District Heating

HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS –** District heating (DH) systems provide heat for space heating and hot water to residential, commercial and service buildings, and to industrial users. In DH systems, heat is generated centrally or derived from an existing heat source, and distributed to consumers by pipelines, mostly in the form of hot water. The DH heat sources include cogeneration plants producing both heat and power (CHP), different types of boilers, industrial facilities producing waste heat, geothermal heat sources, solar heat, heat from waste incinerators, heat pumps. In 2008, DH met about 12% of the heat demands in residential and service buildings in EU27. In Northern, Central and Eastern European countries, DH often accounts for above 50% of the heat market. On average, more than 80% of heat provided by DH is based on renewable sources or waste heat from industrial processes and electricity generation. Therefore, DH contributes significantly to reduce the CO_2 emissions in Europe, and studies indicate further CO_2 reduction potentials from increased use of DH.

■ **PERFORMANCE AND COSTS –** DH offers significant energy savings as it can utilize geothermal, renewable heat, or waste heat from industrial processes and electricity generation. However, large centralised DH systems involve significant heat losses due to the heat distribution network. The cost of a DH system includes the heat generation cost (or collection cost, if heat is derived from an existing source) and the heat distribution cost. Both these costs consist of capital cost and operation and maintenance costs. In general, the capital cost accounts for more than half of the distribution cost. The heat loss of the distribution system also is an important element for the distribution cost. An important parameter to assess the cost effectiveness of a DH system is the linear heat density which is defined as the ratio of the annual heat delivered to the total length of the DH piping and network. High linear densities increase the cost effectiveness of the DH system.

■ **POTENTIAL AND BARRIERS –** DH is widely used in dense populated areas (cities) located in cold climate regions. In these regions DH offers competitive prices for supplying space heating and hot water. DH is highly adaptive to a variety of fuels and heat sources. This results in energy diversification opportunities and reduced dependence on imported fossil fuels, which translate into competitive and stable prices [4] for residential and industrial customers. The most important barriers to further deployment of DH systems include the capital cost of the distribution network and the cost for complementing heat-generation plants to meet peak demand [5]. In addition, the economic competition in the DH market is currently modest. DH providers are often energy companies which hold monopoly in heat production and distribution, and grid operation at local or regional level, and deregulated DH markets where different operators provide heat to customers have not been implemented yet. In terms of potential, as the global heat demand for space heating in the residential sector is projected to reduce due to the global warming, in regions with mild climate and low heat demand the economic competitiveness of DH could decline over time [6].

PROCESS AND TECHNOLOGY STATUS

District heating (DH) is a way to supply residential and commercial buildings, and industrial users with heat for space heating, hot water and process heat, through a heat distribution network. The distribution system is fed with heat from one or several heat sources such as dedicated heat production plants based on renewable energy and fossil fuels, or waste heat from industrial facilities. Large DH systems can meet the heat demand of large urban areas and include a number of heat production facilities, transmission pipelines and distribution grids connecting thousands of heat consumers.

Compared with decentralized, on-site heat production, DH offers advantages, but also has some disadvantages. Positive aspects include:

- The joint production of electricity and heat in highly-efficient cogeneration plants;
- The low specific cost of large-scale, centralized heat production plants (due to economy of scale);
- The flexibility of DH systems which can use low-cost, low-quality fuels such as municipal solid waste (MSW), forestry residues, and industrial waste heat;
- The low environmental impact of DH, and the improvement of the energy supply security.

Negative aspects include:

- The heat losses associated with the distribution network;
- Possible establishment of local monopolies and customer lock-in;
- The need to size the system based on the peak load or to provide peak generation capacity

The DH system can be divided in three subsystems, namely the heat sources or heat production plants, the heat distribution system, and the customer interfaces [3].

■ **Heat Sources** – DH systems can use a number of different heat sources such as combustion-based heat generation plants using biomass or fossil fuels, combined heat and power (CHP) plants, renewable geothermal heat, solar heat, industrial waste heat, heat from municipal solid waste (MSW) incinerators, and heat pumps (HP).

Heat-only Boilers (HOBs) – HOBs produce thermal energy in the form of hot water. Different types of boilers can utilize different energy sources such as fossil fuels (e.g. natural gas, heavy fuel oil and gas oil), MSW and biomass (e.g. wood chips and wood pellets). In the case of fossil fuels, MSW and biomass resources, the basic fuel is burnt in a furnace and the flue gases are used to heat up water [9]. If the moisture content of the fuel is above 30-35%, condensation of flue gases can be necessary. Conversion efficiencies of HOBs are typically very high (above 97%, based on lower heating value) [9]. Devices which burn gaseous or liquid fuels, or using electricity are usually cheaper than other heat production systems, and are mostly suitable to meet peak-load plants in DH systems.

Combined heat and power (CHP) – CHP plants (or cogeneration plants) produce both electricity and heat from a single renewable (biomass) or fossil fuel source (ETSAP E04). They can exploit a large portion of the waste heat of the thermodynamic cycle and offer a total energy conversion efficiency (electricity and heat) ranging from 60% to more than 80%, which is well above the level of conventional fossil-fuel power plants [7]. In such a way, CHP plants can save both energy and costs if compared with the separate production of electricity and heat [15]. CHP technologies are commonly based on steam- or gas-turbine cycles or gas engines with heat recovery units [7]. An advanced option for solid fuels (including biomass) is gasification, in which the solid fuel is converted into a gas which is then burnt in gas engines or gas turbines for CHP generation [9]. Figure 1 shows the share of various fuels used in CHP in different countries in 2009 [14].

Industrial Waste Heat Sources – DH systems can use waste heat (in the form of flue gases or cooling water) from a number of industrial processes through the use of heat recovery boilers or heat exchangers. Residual heat from municipal solid waste incinerators can also be used to supply DH systems. Preferably, the temperature of the heat source should be above 100°C [5]. Ideally, the heat source should be close to the distribution plant and supply continuously heat in the form of hot water or steam [8].

Geothermal Heat – Geothermal heat is a natural, renewable heat source. High-temperature geothermal heat sources are often used for electricity generation, while low-temperature geothermal sources are well suited to supply heat to DH systems [5]. Unfortunately, this resource is available only in specific locations. Currently geothermal DH systems are mostly used in China, France, Japan, Iceland, and the United States. The total installed capacity of geothermal heat-based DH systems (excluding heat pumps using geothermal heat) equalled 15,347 MW_t in 2009, with a yearly heat production of 223 petajoules (PJ); China is the largest producer and user of geothermal heat (excluding heat pumps), totalling 46.3 PJ/yr in 2009. In general, geothermal heat sources offer high operation stability, long lifetime, low CO_2 emissions, low running costs, and the ability to be combined with heat storage. The investment costs are usually high and depend on the specific application, the heat source temperature, the distribution systems, and local parameters such as the labour costs. A short distance between the heat source and heat demand area (city) represents a critical element for geothermal DH cost effectiveness [9]. In locations where geothermal heat is abundant, geothermal DH is often a cheap option and can be used for base-load service [9].

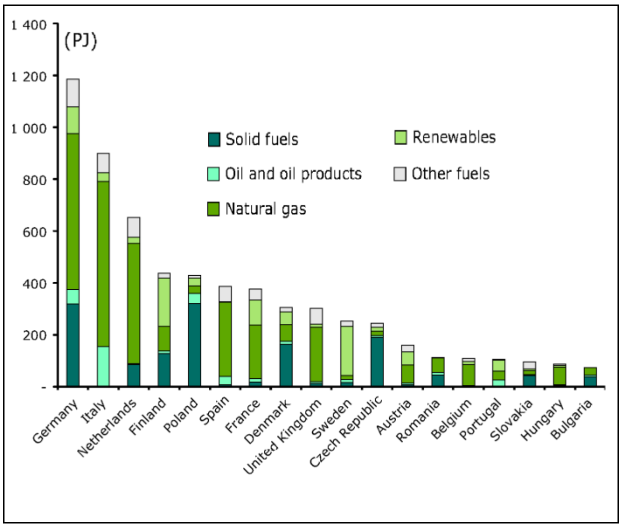

Figure 1 – Fuel Share for CHP plants in 2009 [14]

Solar Heat – Main devices to capture and utilize solar heat in DH systems are solar collectors, i.e. liquid-based heat transfer units to capture and transfer solar heat to demand-side networks or storage tanks. While solar collectors can work even with very low outdoor temperatures (below zero), they offer the highest output in the summer season when DH load is generally low. An important R&D area for solar energy-based DH systems include highly-efficient solar collector concepts combined with seasonal heat storage and other types of heat generation technologies [9]. Concentrating solar power (CSP) plants also represent an important source of solar heat. However, in order to be economically competitive they must be located in the so-called sun-belt region where demand for space heating is low. In addition, they usually collect and store solar heat at high temperature, well above the temperature which is needed for DH and space heating.

Large-Scale Heat Pumps – Heat pumps (HP) are highly-efficient devices which are able to move heat from a low-temperature source to a high-temperature sink based on the thermodynamic refrigeration cycle, and using electricity as the primary energy sources (see ETSAP E19). HP can upgrade various types of low-temperature heat sources (e.g. geothermal heat, industrial waste heat, latent heat of humidity in boiler flue gases and sewage water) to higher temperature levels. HP have been used in large DH systems in Sweden and in Norway. When combined with heat storage facility, HP can be beneficial for electricity systems with high share of intermittent renewable generators (e.g. wind turbines) because they convert electricity into heat at very high efficiencies and can help use excess electricity generation overnight [9]. A measure of the HP efficiency is the coefficient of performance (COP), i.e. the average number of heat units upgraded per unit of electricity consumed). The HP that have been used in DH systems have COP between 1.7 and 3.8 [9]. Modern heat pumps can reach even higher COP values.

Combination of Heat Sources in DH Systems – A DH system can rely on different types of heat sources and technologies. Combining heat production plants with different performance and operation features can provide economic advantages. Technologies with high capital cost and low variable operation and maintenance (O&M) cost are suitable for base-load service while technologies with low capital costs and high variable O&M costs are suited to peak-load service. An example of a load curve and different heat sources for DH systems is available in Figure 2, in which CHP 1 is a biomass-fired CHP plant and CHP 2 is a natural gas-fired CHP plant. CHP plants often have low variable costs but are more capital intensive than HOBs. The dispatching priority in a DH system with different heat production plants depends on a number of technical characteristics of the different technologies. For example, liquid and gaseous fuel boilers are often selected for meeting temporary load variations due to their capability to start operation in a few minutes, much faster than boilers using solid fuels.

■ **Distribution System** – The heat distribution system consists of an insulated pipeline network in which the heat transfer fluid flows to supply heat and return to the heat generation plant. Most of the distribution network is usually buried underground and the heat transfer fluid is usually water. The water temperature in the feed pipes is between 70°C and 150°C depending on the outdoor temperature while in the return lines it ranges between 35°C and 70°C [5]. In general, a low return temperature improves the economics of the DH system. It allows for reduced temperature in the feed pipes, which means more efficient use of the heat source, reduced distribution heat losses and - in the CHP plants - more heat available for power generation while meeting the same DH demand [17]. The heat losses in the distribution system also depend on thermal insulation of pipes, pipe size, feed and outdoor temperatures, and the linear heat density of the DH system, i.e. the heat delivered per year per unit of length (MWh/y-m) of the distribution network, which is a measure of the users' density of the DH systems. Usually, the typical heat loss in a DH network is between 5% and 10%. The heat loss is higher for a lower linear density and can reach the level of 20% to 30% in areas with single family houses [5]. With a linear heat density of 0.4 MWh/m (in areas with single family houses), the heat loss can be 2.5 times higher than in areas with a linear density of 1.4 MWh/m.

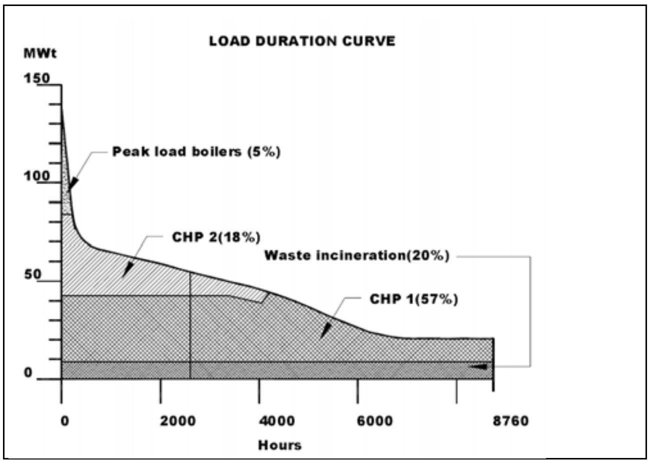

Figure 2 - Example of a load duration curve indicating the proportion of different heat sources [3]

■ **Customer Interfaces** – Customers can be connected to the DH distribution system directly or indirectly. In the indirect connection, a heat exchanger in the customer's building transfers the energy from the DH distribution system to the heat distribution system of the building. In the direct connection, the DH water flows directly through the building to provide heat to internal radiators [4]. Large DH systems often use the indirect connection because the DH water flows at temperatures above 90 °C and pressures above 6 bar. Such a high pressure requires hydraulic separation between the DH (primary) water and the (secondary) heating system of the building. This also enables the DH operator to regulate system parameters with no impact on customers' heating systems.

■ **DH Subsystem Interaction** – In general, a DH network is equipped with four operation control systems [5]. Two of these are managed by customers in the building. They are: 1) flow control valves in the customer's substation; and 2) heat demand control by radiator thermostatic valves and mixing valves for domestic hot water. The other two control systems are managed by the DH operator to control the distribution system (pipeline network) and the heat sources (heat generation plants). These systems include: 3) control of pressure difference between feed and return lines, and speed of distribution pumps; and 4) control of supply temperature by proper management of the heat source facilities [5].

■ **Current Status of DH** – DH is primarily used for space heating and water heating purposes in countries with cold climate and large heating demands. The largest relative diffusion of DH is seen in the Scandinavian countries, Northern and Eastern Europe, Russia and China. However, DH is also used in several other countries, e.g. North America, Western Europe, Korea, and Japan [1]. Table 1 presents the diffusion and characteristics of DH systems in different countries.

PERFORMANCE AND COSTS

As mentioned above, DH systems often use heat from CHP plants, waste heat from industries as well as biomass-based heat and geothermal heat. Consequently, DH systems are usually based on highly efficient energy technologies and systems and do not use high-exergy fuels such as the fossil fuels used by local, on-site heat generation boilers for space heating and hot water [6]. This results in significant energy savings. The nominal thermal efficiency of a conventional boiler for space heating is usually above 80%. However, if cyclic and partial-load operation are accounted for, the actual efficiency on yearly basis ranges between 45% and 65% [3]. For comparison, the thermal efficiency in a MSW-based CHP plant or a heat boiler (HOB) with condensation and treatment of moisture content in the flue gas, can approach 100% on net calorific value basis [9].

Available studies show that even for single family houses in low heat demand areas, DH uses less primary energy not only if compared with electric or pellet boilers, but also in comparison with decentralised heating based on heat pumps [11].

As far as economics is concerned, DH is widely used and cost-effective in dense populated cities located in cold climate regions where it offers competitive prices compared to other heat supply options. Since DH is highly adaptive to a variety of fuel and heat sources, DH providers can reduce their dependence on imported fuels. Therefore, DH customers can often benefit from price stability [4]. Table 2 shows average DH prices in different countries in 2009.

In regions where low-temperature geothermal heat sources are abundant DH is often a cheap option and can be used for base-load service [9]. Geothermal DH systems offer high operation stability, long lifetime, low CO_2 emissions, low running costs, and the ability to be combined with heat storage. The investment costs are usually high, and a short distance between the heat source and heat demand area (city) represents a critical element for DH cost effectiveness [9]. The overall cost of geothermal DH also depends on the heat source temperature and local O&M costs. Typical costs range from €32/MWh_t to €60/MWh_t (about €9 to €17 per GJ) [16]. Investments costs range from €405/kW_t to €1115/kW_t.

If compared with on-site heating technologies, a drawback of the DH systems is the additional cost of the distribution network. The distribution cost consists of two main components, i.e. the capital cost and the O&M cost. In order for the DH to remain competitive the total DH cost should be lower than the cost of local on-site heat generation, as illustrated in Figure 3 [6]. In some countries with high DH deployment, DH based on recycled heat is exempted from taxes while on-site heating by fossil fuels is subject to consumption or carbon taxes. This increases the acceptance and the competitiveness of DH systems in spite of the cost of distribution [6].

As mentioned, an important parameter to assess the

Table 1 – DH deployment and characteristics in different countries (Euroheat & Power, 2009)

	Served citizens	Length of DH system	Supply mix RH/DR/O [a]	DH capacity
	[%]	[km]	[%]	[GW_{th}]
Austria	20	4201	68/14/18	8.2
China		110490		379.3
Croatia	10	460	72/0/28	1.8
Czech Rep.	38	7554	66/2/32	
Denmark	61		64/25/11	
Estonia	53	1447	39/14/47	5.6
Finland	49	12210	75/6/19	20.8
France	8	3321	46/6/48	16.5
Germany	14	19538	91/0/8	51.5
Greece		658	99/0/1	0.4
Iceland	99	6950	20/79/0	2.1
Italy	4	2404		2.2
Japan		736		4.3
Korea	12	2268		13.0
Latvia	64	1000	55/14/31	7.3
Lithuania	60	2535	58/14/29	9.6
Netherlands				5.6
Norway	1	1100	51/26/24	2.3
Poland	50	19286	64/1/35	59.8
Romania	23	7000	92/0/8	53.2
Russia		173100	44/0/56	541.0
Slovakia	41	3471	38/4/58	27.9
Slovenia	17	705	86/1/13	2.2
Sweden	42	21100	67/24/9	15.0
Switzerland		1090	56/23/21	2.1
USA	< 1	3206		87.7

(a) **RH** (**recycled heat**) includes heat from CHP, waste-to-energy plants, industrial waste heat and heat pump generation not allocated to electricity input; **DR** (**direct renewables**) includes the use of renewables in HOBs and installations other than CHP; **O** (**other**). includes fossil fuel HOBs, electricity and heat pump generation allocated to electricity input.

Table 2 – Average DH Prices by Country [2]

	€/GJ		€/GJ		€/GJ
Austria	16.0	Germany	19.6	Romania	14.0
Croatia	8.9	Iceland	2.6	Russia	4.5 a
Czech R.	17.1	Korea	12.1	Slovakia	18.1 a
Denmark	25.0	Latvia	13.9	Slovenia	12.4
Estonia	12.3	Lithuania	17.6	Sweden	16.6
Finland	12.8	Norway	20.8	USA	8.6
France	16.6	Poland	10.4		

a) residential only

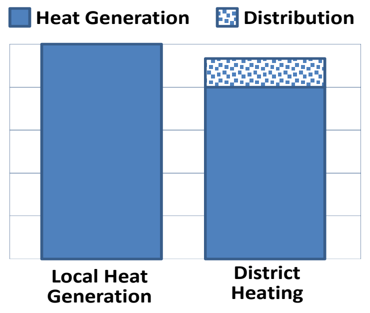

Figure 3 - Cost of DH and on-site heat generation [6]

economic viability of a DH system is the linear heat density, which is defined as the heat delivered per year per unit of length of the distribution system (MWh/y-m). High linear heat density means high economic viability of the DH system [13]. Therefore, areas with high linear heat density have connection priority to the DH systems while areas with low linear density can be connected only in very favourable business situation, i.e. high income and low marginal costs for additional heat generation and distribution [13]. The linear heat density has an important impact on the DH distribution cost, which includes four components [1, 6]:

- **Capital Cost of DH Network** – In general, this cost accounts for more than half of the total distribution cost [6]. The annual capital cost of the distribution system (C_d) depends on the linear heat density (Q_s/L) and other network parameters. It can be expressed as follows [6].

$$C_d = \frac{a \cdot I}{Q_s} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{\left(\frac{Q_s}{L}\right)} \qquad (€/\mathrm{GJ})$$

Where:

a	Annuity (interest rate and debt return time)
I	Total network investment cost (€)
Q_s	Annual heat sold (GJ/a)
C_1	Construction cost constant (€/m) (Table 3)
C_2	Construction cost coefficient (€/m^2) (Table 3)
d_a	Mean pipe diameter (m)
L	Total length of channel dug in earth (m)
Q_s/L	Linear heat density (GJ/m,a)

- **Cost of Distribution Heat Losses** – The annual cost of heat losses depends on factors such as linear heat density, distribution temperatures, piping insulation material and average pipe diameter. Typically, it cost accounts for about 20-25% of the total distribution cost in new DH networks while it can be higher in older networks (with less thermal insulation, etc.) [1].

- **Cost of Distribution Pressure Losses –** The pumping energy required by the distribution system depends on the size and complexity of the network. Typically, 5-10 kWh of pump electricity are needed per MWh of delivered heat [1]. However, apart from direct pump losses which relate to pump efficiencies, the energy lost as piping pressure drop (friction) is converted into useful heat in the DH water. Thus, pressure losses of the distribution system result in a relatively small cost [1].

- **Service and Maintenance Costs –** The annual operation and maintenance cost is often considered to be about 1% of the total capital investment cost or about 10-15% of the (annual) DH distribution cost [1].

Figure 4 shows the distribution cost as function of linear heat density, for different cost levels with piping dimension of DN40. Capital cost is calculated with the interest rate of 6% over a time period of 30 years [13]. Table 3 summarizes the total cost of piping per meter (€/m) for different sizes (mm) and capacities (MW) in inner city and outer city areas (costs recalculated with an exchange rate of 1 Euro to 10 Swedish Krona).

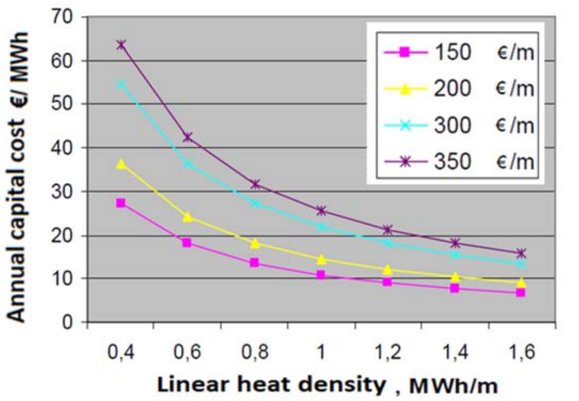

Figure 4 - Distribution cost as function of linear heat density and trench cost [13]

Table 3 – Typical cost coefficients for different DH-served areas [6[

Area characteristics	C1(€/m)	C2(€/m^2)
Inner city areas	286	2022
Outer city areas	214	1725
Park areas	151	1378

Table 4 – Piping cost for various heat capacities [13]

Pipe dia (DN, mm)	Heat capacity [a] (MW)	Total cost for inner-city area (€/m)	Total cost for outer-city area (€/m)
25	0.114	300	200
32	0.22	330	250
40	0.293	380	300
50	0.52	400	350
65	1.0	480	380
80	1.5	500	400
100	3.2	550	430
125	5.5	610	500
150	9.0	700	550
200	19.0	780	600
250	30.0	840	700
300	45.0	1000	800
400	75.0	1200	1000
500	125.0	1380	1150
600	190.0	1580	1300

a) With 55°C feed/return temperature difference

In conclusion, in highly-populated areas of cold climate regions with high heating demand, large-scale DH systems are proved to be fully feasible and cost effective. However, the heat demand is not constant over time. In the future, the heat demand in large cities could decrease due to global warming and energy efficiency measures. As DH systems involve significant investment and long lifetime and operation, the economic competitiveness of new DH systems has to be assessed in the light of present investment costs and possible changes in future demand [6].

In areas with low population density or low heat demand, the profitability of DH is to be carefully assessed based on the distribution cost, the linear heat density and the annual heat use per house. The analysis shows that a linear heat density of 2 GJ/m and an annual heat demand of 50 GJ/house are needed to make DH profitable in low heat density areas. The heat demand of single family houses can also be increased by replacing electricity with DH in appliances such as air conditioners, dish washers and washing machines. Energy saving incentives and CO2 taxes on fossil fuels and electricity can to some extent improve the cost effectiveness of DH in areas with a low population density [11].

POTENTIAL AND BARRIERS

DH is currently used to supply space heating and hot water in dense populated areas in cold climate regions where it offers competitive prices. DH is highly adaptive to a variety of fuels and heat sources. This offers energy savings and diversification opportunities and reduced dependence on imported fossil fuels, which translate into competitive and stable prices [4] for residential and industrial customers. The most important barriers to further deployment of DH systems include the capital cost of the distribution network, the cost of complementing heat-generation plants to meet peak demand or to provide backup heat generation [5], and possible future reduction of heat demand in the residential sector due to climate change [6]. At present, the economic competition in the DH market is currently modest. DH providers are often energy companies which hold a monopoly in heat production and distribution, and grid operation at local or regional level. Therefore, deregulated DH markets where different operators provide heat to customers have not been implemented yet.

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Table 5 – Summary Table - Key Data and Figures on District Heating Technologies [9]

Technical Performance	**Typical current international values and ranges**						
Energy input/ output	Renewable and fossil fuels, waste heat/ DH, space heating and hot water						
	Typical Heat Production Technologies and Sources						Distribution system
Technology Variants	Bio HOB	Bio CHP[a]	MSW CHP	Heat Pumps[b]	HOB[c]	Geothermal Heat Sources[e]	
Thermal efficiency (net calorific value, %)	108		100		97-105		90-95
Typical size (MW)	1-50	10-100	100-120	1-10	0.5-10	26-27	0.1- 190
Technical lifetime (year)	20	30	20	20	20	25	30
Forced outage (%)			1				
Planned outage (weeks/year)			3				
Availability (%)	96-98	90			95-97	66-78	
Electrical efficiency (%)		44.8	20-25				
Heat losses% [d]	0		0	50-65	3-5		5-8 [f] / 15-35[g]
Environment	**Typical current international values and ranges**						
CO_2 emissions (Kg/GJ)			32.5				
SO_2 (degree of desulphurisation, %)	0	0	98		0		
NOx (g per GJ fuel)	90	69	124		42		
CH_4 (g per GJ fuel)	32	2	0.59		6		
N_2O (g per GJ fuel)	4	0.8	1.2		1		
Costs	**Typical current international values and ranges**						
Investment cost (M€/MW)	0.3-0.7	1.3-1.9	7-10	0.5-0.8	0.06-0.12	1.7-1.9	Table3
Fixed O&M cost (€/MW/year)	8,000-29,000	23000	140,000-170,000	3500-7000	2100-4200		See “Performance and Cost”
Variable O&M cost (€/MWh) / (%)		3.2	20-24			6.6-7.9	See “Performance and Cost”

[a] Medium steam turbine, woodchips; [b] Heat source ambient temperature; [c] Natural gas, with heavy fuel oil as back-up as input fuel; based on net calorific value ; [e] Geothermal heat-only plant with steam-driven absorption heat pump, Denmark; [f] Densely populated cities [17]; [g] low heat density areas [17]