.2 fuel oil if a 280 m stack was provided.

For either stack option referred to above, the dispersion modelling was done on the basis of retrofitting the boilers with state-of-the-art low NO_x burners. The existing boilers utilize conventional burners that are estimated to produce as much as 0.129 kg of NO_x for every GJ of natural gas burned. Proposed Canadian Federal Standards for larger Industrial Boilers suggest NO_x emissions should be reduced by approximately 75% to 30 ng/J. Several suppliers of state-of-the-art low NO_x burners were contacted and it was established that burners having guaranteed NO_x emissions as low as 22 ng/J were available. Retrofitting of the Pearl Street Plant boilers with these burners would result in a reduction in NO_x emissions of 83% compared to present levels.

As a result of the exceedance of Regulation 308 standards with the new SunLife Building stack alternatives (reduced height) when burning fuel oil, the possibilities for reducing SO_2 and particulate emissions were investigated. This review revealed that wet scrubbing techniques are available to remove both TSP and SO_2 in sufficient quantities to enable the Pearl Street Plant, with a 60% stack height increase, to meet Regulation 308 standards. Based on preliminary discussions with suppliers, two packed bed scrubbers could be utilized, having sufficient capacity to operate six boilers. However, since TSP and SO_2 reduction is only required under oil-fired conditions (less than 4% of the time), the option of entering into an uninterruptible gas supply contract may prove to be a more cost effective means of avoiding these potentially excessive emission conditions.

4.4.4 Summary of Environmental Benefits

To obtain a Certificate of Approval for the Pearl Street Steam Plant under the current EPA, the facility firing only natural gas would have to significantly reduce the present level of NO_2 emissions by installing low NO_x burners, in addition, a new 135 m stack within the Sunlife Building. Under Canada's proposed Clean Air Program or CAP, significantly more effort will be required to obtain a C of A for the facility. As the contaminants released into the airshed are Level 2 substances, Best Available Control Technology (BACT) will be required in addition to modelling the other sources within the local airshed. The former requirement should be met with the installation of low NO_x burners. If the results of the modelling of other sources indicate non-attainment (i.e., exceedances of CAP Air Quality Standards), then further emission control, or possible relocation of the source may be stipulated as being required by the Ontario Ministry of the Environment (OME). However, preliminary review of the OME air quality monitoring network for Toronto shows only one exceedance of the NO_2 air quality guidelines for 1989. This suggests that Toronto is not in a non-attainment situation and that a new stack, together with low NO_x burners, will enable the Pearl Street Plant to operate within MOEE standards.

4.5 TRACKING THE REDUCTION OF NO_x AND SULPHUR EMISSIONS IN UPPSALA, SWEDEN - CASE STUDY NO.4

4.5.1 Case Study Significance

This study looks at the environmental benefits, specifically reductions in NO_x and sulphur emissions, at the Uppsala district heating plant in Sweden as a result of the implementation of various operating changes. Emission levels for both NO_x and sulphur from 1980 to estimated 1995 levels are presented to demonstrate the benefits which can be realized at central plants which change fuel sources and/or adopt new emission-reducing technologies. An estimate is made of the impact district heating has made on the urban air quality in Uppsala by comparison with a hypothetical case where single home heating exists.

4.5.2 Project Background

Combined heat and power and heating plants in Uppsala's district heating system provide 1900 GWh of heat annually, 95% of the city's heating requirements. The CHP plant also provides about 1/3 of the community's electricity consumption. The district heating system is a medium temperature hot water system with a supply temperature between 80 and 120°C and a return temperature of 50 to 70°C.

In the early 1980's, a large percentage of the heating demand was provided by burning oil. During the next decade, the Uppsala Energy company began to diversify its fuel use, and to depend more upon local low cost and renewable sources of fuel. Boilers were constructed or retrofitted to allow the burning of solid fuels such as domestic waste and peat. Peat, which can be harvested locally and processed to reduce its moisture content, has a heat content of about 5 MWh/ton which is 2/3 the heat content of coal.

Today, Uppsala's heating plants are fuelled with household waste, peat, wood chips, and a small amount of oil. As well, a small percentage of the heating demand is met by heat pumps and solar energy. As the figures on the following page indicate, over the course of a decade the percentage use of oil of the total fuel consumption for heating has fallen from 92% to 5%, while the use of domestic waste has climbed from 8% to 38%.

The operational strategy with solid fuels such as peat and domestic waste which require high capital cost equipment is to maximize the number of hours during which the combustion equipment is operated at full capacity. Biomass and waste incineration are usually used to supply the "base" or minimum load. Ideally, the furnaces should be sized so as to be operated at peak capacity continuously. Waste incineration needs to be used more or less continuously to minimize start-up periods with low combustion temperatures. More expensive, fast-firing fuels such as oil are used to provide the peak demand.

4.5.3 Measures Taken to Achieve Environmental Benefits

Two separate CHP and waste incineration plants supply most of the hot water to the district heating network in Uppsala. A number of changes have been made to the furnaces at these heating plants in order to reduce sulphur and NO_x emissions.

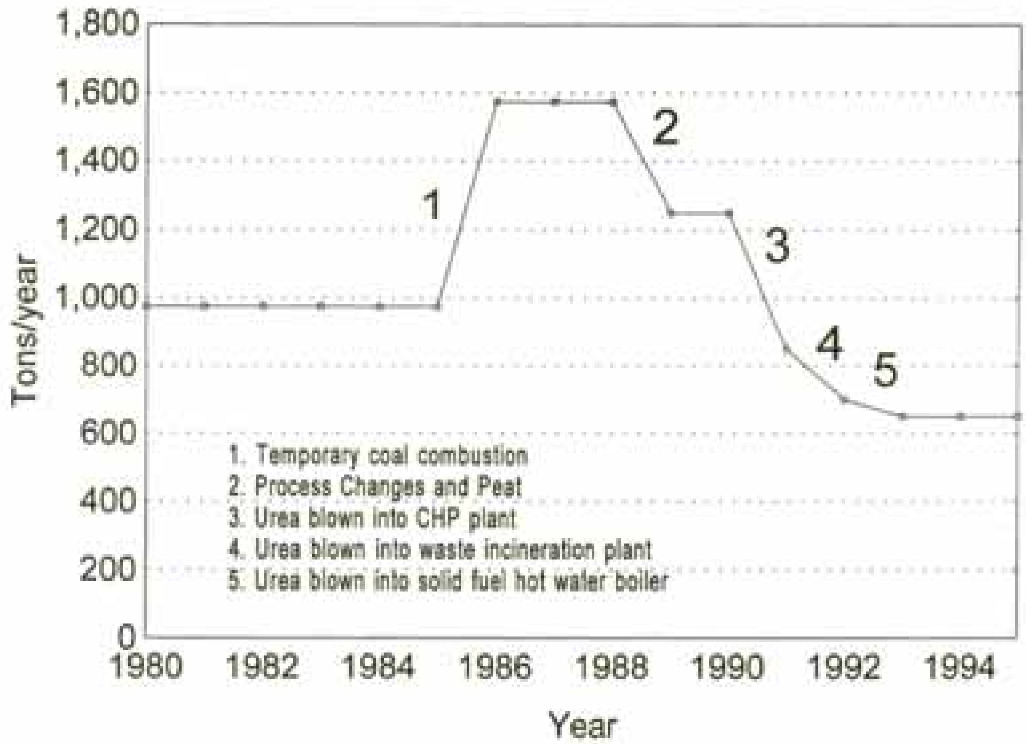
The **CHP plant**, originally an oil-fired unit, has been retrofitted to be able to also burn pulverized peat and coal. The plant is equipped with an electrostatic and textile precipitator for particulate reduction.

To reduce NO_x formation, over-fire air and boxer firing have been introduced. Boxer firing provides a more favourable flow pattern in the boiler and over-fire air allows adjustment to the fuel/air mixture, which results in cleaner flue gases. Urea, which reacts with NO_2 to form nitrogen and CO_2, is also blown into the furnace to further reduce the emission of NO_x.

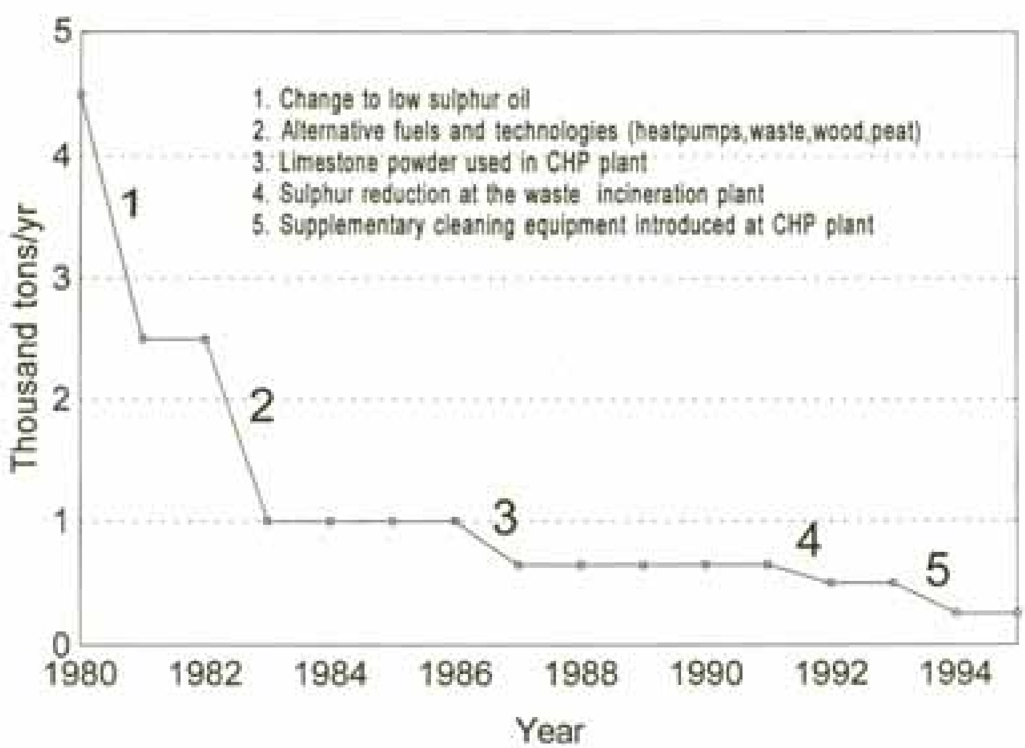
At the **waste incineration plant** 250,000 tons of waste, about 10 percent of Sweden's annual household waste production, are burned every year. The plant has four furnaces which together produce approximately 700 GWh per year, corresponding to approximately 40 per cent of Uppsala's heating demand. The capacity of the four furnaces totals 32 tons of waste per hour.

Following complete and efficient combustion in the furnaces where temperature reaches about 1000°C, the flue gases are passed through electrostatic precipitators. These charge the ashes negatively, after which about 99% of the particles are separated by means of positively charged surfaces. The gaseous pollutants, mainly hydrogen chloride and mercury, are condensed by means of extensive cooling. They are then precipitated and separated by sedimentation and sand filtration.

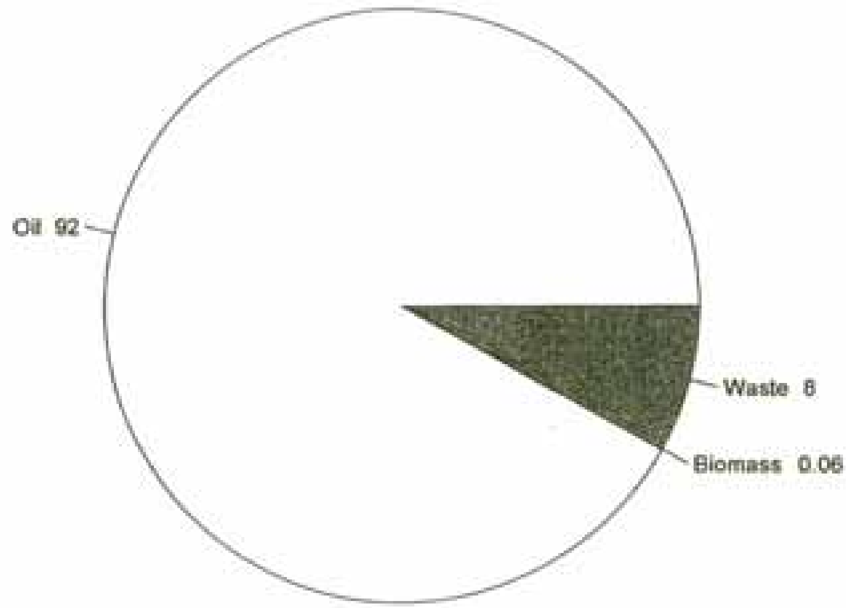
NOx Emissions in Uppsala, Sweden



Sulphur Emissions in Uppsala, Sweden

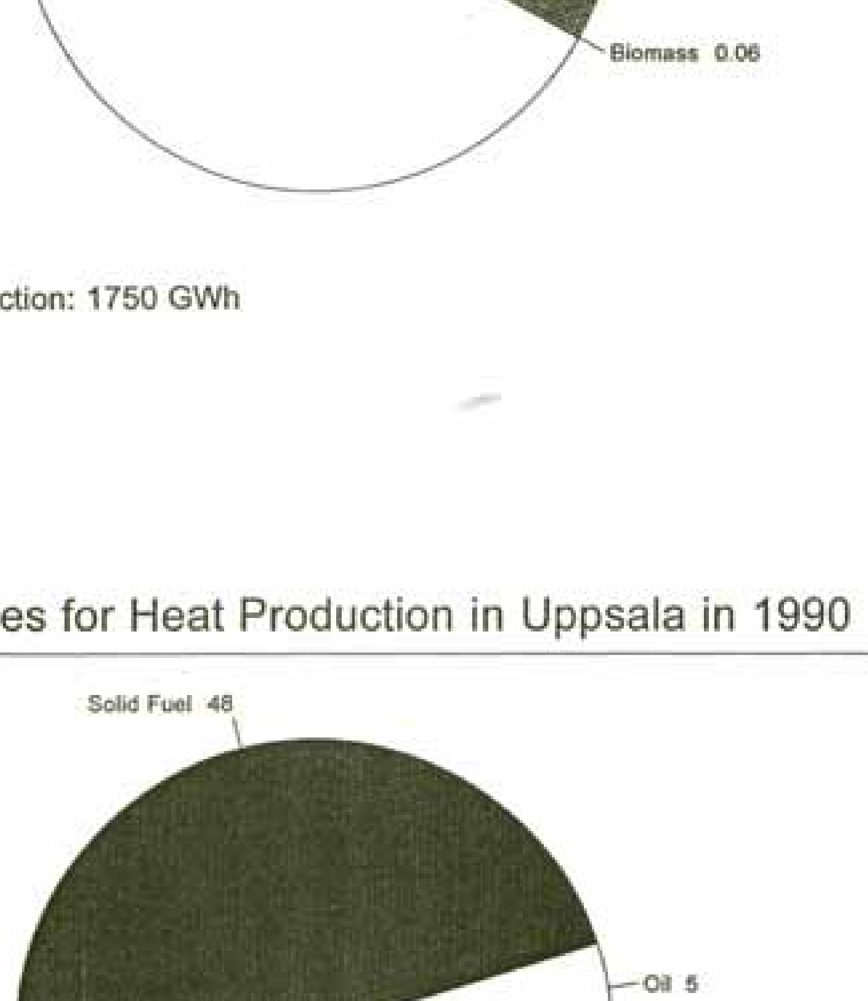


Fuel Sources for Heat Production in Uppsala in 1980



Total Heat Production: 1750 GWh

Fuel Sources for Heat Production in Uppsala in 1990



Total Heat Production: 1900 GWh

The flue gas condensing plant cools the flue gas down to about 35°C with an absorption heat pump. The heat from the heat pump is recovered and used in the district heating system to preheat the return water. The flue gases are cleaned in a textile filter placed in series with the flue gas condensation plant. This filter reduces the emission of sulphur dioxide by 75% and dioxin by 95%.

Some heat is also provided to the network from **heat pumps**, which capture heat from the water leaving Uppsala's sewage treatment plant. **Solar collectors** are also used to generate heated water which is stored through the summer in an underground cavern for use in the winter. Both of these processes are emission free.

4.5.4 Summary of Environmental Benefits

District heating allows the incorporation of emission reducing technologies which would not be economically viable in individual homes. By introducing new technologies at their central heating plants, the Uppsala Energy Company will be able to decrease the amount of total sulphur emitted by 95% (from 4500 ton/yr to 250 ton/yr) and the amount of NO_x emitted by 30% (from 975 ton/yr to 675 ton/yr) from 1980 levels by 1995. This will impact dramatically on the urban air quality as well as acid precipitation in the area.

If the city's heating demand was provided by single home furnaces burning oil, conservative estimates of emissions which would result are 1300 tons/yr for NO_x and 450 tons/yr for sulphur. Both of these values are greater than the annual district heating plant emissions which would result when all of the pollution controlling technologies outlined above are used, 650 tons/yr for NO_x and 250 tons/yr for sulphur. The carbon dioxide emission for single home heating would be 1100 kton/yr compared with 290 kton/yr for district heating. If other environmental factors are considered, such as the benefit that results from burning waste which would otherwise produce greenhouse gases such as CO_2 and CH_4, district heating appears to have provided significant environmental benefits in Uppsala.

4.6 STUDY OF THE EMISSIONS REDUCTION POTENTIAL AT A DISTRICT HEATING FACILITY IN HILLERØD, DENMARK - CASE STUDY NO.5

4.6.1 Study Significance

This study examines the reduction of emissions obtained and expected to be obtained in the future at the DH facility in Hillerød, Denmark, due to various operational changes. The relative ease with which these changes are implemented at a central plant compared to the extent of the work required to achieve similar reduction on numerous individual plants, permits the environmental benefits associated with the emissions reductions to be more readily achieved.

4.6.2 Project Background

Hillerød is a typical Danish town with 40,000 inhabitants.

The first DH network in Hillerød was put into operation in 1962. This was done primarily to benefit from the use of cheaper heavy fuel oil at large DH plants instead of using gas oil in small individual boilers.

The DH system in Hillerød has grown steadily since its inception and today it provides heating for almost the entire town (approximately 3,400 customers), and more than 85% of the heat consumers are expected to be connected before year 2000.

The heat demand connected to the network is around:

1990: 700 TJ/year
2000: 830 TJ/year

The DH system provides 70-75°C supply water which returns at about 50°C. Both indirect and direct systems, as described in Section 3.0, are utilized. The maximum capacity of the DH system is about 140 MW.

In 1985 all the DH plants were converted from heavy fuel oil to natural gas, resulting in significant reductions in SO_2 and particulate emissions.

In 1991 a new natural gas fired combined cycle plant was put into operation and produces more than 90% of the district heat. This combined heat and power plant (CHP) produces 75 MW electricity and 61 MW heat. The electrical efficiency is 45% and total energy efficiency is 82%. A thermal storage system with a capacity of 16,000 m^3 and capable of meeting 10 hours of full load heating demand is also connected to this plant.

4.6.3 Measures Taken to Achieve Environmental Benefits

The measures taken in Hillerød with respect to the past and planned development of their DH system, are described for the year 2000 heat demand of 830 TJ/year as follows:

Step one: 830 TJ supplied by oil fired boilers (gas oil 0.2% S), efficiency 0.75 on average

Step two: 830 TJ supplied by DH. Heat loss in network 150 TJ. Heat source: fuel oil fired boilers (1% S), efficiency 0.85.

Step three: DH as step two. Heat source: natural gas fired DH boilers, efficiency 0.95.

Step four: DH as step three. Heat source: natural gas fired combined cycle plant, efficiency 0.85, 1.2 MW power/MW heat, thermal storage (e.g. for 10 hours of maximum load with load factor of 0.4 to 0.45).

Table 4.6.1 provides a summary of the emissions of CO_2, SO_2 and NO_x for each of the above four steps for the production of 830 TJ heating and 1000 TJ of electricity.

Table 4.6.1 - Summary of Emission for Steps 1 through 4
(830 TJ Heat, 1000 TJ Electricity)

Emission (tonnes)	Step 1	Step 2	Step 3	Step 4
In Town				
- CO_2	74,400	77,100	53,500	125,200
SO_2	91	508	0	0
NO_x	50	156	156	308
Condensing Plant				
- CO_2	249,500	249,500	249,500	0
SO_2	294	294	294	0
NO_x	489	489	489	0
Total country level				
- CO_2	323,900	326,100	303,000	125,200
SO_2	385	802	294	0
NO_x	539	645	645	308

4.6.4 Summary of Environmental Benefits

By dividing the project into the 4 steps shown previously, the emissions-related environmental impact of each step or project component can be analyzed.

Going from step 1 to step 2 total emissions are increased. From practical experience it is known that pollutant concentrations are reduced significantly in most of the town, however, pollution levels may be too high close to the boiler plant, especially for short periods when a boiler is starting. This effect is difficult to meter in general terms, but it is a recognized problem.

Going from step 2 to step 3, SO_2 emissions are reduced to zero and there is no serious local pollution near the plant. Compared to step 1 the total emission of NO_x is higher, but due to the high stack the concentration at ground level in general will be much lower.

Going from step 3 to step 4 the effect of both i) the more efficient CHP production and ii) the change from oil to natural gas in the power production processed is observed.

4.7 STUDY OF THE EMISSIONS REDUCTION POTENTIAL AT A DISTRICT HEATING FACILITY IN COPENHAGEN, DENMARK - CASE STUDY NO.6

4.7.1 Study Significance

This study examines the reduction of emissions obtained and expected to be obtained in the future, at a DH facility in the Copenhagen suburb of Tårnby, Denmark. The study is similar to Case Study No.5 in that readily adopted operational changes at a centralized plant yield environmental benefits. The equivalent benefits at numerous individual plants cannot be realistic.

4.7.2 Project Background

Tårnby is a Copenhagen suburb with 40,000 inhabitants. In the Copenhagen area DH networks in 18 municipalities are supplied by an extensive interconnected DH network. The total heat demand of the Greater Copenhagen system is about 26,000 TJ/year. The heat sources include incineration plants, coal-fired CHP extraction plants and peak load gas and oil fired boilers.

At the large new plants, which produce most of the heat, modern emission control equipment is (or is going to be) installed to reduce emissions of SO_2 and NO_2.

The DH network in Tårnby was constructed and connected to the CHP plants in the years 1985-86.

The heat demand connected to the Tårnby DH network is:

1990: 600 TJ (68 consumers)
2000: 770 TJ (75 consumers)

One large consumer (the airport) covers 38% of the demand. The other consumers are mainly institutional and residential multistorey houses. In the northern part of the suburb almost all buildings having a heat demand of more than approximately 1 TJ/year are connected to the DH network, while all smaller buildings already are (or will be) connected to the natural gas network.

Currently no DH is provided to the single family homes in the southern part of the suburb.

4.7.3 Measures Taken to Achieve Environmental Benefits

The measures taken in Tårnby with respect to the development of the DH system there are described step by step below for the total heat demand of 770 TJ/year as follows:

Step one: 770 TJ supplied by oil fired boilers (gas oil 0.2% S), efficiency 0.75 on average

Step two: 770 TJ supplied by DH, efficiency of network 0.9 on average. Heat source: coal fired CHP extraction plant, normal flue gas cleaning but no removal of SO_2 and NO_x, 1% S coal.

Step three: As step two, but with 80% removal of SO_2 and NO_x.

Table 4.7.1 provides a summary of the emissions of CO_2, SO_2 and NO_x for each of the three steps above.

Table 4.7.1 - Summary of Emissions for Steps 1, 2 and 3

Emission (tonnes)	Step 1	Step 2	Step 3
CO_2	68,900	39,900	39,900
SO_2	83	277	46
NO_x	93	186	78

4.7.4 Summary of Environmental Benefits

By dividing the project into the 3 steps discussed above, the impact of each step or project component can be analyzed.

As expected, total emissions are increased going from step 1 to 2. However, the concentration of the emissions at a few larger (higher) stacks instead of many smaller (lower) stacks makes further flue gas cleaning possible and thus step 3 turns out to have the lowest emission.

DH (going from step 1 to 2) in general reduces the ground level concentration of SO_2 and NO_x in the living areas. Only at locations near the centralized plants does the concentration of pollutants potentially increase.

Unfortunately no data on ground level concentrations is available concerning these 3 steps. As a demonstration project it would be possible to calculate the ground level concentration (SO_2/m^3 air and NO_x/m^3 air) in the suburb area caused by heat production using an advanced model. (Operational Meteorological air quality model).

At the moment only results of calculations made some years ago can be shown, describing the consequence of the whole DH/CHP project in the Copenhagen region.

4.8 STUDY OF THE ENVIRONMENTAL EFFECTS OF THE ENERGY PRODUCTION IN THE CITY OF HELSINKI, FINLAND - CASE STUDY NO.7

4.8.1 Case Study Significance

The study examines the environmental effects of utilizing large-scale cogenerated district heating for the energy supply of the city of Helsinki. Helsinki was awarded the United Nations Environmental Price in 1990 for its district heating program, which has used cogeneration to reduce Helsinki energy demand. The award was given to the city of Helsinki "in recognition of its dedication, leadership and commitment to the enhancement of the quality of the urban environment".

4.8.2 Project Background

Helsinki, the capital of Finland, is situated by the gulf of Finland at a latitude of 60°. The annual mean temperature is +5.4°C. The lowest ever daily mean temperature, -32.5°C, was recorded in January 1987. The population was 496,000 in the end of 1991. With surrounding cities the greater Helsinki area has altogether more than 900,000 inhabitants.

District heating was introduced in Helsinki in 1952. The reason was that after the Second World War fuel was expensive and difficult to obtain. Efforts were needed to improve the efficiency of fuel utilization.

The spread of district heating has resulted in greater efficiency in fuel utilization. At the same time, the self-sufficiency in electricity production has increased to nearly 100%. Fuel is now required 33% less than if electricity would be generated in condensing power plants and heating provided by individual heating boilers. This energy saving corresponds to 460,000 tons of oil yearly.

District heating distribution now covers practically the whole city area. The market share of district heating is 92%. The heat sale is around 6 TWh/a, depending on weather conditions. In 1991, the sale was 5.75 TWh. In the same year, the electricity sale was 3.19 TWh. According to heat sale, the Helsinki Energy Board is the biggest district heating company in western Europe.

The heating energy consumption per cubic meter of space showed a slight increase until the energy crises of 1973, but has since shown a proportional continuous decline. The declining trend is expected to continue even in the future. The heating demand diminished by 31% between 1971 and 1991. It is estimated that the heating demand will still decrease by 1% a year until the year 2000.

From the very outset the district heating tariff was set at an economically competitive level. District heating had to be cheaper than other heating forms. Consequently, district heating spread very quickly, which again resulted in full investment utilization and good profitability. A good profitability for its part ensure the financing of further investments.

4.8.3 Measures Taken to Achieve Environmental Benefits

Modern technology offers a possibility of forestalling a number of potentially harmful environmental effects. Nevertheless, the final result will always be a compromise. We can say, however, that the new energy plants of Helsinki fulfil the environmental requirements quite well. As examples are the coal power plants Salmisaari and Hanasaari B, which have both been equipped with desulphurization and will be equipped with low NO_x burners.

Sulphur dioxide mainly emanates from energy production. In 1991 the sulphur dioxide emissions originating from centralized energy production amounted to some 13,000 tons in Helsinki. The total emission within the city area was about 14,000 tons.

The sulphur dioxide content in the air has greatly diminished because of the increased use of district heating. Research showed a sharp decline of sulphur dioxide content in the early 1970's, when district heating achieved a market share of 50%. Meanwhile, however, the share of long-range sulphur dioxide, originating from Central and Eastern Europe, has increased, and it nowadays accounts for about half or one-third of the annual average of 10 to 20 $\mu g/m^3$ in the air in the city centre. Daily levels seldom reach about 100 $\mu g/m^3$.

It is predicted that the insignificant amounts of sulphur dioxide now to be found will continue diminishing in spite of increased energy production. This decrease will be due to the gradual change-over to desulphurization of flue gases. According to plans, the last coal boiler without desulphurization will be out of use in 1997. Coal will still remain as a main fuel in Helsinki, even though natural gas has also been utilized for CHP production since 1991. The increasing use of natural gas will also contribute to lower sulphur dioxide emissions. It is estimated that the sulphur dioxide emissions in Helsinki will then be about 6,000 tons annually, which is around 60% lower than the emissions today.

The nitrogen oxide content in the air of Helsinki has been measured and investigated since mid-1980's. As district heating has become more common, the average emission heights have increased, and the nitrogen oxide content originating from energy production has decreased. The increase of traffic has strongly affected the nitrogen oxide content. In Helsinki the estimated nitrogen oxide emissions emanating from energy production were 12,000 tons in 1991, whereas nitrogen oxide emissions from traffic were estimated at some 7,500 tons expressed as NO_2.

It is estimated that in 1995 the nitrogen oxide emissions from the Helsinki power plants will be only about 9,500 tons of NO_2. The lowering of NO_x - emissions is due to the NO_x - reduction measures coming into use at Helsinki Energy Board before 1995. The prognosis for the year 2000 is 7,500 tons of NO_2, which is about 50% less compared to the situation of today. The use of natural gas and new power plants will also contribute to lower emissions.

Only the old power plants contribute to the emissions of energy-production-based airborne particles. As new technology is utilized, it is likely that the air particle content from energy production will be insignificantly compared to that of traffic. In 1991, about 1,500 tons of particles were emitted from power plants. It is estimated that in 2000 the dust emissions from Helsinki energy production will be about 300 t/a.

The storing and transfer of coal at the power stations causes emissions of coal dust. According to the measurements the downfall is limited mainly to the power plant area. The coal dust emissions are largely dependent on weather conditions and climate, which effectively reduce the amount of airborne dust in Helsinki during most of the year.

The municipal water authorities monitor continuously the state of the sea area around Helsinki since 1973. The follow-up indicates that energy production in Helsinki does not cause direct water pollution. Heat emissions into the sea are relatively small as practically all heat is utilized for district heat production.

The burning of coal leads to significant amounts of fly ash and furnace ash as by-products. Desulphurization of flue gases also produces considerable amounts of solid waste.

The waste production levels were, in 1991, as follows:

-	fly ash	-	150,000 ton/year
-	furnace ash	-	38,000 ton/year
-	desulphurization products	-	22,000 ton/year

A part of the fly ash is used as a raw material for concrete production. The remainder, as well as all furnace ash, is used for landfills. A part of the fly ash is mixed with the desulphurization waste in order to produce suitable landfill materials. Studies are underway for finding better alternative uses. Solid wastes from coal are alkaline and with suitable treatment they will harden. These characteristics and a proper treatment will make them environmentally useful.

According to the Finnish regulations, the noise levels should not exceed 45 dB(A) at populated areas. This means that continuous noise from power plants and heating stations must be eliminated at the constructing stage. Power production will, however, from time to time emit noise. When this happens the authorities must be notified in advance.

4.8.4 Summary of Environmental Benefits

Due to the high degree of cogenerated district heating in Helsinki, a substantial amount of energy is saved. The energy saving corresponds to 460,000 tons of oil yearly. This has been achieved in an economically competitive and profitable way.

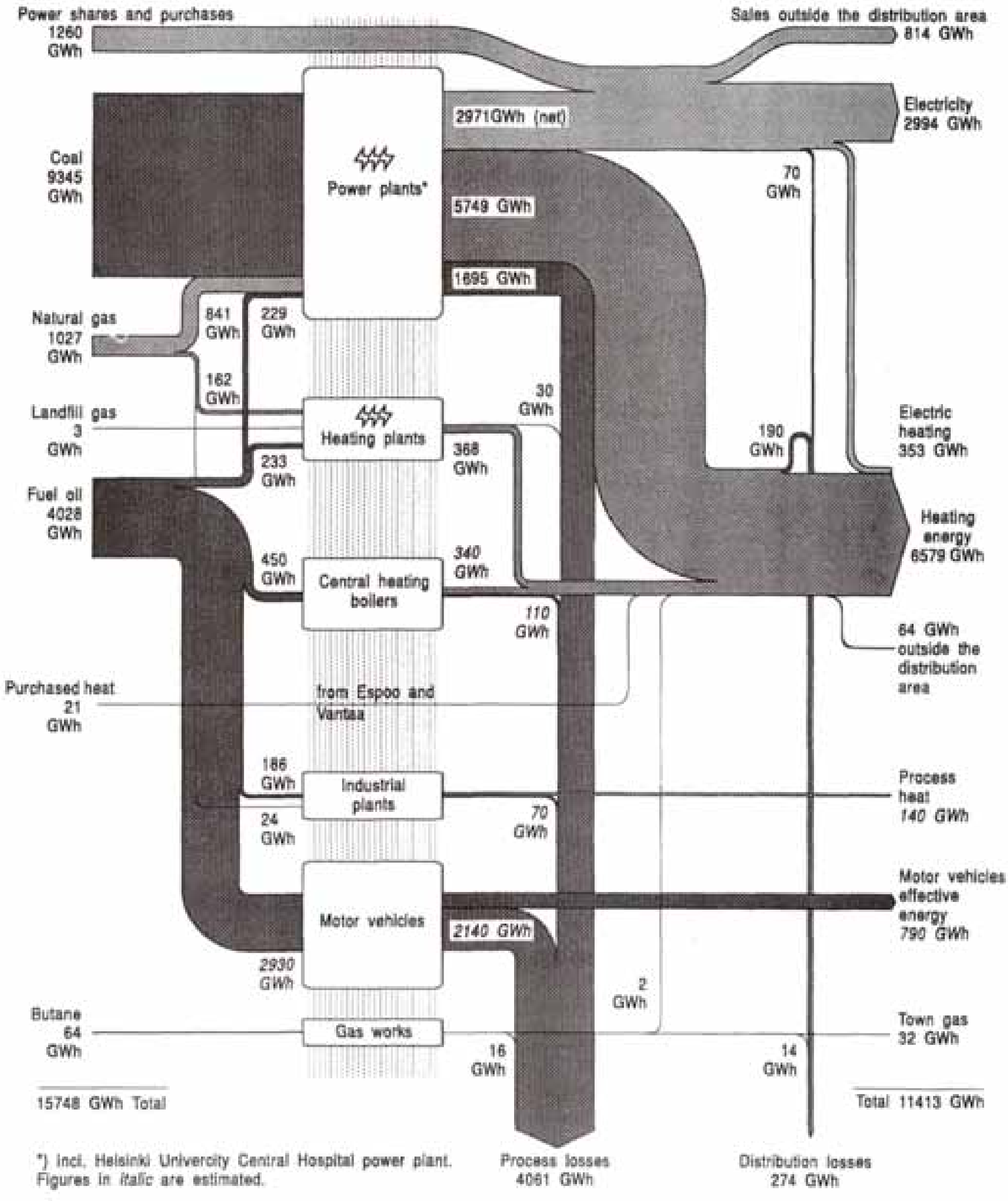
The sulphur dioxide content in the air has decreased by more than 50% since 1970's, despite of the increase of the energy demand. The emissions will still be diminished by 60% towards the year 2000.

The nitrogen oxide contents originating from energy production have decreased. By new investments in power plants, the NO_x emissions will still be diminished by 50% until the year 2000.

The dust emissions of the power plants are limited by electrofilters. As new technology is utilized the emissions of airborne particles will still decrease by 80%.

The sea areas around Helsinki do not suffer from the energy production, since practically all heat is utilized for district heating. The solid wastes from energy production are used in an environmentally useful and acceptable way for raw material and landfill purposes. The noise levels of the energy production are to be kept low according to the environmental regulations. The architecture of the power plants has been designed to fit to the city structure so well that the main power plant of Helsinki was awarded by the local press as the most beautiful modern building of the city.

ENERGY BALANCE 1991 FOR HELSINKI



*) Incl. Helsinki University Central Hospital power plant.
Figures in *italic* are estimated.

$$\text{Energy efficiency in Helsinki} = \frac{11413\ \text{GWh}}{15748\ \text{GWh}} = 0{,}72$$

Efficiency of Energy Board = 0,81 and gross efficiency of own production = 0,85.

4.9 BIOMASS BASED DISTRICT HEATING IN PRINCE EDWARD ISLAND - CASE STUDY NO.8

4.9.1 Case Study Significance

The Charlottetown and University of Prince Edward Island district heating systems demonstrate the economic advantages of using local resources, and the environmental advantages of using biomass as a fuel. Biomass is the only combustible fuel that does not contribute to the build-up of CO_2 in the atmosphere. Harvested land is replanted with young trees which fix CO_2, leading to an overall balance in CO_2 in the atmosphere over time.

4.9.2 Project Background

The district heating systems in P.E.I. were developed by the P.E.I. Energy Corporation, a provincial crown corporation whose role is to demonstrate energy efficient systems within the province. In 1985, the Corporation initiated its first wood fired district heating system in the downtown area of Charlottetown. The original system was designed to serve a large seniors' care facility and the Provincial Government Administrative complex.

Since 1985, the system has been expanded several times and now supplies heat to over 20 customers, including a significant section of the downtown commercial district including office towers, retail malls, hotels and municipal buildings. Another expansion is ready for commissioning of both boiler capacity and the district heating lines to extend the service to two large high schools and a health care facility located in a residential area of the city.

The second of P.E.I.'s district heating systems also burns wood chips and is centred at the University of Prince Edward Island. The system provides heat to the University campus as well as a large regional shopping centre, many apartments and seniors' care complexes, and a number of institutional and commercial facilities. It is almost 7 km in length. Both systems are medium temperature hot water systems, similar to those operated in Europe.

4.9.3 Summary of Environmental Benefits

Charlottetown's wood-fired boiler operates at 63% efficiency, a value higher than for the older oil-fired boilers which it has replaced. This increased efficiency, coupled with the diversification effect of the district heating system, has led to a decrease in the total amount of fuel which must be consumed and a reduction in the amount of pollutants released to the atmosphere. In particular, SO_2 emissions have decreased. The sulphur dioxide emissions from the P.E.I. wood fired boiler are 0.013 g/MJ while emissions from standard oil fired boilers are 0.068 g/MJ (source: US EPA AP-42). When the relative efficiencies of the boilers and distribution system are considered, the SO_2 emissions from biomass combustion will be lowered further.

For wood with a moisture content of 84% (dry basis), 224 litres of light fuel oil are displaced for every ton of green wood chips burned. The Charlottetown system currently displaces a total of 5,000 m^3 of fuel oil every year. As well, because of the CO_2 neutral impact of biomass fuel, P.E.I.'s two district heating systems decrease the net output of CO_2 to the atmosphere by 9,500 tons annually.

5.0 REFERENCES FOR CASE STUDIES

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8) Dr. John te Raa, Prince Edward Island Energy Corp., direct correspondence.

Report on the Environmental Benefits of District Heating and Cooling

Dear Reader:

The Executive Committee of the Implementing Agreement on District Heating and Cooling is interested in improving the impact of the R&D activities and the effectiveness of the programme. For this reason, the Operating Agent needs your support. Please can you complete the following questionnaire and send it back to:

Novem BV
Attn. Mr. J.C. Resing
P.O. Box 17
NL-6130 AA SITTARD

- Please complete your name and address.

  Name: ______________________________

  Address: ______________________________

- What is your professional interest in the subject of the report?

  ____

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- How did you receive your copy of the report?

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- Do you appreciate the activities described in the report?

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- Do you have any suggestions for further dissemination of the results presented in the report?

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- Do you have any suggestions for further tasks, or comments about the activities of the Implementing Agreement?

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Thank you for taking the time to fill out this questionnaire.

IEA District Heating

THE ENVIRONMENTAL BENEFITS OF DISTRICT HEATING AND COOLING

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