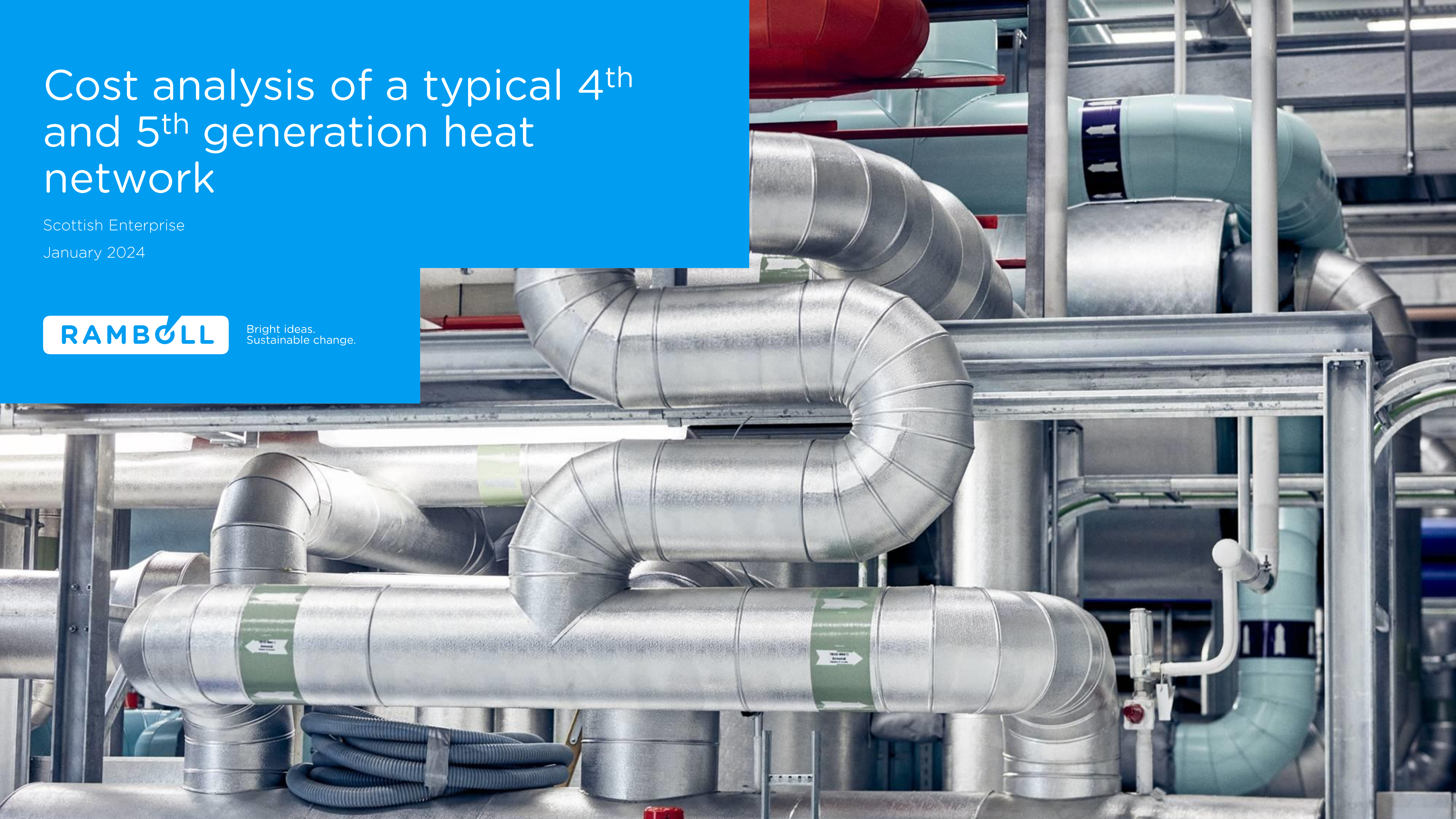
# Cost analysis of a typical 4th and 5th generation heat network

Scottish Enterprise

January 2024



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# Contents

# Executive summary | Cost analysis

**Introduction**
Increasing demand and new opportunities will happen across the heat network supply chain as the number of heat networks grows in Scotland thanks to supportive legislation and ambitious climate targets. This study has been commissioned by Scottish Enterprise to understand the current heat network supply chain and covers two focus areas; a cost analysis and a supply chain analysis of heat networks.

The cost analysis is further divided into four sections:
- The energy centre
- A deep dive on wastewater heat recovery
- The distribution network
- Case studies

**Energy centre**
The energy centre typically makes up 25-30% of the total cost of a heat network. This includes the energy centre building, connection to the local grid, heat production assets, consultancy fees, design costs, and preliminaries.

The 21MW energy centre at Granton Waterfront cost £26 million of which half was uplifts and £5.5 million was the cost of the energy production assets.

Uplifts include preliminaries, contractor's cost, contingency, and consultancy fees.

This study provides an in-depth analysis of three types of heat production assets – air-source heat pumps, water-source heat pumps and electric boilers – and thermal storage. The analysis finds that there are clear economies of scale for all four types of equipment.

The heat production assets in 5$^{th}$ generation networks are multiple smaller heat pumps, rather than one large centralised heat source. This is likely to drive up the cost per kW and contribute to the often higher capital costs in 5GDHC relative to 4GDH.

**Deep dive: Wastewater Heat Recovery Systems**
Wastewater Heat Recovery (WWHR) is an innovative technology that allows the recovery of heat from wastewater and its reuse for heating purposes. The technology is used in the AMIDS district heating network in Glasgow, where the energy centre is a wastewater heat recovery system.

This cost analysis finds that the cost of WWHR systems is highly variable and dependent on local conditions.

Firstly, there are two main types of WWHR systems – sewer pipe level and wastewater treatment plant (WWTP) level. Sewer pipe level systems are more costly, due to the complexity of adding the heat recovery system to the existing sewer and because more equipment is needed.

Secondly, costs are impacted by the depth of the sewer, the distance between the sewer and the energy centre, labour availability, and other factors.

The cost of the AMIDS 4MW energy centre – a simple wastewater heat recovery system at the WWTP level – was £2 million (£500 per kW).

The analysis of available price data finds that sewer pipe level WWHR systems range from £500-£4,500 per kW.

**Distribution network**
The distribution network typically makes up 40-45% of the total cost of a heat network. This covers the pipework (material cost), installation (labour cost) and trench excavation (labour and groundworks cost).

This study finds that the most significant cost is trench excavation, which on average makes up 65-75% of the total cost of the distribution network.

Costs are highly dependent on pipe diameter and local conditions. When the external pipe diameter is larger, it drives up trench excavation costs leading to significantly higher total costs. This is clear from the difference in cost between mains pipes (the largest pipes) and distribution pipes (the second-largest pipes). Under average local conditions, the total cost of mains pipes is £1,248-1,815 per meter, while for distribution pipes it is only £201-412 per meter.

Local conditions that affect installation and excavation costs include the presence of buried services (cables, pipes, etc.), archaeological artefacts, and crossing highways, railways and other major obstacles.

This analysis finds that trench excavation under "very complicated" conditions is up to 12 times more costly than "easy" conditions.

Three types of pipes are considered in this cost analysis: pre-insulated steel, pre-insulated plastic, and uninsulated plastic.

Plastic pipework is less expensive to acquire and install compared to steel.

However, the uninsulated plastic pipes used in 5G networks are significantly larger than the pre-insulated pipes used in 4G networks, which drives up the cost to be comparable to pre-insulated steel.

# Executive summary | Cost analysis

**Case studies**
This study presents an in-depth cost analysis of three case studies:

- 3GDH in Aberdeen: The Torry Heat Network (Phase 1)
- 5GDHC in Glasgow: The AMIDS Network (Phase 1)
- 5GDHC in New York State: A US college campus

In addition to this, a summary of costs associated with three other Scottish projects is provided:

- 4GDH in Forthside: Stirling Council
- 4GDH in Shawfair: The Millerhill project
- 4GDH in Fife: The Glenrothes project

The analysis of these case studies highlights how much costs vary between different projects.

The five Scottish case studies range in size from 4MW to 20MW with total costs ranging from £3.4 million to £51.6 million.

Further analysis of the AMIDS network in Glasgow finds that 58% of the value was delivered by Scottish suppliers.

This is mainly driven by the distribution network cost, as the trench excavation and installation were done by a Scottish company. For this project, the pipes were manufactured by an English company, but all pre-insulated pipes used in 3rd and 4th generation networks are imported, as there are currently no manufacturers in the UK.

The imported value in the AMIDS project was primarily in the equipment for the energy centre, including heat exchangers, pumps, pressurisation units, and low-temperature hot water pipework.

Based on project experience in Scotland and the rest of the UK, the experts consulted for this study find that installation and construction work is often done by Scottish companies, while the imported value is typically in the equipment.

This is especially the case for large and bespoke equipment. A reason for this is that ESCOs developing heat networks have well-established relationships with trusted suppliers and sub-contractors.

**Key take-aways**

| | |
|---|---|
| Economies of scale | There are significant economies of scale when developing heat networks. This is particularly significant for thermal storage and air-source heat pumps. |
| Complexity adds to costs | The cost of delivering a heat network increases significantly when complexity increases. This is particularly driven by high trench excavation costs where ground conditions are complicated, for example in cities. |
| Imported equipment | Most equipment used in heat networks in Scotland is imported, particularly from the Nordics, Germany and Japan. There are various barriers to entry for Scottish companies, incl. economies of scale and existing supplier relationships. |
| Local labour and services | Construction work is mostly done by Scottish companies, and engineering services are often provided by the Scottish division of international engineering companies. |

# Executive summary | Supply chain analysis

| | Energy Planning (out of scope) | Feasibility | Design | Equipment | Construction | Commissioning | Operations (out of scope) |
|---|---|---|---|---|---|---|---|
| | RIBA 1 | RIBA 2 | RIBA 3/4 | RIBA 5 | RIBA 5 | RIBA 6 | RIBA 7 |
| DESCRIPTION | | Two main activities: design and costing.<br>**Design** is focused on adding quality and detail to the masterplan.<br>**Costing** is when the design is transferred to a techno-economic model to determine cost of heat to consumer and build out the cost to the developer. | Two main activities: detailed design and design for construction.<br>**Detailed design** is the specification of components and their technical characteristics.<br>**Design for construction** includes the procurement of equipment. | **Equipment** may have been procured prior to this stage. If not, the contractor is asked to procure what was specified in the design stage. | **Construction** of the network. The principal contractor has the overall responsibility and hires sub-contractors, such as local labour, as needed. | **Commissioning** of the network. This is usually a sub-contract of the construction contract and is undertaken by dedicated commissioning departments of construction companies.<br>Certain parts of commissioning can be undertaken by M&E building services companies. | |
| SCOTTISH POTENTIAL | | HIGH POTENTIAL<br>This work is generally carried out by large UK and international engineering firms. These firms have staff in Scotland, which ensures that the right skills and experience are developed domestically.<br>This creates potential for Scottish companies to carry out feasibility and design work. | HIGH POTENTIAL<br>This work is generally carried out by large UK and international engineering firms. These firms have staff in Scotland, which ensures that the right skills and experience are developed domestically.<br>This creates potential for Scottish companies to carry out feasibility and design work. | LOW POTENTIAL<br>Standard components are typically procured locally, while bespoke and larger equipment is typically imported. There is potential for more equipment to be produced in Scotland, though economies of scale are a barrier. | HIGH POTENTIAL<br>A significant share of the cost in the construction phase is labour, which is more often undertaken by Scottish companies. | MODERATE POTENTIAL<br>There is good potential for Scottish companies and evidence they are already undertaking this role. Commissioning of pipework is more specialised and carried out by EU/UK contractors. There is significant potential for Scottish companies, but training is required. | |
| INDICATIVE SPLIT OF COSTS ACROSS PHASES*: | | Approx. **5%** of total cost | Approx. **15%** of total cost | Approx. 70**%** of total cost (Equipment and Construction) | | Approx. 10**%** of total cost | |

* The indication of how costs are distributed across the stages of the project is based on high-level professional judgement and insights from the cost analysis in this study.

# Introduction

### Background and objectives

Scottish Enterprise (SE) aims to establish a globally competitive green heat supply chain in Scotland by 2030. The 2021 Act has set statutory targets for heat networks to supply 2.6TWh of output by 2027 and 6TWh of output by 2030. The Scottish Parliament has also set targets for heat networks to supply 6TWh of thermal energy (heat and cooling) by 2030, equivalent to 8% of Scotland's current non-electrical heat consumption. In the rest of the UK, the potential contribution of heat networks to total heat demand in 2030 is estimated at 36TWh. SE commissioned research on market sizing estimated a cumulative value of £5.2 billion from 2022 to 2030 based on Scottish Government targets. The UK-wide Heat Network Market was estimated at a cumulative value of £26.7 billion from 2022 to 2030.

The overall European market share of heat networks is expected to increase from 13% to 30% in 2030 and could meet almost half of Europe's heat demand by 2050. The largest heat network market in Europe is Germany, followed by Poland and Sweden. The UK is viewed as an emerging market.

Local authorities in Scotland are completing their Local Heat and Energy Efficiency Strategies (LHEES)*, which will provide information on indicative zones for heat networks. The Scottish Government's Heat Network Support Unit is supporting a growing pipeline of heat network projects with £300 million of capital funding available through Scotland's Heat Network Fund to accelerate deployment. Recent research by SE indicates that while there is definite Scottish capability and capacity in the design and construction of heat networks, including energy centres, the Scottish content in equipment provision is minimal. This presents a significant opportunity to stimulate and grow the Scottish heat network supply chain.

The objective of this study is to obtain a full supply chain and cost breakdown to establish the potential value of the different heat network elements and identify gaps and opportunities for Scottish companies. This report consists of two main elements; a cost analysis and a supply chain analysis.

### Cost analysis

The purpose of the cost analysis is to understand the actual capital costs of 4th and 5th generation heat networks. To do this, cost data from various sources, including suppliers, network operators, and engineering firms, has been analysed and compared.

The analysis and results are presented in four sections.

1. Energy centre: The first section outlines the cost elements of the energy centre with a focus on the 4th generation (4GDH) energy centre, as there is more available data, and most of the costs are also applicable to 5th generation (5GDHC) energy centres.
2. Deep dive: Wastewater heat recovery systems: The analysis of energy centres is followed by a deep dive into wastewater heat recovery systems, a type of energy centre used both in 4GDH and 5GDHC.
3. Distribution network: The third section presents the cost elements of distribution networks, divided into pipework, installation, and trench excavation and covering both 4th and 5th generation networks.
4. Case studies: Finally, the fourth section presents three case studies; a 3rd generation network and two 5th generation networks. These provide insight into whole-project costs and highlight the variation in cost caused by project- and location-specific conditions.

### Supply chain analysis

The cost analysis is followed by a supply chain analysis. The purpose of the supply chain analysis is to understand which companies deliver heat networks in Scotland, including who supplies the equipment, construction companies, operators, and engineering companies. The analysis includes an overview of where each supplier is based to understand which parts of heat networks and associated services are provided by Scottish companies and what is imported. This is followed by a brief discussion of the import substitution and growth potential for the Scottish supply chain.

### Definitions

This study focuses on 4GDH and 5GDHC. A key differentiator between 3rd, 4th, and 5th generation heat networks is the temperature of the hot water in the distribution network. In a 3rd generation network, the supply temperature is 90°C, while in a 4th generation network, it is 30-70°C. The supply temperature in a 5th generation network is even lower, at 5-25°C.

#### 4TH GENERATION DISTRICT HEATING

4GDH is an emerging technology in Scotland that offers a sustainable and cost-effective solution for heating and cooling buildings. These systems are designed to be highly efficient, utilising waste heat from various sources such as industrial facilities, wastewater treatment plants, and data centres. By harnessing this waste heat, 4GDH networks can significantly reduce energy consumption and lower carbon emissions. 4GDH is characterised by:

- Higher efficiency and lower temperatures in the same centralised design.
- Incorporation of low-temperature waste heat and renewable heat sources as part of supply.

#### 5TH GENERATION DISTRICT HEATING AND COOLING

5GDHC differs from the previous generations in that heating and cooling are supplied by the same network via decentralised energy transformation units, enabling energy sharing. These networks are designed to be low-temperature, which means they require less energy to operate and have a reduced environmental impact. 5GDHC networks are characterised by:

- Their ability to recover and reuse waste heat, making them more efficient and cost-effective than traditional systems.
- A combination of heating and cooling capacity through the use of distributed heat pumps.
- A wide variety of heat or cooling sources.

For further elaboration on the definitions, please see the appendix.

* The deadline for completing LHEES was 31 December 2023. Many have been published, but there are more to come, as some local authorities have asked for an extension.



# Cost analysis

# Energy centre

**The capital cost of a typical 4GDH energy centre includes various equipment and services. These include, but are not limited to:**

- Material and labour to construct the energy centre building.
- Electrical wiring, ventilation, and low-temperature hot water (LTHW) pipework.
- Costs related to connecting to the local electrical grid.
- District heating-specific equipment, such as water treatment, pumps, heat production units, and thermal energy storage.
- Consultancy fees, design costs, and preliminaries.

**A proposed 4GDH energy centre at Granton Waterfront in Edinburgh is investigated as a case study.**

- Ramboll was tasked by the City of Edinburgh Council to investigate the technical and economic feasibility of a low-carbon heat network supplying a mixed-use regeneration scheme.
- The circa 21MW energy centre is to be fully electric by way of a wastewater heat recovery system (base load) and electric boilers (peak load).
- Once operational, the energy centre will produce approximately 25,000 MWh/year of low-carbon heat.
- This was selected as a case study, as it is one of the few 4GDH networks in Scotland, data was available to the research team, and it is a current and a larger scale example.

**The capital costs of air-source heat pumps (ASHPs), water-source heat pumps (WSHPs), electric boilers, and thermal stores are investigated.**

- Data from suppliers, manufacturers, and the Danish Energy Agency has been collected to better understand the costs of important 4GDH equipment.

**Limitations and assumptions in this section**

- Costs presented in this section can vary considerably depending on equipment selection, labour costs, and site-specific conditions.
- The costs presented in the case study are based on estimates and assumptions applied in the feasibility study.

**KEY TAKE-AWAYS**

- The estimated total cost of a 21 MW 4GDH energy centre in Scotland (incl. a sewer source heat pump, electric boilers and solar PV) is approx. £26 million (£13 million if excluding uplifts), equal to a cost of 1,300 £/kW installed capacity.
- The cost of the electrical connection and transformers is expected to be significant for energy centres with fully electrified heat production.
- Preliminaries, contractor’s cost, contingency, consultancy fees and other uplifts are likely to represent approximately 50% of the total capital cost of an energy centre.
- The cost-effectiveness of ASHPs, WSHPs, electric boilers, and thermal stores improves as the units become larger.

# Energy centre | Background

Contents

**Introduction**
The energy centre consists of many different components, and the capital costs vary according to size, heat source, electrical infrastructure, and other factors. There is no commonly agreed-upon way to structure the expenditures which makes it difficult to compare costs across different projects. In this section, costs have been structured based on Ramboll's method of high-level cost estimation. Please note that many of the cost elements presented here are not unique to 4GDH energy centres but can also be applied to 3GDH and 5GDHC networks.

**Energy centre equipment**
The costs associated with the energy centre range from water treatment equipment to the cost of the building itself. Some of the costs can be estimated based on the floor area of the energy centre, such as the cost of the energy centre structure, the cost of ventilation, electrical wiring, and the control system. Other costs are related to factors, such as the electrical load of the energy centre equipment or the number of heat generation units. Table 2 (on the following page) provides an outline of the main equipment present in a typical 4GDH energy centre as well as what affects their respective costs.

**Energy centre uplifts**
Additional costs such as testing and commissioning, design, contractor's fees, project management, legal, preliminaries, and consultancy fees can make up a large part of the total CAPEX of an energy centre. For high-level assessments, Ramboll estimates these costs as a percentage of the total material cost of the energy centre. Table 1 outlines the assumptions and provides a summary of each of these costs.

| Uplift | Description | Assumption |
|---|---|---|
| Planning support (air quality, noise, transport) | Cost to cover planning applications. | £25,000 |
| Builders work in connection | Allowance made for works such as building access, clearance, lighting, painting etc. | 5% of the cost of the energy centre structure |
| Testing and commissioning | Commissioning of the completed energy centre. | 5% of the total equipment cost of the energy centre. |
| Consultancy fees | Costs arising from independent review of design. | 7.5% of the total equipment and labour cost of the energy centre. |
| Design costs | Design services. | 10% of the total equipment cost of the energy centre. |
| Contractor's costs | Costs associated with delivering the works such as materials, equipment, deliveries, and labour. | 10% of the equipment cost of the energy centre. |
| PM and legal costs | Costs related to project management of the design and build process and any legal fees. | 5-10% of the equipment cost of the energy centre. |
| Contingency | A factor applied to account for uncertainty. | 10% of the equipment cost of the energy centre. |
| Preliminaries | Works required to complete a project that do not form part of the completed work such as building preparation, site setup, making good of services and similar activities required prior to works that do not fall within contractor costs. | 15% of the equipment cost of the energy centre. |

Table 1: Assumptions applied for uplifts

# Energy centre | Background

| Cost Element | Description | Cost considerations |
|---|---|---|
| Energy Centre Structure | The cost of the energy centre building. | Cost depends on the size of the energy centre i.e. the internal floor area. |
| LTHW Pipework | The pipework inside the energy centre that connects the thermal stores, heat generation units and main distribution pumps to the wider network. | Costs depend on the length of pipework and thus the floor area of the energy centre. |
| Ventilation | The energy centre requires adequate ventilation to allow for good working conditions. | Costs are dependent on the floor area of the energy centre. |
| Electrical Wiring | Pumps, control systems, heat generation assets, lighting and other equipment that need to be connected to the energy centre's electrical supply. | Cost can be estimated based on the floor area of the energy centre. |
| Pumps | Cost of the main distribution pumps (pumps that provide flow to the distribution network) and smaller pumps needed for energy centre equipment. | The cost is dependent on the number of pumps required as well as the flow needed. |
| Thermal Stores | The thermal stores are insulated steel tanks used to store heat. The stores ensure smooth operation of heat generation equipment but can also be used strategically to limit peaks on the network. | The cost is directly linked to the volume of the store(s). Energy centres with higher installed capacity will in general require larger stores but the size will depend on the strategy utilized. |
| Water treatment | A water treatment system generally consists of a water softener, side stream filter, and a degasser. The purpose of the system is to maintain good water quality to protect pipework, pumps, and other equipment from fouling. | The cost of the system depends on the total volume of the distribution network and thermal stores. |
| Pressurization and Expansion | The pressurization and expansion equipment are utilized to ensure that the system operates at the correct pressure. | The cost of the equipment is usually dependent on the total system volume (distribution network and thermal store). |
| Metering | Heat meters are installed in the energy centre to allow for analysis and fault detection. | Usually 1 meter per heat generation unit. |
| ICA and SCADA | Central control system that regulates the operation of the energy centre equipment. | Dependent on the size of the energy centre as well as the length of the distribution network. |
| Heat Production assets | Equipment producing the heat such as: ASHPs, WSHPs, and electric boilers. | Dependent on the heat demand of the network and heat production strategy. |
| Electrical Connection | Works associated with connecting the energy centre to the local electricity grid. | This largely depends on the power requirement of the energy centre and the local electricity grid. Costs can vary considerably depending on the proximity of an appropriate point of connection. |
| Electrical Substation | The substation includes several different components, but the main element is the transformer. The substation's main purpose is to provide the energy centre with the required voltage level. | The cost depends on the power rating of the energy centre equipment. |

Table 2: Main equipment present in a typical 4GDH energy centre

# Energy centre | Overview of major equipment

## Introduction

Air-source heat pumps (ASHPs), water-source heat pumps (WSHPs), electric boilers, and thermal storage form the most important equipment options for delivering low-carbon heat at scale. This section provides a brief description of the technologies and their role in 4GDH networks. Furthermore, an analysis of the current cost of this equipment is presented.

## Air-source and water-source heat pumps

Heat pumps are expected to play an important role in future low-carbon district heating networks. Currently, they are considered the most economically viable technology to provide renewable heat to UK district heating networks. Heat pumps should always be used to supply the network's baseload[1]. The high investment cost makes it uneconomical for heat pumps to supply 100% of the heat demand.

Heat pumps are typically classified according to which low-grade heat source they extract heat from. ASHPs extract heat from ambient air, while WSHPs can utilize a wide array of sources, such as wastewater from a sewer pipe, water from a river, and waste heat from industrial processes. The available low-grade heat is often the limiting factor for the heat output from WSHPs. Moreover, the low-grade heat source can be costly to access, and additional equipment is likely required, such as pumps, heat exchangers, and piping. For ASHPs, the limiting factor is usually the space required for the air coolers (the evaporators of the unit). However, ASHPs can practically be installed anywhere. This study finds that ASHPs are more expensive than WSHPs. The likely reason for this is that the price of ASHPs includes evaporators (usually dry air coolers) and various other associated equipment, such as valves, control panels, etc., that are not needed for a WSHP. WSHP have costs associated with water abstraction, which are not included in this study, as they are project-specific.

The efficiency of heat pumps depends on the temperature difference between the low-grade heat source and the supply temperature. To obtain high efficiencies, the difference should be as small as possible. For an ASHP, the efficiency will always vary over the course of the year according to the outdoor temperature. This presents a problem in winter when the efficiency of the unit is relatively low and demand high. For WSHPs – depending on the source – the efficiency is likely to be higher and more consistent.

The type of refrigerant used can have a big impact on the efficiency and capabilities of a heat pump. Traditionally, refrigerants containing various hydrofluorocarbons, such as R-134a and R-410a, have been used but are now being phased out due to their high global warming impact. Today, heat pumps commonly utilise refrigerants based on carbon dioxide, ammonia, and propane. Propane and ammonia heat pumps are only capable of supplying heat up to 65-70°C [2]. Carbon dioxide heat pumps are capable of 80°C supply but require a maximum return temperature of 40°C to operate efficiently. This represents a difference of 40°C between supply and return which can be difficult to obtain, depending on the buildings connected to the network.

## Electric boilers

Whereas heat pumps should be utilised to provide baseload, electric boilers are more suited to supply peak demands. In contrast to heat pumps, the investment cost (£/kW) of an electric boiler is relatively low. However, running costs are high, which means they should be used sparingly. Generally, two types of electric boilers are available;

- Resistance boilers – smaller applications (up to 2MW).
- Electrode boilers – larger-scale applications (up to 50 MW).

In addition to supplying peak heat demands, electric boilers can help balance the electricity grid by using more electricity (using the boiler to produce heat) when production is high, but demand is low. This is increasingly important as electricity production becomes dominated by intermittent renewable sources.

## Thermal energy storage

There are several different types of thermal energy storage technologies. Some are used to seasonally store energy (over the course of months), while others have shorter charge and discharge cycles that take place over the course of a day or a week. The latter is the most implemented and typically comes in the form of an insulated steel tank. The technology is commonly referred to as a stratified hot water tank. It is the thermal energy storage that is considered in this section unless otherwise specified.

The most common function a thermal storage serves is to allow for good operation of production units. Production units might have limited turndown capabilities (the ability to increase and decrease heat production to meet changing demand), requiring expensive and potentially damaging start and stop sequences. This is especially true for heat pumps. Thermal stores that are sized only for this reason are typically relatively small. Some thermal stores are sized with load shifting and peak shaving in mind. Load shifting is a strategy used to partly decouple demand from production. In the context of heat pumps and electric boilers, variations in electricity prices can be exploited by producing excess heat at times of low prices and charging the thermal store. The stored heat can be released to the network later when prices are high. In some cases, this type of operation can be a revenue stream by providing ancillary services to the electricity grid. Peak shaving works in a similar way, producing excess heat at times of low demand and discharging the store when demand is high. This can help reduce the required capacity of production units.

The two latter functions – load shifting and peak shaving – are especially relevant for 4GDH networks. Future district heating networks will need to be an integrated part of the wider energy system. Large-scale implementation of intermittent renewable electricity production will require flexible demands. Electric boilers and heat pumps coupled to thermal storage are one way of addressing this issue.

Seasonal thermal storage is not as commonly implemented, due to high capital costs and space requirements. It is usually used when there is high-temperature waste heat, e.g. from an energy-from-waste plant, with case studies mainly in Denmark. The cost of seasonal thermal storage is therefore not included in this study.

[1] Baseload refers to the heat load most commonly experienced by a heat network. It usually represents more than 80% of the total annual heat demand.
[2] Ammonia and propane heat pumps can supply higher temperature, but this requires 2-stage compression which adds significant cost to the unit and lowers efficiency.

# Energy centre | Air-source heat pumps

**Cost of ASHPs**

To better understand the capital cost of ASHPs, several different suppliers and manufacturers were approached. Data was also gathered from Ramboll's internal database and the Danish Energy Agency's technology catalogue for district heating and electricity generation[1]. Please note that the costs presented here only include the equipment itself. Installation adds approximately 20-25% to the equipment cost.

The results, shown in Figure 1, show that there is a lot of variation in the cost per kW. For example, Supplier C's ASHPs vary between 1,065 - 2,480 £/kW while Suppliers A and B provided costs of 470 - 610 £/kW and 530 - 830 £/kW, respectively. All sources show that larger units have a lower cost per kW. This is most clear in the data provided by Supplier C where the cost of a 1,500kW unit is 57% lower than their smallest available unit at 260kW. At other suppliers, the cost difference of larger units is not as great but still significant. Supplier B's largest unit has a 47% lower cost than their smallest.

Because there is a clear relationship between the capacity and the cost of an ASHP, simply stating an average fails to highlight the cost-effectiveness of larger units. To study the average cost, three size categories are defined;

- Small – Units with a capacity of less than 500kW.
- Medium - Units with a capacity between 500kW-1,500kW.
- Large - Units with a capacity greater than 1,500kW.

Table 3 outlines the average cost for each size category. Costs are higher than for WSHP, as ASHP include evaporators and other associated equipment.

| Category | Average cost (£/kW) |
|---|---|
| Small | 1,450 |
| Medium | 800 |
| Large | 730 |

Table 3: Average cost for ASHPs according to capacity.

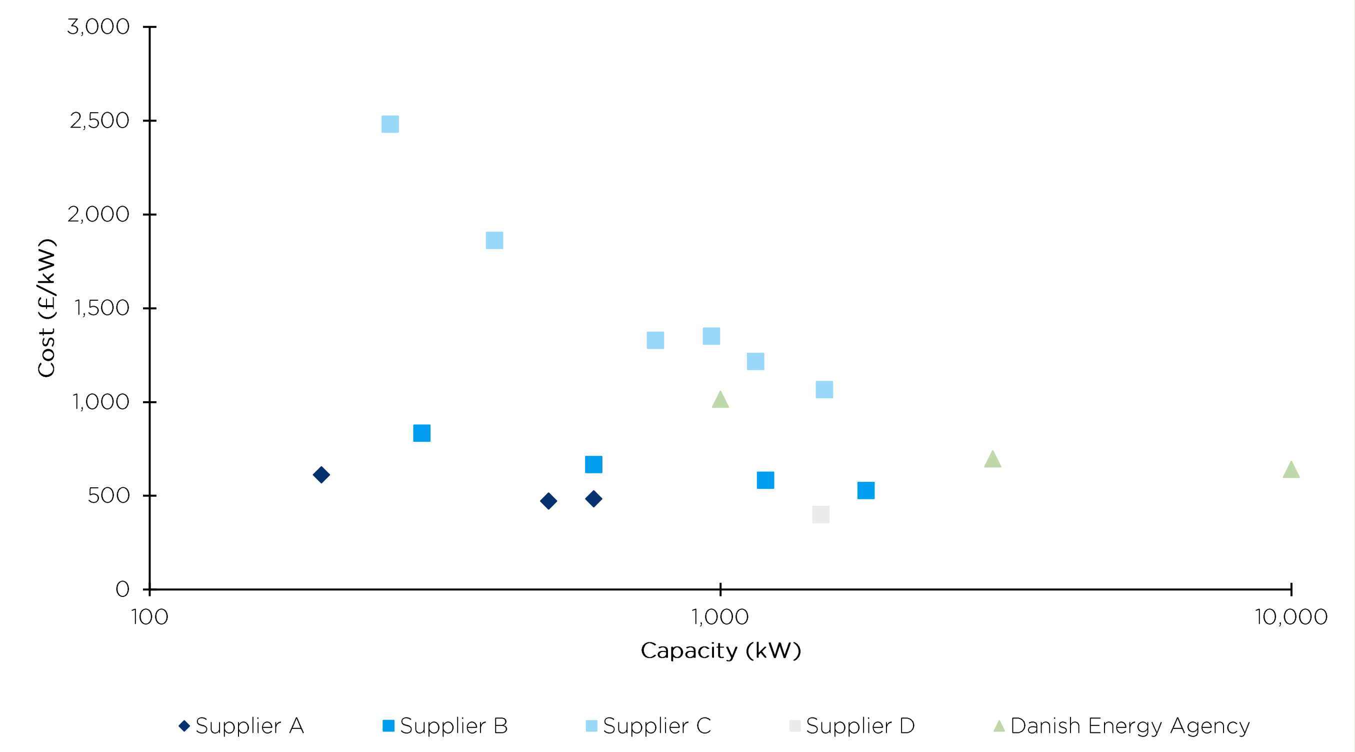



Figure 1: Cost per kW of ASHPs at different capacitates. Please note that the horizontal axis is plotted on a logarithmic scale.

[1] This data is based on various Nordic installations and available online at: Technology Data for Generation of Electricity and District Heating | Energistyrelsen (ens.dk)

# Energy centre | Water-source heat pumps

**Cost of WSHPs**

To better understand the capital cost of WSHPs, several different suppliers and manufacturers were approached[1]. Data was also gathered from Ramboll's internal database and the Danish Energy Agency's technology catalogue for district heating and electricity generation[1]. Please note that the costs presented here only include the equipment itself. Installation normally adds approximately 20-25% to the equipment cost. Furthermore, the costs associated with accessing the low-grade heat source are not included. These are typically project-specific costs related to water abstraction, such as abstraction and filtration of river water.

The results, shown in Figure 2, show that there is a lot of variation in the cost per kW. For example, Supplier C's WSHPs vary between 320 – 980 £/kW while Supplier B provided costs of 300 - 530 £/kW. Data from Supplier C, Supplier B, and the Danish Energy Agency indicate that larger units have a lower cost per kW. This is most clear in the data provided by Supplier C. Their largest model (approximately 2,300kW) is circa 73% less expensive than their smallest unit when comparing the cost per kW.

Because there is a clear relationship between the capacity and the cost, simply stating an average fails to highlight the cost-effectiveness of larger units. To study the average cost per kW, three size categories are defined;

- Small – Units with a capacity of less than 500kW.
- Medium - Units with a capacity between 500kW-1,500kW.
- Large - Units with a capacity greater than 1,500kW.

Table 4 outlines the average cost for each size category.

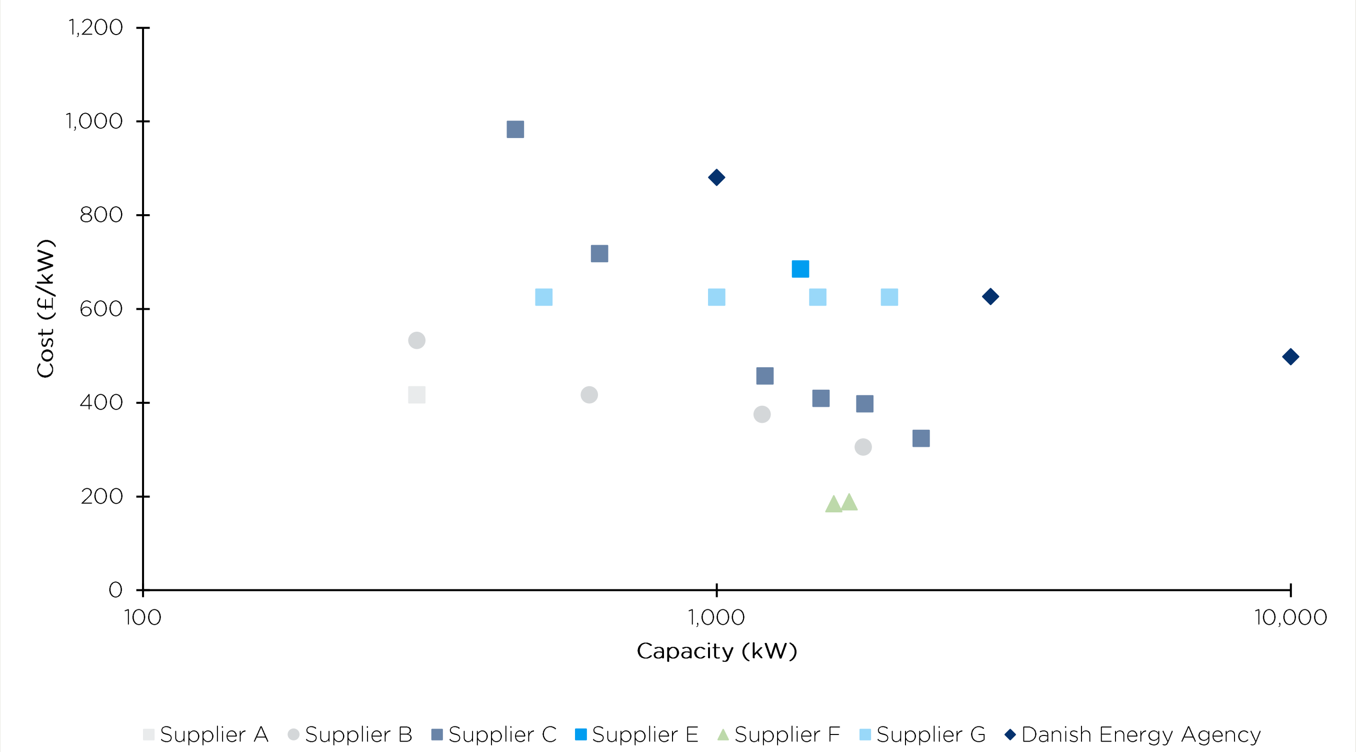



Figure 2: Cost per kW of WSHPs at different capacitates. Please note that the horizontal axis is plotted on a logarithmic scale.

| Category | Average cost (£/kW) |
|---|---|
| Small | 650 |
| Medium | 580 |
| Large | 370 |

Table 4: Average cost for WSHPs according to capacity.

[1] This data is based on various Nordic installations and available online at: Technology Data for Generation of Electricity and District Heating | Energistyrelsen (ens.dk)

# Energy centre | Electric Boilers

**Cost of electric boilers**
Data from a supplier and the Danish Energy Agency was used to analyse the capital cost of electric boilers. The results are shown graphically in Figure 3.

Capacity and pressure rating are key components that influence the costs.

Due to limitations in data availability, the electric boilers shown here are large units for industrial and large-scale district heating applications. Electric boilers of this size and capacity are operational in many large-scale district heating networks in the Nordics. The cost estimates for >10MW are considered the most representative. These estimates range from approx. £50 to £115 per kW.

From past projects, it is Ramboll's experience that smaller boilers (<5MW) range from approx. £40 to £120 per kW. These are more applicable to the smaller scale of many district heating networks currently in operation in Scotland.

Because there is a clear relationship between the capacity and the cost per kW of an electric boiler, simply stating an average fails to highlight the cost-effectiveness of larger units. To study the average cost, two size categories are defined;

- Small – Units with a capacity of less than 500kW.
- Large - Units with a capacity greater than 1,500kW.

Table 5 outlines the average cost for each size category.

| Category | Average cost (£/kW) |
|---|---|
| Small | 50 |
| Large | 70 |

Table 5: Average cost for Electric boilers according to capacity.

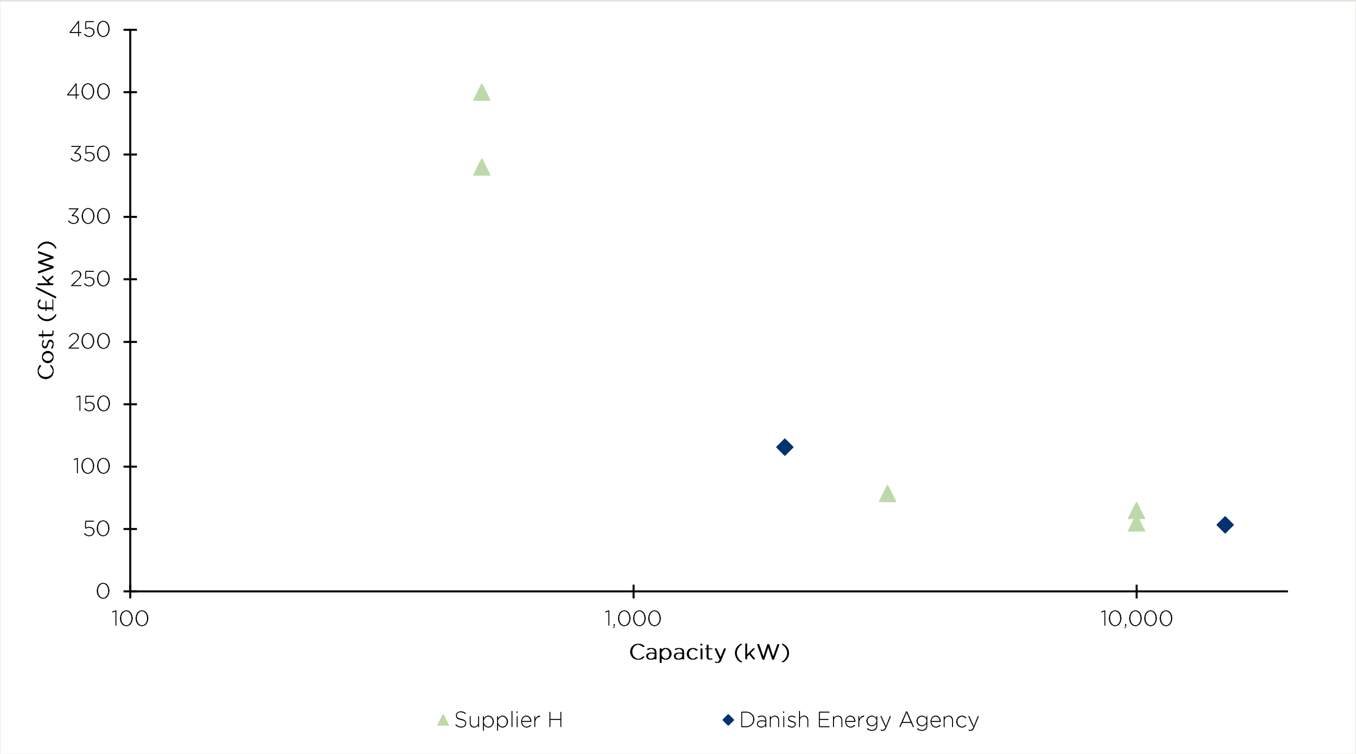



Figure 3: Cost per kW of electric boilers at different capacities. Please note that the horizontal axis is plotted on a logarithmic scale.

# Energy centre | Thermal Storage

**Cost of thermal storage**
Data from suppliers and the Danish Energy Agency's technology catalogue for energy storage[1] has been employed to analyse the capital cost of thermal storage. The results are shown graphically in Figure 4.

The volume of the storage has a large impact on the cost per $m^3$. The largest thermal storage offered by Supplier J (200$m^3$) has a 76% lower cost per $m^3$ than the smallest (10$m^3$). While the data from suppliers is limited to smaller thermal storage – up to 200$m^3$ – the Danish Energy Agency data includes the costs of larger vessels commonly seen in large, Nordic district heating networks. The data shows that these vessels are significantly more cost-effective than the smaller tanks.

Because there is a clear relationship between the volume and the cost per $m^3$ of thermal storage, simply stating an average fails to highlight the cost-effectiveness of larger tanks. To study the average cost, three size categories are defined;

- Small – Tanks with a volume of less than 50$m^3$.
- Medium - Tanks with a volume between 50-500$m^3$.
- Large - Tanks with a volume greater than 500$m^3$.

Table 6 outlines the average cost for each size category.

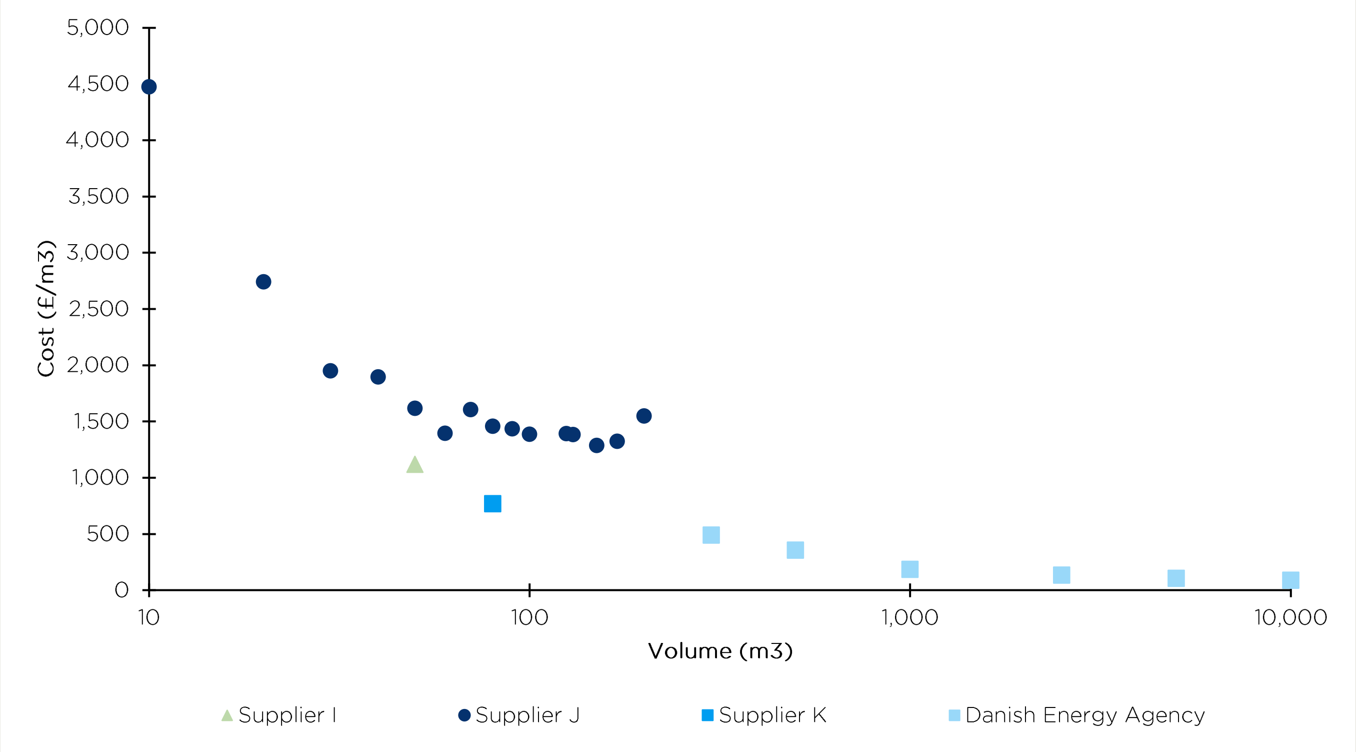



Figure 4: Cost per $m^3$ of thermal stores at different volumes. Please note that the horizontal axis is plotted on a logarithmic scale.

| Category | Average cost (£/$m^3$) |
|---|---|
| Small | 2,370 |
| Medium | 1280 |
| Large | 170 |

Table 6: Average cost for thermal storage according to volume.

[1] This data is based on various Nordic installations and available online at: Technology Data for Energy Storage | Energistyrelsen (ens.dk)

# Energy centre | Case study: Granton Waterfront



**Background**
To put the energy centre costs into context, a recently conducted feasibility study investigating the technical and economic viability of a 4GDH network at Granton Waterfront in Edinburgh has been analysed.

The Granton Waterfront is a 140-ha brownfield, ex-industrial neighbourhood located in an economically disadvantaged area of Edinburgh. The council is leading a major mixed-use regeneration of Granton Waterfront that will deliver around 3,500 homes (more than 1,000 of them affordable) and more than 9,000 $m^2$ of non-domestic space, including a primary school, a medical centre, and business, retail, and leisure space. As part of this regeneration and to work towards meeting the target of Edinburgh achieving net zero carbon by 2030, the council wishes to progress the delivery of a heat network that will supply cost-competitive low-carbon heat to new and existing households and non-domestic properties throughout Granton Waterfront and the surrounding areas, where deemed viable.

**Design summary**
The energy centre is to provide approx. 25,000MWh/year. The main heat source of the proposed district heating network is a 4.2MWth WSHP system utilizing low-grade heat from a local sewer main. The heat pumps have been sized to provide nearly the entire annual heat demand (94%). The remaining heat demand is supplied by electric boilers with a total of 16.5MWth installed capacity. The electric boilers produce heat at times of peak demand and function as a backup in case the heat pump system fails. Part of the electricity consumption will be covered by installing 1MWe of solar photovoltaic. The design also incorporates a 450$m^3$ thermal storage tank that ensures smooth operation of the heat pumps and load shifting. The fully electrified system will require three 5MVA transformers to be fitted in the energy centre. To avoid additional costs, the planned energy centre will be placed near the sewer pipe. The energy centre is expected to have a total floor area of 1,500$m^2$. A conceptual schematic of the system is presented in Figure 8 on the following page.

**Total cost**
The estimated total cost of the energy centre is approximately £26 million (£13 million excluding uplifts). A graph outlining the breakdown of the costs excluding uplifts can be found in Figure 6. Please note that the costs of electrical wiring, LTHW pipework, and ventilation have been combined and are referred to as “Electrical and mechanical fit out”. Similarly, the heat pump system, electric boilers, and solar photovoltaics make up the “energy production assets” category. The costs associated with the energy production assets represent approx. 41% of the costs. A large part of this is the sewer source heat pump system, representing a total cost of £3.6 million (approx. 870 £/kW). The electric boiler and solar photovoltaics costs are lower: £1 million and £0.9 million, respectively. The electrical connection and transformer cost is also significant, representing 15.3% of the equipment cost.

A breakdown of the uplift costs is presented in Figure 7. The contingency represents the largest uplift cost (20% of the energy centre equipment cost). A larger contingency than normal was applied to account for the risks of the sewer source heat recovery system.

The cost of the energy centre measured in total capital cost per installed thermal power output is approximately 1,300 £/kW.

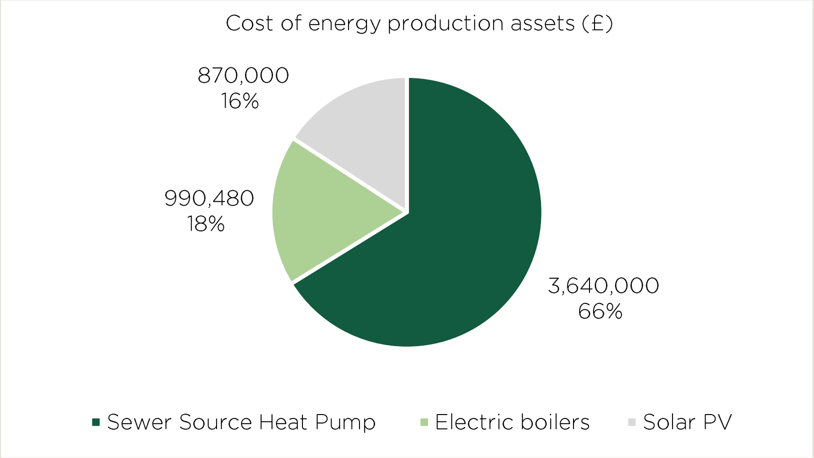



Figure 5: Cost of the energy production assets

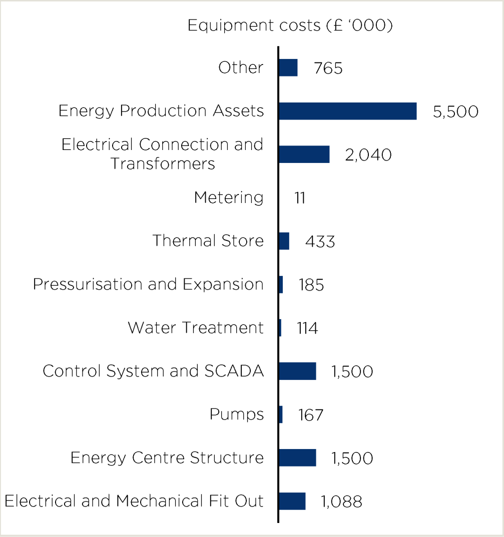



Figure 6: Energy centre equipment cost (excl. uplifts).

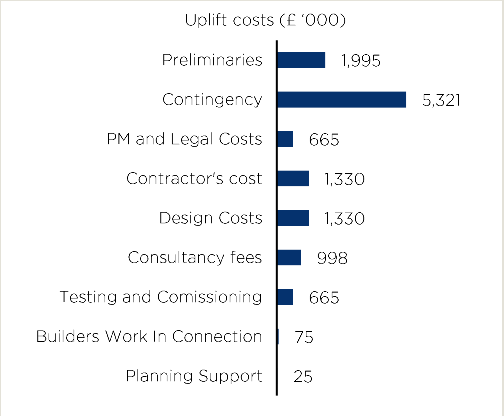



Figure 7: Energy centre uplift costs.

# Energy centre | Case study: Granton Waterfront (illustration)

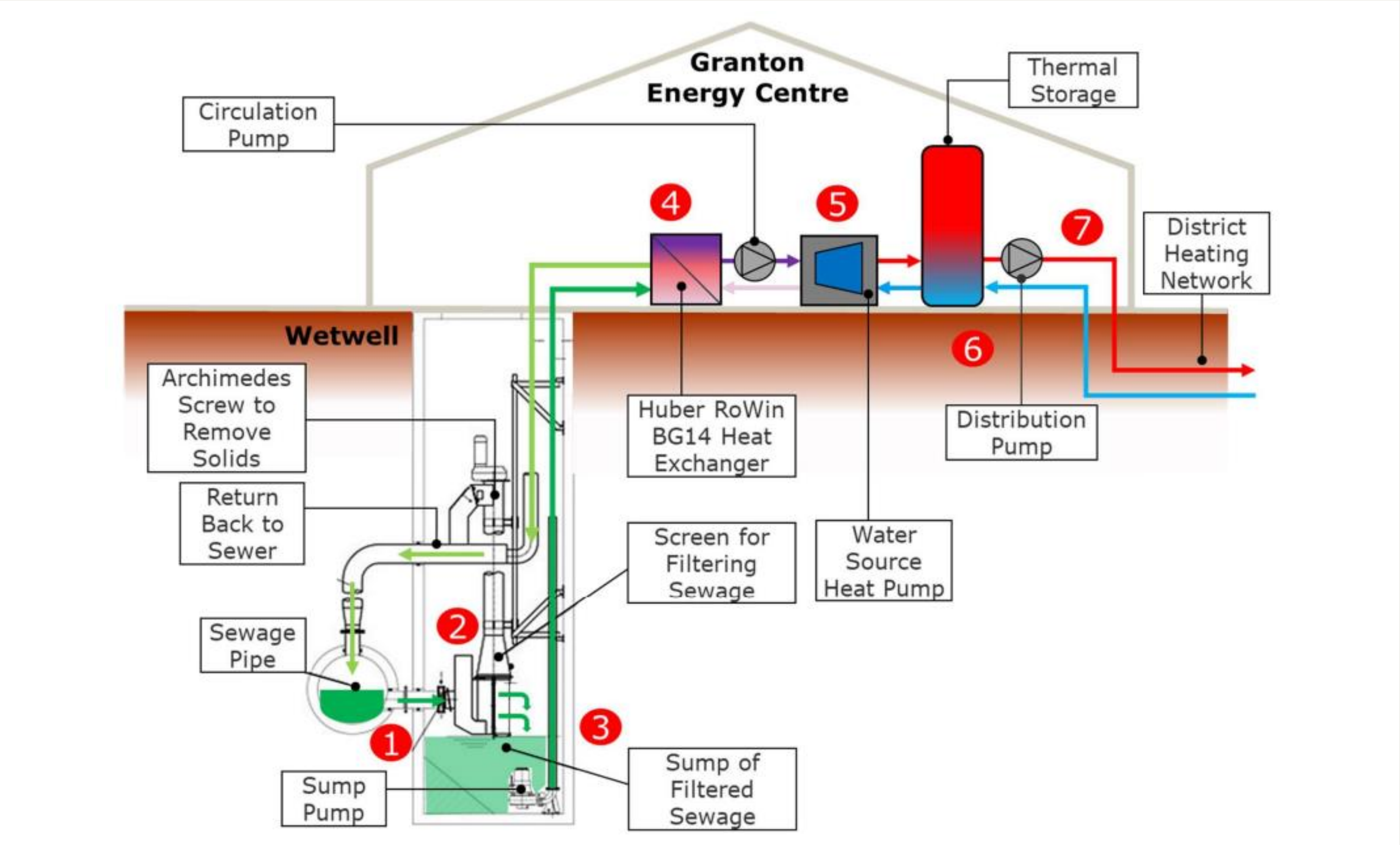
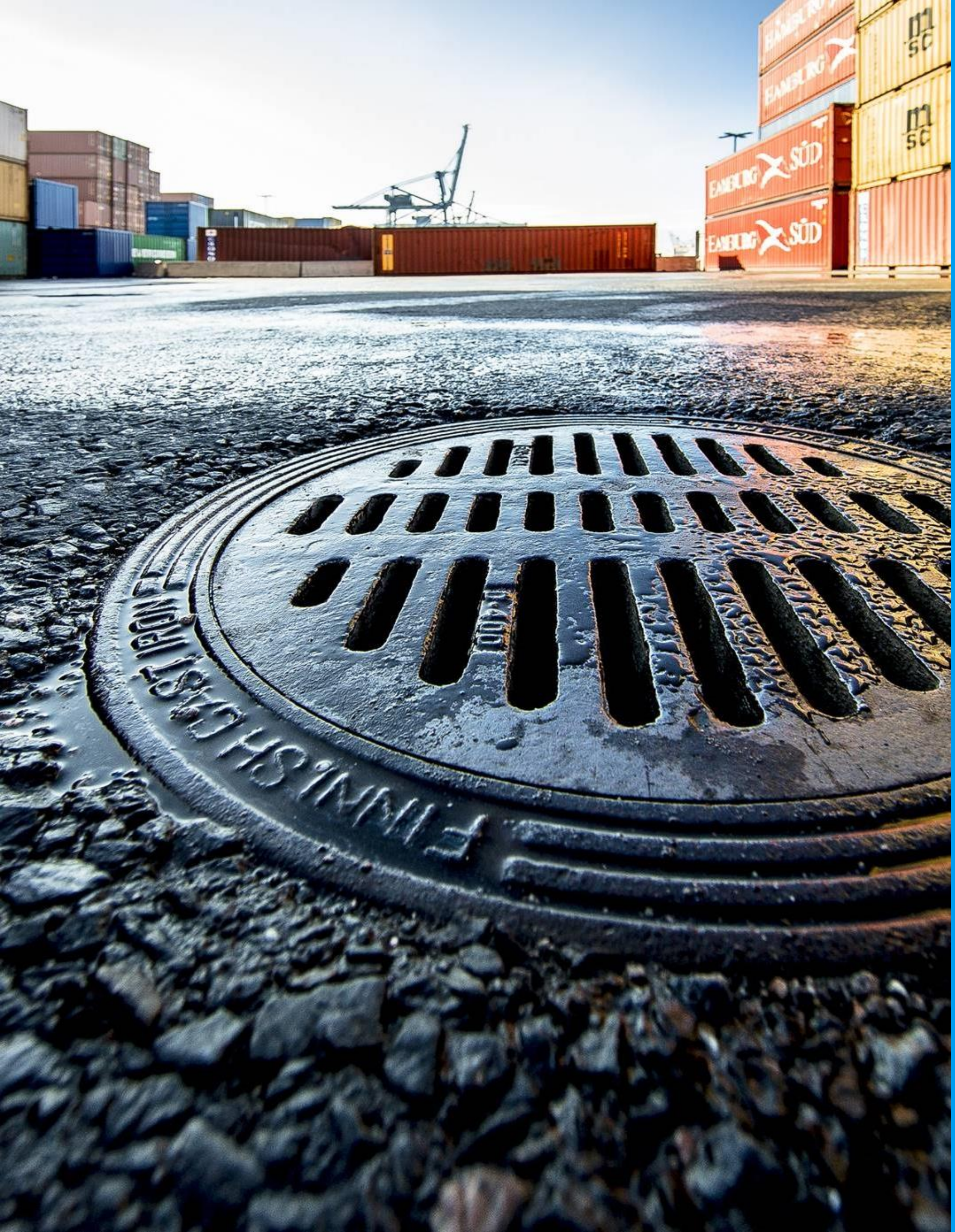



Figure 8: Schematic of the proposed Energy Centre. Source: Ramboll




# Deep dive: Wastewater Heat Recovery Systems

**Water from the sewer is a promising low-grade heat source**

Heated water used in washing machines, showers, and dishwashers is discharged to the sewer system. The wastewater found in sewer pipes maintains temperatures of 10-25°C. District heating networks can exploit this low-grade heat from the sewer system at two different levels:

- **Sewer pipe level**: Exploiting heat from a sewer pipe has the benefit of proximity to heat demands but capacity can be limited. Furthermore, space limitations and underground services can make it difficult to access the sewer pipe.
- **Wastewater Treatment Plant (WWTP) Level**: The accumulation of a city's or town's wastewater is transported to the treatment plant. The amount of available low-grade heat is great, but plants are usually situated far away from heat demands.

**Components and mode of heat recovery**

- The key component of wastewater heat recovery is the heat exchanger. Other important equipment is piping, pumps, filters, and controls.
- Depending on the system, the heat exchangers can be placed on the bed of the sewer pipe or placed externally in the energy centre.
- For systems with external heat exchangers, a screen is required to remove larger solids from the water before it is passed through the heat exchangers.
- 4GDH systems upgrade the heat via water source heat pumps (WSHP) while 5GDHC networks can utilize the low-grade heat directly.

**Limitations and assumptions in this section**

- All costs presented here are based on high-level estimates and vary considerably depending on several factors, such as sewer depth, distance between sewer and energy centre, and labour availability.
- Detailed real-project cost breakdowns for wastewater heat recovery systems could not be sourced to inform this study. The findings are, therefore, based on cost benchmark databases and validated at an aggregate level with high-level real-project cost data. In practice, there may be some variation in real-life projects with the individual cost components presented here.

KEY TAKE-AWAYS

- As evidenced by the price quotes provided by three suppliers, the cost of wastewater heat recovery systems is highly variable and dependent on local conditions. The cost is impacted by the depth of the sewer, distance between sewer and energy centre, labour availability, and more.
- This study finds that the cost of a 4G WWHR system ranges from £1,700 to £3,500 per kW. 5G systems range from £4,000 to £4,600. The variation in cost is somewhat due to economies of scale, as the higher cost per kW applies to smaller systems. Cost data for 5G systems could only be obtained from one supplier, leading to less variation in price.
- The total cost of the energy centre in the AMIDS heat network is £2.02 million. As the installed capacity is 4MW, this corresponds to 500 £/kW. This is notably lower than the price data collected for this study, further highlighting the sensitivity of costs depending on local conditions.

# Wastewater Heat Recovery | Background



### Background

Wastewater discharged from residential, commercial, and industrial buildings represents an interesting opportunity for district heating networks. The water that is discharged to the sewer system typically maintains temperatures in the range of 10-25°C year-round and thus can be exploited as a low-grade heat source for a WSHP system. The wastewater heat can be recovered at different points. The smallest applications involve recovering heat from a single shower drain. For large-scale applications, such as district heating networks, the heat is extracted from large sewer pipes (wastewater from several buildings) or at a wastewater treatment plant (WWTP) (see Figure 9). There are advantages and disadvantages to both options. More heat can be recovered at the WWTP level (water temperature is higher), but plants are usually located outside of city centres, leading to additional costs to transport the heat. Conversely, recovering heat from a sewer pipe means that the heat source is close to heat demands, but the amount of heat that can be recovered is lower.

In the context of a 5GDHC network, the thermal energy can be used as a source to thermally balance the ambient grid. As the thermal upgrade happens in decentralised energy substations where heat pumps are located, no temperature upgrade is needed in the sewer system plant room.

### Heat recovery at WWTP level

The wastewater travelling in the sewer pipes eventually ends up at a WWTP. Heat recovery at this stage is another viable option. Heat recovery can happen either before, during, or after the wastewater has been treated. Recovering the heat before treatment is similar to heat recovery at sewer pipe level. The available energy at this point is the highest, but the water is of bad quality which means that additional equipment or maintenance is required to exploit it. The water quality after treatment is much higher, but this is at the expense of a lower temperature.

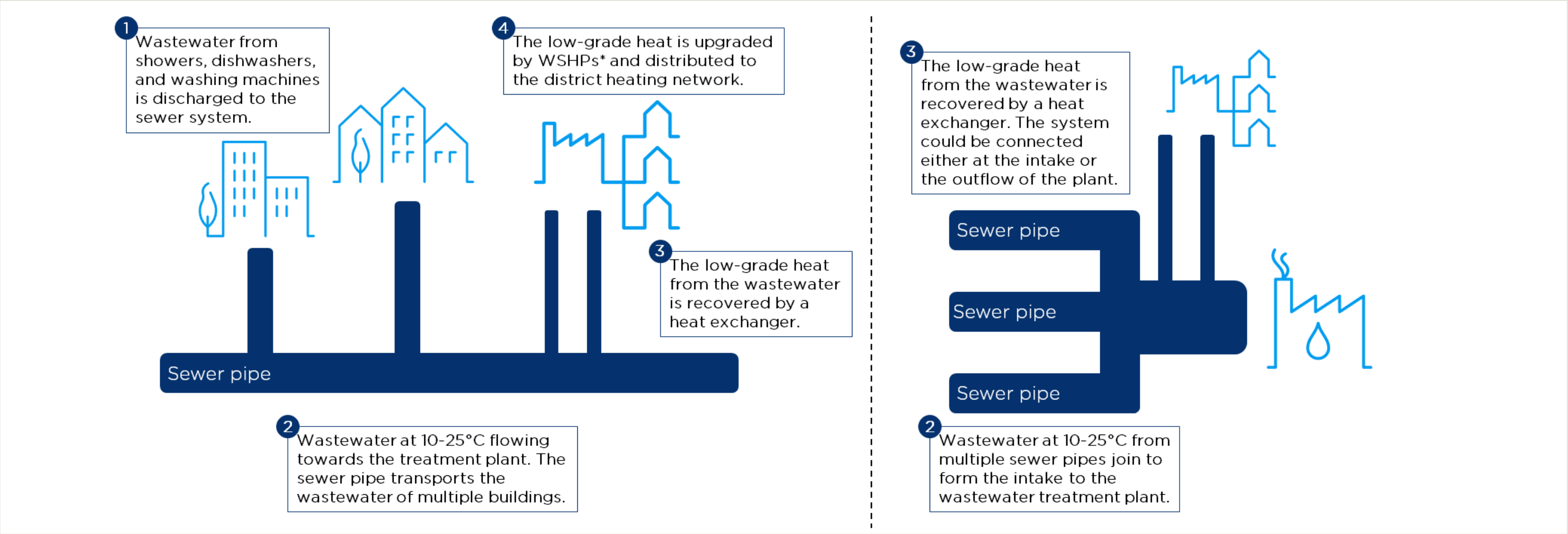



Figure 9: Wastewater heat recovery at sewer pipe level (left) and WWTP level (right)

*A 5GDHC network does not require the use of heat pumps

# Wastewater Heat Recovery | Background

**Heat recovery at sewer pipe level**
There are two possible ways to exploit the heat from a sewer pipe – both involve the installation of heat exchangers. The first option is installing heat exchangers above ground (please refer to Figure 10, left). For this option, a wastewater screen is required to filter solids before the water passes through the heat exchangers. The second option is to install a heat exchanger in the bed of the sewage pipe, as seen in Figure 10 (right). The heat exchanger can either be integrated into the sewage pipe or simply placed separately in the pipe. The second option requires less space than the first, and the wastewater does not need to be pumped out of the sewer. However, system maintenance is more complicated and might require that the sewer pipe be taken out of service. There are also more strict requirements regarding the wastewater flow and sewer pipe diameter for the second option, requiring sewer pipe diameters of at least 800mm and a minimum flow of 30L/s. The first option is easier to maintain since most of the equipment is located outside of the sewer pipe. This option can also exploit wastewater heat from sewage pipes with smaller diameters.

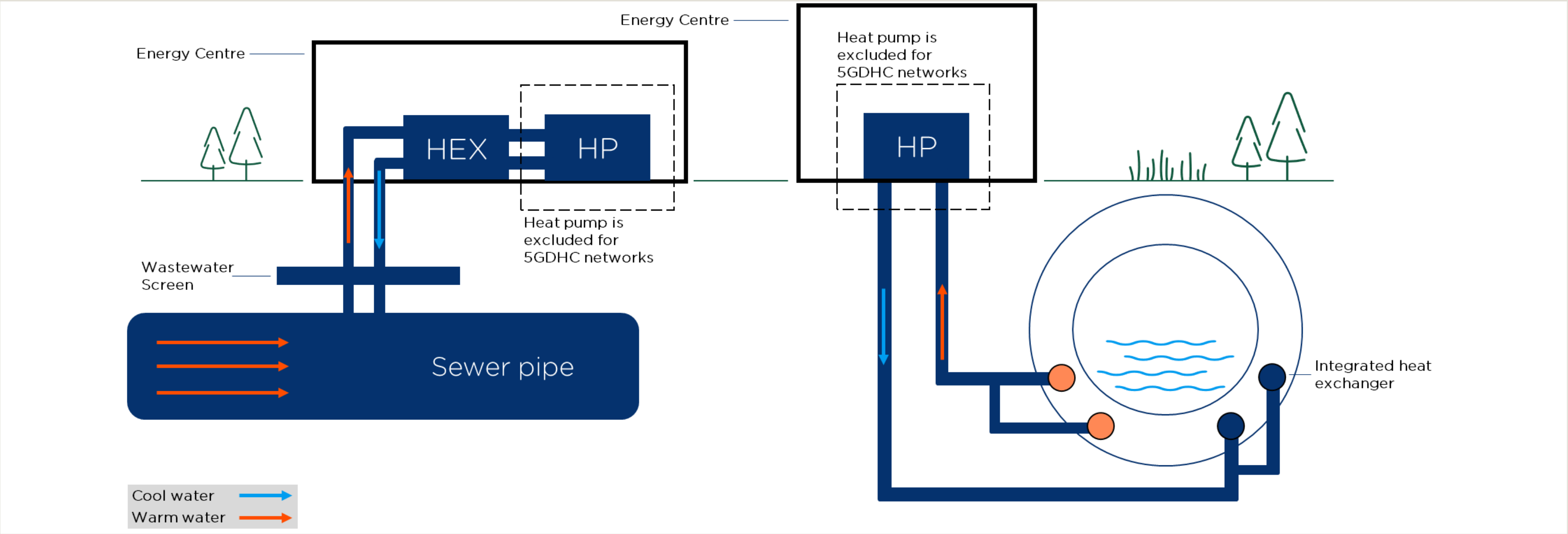


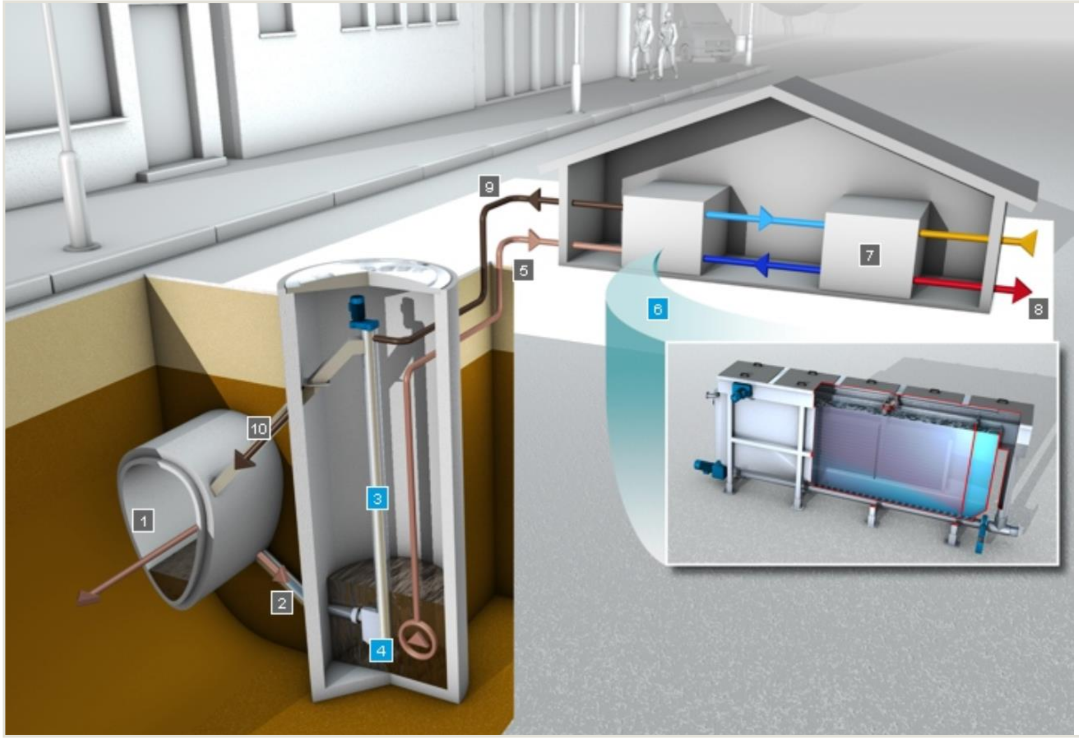

Figure 10: Two options of wastewater heat recovery at sewer pipe level. External heat exchangers and wastewater screen (left) and internal heat exchanger (right).

# Wastewater Heat Recovery | Illustration

**Description of the structure**
A typical WWHR system at sewer pipe level with external heat exchangers and wastewater screen (similar to the one depicted in Figure 10, left) consists of:

- A wet well: An underground structure built adjacent to the sewer pipe where the wastewater is transported and filtered before being pumped to the heat exchangers. The wet well is usually made of concrete and there are two points of connection to the sewer, allowing the wastewater to be extracted and then discharged after passing through the heat exchangers.
- An energy centre: The heat exchangers are placed above ground in the energy centre.

A simplified schematic of the system manufactured by Huber, a multinational company specializing in wastewater treatment equipment, is presented in Figure 11 below.




1. Sewer
2. Sewage outflow
3. Pumping stations screen
4. Screen basket
5. Screened wastewater
6. Compact heat exchanger
7. Heat pump (+ heat storage tank)
8. Heating water connection to consumers
9. Cooled sewage return
10. Screenings and sewage return into sewer

Figure 11: Schematic of the Huber wastewater heat recovery system. Source: Huber.co.uk

# Wastewater Heat Recovery | Cost

**Data collection**
To understand the cost of a wastewater heat recovery (WWHR) system, Ramboll has collected data from two suppliers[1] and consulted Ramboll experts that have worked with these systems. The data shows that there are significant differences in the cost per kW of the different types of WWHR systems. This is due to the range of cost elements present that can vary significantly depending on the project parameters. The key cost elements are:

- Energy centre (structure and ancillary equipment)
- Wet well (Filtration and pumping)
- Pipework between wet well and energy centre
- Heat exchangers and heat pumps (if required)

The data indicates that cost per kW can vary between £1,700 and £4,500 depending on project characteristics such as depth of installation, ease of access and diameter of the sewer.

In addition, a key parameter is whether additional filtration is needed, which depends on whether the abstraction point is before or after wastewater treatment.

Our analysis finds that the heat exchangers and pumping station make up approx. 50% of the costs, installation 20%, and design and civil engineering works 10% each.

**Economies of scale**
Moreover, the cost per kW varies for systems of different capacities. Two categories are defined for this analysis:

- Small – 750kW
- Large - 3,500kW

The capacity refers to the thermal power supplied by the system, i.e. heat supplied by the heat pumps and not the low-grade heat extracted from the wastewater[2]. Typical costs are presented in Figure 12. It shows that larger systems have a lower cost per kW. Large systems cost approx. 10-15% less per kW than small systems.

Based on project experience, Ramboll estimates that the total cost of a small and large system is circa £2.6 million and £9.0 million, respectively. The wet well makes up approximately 10-20% of the total cost, depending on the capacity (thermal power output).

**4th and 5th generation systems**
Figure 12 shows the cost per kW for 4GDH and 5GDHC. The cost per kW is significantly higher for 5GDHC, even though this system does not include heat pumps. This is because a larger heat input (amount of heat recovered from wastewater) is needed to achieve the same heat output for the network. In 4GDH, a smaller amount of heat is recovered from wastewater, which is then upgraded by a heat pump to achieve the same heat output.

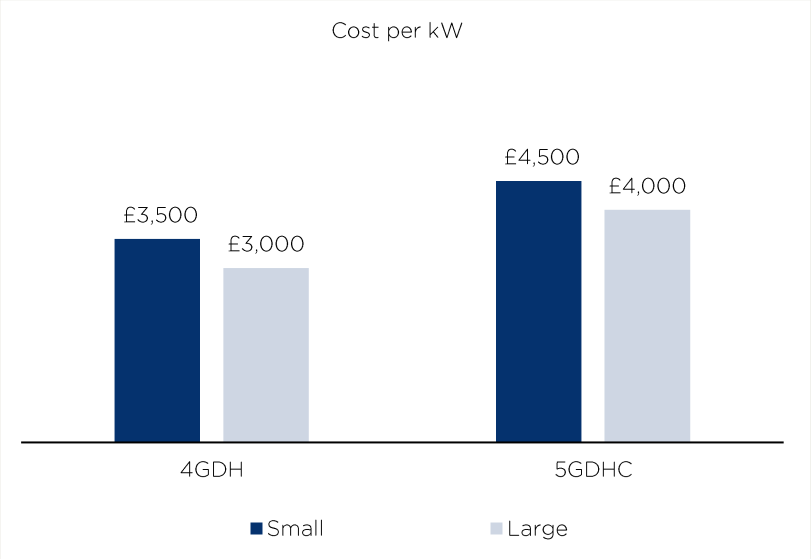



Figure 12: Cost (£/kW) of a small and large wastewater heat recovery system.

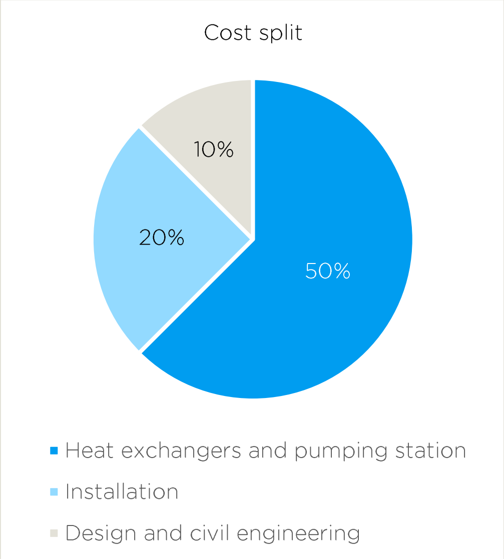



Figure 13: Typical cost split when delivering a WWHR system.

[1] The suppliers were selected based on their involvement in Scottish heat network projects. [2] Assuming a COP of 3.5, the small and large thermal output corresponds to approximately 550 and 2,500kW low-grade heat extraction, respectively.

# Distribution Network

**The total cost of the distribution network is made up of three main costs:**

- Pipework – Cost of the material.
- Installation – Labour associated with the assembly of the network.
- Trench Excavation – Cost of the groundworks required to bury the pipework.

**3 types of pipes are considered:**

- Pre-insulated steel: Conventionally used for 3GDH and 4GDH. Service life is usually expected to be approximately 50 years at high operating temperatures (90°C). Service life is likely to be considerably longer at 4GDH operating temperatures (<70°C).
- Pre-insulated plastic: Applicable to 4GDH but operating temperatures and pressures must be carefully considered to maintain optimum service life.
- Uninsulated plastic: Typically considered for 5GDHC where operating temperatures are at ambient temperatures (<30°C). Service life is approximately 100 years depending on operating temperatures and pressures.

**Limitations and assumptions in this section**

- When comparing uninsulated and insulated pipework costs, it is important to keep in mind that 4GDH networks operate at higher temperature differences than 5GDHC networks. Due to lower temperatures, the pipe internal diameters will be higher for 5GDHC than 4GDH (approximately 1.5 times[1]). However, no insulation means that the outer diameter of the pipes may be comparable. The trench costs will thus be comparable. Altogether, the CAPEX for the two systems is comparable[2].
- Network topology can have a big impact on the cost. Bidirectional 5GDHC networks require pipes with large diameters throughout the network while 4GDH and 5GDHC networks with unidirectional flow can utilize narrower pipes in branches.
- In this study, all excavation costs are based on pre-insulated steel pipes.

**KEY TAKE-AWAYS**

- Trench excavation dominates the total cost of the network.
- Cost of plastic pipework is found to be highly variable depending on manufacturer and system specification.
- Costs are highly dependent on pipe diameter and local conditions. Complicated local conditions can cause excavation to be up to 12 times more expensive.
- Excavation can make up more than 50% of the distribution network costs.
- Plastic pipework is less expensive to acquire and install compared to steel, but the saving potential decreases in line with increased excavation costs.
- Considering average installation and excavation costs, 10,000 m of distribution network costs approximately £18 million for steel, £16 million for pre-insulated plastic, and £12 million for uninsulated plastic (assuming pipe diameters in the span of DN200-DN600 typical of the main spine of a district heating network).

[1] Millar, M.-A., Elrick, B., Jones, G., Yu, Z., Burnside, N.M., 2020. Roadblocks to Low Temperature District Heating. Energies 13, 5893.; [2] Gudmundsson, O., Schmidt, R.-R., Dyrelund, A., Thorsen, J.E., 2022. Economic comparison of 4GDH and 5GDH systems – Using a case study. Energy 238, 121613.

# Distribution Network | Background

### Cost of installation and excavation

District heating pipework is normally buried 0.5-2 m below the surface. The excavation cost mainly depends on the size of the trench and the site's local conditions. Costs can vary considerably depending on the circumstances of the site and the network route. Factors that impact costs include traffic disruptions, crossing of major roads, labour costs, buried services, hard vs. soft dig conditions and more.

"Costs can vary considerably depending on the circumstances of the site and the network route."

The installation cost of the pipework is another important cost to consider. The material of the pipework, diameter, and local conditions all contribute to the final cost.

### Cost of pipework

The cost of the pipework depends on the material and pipe diameter. Pipes with larger diameters are more costly but can transport more thermal energy.

### Service life considerations – steel pipes

Pre-insulated steel pipes are by far the most common choice for district heating applications. Steel pipes can operate at relatively high pressures (up to 25 bar) and temperatures of up to 120°C. The operating pressure and temperature have a big impact on the expected service life of the system. The minimum service life for steel pipes is 30 years. However, this is based on continuous operation at 120°C and is therefore to be considered as a low estimate.

Since 4th generation systems operate at temperatures below 70°C, the pipework is expected to have a considerably longer service life. There are some indications that steel pipes could last as long as 50 years if they are operated at 115°C. This means that it is likely that, at low operating temperatures, steel pipes could have a service life of at least 50 years, but it is likely to be longer.

"Steel pipes operating at low temperatures are likely to have a service life of well above 50 years."

### Service life considerations – plastic pipes

Plastic pipes (both pre-insulated and uninsulated) are not as widely employed for district heating purposes. This is due to limitations of operating pressure and temperature. At ambient operating temperatures, typical for 5GDHC, plastic pipes can support a high operating pressure while ensuring a long service life. Based on manufacturer's specifications, plastic pipes have an expected service life of 100 years at an operating temperature of 20°C and pressure of 20 bar. At operating temperatures typically associated with 4th generation systems, the service life and maximum operating pressure are greatly reduced. A pipe operating at 60°C and 10.3 bar has an expected service life of 50 years. Figure 14 shows the relationship between temperature and pressure if a service life of 50 years is to be achieved.

### Pipe sizes and categories

As the cost of the distribution network is dependent on the diameter of the pipe, four size categories are defined to simplify the analysis: mains, distribution, street, and connector. The mains category refers to large diameter pipes that transfer the bulk of the thermal energy, while the three other categories form the branches of the network (see Figure 15 on the following page). Table 7 outlines which pipe diameters belong to which category. It is important to bear in mind that a branched network topology (as seen in Figure 15) is only valid for unidirectional networks.[1]

Pipe diameter (DN) refers to the internal diameter of the pipe in millimetres. The internal diameter is larger for the plastic pipes typically used in 5GDHC, due to greater volumes of water as the temperature is lower. However, the outer diameter is larger for pipes used in 4GDH networks as they include insulation, while this is not the case for 5GDHC networks. The outer pipe size dictates trench size and therefore impacts excavation costs.

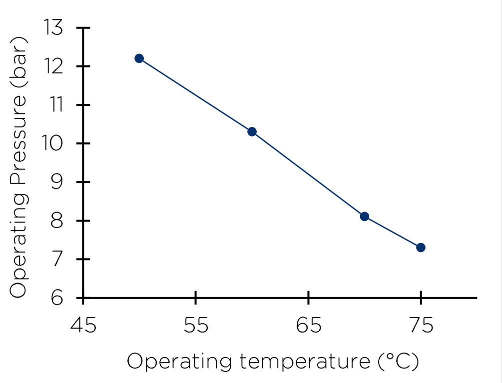



Figure 14 – Maximum operating pressure for plastic pipes at different temperatures, if a service life of 50 years is to be achieved.

| Category | Pipe diameters (DN) |
|---|---|
| Mains | 200-600 |
| Distribution | 65-150 |
| Street | 25-50 |
| Connector | 15-20 |

Table 7 – Pipe size categories

[1] In a unidirectional network, the fluid flows in one direction via dedicated supply and return pipes. All 4GDH networks are unidirectional. 5GDHC networks can be either bidirectional or unidirectional. For bidirectional networks, a ring or meshed topology might be more suitable. This means that the network will mostly consist of pipes with large diameters.

# Distribution Network | Background

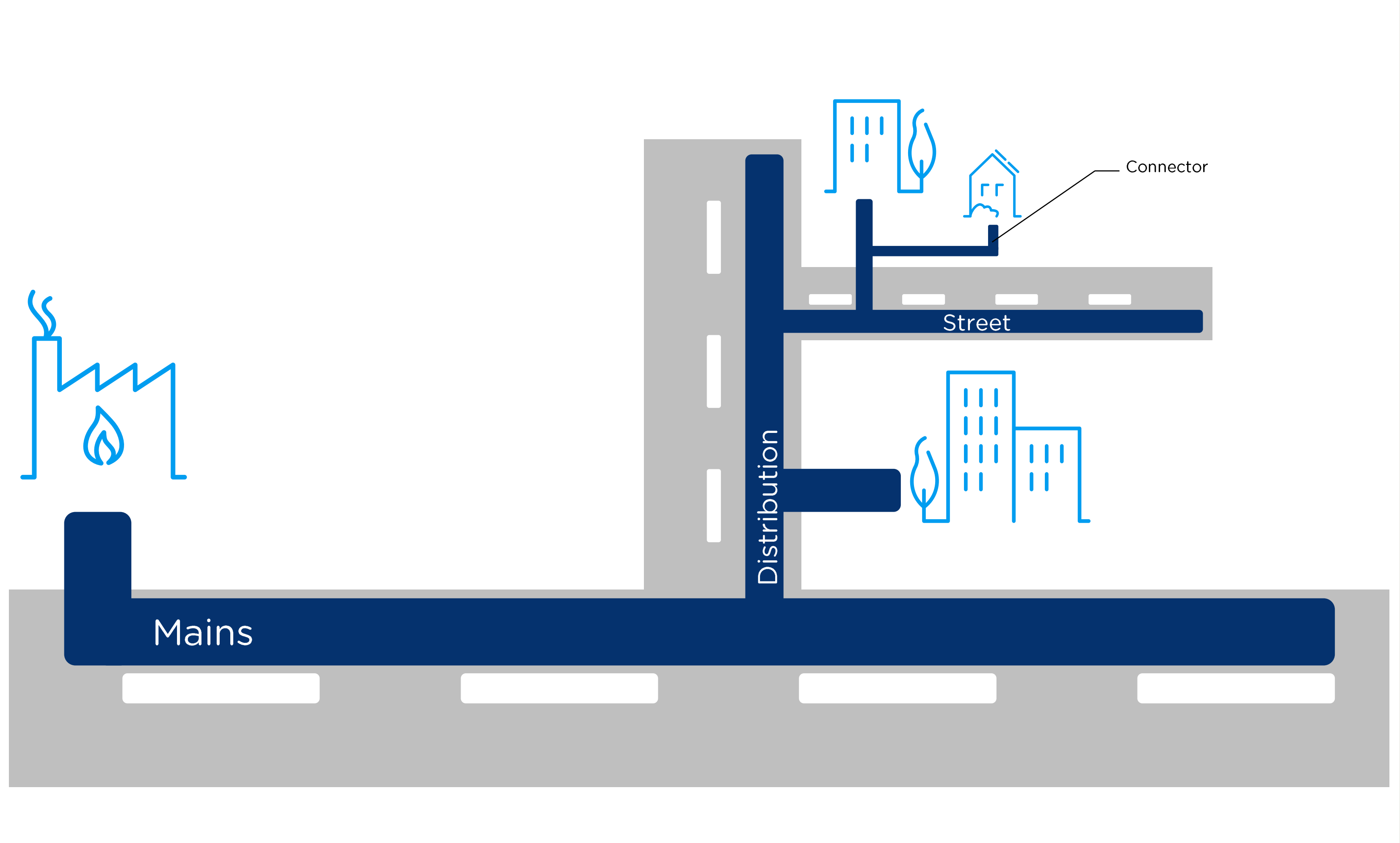



Figure 15 – Contextual overview of the pipe size categories

# Distribution Network | Cost of Pipework

**Data gathering, sources, and general considerations**
To understand the cost of district heating pipework data from four manufacturers has been analysed; Logstor, Isoplus, Aquatherm, and Rehau. The pricing data includes the price of various types and sizes of pipes, as well as related installation costs and typical excavation costs.

One thing to note about the data is that the different manufacturers do not cover the same span of pipe diameters. This affects the average costs presented in Figure 16, as some of the estimates of average cost are based upon multiple data points, while others are based on a single data point.

Costs for pre-insulated plastic pipes have only been provided up to DN355, while costs for steel pipes and uninsulated plastic pipes are up to DN500 and DN630, respectively. Another important aspect to consider is the level of insulation. For pre-insulated pipes, an "average level" [1] of insulation has been considered.

**Cost of pre-insulated steel pipework**
The cost of pipework depends on the diameter of the pipe, the type of pipe, and the insulation level. Figure 16 shows the average cost per meter of the pre-insulated steel pipework by pipe size category. A more detailed graph of the costs can be found in Figure 17. From the data, one can conclude that the rate of increase is higher at larger pipe diameters.

**Cost of pre-insulated plastic pipework**
The cost of pre-insulated plastic pipework is highly variable. For example, at DN110, the cost ranges from £48 to £221 per meter (see Figure 18). The high costs of Supplier D's system have a significant impact on the average cost per meter of the pre-insulated plastic pipes.

**Cost of uninsulated plastic pipework**
As with the cost of the pre-insulated plastic pipework, the costs of uninsulated plastic pipes are highly variable (see Figure 19). Supplier D offers two different models of uninsulated pipework that differ considerably in cost. At DN160, the cost per meter ranges from £14.5 to £147.

**Cost per meter by pipe size category**
Figure 16 presents the pipework cost by size category. Pre-insulated plastic pipework is overall the most expensive type of pipe, and the cost per meter varies between £12 and £282 depending on size. The cost per meter of pre-insulated steel pipework is significantly lower, particularly when looking at distribution pipes (distribution pipes made of pre-insulated steel cost approximately 70% less than pre-insulated plastic). This difference in price averages is driven by the high cost of supplier D's pipes.

Uninsulated plastic pipes have the lowest cost per meter. The cost of the uninsulated pipes (as was the case for the pre-insulated plastic pipes) is significantly impacted by the relatively high cost of Supplier D's pipes.

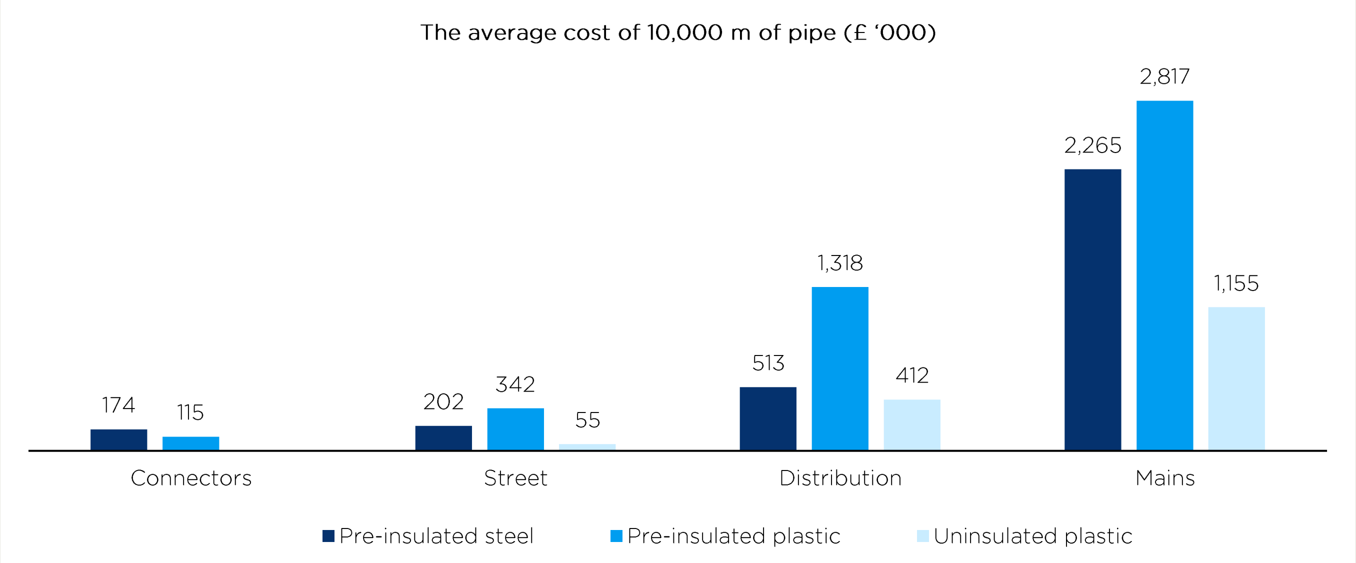



Figure 16 – The average cost of 10,000m by pipe size category for pre-insulated steel pipes, pre-insulated plastic pipes, and uninsulated plastic pipes.

[1] Insulation levels are usually divided into 3 categories, series 1, 2, and 3 referring to the thickness of the insulation. The degree of insulation impacts the heat losses of the network which is heavily impacted by the operating temperatures. An average level of insulation is considered as series 2 insulation.

# Distribution Network | Cost of Pipework

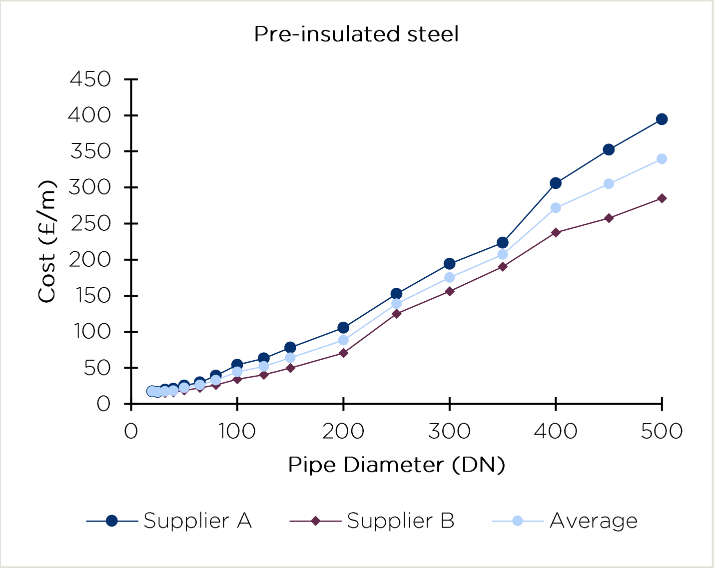



Figure 17 – Cost of pre-insulated steel pipes in relation to diameter

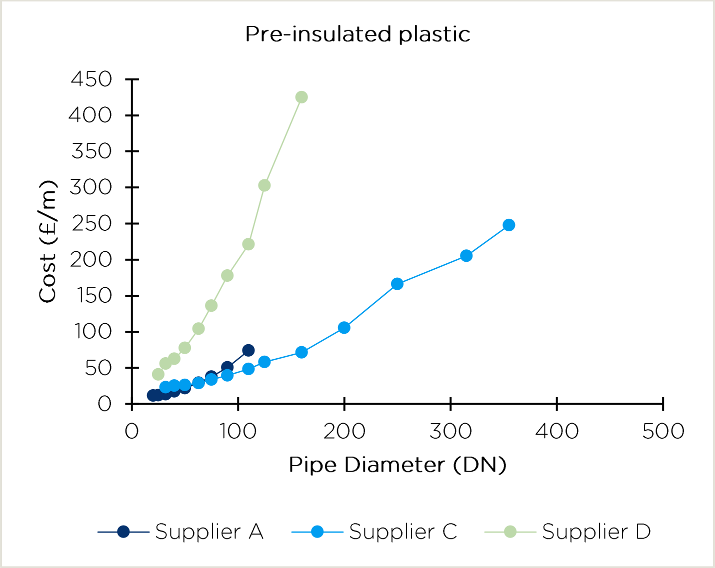



Figure 18 – Cost of pre-insulated plastic pipes in relation to diameter

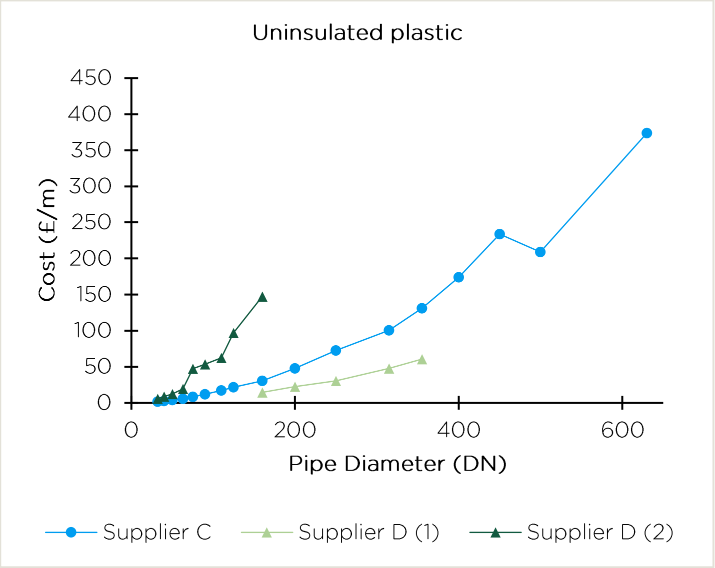



Figure 19 – Cost of uninsulated plastic pipes in relation to diameter (please note that one supplier has provided price data for two different types of uninsulated plastic pipes)

# Distribution Network | Cost of Installation and Excavation



**Data gathering, sources, and general considerations**
The cost of installation and excavation is difficult to estimate due to the many factors that influence these costs. Average costs fail to account for the impact of local conditions, which require a high degree of familiarity with ground conditions, potential buried services, crossings, labour costs and more to make a good estimate.

To understand the variation in cost arising from varying conditions, Ramboll has analysed data from suppliers, who, through extensive European experience, have provided a range of costs depending on the complexity of the site. Four scenarios are defined:

- Easy - This represents a best-case scenario. Local conditions are favourable to a quick pace of installation, and labour costs are low. The works cause minimal disruption, and the excavation happens mainly under soft dig conditions with little or no buried services. These conditions could apply to a countryside area, small town or village.
- Average - This scenario represents a mean cost calculated based on multiple projects and can be considered the "typical cost".
- Complicated - The conditions are particularly difficult, with high labour costs and significant disruption. The excavation takes place under mainly hard dig conditions with plenty of buried services in the area. Conditions like this could apply to a busy area of a major city.
- Very complicated - An extreme case representing a worst-case scenario, where work has to stop due to some unforeseen conditions. Perhaps the excavation uncovers artefacts of archaeological importance, or the pipe route cannot avoid crossing a river, highway, railway or other major obstacle.

**Impact of pipework material on installation and excavation**
The installation cost is partly dependent on the material of the pipe since this impacts the method of assembly. Due to data availability, the analysis of installation and excavation costs in different scenarios assumes that pre-insulated steel pipes are used. Through communication with other suppliers, Ramboll obtained installation costs for pre-insulated and uninsulated plastic pipes in average conditions.

For this report, it is assumed that the material of the pipe does not affect the cost of excavation. In reality, the material can somewhat affect the excavation cost. Due to limitations in data availability, the variation associated with pipe type has not been analysed in this study.

The insulated pipes have larger overall diameters due to the insulation thickness, requiring larger trenches than uninsulated pipes. For this reason, the excavation costs for the uninsulated plastic pipes have been adapted to reflect this.

**Excavation**
The cost of excavation for pre-insulated steel and plastic pipes is presented in Figure 20. Costs vary considerably depending on the scenario and pipe diameter. Excavation in a busy city area can be 6-12 times more expensive than in the countryside. The excavation costs for uninsulated pipes can be found in Figure 21. Please note that no excavation costs for the two smaller pipe size categories could be obtained.

**Installation**
The specific installation costs for pre-insulated steel pipes are presented in Figure 22. The costs are highly variable and increase in line with the pipe diameter. In very complicated conditions, installation can be 6-12 times more expensive than in easy conditions.

The installation cost for pre-insulated and uninsulated plastic pipes can be found in Figure 23. The installation cost for uninsulated plastic pipes is significantly lower than for pre-insulated plastic and pre-insulated steel. This is because plastic pipes are lighter and more flexible, making them easier to handle and simpler to install. To branch them, butt fusion or electric fusion is used, compared to welding for steel pipes, where the labour and equipment needed is simpler. Plastic pipes are also easier to transport and store on-site.

# Distribution Network | Cost of Installation and Excavation

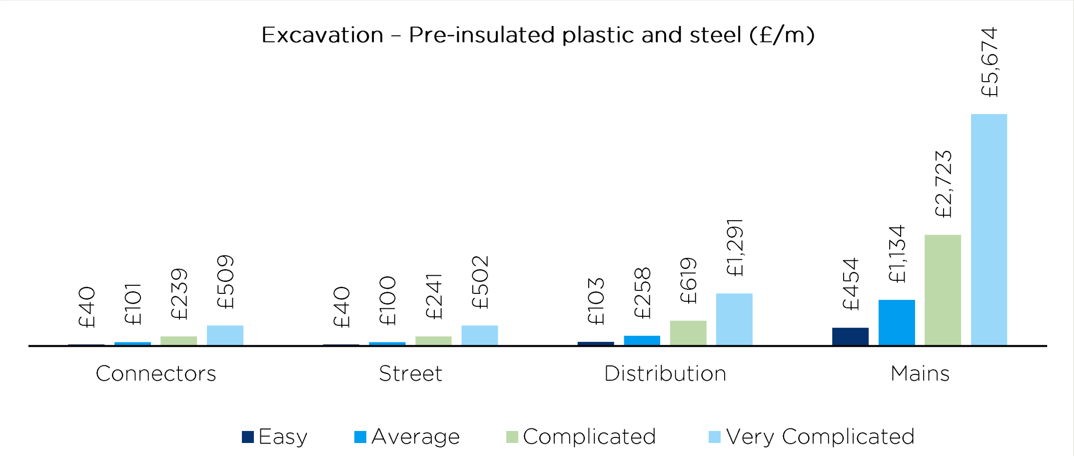



Figure 20 – Excavation cost for pre-insulated plastic and steel pipes depending on pipe size category

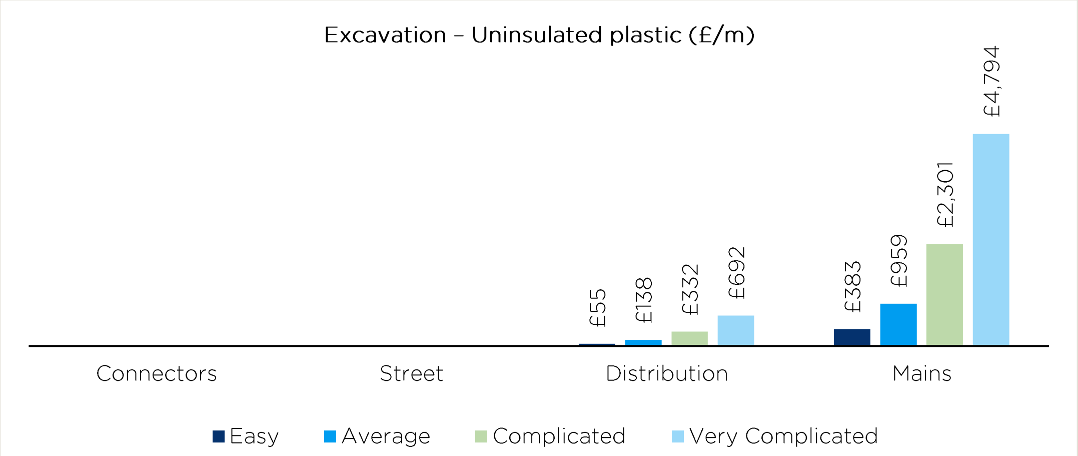



Figure 21 – Excavation cost for uninsulated plastic pipes in relation to pipe size category.

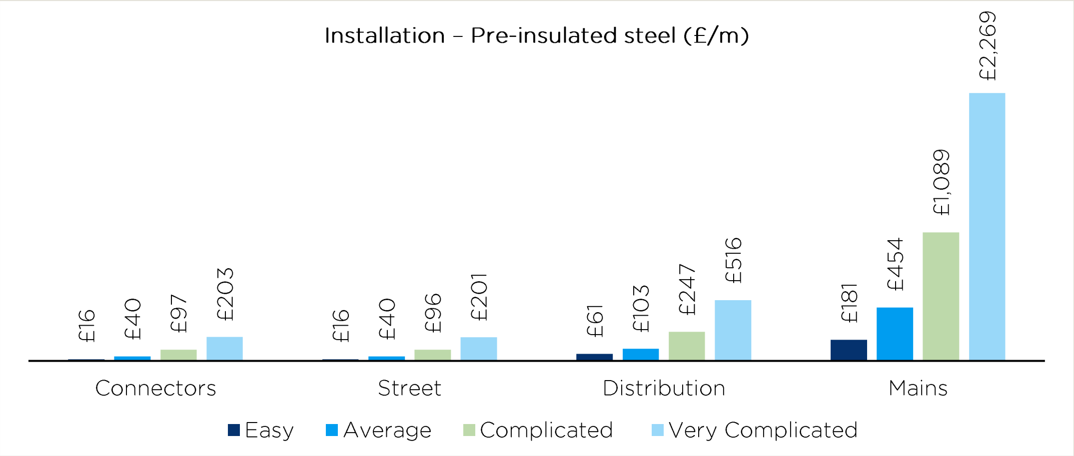



Figure 22 – Installation cost for pre-insulated steel in relation to pipe size category.

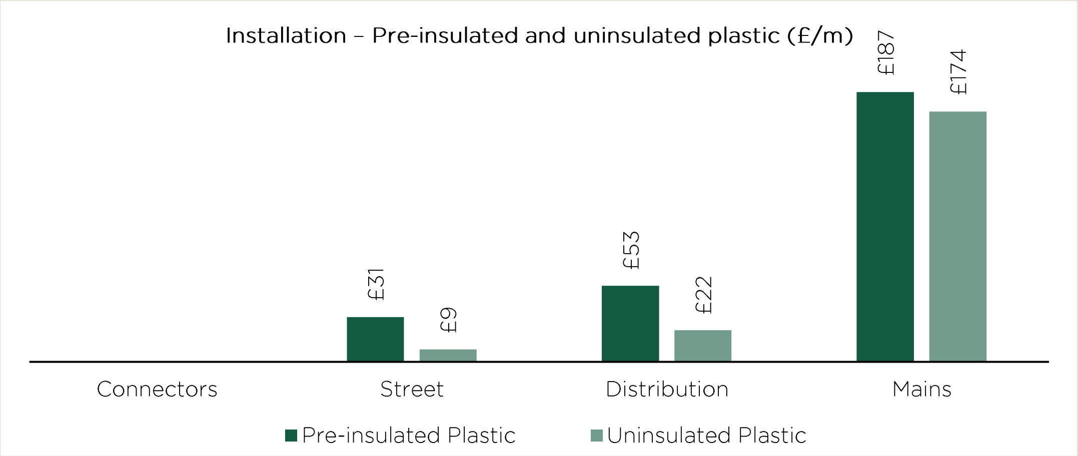



Figure 23 – Average installation cost for pre-insulated and uninsulated plastic pipes by pipe size category.

# Distribution Network | Total Cost

**Total cost of the distribution network**

As seen previously in this section, the cost of the distribution network can vary considerably depending on the pipe diameter and site conditions. Considering average excavation costs and average installation costs, the total cost per meter of pre-insulated steel pipes (the pipework, excavation, and installation cost combined) is found to be within the span of 160 £/m to 1,820£/m. For pre-insulated plastic pipes, the cost per meter varies between 160£/m and 1,600 £/m. The uninsulated plastic pipes are found to have the lowest total cost per meter: 110£/m-1,250 £/m. Comparing the mains pipe size, uninsulated plastic pipes are approximately 30% cheaper than pre-insulated steel. The total cost per meter for the three different pipe types can be found in Figure 25. As seen in Figure 24, the total cost per meter increases at a faster rate as the pipe diameter increases; distribution pipes are approximately 2.5 times as expensive as street pipes while the cost per meter of mains pipes is circa 4 times that of the distribution pipes.

Figure 25 shows the total cost of mains pipes, where the excavation cost is the dominant component. Depending on the pipe type, the excavation cost represents 60%-75% of the total cost (considering average installation and average excavation cost).

It was previously mentioned that uninsulated plastic pipes were found to have the lowest total cost per meter of all pipe types investigated. Nevertheless, the total savings are significantly impacted by the cost of the excavation as is demonstrated in Figure 26. Considering favourable site conditions, savings can be as high as 40% compared to pre-insulated steel pipes. As the excavation cost increases, the saving potential decreases as a result of the excavation dominating the total cost.

The cost of 10,000 m of distribution network, considering mains pipes and average installation cost, is outlined for the three pipe types and two excavation scenarios in Table 8. The pre-insulated steel network exhibits the highest costs: £11 million and £34 million for the easy and complicated excavation scenario, respectively. The costs for the pre-insulated and uninsulated plastic network are £9 - £32 million and £11 - £39 million, respectively. It should be pointed out that a distribution network might span areas with different excavation conditions. For example, part of the excavation work might be carried out in a brownfield (easy) while the other part involves excavating a main road (complicated). Furthermore, the costs listed in Table 8 are based on mains pipes, which represent the main spine of a network.

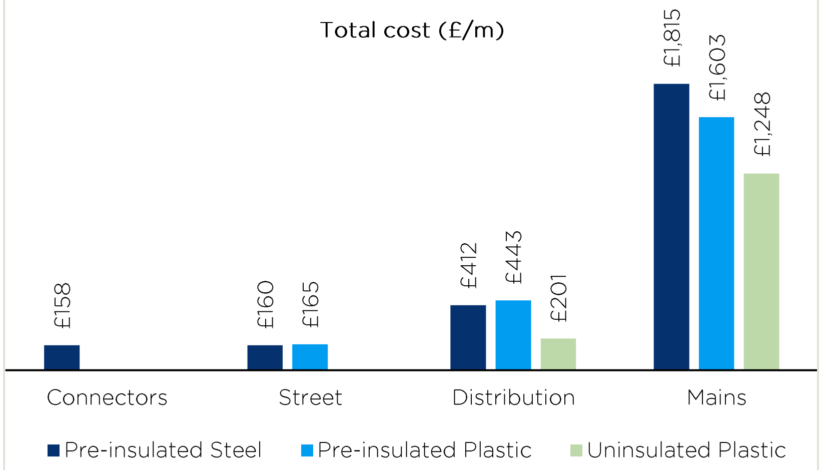



Figure 24 – Total cost per meter of distribution network considering average installation and excavation costs

| Pipe type | Easy excavation | Complicated excavation |
|---|---|---|
| Pre-insulated steel | £11 million | £34 million |
| Pre-insulated plastic | £9 million | £32 million |
| Uninsulated plastic | £11 million | £39 million |

Table 8 – Approximate total cost of 10,000m of distribution network considering mains pipe size and average installation cost.

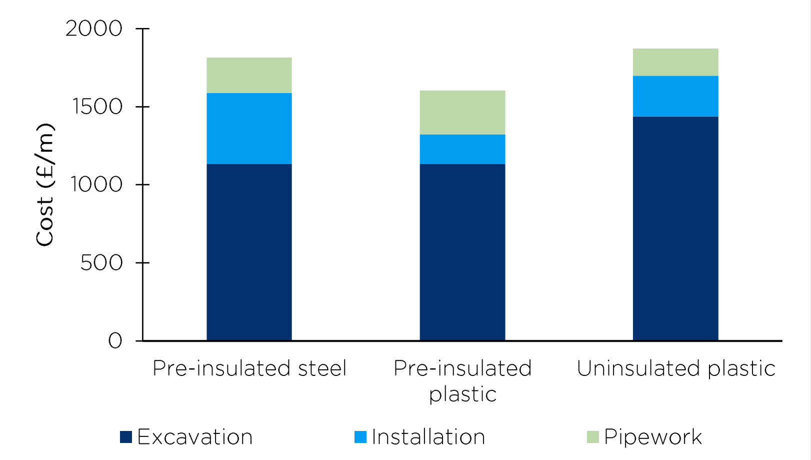



Figure 25 – Total cost per meter of distribution network considering mains pipe size and average installation and excavation costs.[1]

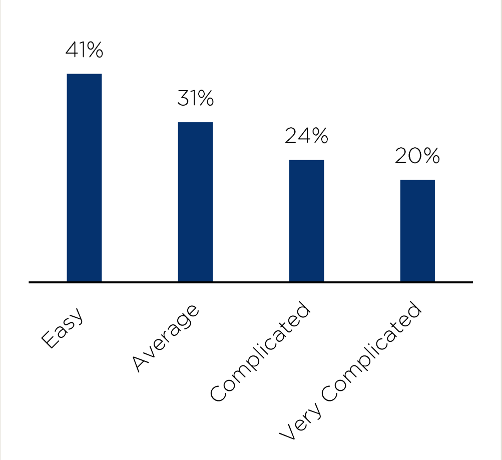



Figure 26 – Potential savings of installing uninsulated plastic pipework compared to pre-insulated steel for different excavation scenarios.

[1] Representative size of mains pipes is assumed. Uninsulated plastic pipes used in 5GDHC are assumed to be 1.5x larger to reflect that a larger diameter is needed for the same demand.

# Case studies

### Three case studies have been analysed:

- 3GDH in Aberdeen – The Torry Heat Network (Phase 1)
- 5GDHC in Glasgow – The AMIDS Network (Phase 1)
- 5GDHC in New York State – A US college campus

### Data collection

- Vital Energi, WSP, and Aberdeen City Council provided cost data and background information related to the recently constructed phase 1 of the Torry heat network.
- FES group provided input and capital costs of the AMIDS heat network
- Ramboll provided the data related to the 5GDHC network at an American college campus, as the technical and economic feasibility study was done by Ramboll.

### 5th generation networks

- 5GDHC networks are not yet widely applied in the UK, with existing examples still relatively small-scale and specific in nature. A case study from the US has been included due to its larger size.
- 5GDHC networks are highly dependent on the topology of the network, which shows in the significant variation in costs.

### Highlighting the Scottish Content

A further classification of the received cost data is performed to quantify the impact of these two projects on the Scottish value chain. Scottish value is mostly based on the construction and installation of the energy centre, distribution network, and building connections. Most of the equipment is imported, but labour and services necessary for construction are delivered by the Scottish value chain.

### Summary of relevant Scottish projects

Finally, a summary of other key existing Scottish schemes is shown including projects from the Stirling Council in Forthside, the Millerhill project in Shawfair and the Glenrothes project in Fife.

### KEY TAKE-AWAYS

- The total cost of the Torry heat network is approximately £12.5 million with the distribution network being the largest cost component, namely 47% of the total expenditure (£5.9 million).
- The total cost of phase 1 the AMIDS heat network Phase 1 is £6.9 million. The largest part of the cost is associated with the distribution network which represents approximately 40% of the total cost.
- Based on AMIDS and Torry heat networks, the Scottish value mainly originates from construction and installation. Most equipment is imported.
- The estimated total cost of the 5GDHC network in New York was £81 million including £35 million for uplifts. The largest part of the cost is substations. With 34 substations, the total cost was £27.7 million.
- The analysis indicates that substations with a relatively low installed capacity (<200kW) are significantly less cost-effective than larger substations.

# 3GDH in Aberdeen | Torry Heat Network Phase 1 – Background

**Introduction**
Phase 1 of the Torry heat network – mostly constructed in 2022 and commissioned in 2023 – supplies heat to both residential and commercial customers. The scheme is situated in Torry, Aberdeen and is a 3GDH network, utilizing a newly constructed energy-from-waste plant as its main heat source. The network is connected to:

- Twelve 5-storey maisonette blocks, referred to as "Farquhar Road flats",
- Five 3-storey blocks of flats known as the "Balnagask Circle" blocks,
- One school (including a community swimming pool), and
- One social work office building.

The residential buildings comprise 139 flats. In addition, the network is connected to a pre-existing scheme called Heatnet that supplies 146 residential customers and 2 commercial buildings. The network layout is presented in Figure 33.

**Energy centre**
The energy centre (referred to as a heat distribution facility in Figure 33) is located next to the energy-from-waste site. The building, a former waste recycling centre, was retrofitted to contain the equipment housed in the energy centre (577m$^2$ floor area). The 2x5MW heat exchangers for the heat offtake are housed in the energy-from-waste plant with underground pipes transporting heat to the energy centre. The energy centre includes standard district heating ancillary equipment such as distribution pumps, expansion vessels, and water treatment systems. Furthermore, 3x3MW gas boilers were installed as backup, used when heat from the energy-from-waste plant is insufficient or unavailable due to maintenance. 2x150m$^3$ thermal stores are located outside the energy centre to allow for maximum heat offtake from the energy-from-waste plant. Currently, the 10MW heat offtake from the energy-from-waste plant can easily supply phase 1 demands, with a considerable margin for accommodating future network expansions.

**Distribution network and building connections**
The distribution network consists of 3,200m of pre-insulated steel pipework (not including the pre-existing Heatnet network). Approximately 2,000m of the network makes up the main spine. The main spine is sized to DN250 (intentionally oversized to allow for future expansion) and spans from the energy centre to Farquhar Road flats (see Figure 33). After Farquhar Road flats, the network diameter is DN150 (except for building branch connections where smaller pipe sizes are present) and connects to Balnagask substation, which serves as the connection point to the pre-existing network. Other than the Balnagask substation, two new substations are present; one at Tullos Primary School and the other at the social work office. 139 heat interface units (HIUs) are installed, one for each residential dwelling connected to the scheme.

The main purpose of substations in 3GDH and 4GDH is hydraulic separation. This is the separation of the primary network (which carries the hot water from the energy source) from the secondary network (which carries the hot water to individual buildings) and is done to prevent any contamination or mixing of the two networks, which can cause issues such as pressure imbalances, corrosion, and reduced efficiency. By keeping the two networks separate, it ensures a more reliable and efficient heat transfer to the buildings.

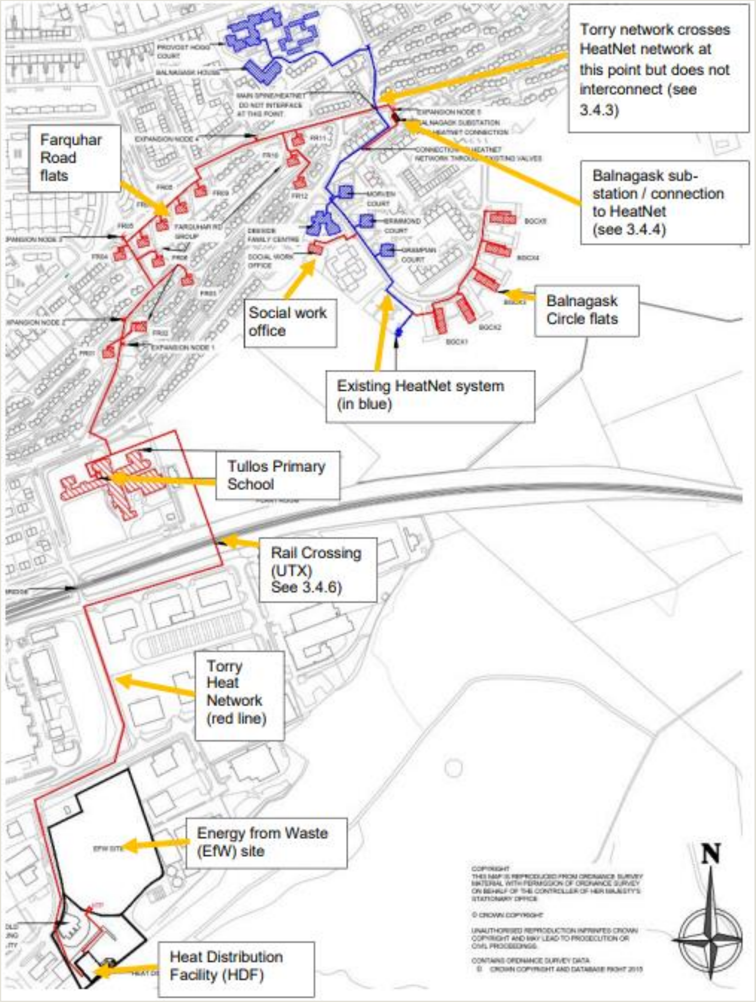


Figure 33 – Network Layout of phase 1 of the Torry heat network, courtesy of Aberdeen City Council.

# 3GDH in Aberdeen | Torry Heat Network Phase 1 – Cost analysis

**Total cost**

Vital Energi was employed as the main contractor and has provided a breakdown of the cost of delivering phase 1 of the Torry Heat Network. The total cost is £12.5 million. Figure 34 shows a high-level breakdown of the costs. The cost of the distribution network represented 47% of the total expenditure (£5.9 million), making it the biggest cost of the scheme. The cost of the energy centre also represented a significant part of the capital investment – 26% (£3.2 million). The building connections and various other costs represented 15% (£1.9 million) and 12% (£1.5 million), respectively.

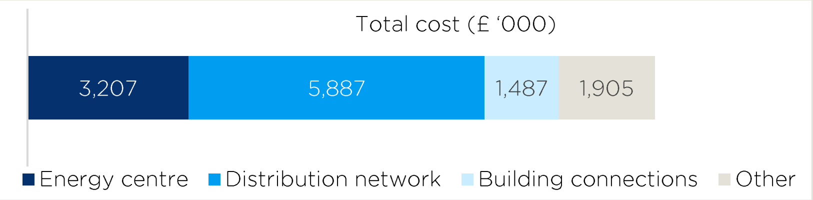



Figure 34 – Total cost of phase 1 of the Torry Heat Network.

**Energy centre**

The energy centre consisted of various cost elements and was divided into 7 categories;

- Energy centre electrical and mechanical fit-out (Mechanical and electrical installation, thermal insulation, scaffolding and access, and ventilation)
- Energy centre structure (Enabling works, steel works, internal builder works, floorings, and external bases)
- M&E Plant items (Distribution pumps, equipment pumps, pressurisation & expansion equipment, thermal stores, side stream filtration, metering)
- Gas boiler units (3x3MW boilers)
- BMS (control system)
- Utility works (connection to the gas grid)
- Testing and commissioning & water treatment

Figure 35 outlines the costs associated with each category listed above. The cost of the heat exchangers in the energy-from-waste plant is not included here, as the energy-from-waste plant is responsible for equipment located at their premises.[1] This capital cost is typically passed on to the network via an increase in the tariff charged for using the heat. The electrical and mechanical fit-out represented approx. 27% of the total cost. The energy centre structure and M&E plant items made up 21% and 18%, respectively.

**Distribution network and building connections**

The cost of the distribution network is outlined in Figure 36. Considering the trench length is 3,200 meters, the cost per meter is approximately 1,840 £/m. The tunnelling works required to cross the railway tracks are 26% of the total cost of the distribution network. The pipework and installation cost represent approximately 32% of the cost and include welding, testing, and the pre-insulated steel pipework.

The cost of the building connections included 3 district heating substations, 139 HIUs, and the works connected to the risers and laterals installed in the apartment blocks. The costs are summarized in Figure 36.

**Other costs**

The design and feasibility work as well as project management, legal, site cabins, and running costs are included in this category. The design and feasibility work cost £300,000 and £60,000, respectively. All other costs amount to £1.6 million.

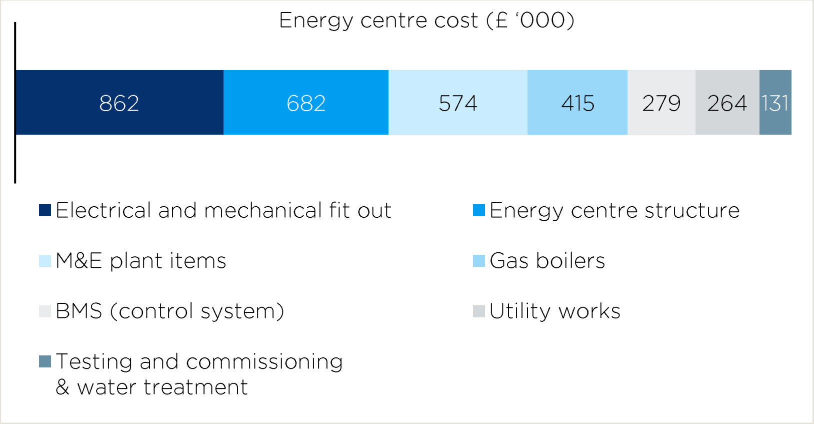



Figure 35 – Breakdown of the costs associated with the energy centre.

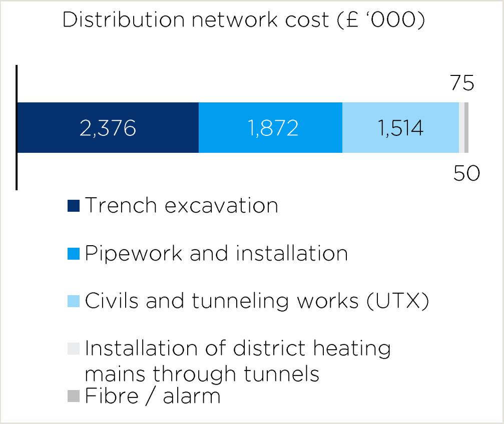



Figure 36 – Breakdown of the distribution network costs.

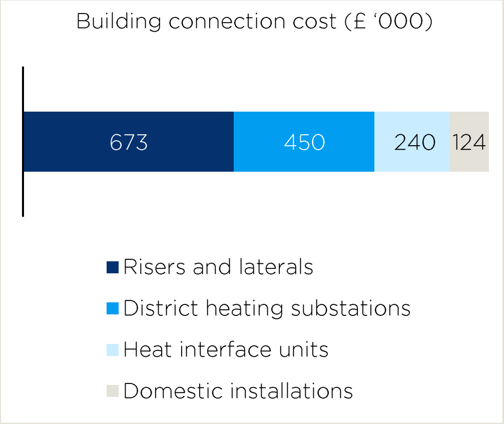



Figure 37 – Breakdown of the costs associated with the building connections.

[1] For reference, the cost of this type of equipment at a 20MW waste heat extraction facility in England was £2.4 million (120 £/kW), including network connection.

# 5GDHC in Glasgow | AMIDS Phase 1 – Background

**Introduction**
The AMIDS district heating network, located on the outskirts of Glasgow, is the first of its kind to be built in Scotland. This innovative scheme utilises low-grade heat from Laighpark Wastewater Treatment Plant (WWTP) to supply the AMIDS development – a new manufacturing and innovation district. Phase 1 of the network was finished in 2021 and currently supplies 2 buildings (approximately 1,200 MWh/year); the National Manufacturing Institute Scotland (NMIS) and the Medicines Manufacturing Innovation Centre (MMIC). More buildings are planned to connect in the future as the AMIDS development is completed. Please refer to Figure 38 for a simplified schematic of the network.

**Energy centre**
The energy centre is located alongside Laighpark WWTP and has an installed capacity of 4MW. Space has been allocated to accommodate future expansion of the network. At full build-out, the energy centre will have an installed capacity of 10MW. Low-grade heat from the treated effluent is extracted via heat exchangers and then fed directly to the distribution network. The equipment housed in the energy centre includes heat exchangers, expansion vessels, distribution pumps and water treatment. The floor area is approximately 90m$^2$.

**Distribution network and building connections**
The distribution network consists of uninsulated plastic pipes. Currently, the network largely operates as a conventional district heating network. Low-grade heat is distributed from the energy centre and travels unidirectionally to the building connections. The supply temperature is approx. 5-15°C. The water in the network contains around 12% glycol to avoid freezing in winter. The pipework consists mainly of DN500-DN630 pipes and stretches approx. 2,600m from the energy centre to the AMIDS development.

The two existing substations consist mainly of WSHPs (2x700kW) that are directly connected to the network. At present, no cooling is provided by the substations. This is planned to be incorporated in the future. Electric boilers (2x500kW) are also installed in the substations to provide top-up and back-up capacity.

The substations in a 5GDHC network are energy substations. These differ from the hydraulic substations in a 4GDH network, where hydraulic separation happens through heat exchangers.

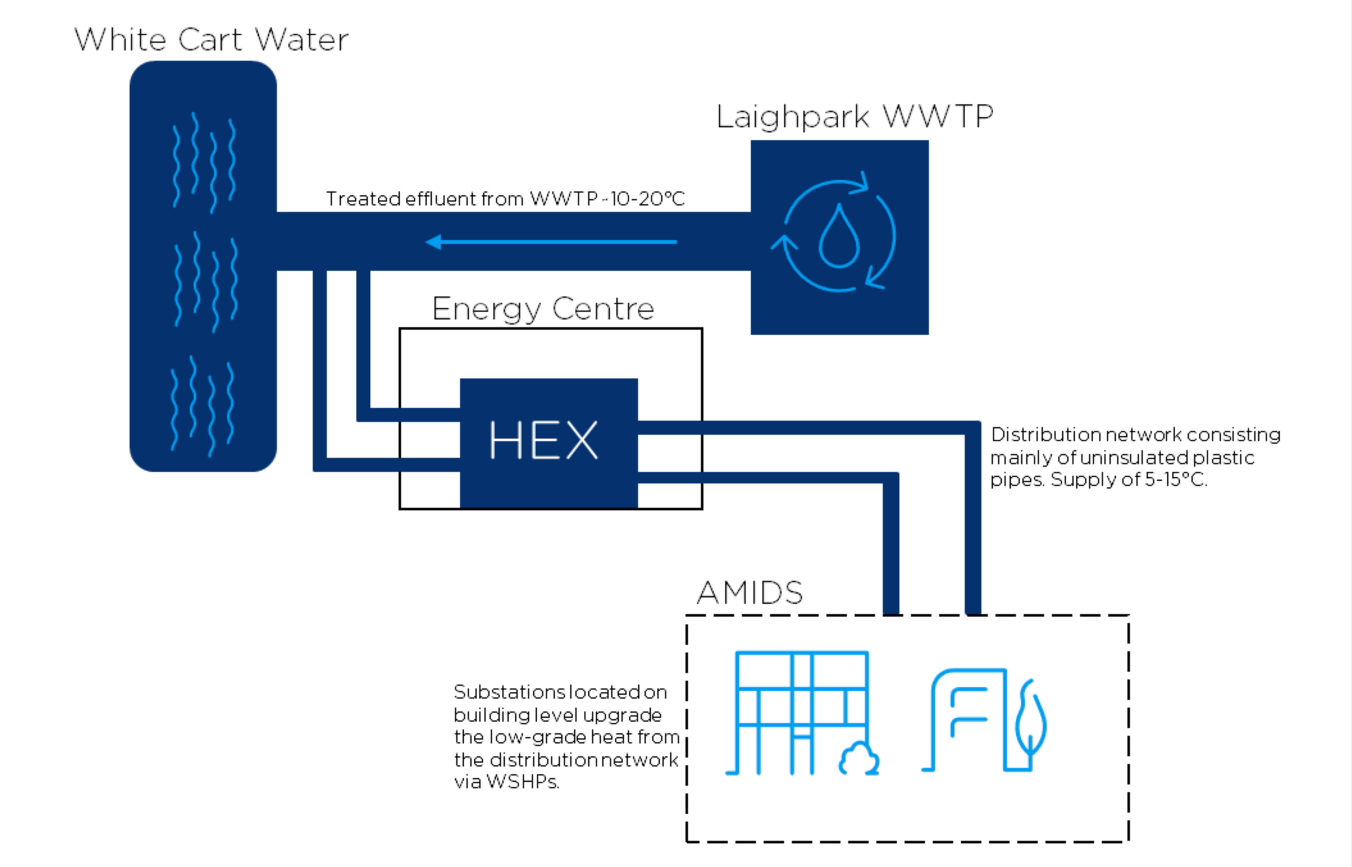



Figure 38 – Simplified schematic of the AMIDS heat network

# 5GDHC in Glasgow | AMIDS Phase 1 – Cost analysis

### Total cost

FES group was the main contractor employed to construct the network. The cost data presented here is based on input from FES and Ramboll (Ramboll was hired as an NEC supervisor). The total cost of Phase 1 of the AMIDS heat network is £6.9 million. The largest part of the cost is associated with the distribution network, which represents approximately 40% of the total cost. The energy centre accounts for 29% of the costs while the building connections and design, site mobilisation, and preliminaries for 12% each. The cost relating to the feasibility work is the smallest, at 6% of the total cost.

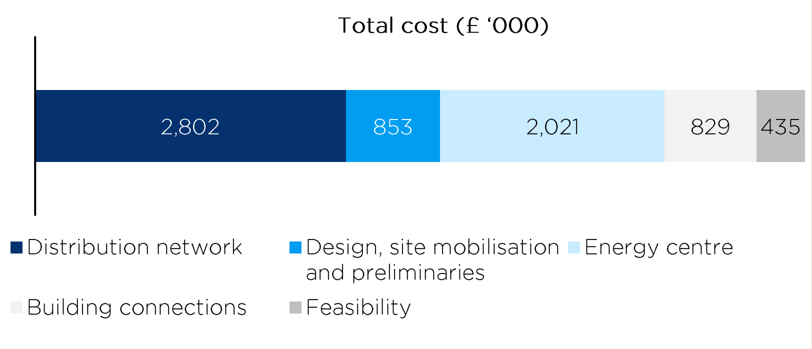



Figure 39 – Total cost of phase 1 of the AMIDS Heat Network.

### Energy centre

The energy centre consists of various cost elements and includes, among other things, the costs related to the energy centre structure and groundworks, the cost of the mechanical and electrical fit-out, and the cost of heat exchangers, pumps, and water treatment. The cost of the energy centre is circa £2 million, and a breakdown is available in Figure 40. The electrical and mechanical fit-out represents approximately half of the costs. A large part of this is related to the LTHW pipework. The control system hardware, pumps and pressurisation unit, and energy centre structure are also significant costs, making up 15%, 11%, and 11%, respectively. Considering that the energy centre has an installed capacity of 4MW, the cost per kW is approximately 500 £/kW.

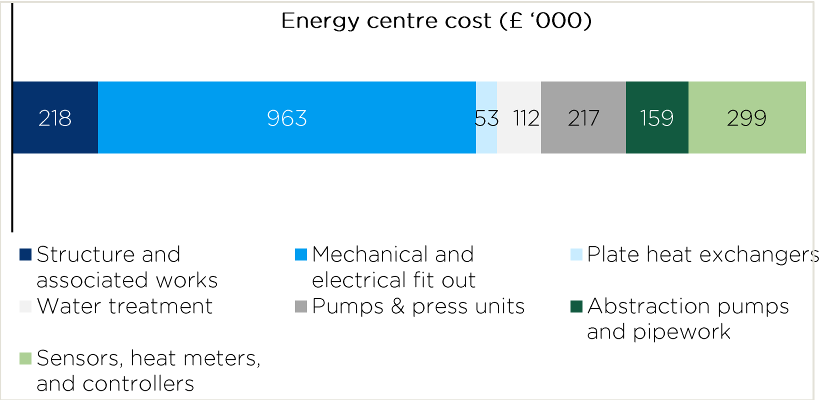



Figure 40 – Breakdown of the costs associated with the energy centre.

### Distribution network

The cost of the distribution network is approx. £2.8 million. Please refer to Figure 41 for an overview of the costs. The largest cost is the excavation and installation works, representing circa 67%. The plastic pipework makes up 15%, the same proportion as the commissioning and glycol treatment. A small amount of costs are associated with miscellaneous works, such as fibre optic cabling. The cost per meter of the network is 1,080 £/m.

### Building connections

The building connection cost refers to the expenditures of the two building substations at MMIC and NMIS. The total cost of the substations is £0.8 million, and a breakdown of the cost is outlined in Figure 42. The 2x700kW heat pumps represent the biggest cost, approximately 38%. The LTHW pipework is also significant, making up 33%. Considering that the substations have an installed capacity of 2,400kW, the cost per kW is circa 350 £/kW.

### Design, site mobilisation, and preliminaries

This cost includes works such as; civil and structural design, architectural design, mechanical and electrical design, and various other costs such as consultancy fees and site investigations. The construction preliminaries are the largest part of these costs representing £0.4 million. The design costs alone make up 4% of the total CAPEX.

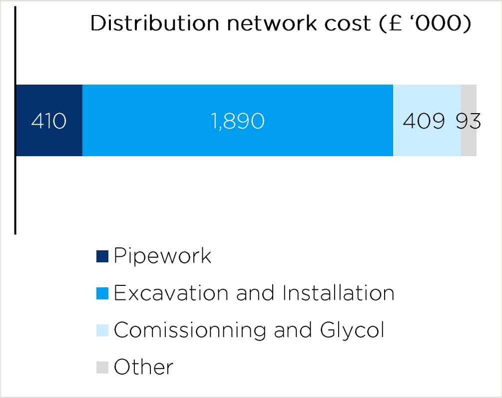



Figure 41 – Breakdown of the distribution network costs.

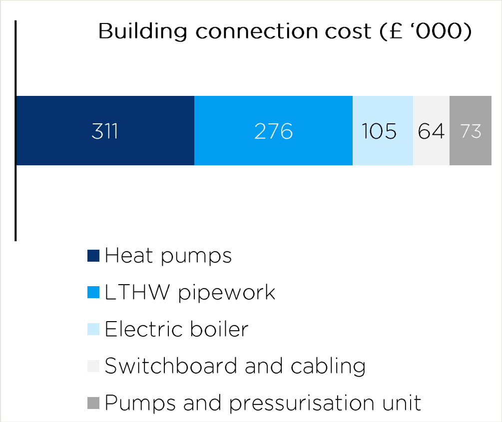



Figure 42 – Breakdown of the costs associated with the building connections.

# Case studies | Scottish share of the supply chain

Based on the AMIDS and Torry heat networks, Scottish companies are most active in the construction and installation of the energy centre, distribution, network, and building connections. The equipment is generally imported. It is important to keep in mind that a large part of the total CAPEX of a heat network relates to the labour and services necessary for construction.

**AMIDS**

For AMIDS, Scottish companies represented 58% of the total value of the network. Figure 43 shows the value of Scottish, English and Welsh, and imported content. A large part of the Scottish content relates to the distribution network. This is largely due to the installation and trench excavation performed entirely by a Scotland-based company. The commissioning and glycol treatment was also a large contributor to the Scottish value. The design, site mobilisation, and preliminaries are another large share delivered by Scottish companies. Construction preliminaries made up a considerable part of this, but the combined cost of design and consultancy fees is also significant.

Of the energy centre cost, 43% was delivered by Scottish companies, while 20% was from the rest of the UK and the remaining was imported. Equipment such as heat exchangers, pumps, pressurisation units, and LTHW pipework was generally imported. One thing to note is that the LTHW pipework increased the value of the imported content by a significant amount (circa £500,000). Scottish-based companies were responsible for the structure, groundworks, ventilation system, lighting, and installation of equipment, as well as the building connections. However, the proportion of the Scottish value in building connections was less because equipment represented a larger part of the costs.

While most pipes used in Scottish networks are imported, the AMIDS network uses uninsulated plastic pipes from England.

**Torry Heat Network**

The installation, construction, design, and feasibility have generally been performed by Scottish-based companies. According to Aberdeen City Council and Vital Energi, most equipment was imported. The trench excavation and tunnelling works, which represent a significant portion of the total cost, were done by Scotland-based companies. Builder works, ventilation, mechanical and electrical installation, and various other services were mainly performed by Scottish companies, and to a lesser extent English companies.

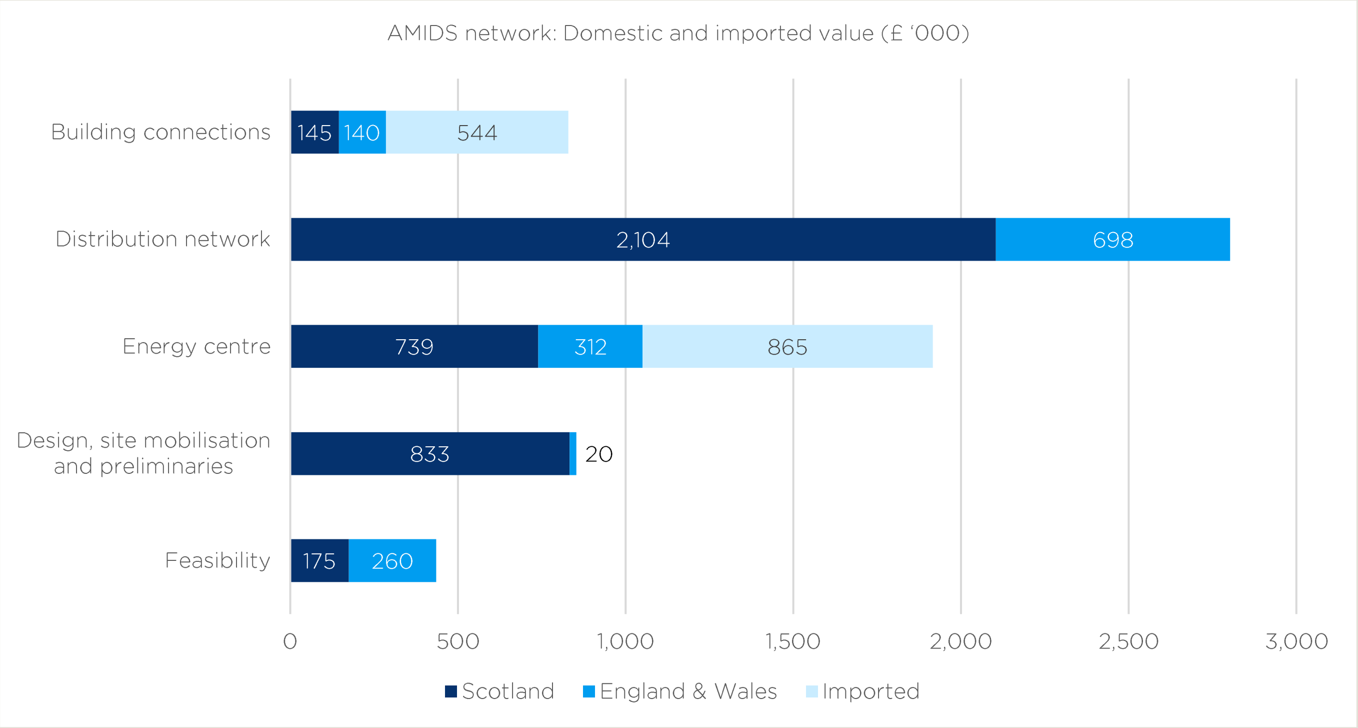



Figure 43 – Breakdown of the Scottish, English & Welsh, and imported value of phase 1 of the AMIDS heat network



Note: The analysis on this page is limited by data availability. Quantitative data has been provided from the AMIDS network and qualitative data for the Torry Heat Network.

# 5GDHC in New York State | Background

The costs presented in this section are based on a feasibility study that Ramboll recently conducted for a US college campus. Part of the scope of the study was to develop a concept design for a 5GDHC network as well as investigate the operational and capital costs. Ramboll's design consisted of 4 main elements:

- 5GDHC substations – Equipped with WSHPs, electric and gas boilers, thermal stores, and bidirectional pumping system.
- Borehole thermal energy storage – A large borehole field to thermally balance the network.
- Balancing unit – Centralized ASHPs to add additional thermal balancing to the network.
- Distribution network – Uninsulated plastic pipework to transport the low-grade heat and cooling to the substations.

A simple schematic of the network is presented in Figure 27. The heating and cooling demand of the connected buildings is highly seasonal, meaning that the heat demand dominates in winter and vice versa in summer. To maintain reasonable temperatures in the network, a large borehole field and a centralized ASHP plant have been incorporated into the design. The borehole field can seasonally regulate the network temperatures by absorbing the excess cooling from the WSHPs in winter and releasing it during the summer when excess heat is produced. The ASHP plant supplies additional heat or cooling in shoulder seasons and acts as a top-up in case imbalances are particularly great.

The proposed network consisted of 34 buildings (and 34 substations) with a total heat and cooling demand of 25,500 MWh and 4,454 MWh, respectively. Most of the buildings were lecture halls, libraries, and other educational facilities. The design considered using the existing building plant rooms to house the new 5GDHC substations.

The substation level WSHPs were sized to cover the baseload of the heat demand (around 85% of the annual demand) while the electric boilers were sized to be utilized as top-up. Gas boilers are intended to function as backups to increase the resiliency of the heat supply. Thermal stores were sized and installed to allow for better operation of the WSHPs. The bidirectional pumping system allows the substation to extract and inject water into the 2-pipe ambient temperature distribution network.

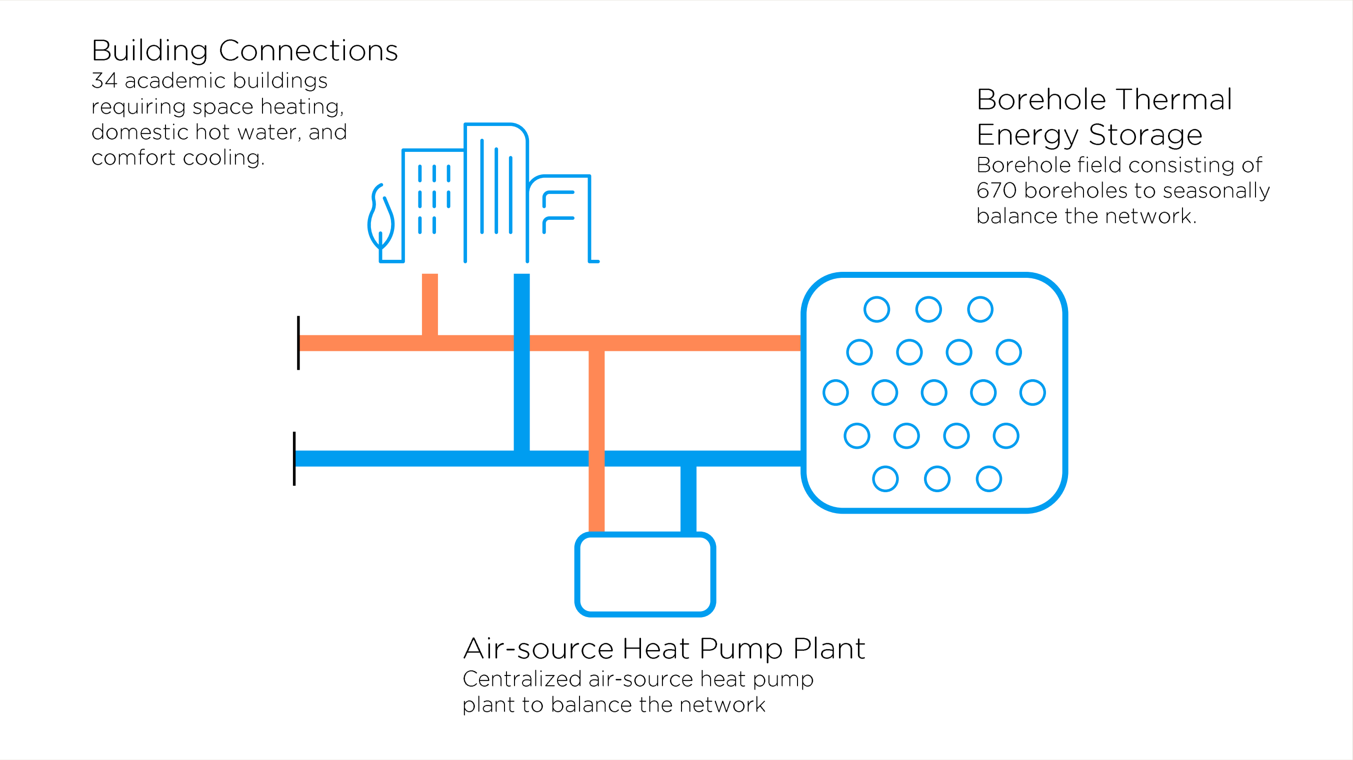



Figure 27 – Conceptual overview of the 5GDHC network



Note: The CAPEX of the system was prepared by an external cost consultancy company (with input from Ramboll). All costs were originally provided in USD.

# 5GDHC in New York State | Total Cost

The total cost of the system – only including equipment and labour, not uplifts – was approximately £46 million. A breakdown of the costs is presented in Figure 28. Including uplifts – such as overhead, profit margin, and contingencies – the cost was circa £81 million. Focusing on the cost of materials and labour, the single biggest cost was the 5GDHC energy substations, where the WSHPs, boilers, and short-term thermal storage are located, making up approximately 60% of the total cost. Another substantial cost of the system was the seasonal thermal energy storage, consisting of 670 boreholes which store a total of 3,900 MWh of heating and cooling annually. 40% of the cost of the seasonal thermal energy storage was the labour associated with installing it.

The distribution network made of uninsulated plastic pipes represents 12% of the total equipment and labour cost (£5.4 million). The proposed network is 8,977 m long, consisting of pipes in the range of DN30 – DN400. The cost of the pipework makes up 52% of the total cost of the distribution network, while installation and excavation amounted to 31% and 18%, respectively. The total cost is 606£/m. At 18%, the excavation cost makes up a significantly smaller share than indicated by other data analysed in this study (see previous section: Distribution Network). This highlights the high variability of excavation costs depending on project conditions, particularly ground conditions. It should also be noted that this project is in the US, where wages and other factors may differ from the Scottish context.

The smallest fraction of the total cost of labour and material was associated with the centralized ASHP plant (balancing unit). The cost of the plant is estimated to be £2.9 million, approximately 6% of the total cost.

Figure 29 shows a breakdown of the different cost elements of the substations. The cost of replacing existing plant room equipment and space additions represented a large part of the total cost (approximately 54%). The second largest cost was linked to the WSHPs, representing approximately 13% of the costs. Backup gas boilers and electrical infrastructure upgrades are also substantial at 11% and 9%, respectively.

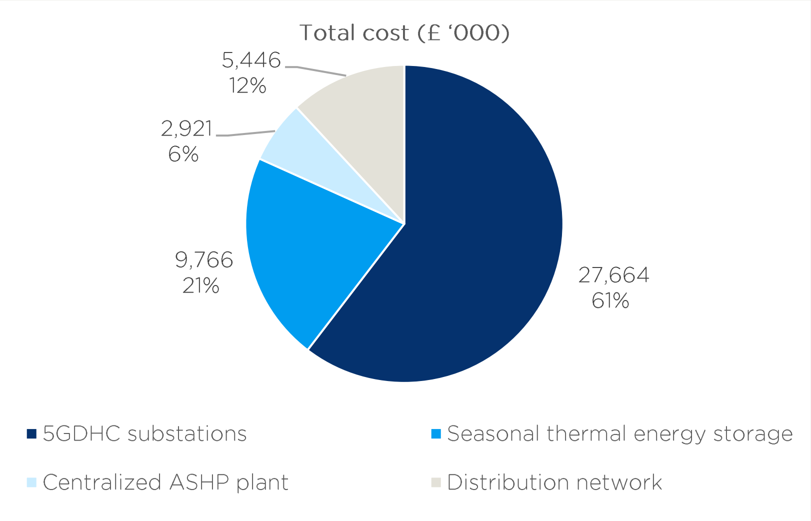



Figure 28 – Total material and labour cost

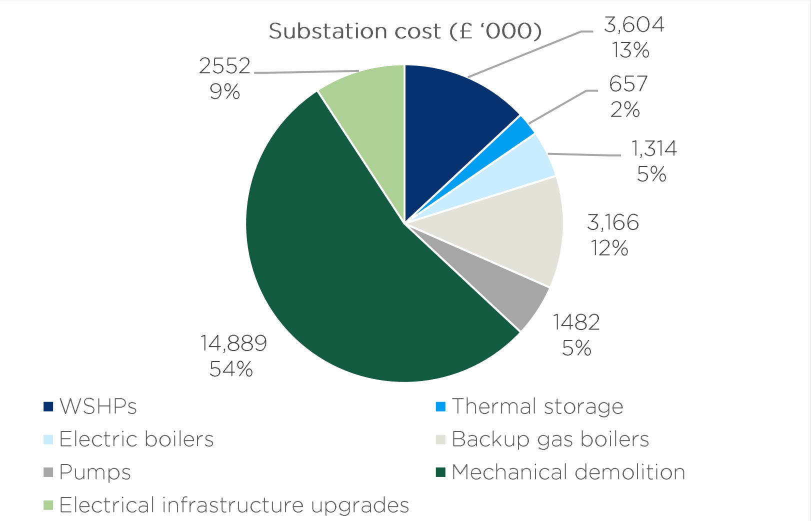



Figure 29 – Cost breakdown of the 5GDHC energy substations



Contents

# 5GDHC in New York State | A closer look at the 5GDHC energy substations

One of the distinguishing elements that separates 5GDHC from the earlier DH generations is the energy substation. In earlier generations, the substation functions as a heat transfer unit, transferring the heat from the distribution network to the connected building. 5GDHC substations produce usable heat by utilising the distribution network as a source of low-grade thermal energy. Therefore, 5GDHC substations can be described as decentralized energy centres. The equipment of the substation will vary depending on the connected building(s) but in this particular case, all substations consist of WSHPs, bidirectional pump systems, electric and gas boilers, and thermal stores. To analyse the cost of the substations in a more generalized manner, we will exclude the cost of the demolition and space addition.

The pie chart in Figure 32 presents the distribution of the costs (excluding demolition and space addition) of the substations. The installation cost represents the total cost of installing all equipment in the plant room and makes up 36% of the costs. The WSHPs proved to be the most considerable equipment cost, followed by the backup gas boilers. The electric boilers and the bidirectional pump system represented 8% and 7%, respectively. The thermal stores were by far the smallest expenditure, only making up 4% of the costs.

An important aspect of district heating is the economy of scale effect. Typically, the cost per kW of an energy centre (£/kW installed capacity) decreases according to installed capacity, making larger energy centres more cost-effective. Since 5GDHC substations can be likened to an energy centre, the installed capacity of all substations was plotted against their cost per kW. The result of this exercise can be found in Figure 30. The graph displays a clear relationship between the installed capacity and cost per kW. Substations with less than 200kW installed capacity are significantly more expensive on a £/kW basis, ranging from 1,000 to 2,000 £/kW compared to larger substations. Based on the findings in Figure 30, the substations have been divided into three categories: small (<200kW), medium (200-400kW), and large (>400kW). The average cost per kW of a small, medium, and large substation is presented in Figure 31. The cost per kW of a large substation is 64% lower compared to a small substation and approximately 40% lower compared to a medium substation. Please note that these costs only include the equipment and installation costs.

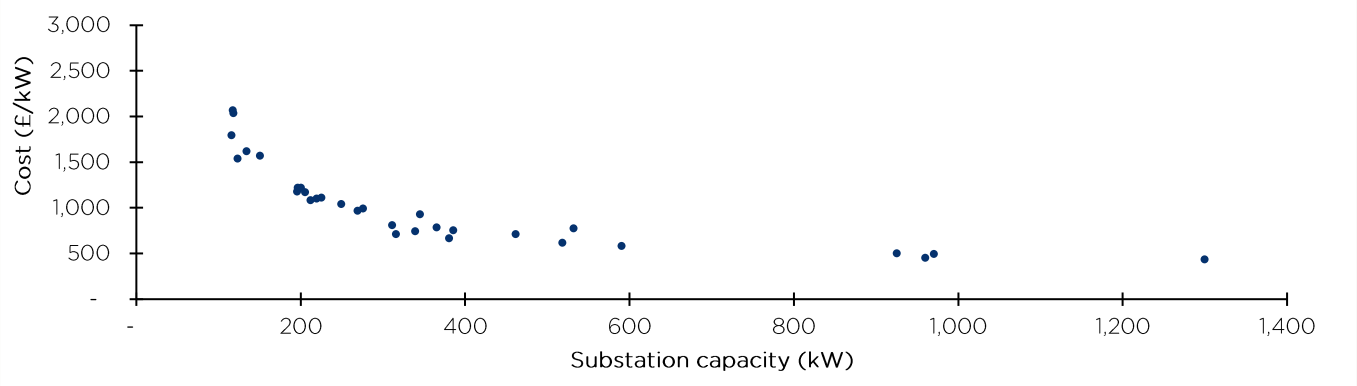



Figure 30 – The cost per kW plotted against the installed capacity of the substations

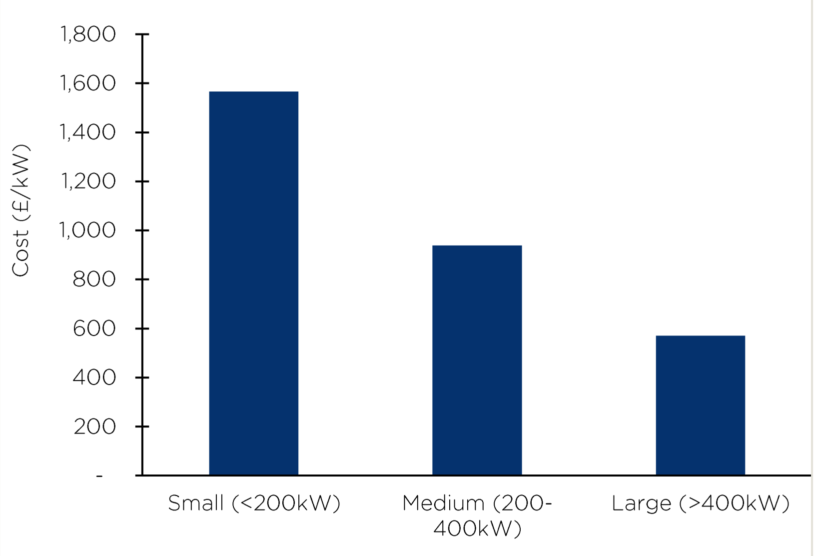



Figure 31 – Cost of substation considering the installed capacity

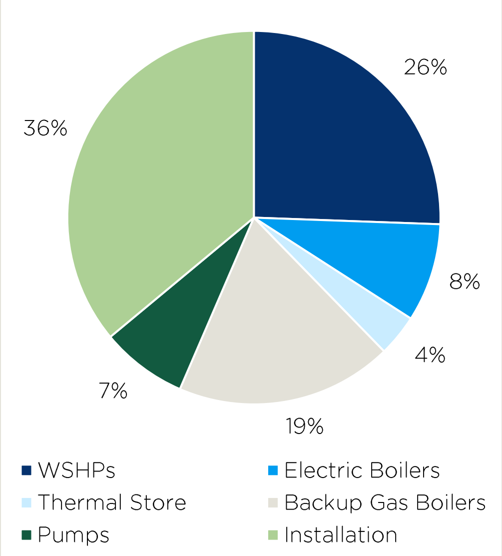



Figure 32 – Breakdown of the substation cost (excluding space addition and demolition)

# Case studies | Existing networks – additional data

The development of district heating networks in Scotland is part of a wider strategy to reduce carbon emissions and tackle climate change. The Scottish Government has set ambitious targets to achieve net-zero greenhouse gas emissions by 2045, and district heating is seen as a key part of the solution. To achieve this goal, the Scottish Government has provided funding and support for the development of new heat networks, as well as for the expansion and improvement of existing ones. The table below summarises the capital costs of five networks that have received funding from the Scottish Government.
The heat networks sector in Scotland is at the start of growth, and this impacts the cost of delivering new networks. Many networks, including the Torry, AMIDS, and Stirling networks, have been deliberately oversized to allow for future expansion. This leads to a higher cost per kW when compared with networks in more mature markets, such as the Nordics.

| Network | Generation | Capacity | Description | Energy centre | Distribution network | Building connections | Other costs | Total cost |
|---|---|---|---|---|---|---|---|---|
| **Torry Phase 1 (Aberdeen City Council)** | 10MW | 3G | A new district heating network is developed, distributing heat from a Heat Distribution Facility at Tullos Recycling Centre and a heat offtake facility at the new energy-from-waste plant at Tullos. The project will link to the existing Heatnet district heat network to provide additional connections to domestic, local authority and third-sector customers, including Tullos Primary School. | £3.2 million | £5.9 million | £1.5 million | £1.9 million | **£12.5 million** |
| **Stirling Council** | n.a. | 4G | A new energy centre and district heating network were developed in the Forthside area of Stirling providing low-carbon heat to multiple end users, such as The Peak Leisure Centre, Forthbank Stadium, Enterprise House and St Modan's High School. The project combines a fuel cell, heat recovery system from Stirling Wastewater Treatment Plant (WWTP) and a heat pump to supply heat to the new district heat network. | *n.a.* | *n.a.* | *n.a.* | *n.a.* | **£3.4 million** |
| **AMIDS (Renfrewshire Council)** | 4MW (10MW at full build-out) | 5G | Renfrewshire Council has constructed a state-of-the-art, low-carbon heating network at the Advanced Manufacturing Innovation District Scotland (AMIDS). The first of its kind in Scotland, this 5th generation renewable energy network works by directing treated water into a new energy centre, where low-temperature heat is extracted and channelled through a 3.7km underground pipe loop. Heat pumps at each building upgrade this heat to suitable levels for heating and hot water. | £2.0 million | £2.8 million | £0.8 million | £1.7 million | **£6.9 million** |
| **Millerhill (Midlothian Council)** | 20MW | 4G | An exemplary low-carbon DH network will be installed at the new, emerging town of Shawfair using heat from the Millerhill energy-from-waste plant to deliver heat to the first plots of the Shawfair development. This initial network will be capable of expansion into the wider Midlothian, East Lothian and Edinburgh areas. A joint venture ESCO between Midlothian Council, Vattenfall Heat UK and Midlothian Energy Limited has been established. | £12.6 million | £19.6 million | £2.1 million | £17.3 million | **£51.6 million** |
| **Glenrothes (Fife Council)** | 4MW (6MW at full build-out) | 4G* | This heat network utilises steam produced from the RWE CHP biomass plant to provide heat to a range of customers including a theatre complex, 33 homes comprising very sheltered housing, 9 business units and Fife Council's corporate headquarters. The project demonstrates the potential of unused existing infrastructure for heat networks, with the heat output from the RWE Markinch Biomass plant repurposed for district heating. It also demonstrates how the relative strengths of the public and private sectors can be combined through partnering, in tackling climate change. Back-up boilers help meet peak demand. | £12.1 million | £7.6 million | *n.a.* | *n.a.* | **£19.7 million** (This may exclude fees) |

Source: Information on the networks has been provided by the Heat Network Fund (Heat & Energy Efficiency Scotland). Cost information for each network has been provided by the relevant network. * While not explicitly stated in Vital Energi's description of the project, the Glenrothes project is classified as 4G in this report, as the network utilises waste heat.


Contents

# Supply chain analysis

The supply chain for heat networks includes many niche markets which have the potential to grow as the demand for heat networks increases with a positive regulatory environment and new funding.

### Current levels of Scottish content

- The area with the most Scottish content is in the construction and installation of heat networks due to local construction companies being contracted and/or subcontracted to carry out certain phases of installation (e.g. civil works and groundworks).
- Scottish companies are well-represented in the ESCO market due to the presence of local authority (LA) operated networks. However, contracts for district-scale networks tend to be operated by international firms (e.g. Vattenfall) who have the necessary resources, capital, experience and risk appetite.
- There are a limited number of Scottish companies manufacturing equipment such as heat pumps, heat exchangers, and thermal storage. For the companies manufacturing in this space, there is potential to expand and sell their products to the wider UK DH market with supporting financial incentives.
- Thanks to a robust energy sector and excellent research institutes, Scotland's engineering services are world-leading. Scottish heat network engineers tend to work for international companies, which builds the skill level in Scotland. However, there is strong competition for expertise in this market due to the high demand for M&E services.

### Import substitution

- Most components for heat networks are imported from the US, Denmark and Germany, and this study identifies significant market entry barriers for Scottish companies. Existing technologies are dominated by well-known international companies that can manufacture at large scale at competitive prices and whose products have become industry standard for designers. As a result of this, interventions are required to support Scottish manufacturers who are in the supply chain.

### Growth potential

- Historically, connection uncertainty and lack of demand have hindered the growth of heat networks. The Scottish Government is addressing this with a comprehensive package of regulations to support heat network development. Powers such as zoning and attractive financial support (£300 million of public funding) also provide a strong context to support the growth of Scotland's heat network sector.
- Scotland is advantageously positioned to supply specialist skills (e.g. welding) due to these skills being present in the oil and gas industry.

**KEY TAKE-AWAYS**

- There are substantial resources and significant growth potential for constructing and installing networks in Scotland. Numerous Scottish companies are engaged in these projects.
- Skills and competencies within the O&G sector are transferable to the heat network sector. This includes expertise in welding and joining pipes, proficiency in project management, and the capability for prefabricating structures.
- While the majority of heat network equipment is imported into Scotland, there are several prominent manufacturers with the potential to grow and supply to the UK district heating market. Providing financial incentives and removing wider market barriers would support this.

# Introduction to supply chain analysis

## Supply chain analysis

The supply chain analysis breaks the supply chain into six areas; operators and ESCOs (energy service companies), engineering services, electric boilers, heat pumps, pipework, other equipment manufacturers and construction companies. The following information is provided:

- A short analysis of the companies and key capabilities
- A categorisation of companies by size; SME (<250 employees) or Large Enterprise (>250 employees)
- Overview of companies currently winning contracts in Scotland/UK
- An indication of whether the equipment is manufactured locally or imported, and if imported where it is imported from
- A conclusion summarising current levels of Scottish content, import substitution and growth potential for Scottish companies across Scotland and the wider UK.

This analysis is high-level and does not present an exhaustive list of companies delivering heat networks or manufacturing components for heat networks in Scotland.

Further research and in-depth analysis will be conducted by Scottish Enterprise to further understand the supply chain and the opportunities that exist for Scotland.

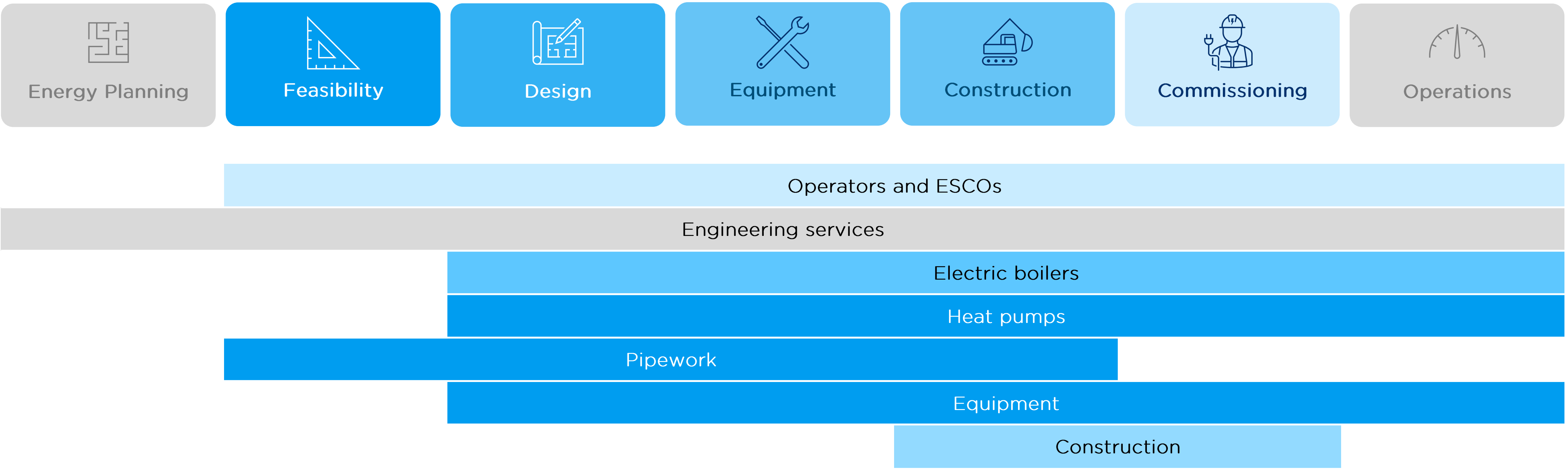
## Policy and regulation

The opportunities for growth in the supply chain need to be understood in the context of a changing policy and regulatory environment, anticipated to greatly grow the sector:

- The Scottish Parliament has set ambitious targets for decarbonizing heat within the Scottish Economy. The statutory targets are for the amount of heat (and cooling) to be supplied by heat networks to reach 2.6TWh of output by 2027, 6TWh of output by 2030 and 7 TWh of output by 2035. These figures are equivalent to around 3%, 8% and 9% of Scotland's non-electrical heat consumption, respectively, compared to the current level of about 1.5%.
- To achieve these goals, the Scottish Government is developing a comprehensive package of regulations to support heat networks using powers introduced by the 2021 Heat Network (Scotland) Act and continues to work with the UK Government to give consumers more confidence in heat networks through the development of regulations, under the UK Energy Act 2021, to deliver protections for all heat network consumers in Great Britain. A key aim is to make Scottish regulations interoperable and, where appropriate, aligned with UK Government regulations.
- Scottish Government is also consulting on proposals for further regulatory interventions (a proposed Heat in Building Bill) to promote the transition to fossil fuel-free heating sources, including the expansion of low-carbon heat networks. If implemented, these proposals will enforce a ban on fossil fuel heating by 2045 and introduce regulatory trigger points requiring a shift away from fossil fuel heating at the point of property sale from around 2028.
- In addition to the proposed regulatory heat and energy efficiency standard, the Scottish Government is also proposing measures to safeguard heat network development. Proposed allowances for properties within designated heat network zones would be triggered by regulations, allowing them to wait until heat network infrastructure is available. Local authorities would also be granted powers to require certain buildings in a designated heat network zone to connect earlier. These measures collectively aim to advance Scotland's transition to a more sustainable and environmentally friendly heating system.
- This, alongside attractive financial support, with £300 million of public funding available to support heat network projects in this parliamentary term, provides a strong context to support the growth of Scotland's heat network sector.

# Introduction to supply chain analysis

**Supply chain analysis**
The diagram below illustrates how the supply chain interacts with different phases of heat network development. Some companies provide services and/or components across different areas of heat network development, which means they fit into multiple categories of this analysis. To avoid repetition and present as many companies as possible, the analysis will assign each company to a single area.



# Supplier overview | Operators & ESCOs

## Both international and Scottish companies operate heat networks in Scotland

**Supplier landscape and key capabilities**

The supplier landscape for ESCOs is a mix of large, multinational companies, local authority (LA) run networks, and smaller companies operating small schemes. In general, the size of the opportunity, the contractual preferences and the objectives of the LA influence who wins contracts and who is supplying the market.

For district-scale heat networks, the ESCO market is dominated by large multinational companies due to their expertise and reputation (e.g. Vattenfall, Hemiko, Vital Energi). Vattenfall is winning bids and delivering heat networks in Scotland, having recently entered a joint venture with Midlothian council at Granton, and Vital Energi operates the Queens Quay network in Scotland. The key capabilities of these companies are their experience in running networks, large amounts of capital, a high risk appetite and a reputation for being a reliable partner - important factors for the operation of long-term, expensive infrastructure projects like heat networks. These factors make it difficult for new entrants in the ESCO market.

In terms of large private Scottish ESCOs, SSE, who own and operate 18 heat and cooling networks across the UK demonstrate that there is potential for energy companies to move across sectors. Small energy companies may operate small networks, like Recirc Energy (an equipment supplier) which owns and operates a WWHR system in Tweedbank.

In addition to this, there are examples of LA ESCOs across Scotland. Dundee has four heat networks which are owned by Dundee City Council. Fife, Edinburgh, Stirling and Shetland similarly have LA-owned networks. Many university schemes are operated by the university, rather than contracting operations out. Some examples include the University of Dundee and the University of Edinburgh. Other types of ESCO models exist, such as Aberdeen Heat & Power which is public sector-owned but now operates as a not-for-profit organisation.

| Company | Description | Headquarters | Offices in Scotland |
|---|---|---|---|
| VATTENFALL | Vattenfall is a Swedish ESCO with experience in the construction and operation of heat networks. They've also entered a 50/50 joint venture with Midlothian council for green energy projects and are developing a district-scale heat network at Granton<br>*Large Enterprise* | Sweden | Yes |
| HEMIKO | Hemiko (formerly Pinnacle) is a British ESCO with experience in a wide range of projects. Actively looking for contracts to build and operate large networks in Scotland.<br>*Large Enterprise* | UK | No |
| sse | Leading generator of renewable electricity. Develop, own and operate low carbon infrastructure. SSE has SSE Heat Networks can design, build and/or takeover heating and cooling networks. They currently have 18 operational heat networks across the UK<br>*Large Enterprise* | UK (Scotland) | Yes |
| VITAL ENERGi | A British ESCO that is engaged in a number of projects across the UK including several projects with Scottish Universities and councils.<br>*Large Enterprise* | UK | Yes |
| Aberdeen Heat & Power | Not-for-profit enterprise, organised as a company limited by guarantee. Established by Aberdeen City Council connecting residential and commercial buildings.<br>*SME* | UK (Scotland) | Yes |
| EQUANS | A French ESCO with wide ranging expertise. Has existing projects with cities all over the UK including Southampton, Coventry and Birmingham.<br>*Large Enterprise* | France | Yes |

# Supplier overview | Engineering services

## Engineering services are supplied by the Scottish divisions of international firms

### Supplier landscape and key capabilities

Scotland has a strong presence in engineering services linked to its energy sector and excellent research capabilities. This has led to Scotland being an attractive market for multi-national engineering firms such as the ones presented here. Most of these firms are multi-disciplinary and have heat network teams who offer similar skills and services across different phases of network development, as well as heat network-related policy services and advice. These companies have all been involved in network development across Scotland.

The key capabilities of these firms are heat mapping, feasibility studies, techno-economic modelling, pipe routing, design, network optimisation, and project management skills. Furthermore, some firms have access to international teams in countries where heat networks are well established, such as the Nordics (e.g. Ramboll, Arcadis). These firms train Scottish engineers and provide them with the expertise and experience which is difficult to find in a niche sector. Joint bidding for contracts is a useful method for bringing in well-established and smaller companies onto heat network projects.

Two Scottish firms have been identified that are winning contracts for network development. First, Synergie Environ is one of the engineering companies with a legacy in oil and gas that are transitioning into low-carbon technologies. Second, Hulley and Kirkwood are a Scottish building and services consultancy and demonstrate that there may be opportunities for firms not obviously linked to heat networks to move into this area.

A barrier across this area of the supply chain for all companies is that M&E engineering design services are in high demand in the market, and it is challenging to attract engineering expertise to work in the heat networks sector as it is currently niche.

| Company | Description | Headquarters | Offices in Scotland |
|---|---|---|---|
| Mott MacDonald | UK based engineering company with two offices in Scotland. Currently the client engineer for the Heat Networks Fund Scotland and Social Housing Heat Network Fund. *Large Enterprise* | UK | Yes |
| ARUP | Policy development, heat mapping and capacity building, feasibility and techno-economic modelling to detailed design, financial modelling, commercial structuring, procurement and contract advice and procurement management. *Large Enterprise* | UK | Yes |
| AECOM | Heat network design , techno-economic modelling, design, planning and construction and project management *Large Enterprise* | US | Yes |
| Synergie Environ | Involved in the development of district heating networks for over 20 years for public and private sector clients. Offer early stage of network development, business case, network design and full project management over the project lifecycle. *SME* | UK (Scotland) | Yes |
| Hulley & Kirkwood | Independent building Services Consultancy providing national coverage specialising in all aspects of Mechanical, Electrical, Public Health and Sustainable Design services *SME* | UK (Scotland) | Yes |
| Ramboll | Heat mapping, feasibility studies, techno-economic modelling, pipe routing, design, network optimisation, project management. *Large Enterprise* | Denmark | Yes |
| Buro Happold | Multi-disciplinary energy consulting team. Buro Happold have been involved in heat network zoning in Scotland *Large Enterprise* | UK | Yes |
| WSP | Multi-disciplinary engineering consultancy. WSP's heat networks specialists provide feasibility, design, procurement support and technical advisory services. *Large Enterprise* | Canada | Yes |

# Supplier overview | Electric Boilers

## Typically imported from small, specialised companies in the Nordics and Germany

**Supplier landscape and key capabilities**

This overview presents UK companies which distribute electric boilers manufactured abroad and companies which manufacture industrial electric boilers. Our analysis indicates that most electric boilers used in heat networks are imported. Manufacturing is mostly in Denmark, the United States, Switzerland, Germany, and Norway.

The market is characterised by several relatively small firms without the presence of multinational conglomerates. This indicates lower barriers to entry for Scottish companies, as the economies of scale are less significant than areas of the supply chain dominated by multinationals. However, as companies are highly specialised and trusted by developers, this may be a barrier to entry for potential new suppliers.

The key capabilities of these companies vary based on their specific products. However, efficiency, safety standards, installation services, maintenance and repairs, customization, smart technology integration, customer support and warranty and guarantee are important. Significant know-how is required to produce boilers, and they are often sold as turn-key solutions

Cochran, a Scottish company in Dumfries and Galloway, manufactures industrial steam, hot water, and heat recovery boilers. They sell their boilers worldwide and are well-known in the UK DH market. They also provide services to run, watch, and maintain entire boiler plants, offering reassurance to operators. While they don't produce electric boilers, their products can be part of a low-carbon heat network, making them a crucial player in this part of the supply chain.

| Company | Description | Headquarters | Manufacturing |
|---|---|---|---|
| FLEXIHEAT UK LTD | English distributor of German-made boilers (Kroll energy)<br>*SME (Medium sized enterprise)* | England | Germany |
| VINOPOWER ELECTRIFICATION SOLUTIONS | Danish manufacturer of electric boilers<br>*SME (Medium sized enterprise)* | Denmark | Denmark |
| Fulton | American manufacturer with UK manufacturing capabilities<br>*SME (Medium sized enterprise)* | US | Global* |
| VAPEC | Swiss manufacturer of industrial electric boilers<br>*SME (Medium sized enterprise)* | Switzerland | Switzerland |
| WORCESTER BOSCH | English manufacturer owned by German group, Bosch. Bosch is a multinational engineering firm headquartered in Germany.<br>*Large Corporation* | Germany | England |
| PARAT | Norwegian manufacturer, subsidiary of Babcock Wanson, a French multinational heating solutions firm<br>*SME (Medium sized enterprise)* | Norway | Norway |
| COCHRAN | Global Specialists in Manufacturing & Supplying Industrial Steam & Hot Water Boilers (not electric boilers)<br>*SME (Medium sized enterprise)* | UK (Scotland) | Scotland |

* Global manufacturing refers to manufacturing taking place in multiple countries

# Supplier overview | Large-scale heat pumps

## Most are imported by large, multinational conglomerates and distributed by local companies

### Supplier landscape and key capabilities

The market for heat pumps is dominated by large multinational conglomerates based in the US, Japan, Germany and Denmark. The size of these companies constitutes a barrier to entry for Scottish companies due to significant economies of scale. Furthermore, some of these firms are likely to be the preferred suppliers for ESCOs and network designers, who are familiar with their operations.

Nonetheless, there are companies successfully manufacturing heat pumps in Scotland and the UK. The presence of STAR, a Scotland-based heat pump manufacturer, indicates that Scottish companies are able to compete in this space. STAR's industrial-scale water-source heat pump is currently used in the Queens Quay Heat Network operated by Vital Energi in Glasgow. Other UK-based heat pump manufacturers include CLADE and Pure Thermal.

There are many important key capabilities of large-scale heat pump manufacturers. These include; reliability and durability, ease of installation, service and maintenance, smart technology and renewable energy source integration, customer support and technology innovation. The precise capabilities required depends on the network.

In previous interviews completed by Ramboll for Scottish Enterprise, heat pump manufacturers discussed wider energy market trends which are barriers to growth. These include individual gas boilers being cheaper than connecting to heat networks, and the high costs of electricity due to the structure of electricity charges and taxes. Growth is expected in this sector as Scottish Government legislation and policies begin to addresses these wider energy market issues.

| Company | Description | Headquarters | Manufacturing |
|---|---|---|---|
| CLADE | English manufacturer specialising in natural refrigerant heat pumps<br>*SME* | UK | UK |
| pure THERMAL | English manufacturer specialising in natural refrigerant heat pumps<br>*SME* | UK | UK |
| STAR REFRIGERATION | A Scottish heating solutions firm manufacturing heat pumps.<br>*Medium-large Corporation* | UK (Scotland) | Scotland |
| TRANE | World leader in air conditioning systems, services and solutions, including heat pump systems<br>*Large Corporation* | Ireland | Global* |
| Johnson Controls | Designs, manufactures, and installs water-source and air-source heat pumps and HVAC products . Johnson Controls took over Fisher Group (HVAC) in Cumbernauld.<br>*Large Corporation* | Germany | Global* |
| Bitzer | German heat pump manufacturer<br>*Large Corporation* | Germany | Global* |
| Carrier | US-based heat pump manufacturer supplying water-source heat pumps<br>*Large Corporation* | US | Global* |

* Global manufacturing refers to manufacturing taking place in multiple countries

# Supplier overview | Pipework

## Highly monopolised niche market with most pipework imported

### Supplier landscape and key capabilities

The manufacturing of steel 4G pipework is a highly specialised process involving sophisticated methods of sealing, welding and joining to prevent leaks and ensure the insulation is stable. Leak detection software may be added to the pipes to ensure the system is running efficiently and to quickly locate and fix issues. Scotland has these capabilities in the oil and gas industry as oil pipelines have the same welding and joining requirements. Currently, wages in oil and gas are higher than in heat networks and this presents a barrier to the transfer of these skills.

The 4G pre-insulated steel pipework market is dominated by Isoplus and Kingspan Logstor. Isoplus and Logstor have supplied many projects across the UK. For example, they provided pre-insulated pipes to the upgrade of the Glasgow University District Heating Network. Logstor provided pipes for the Aberdeen Heat and Power Project.

High repair costs and disruption caused by repairing installed pipework drives customer demand for high-quality, reliable products. The market is also driven by specifications, typically set by designers, which can favour existing, well-known manufacturers.

Specialist pipework suppliers and installers have also been included in this category. Therma Mech is an exclusive buyer of premium piping products and states that it has contracts in place to provide for any specification. These companies offer design work, installation, specialist welding and joining as well as testing and commissioning.

There is potential for entry of Scottish firms in standard, low-technical pipework, such as plastic pipework for a 5G network.

| Company | Description | Headquarters | Manufacturing |
|---|---|---|---|
| aquatherm | A leading manufacturer of polypropylene pipe systems.<br>*Large Corporation* | Germany | Germany |
| LOGSTOR / Kingspan | Logstor is a Danish world-leading manufacturer of district heating solutions and pre-insulated pipe systems. They were acquired by Kingspan, an Irish conglomerate with 212 manufacturing sites across the globe.<br>*Large Corporation* | Ireland | Global* |
| isoplus | Danish manufacturer of district heating solutions and pre-insulated pipe systems.<br>*Large Corporation* | Denmark | Denmark |
| REHAU | German polymer solutions specialist with experience in creating pipework solutions for district heating.<br>*Large Corporation* | Germany | Germany |
| POWERPIPE MADE IN SWEDEN | Manufacturers of pre-insulated district heating pipes in Sweden. Specialise in vacuum-insulated district heating pipes and efficient peripherals.<br>*Large Corporation* | Sweden | Sweden |
| trentENERGY | Supply pre-insulated pipework, in-house capability to carry out pipe related civil engineering works, welding and joining (class 1 welders), testing and commissioning of pipework and leak and maintenance repair.<br>*SME* | UK | *N/A (specialist supplier & installer)* |
| Therma Mech | Specialist suppliers who also offer design services, commissioning, maintenance and repair. Currently working with 1 Energy in Exeter.<br>*SME* | UK | *N/A (specialist supplier & installer)* |

* Global manufacturing refers to manufacturing taking place in multiple countries.

# Supplier overview | Equipment manufacturers

## Large firms with some small Scottish entrants

**Supplier landscape and key capabilities**

There are many components in heat networks such as pumps, thermal stores, control components, valves, heat recovery systems and heat exchangers. This equipment is mostly imported into Scotland from companies based in Denmark, Germany and Canada. This overview presents the market leaders providing components for heat networks across the UK. Of these firms, Danfoss is the only firm to have an office in Scotland and have invested in manufacturing facilities, although for a different market (transport sector).

Armstrong specialises in fluid management systems (FMS) and has worked with Vital Energi at the Riverside Dene Estate network in Newcastle, installing an FMS with integrated controls.

Hartwell was contracted by E.ON to design, fabricate and install an exhaust system for the energy centre at Westfield heat network in London. They have also worked with Aberdeen Hospital. An important capability of Hartwell is that its equipment (e.g. energy centre) can be pre-fabricated and therefore quickly installed on site, reducing cost and disturbance. The oil and gas industry requires similar pre-fabrication of equipment, and there may therefore be transferable skills for pre-fabricating energy centres.

In general, the companies listed have economies of scale, established relationships with major ESCOs, and their products might be preferred by designers and therefore designed into networks. For these reasons, it is difficult for new entrants to compete with the incumbents. However, certain companies, such as Recirc Energy who specialise in sewer heat recovery, are market leaders and demonstrate the opportunity for Scottish firms in very niche areas.

| Company | Description | Headquarters | Manufacturing |
|---|---|---|---|
| ARMSTRONG | Specialises in fluid technologies for HVAC. Carries out the design, engineering and manufacturing of intelligent fluid flow equipment, control solutions and optimization technologies.<br>*Large Corporation* | Canada | 8 facilities across 4 continents |
| GRUNDFOS | Danish pump specialist and manufacturer<br>*Large Corporation* | Denmark | Global |
| SIEMENS | German Technology conglomerate, production of electronic control components for heat networks.<br>*Large Corporation* | Germany | Global |
| Danfoss | Danish engineering firm with wide ranging capabilities including valve manufacturing<br>*Large Corporation* | Denmark | Global |
| Hartwell Manufacturing & Mechanical Services | Major international provider of industrial process heating equipment and solutions, including boilers, heat recovery systems<br>*Large Corporation* | France | Global |
| Recirc Energy | Wastewater heat recover specialists offering (amongst other) end-to-end, turn-key design service, sewer agreements, project management, installation services, operation and maintenance services.<br>*Medium sized enterprise active in Scotland (Stirling, Campbeltown) and exporting internationally (US)* | UK (Scotland) | n.a. |
| Noventa | Small Canadian sewage heat recovery system provider and HVAC specialist. Noventa have registered a company in Scotland.<br>*SME* | Canada | Canada |

* Global manufacturing refers to manufacturing taking place in multiple countries.

# Supplier overview | Construction companies

## The majority of construction work is done by Scottish companies

### Supplier landscape and key capabilities

The construction of heat networks is often contracted out by the ESCO/LA to large, well-known construction companies. Prime contractors (e.g. Balfour Beatty, FES) often win major contracts due to their experience and capacity to bid for this scale of work. Their key capabilities are; project management, regulatory compliance, quality control, and experience and track record. The management of risk, safety, contracts, supply chains and scheduling is also important.

There are many opportunities in this area of the supply chain for local subcontractors, such as the Purvis group who have key capabilities in civil works and groundworks. These are generally non-specialised small/medium-sized local construction firms. Utility firms such as WPS have also been contracted for groundwork due to their expertise in trenching. Scottish Water Horizons, though not a construction company, was involved in the installation of two heat-from-wastewater schemes in Stirling and Galshields.

Local pipe fitters, electricians and plumbing companies can be employed to carry out building connection works including installing substations and connecting energy centres. There is therefore good local potential for Scottish companies in this area of the supply chain due to the strength of these vocational skills in Scotland.

More specialised suppliers in this area of the supply chain are welders and joiners, who must be certified. The presence of welders and joiners in the oil and gas industry means that Scotland has good local potential to fulfil this highly specialised work. However, wages within the heat network industry are not competitive against those in oil and gas. As a result, welders are often brought in from across the UK.

| Company | Description | Headquarters | Offices in Scotland | Principle or sub-contractor |
|---|---|---|---|---|
| Hitachi Zosen INOVA | Engineering, procurement and contractors. Specialise in EfW. Constructed the South Clyde energy centre in Glasgow and Westfield energy centre in Fife. Currently have 19 contracts across the UK. *Large Enterprise* | Switzerland | Yes | Principle contractor |
| Clugston / CNIM Innovate and Act | Franco-British joint venture composed of CNIM, expert in waste-to-energy technologies, and engineering firm Clugtson. Contractor for the Earls Gate Waste-to-Energy plant in Grangemouth Scotland. *Large Enterprise* | France, UK | Yes | Principle contractor |
| Balfour Beatty | Constructed the energy centre in Gateshead, Newcastle and was appointed the construction partner for the Glenrothes network. *Large Enterprise* | UK | Yes | Principle contractor |
| FES | Construction services and installation of low-carbon heat schemes. FES can prefabricate and test energy centres before installation at its headquarters in Stirling. Involved in the design, installation and commissioning of the Stirling Renewable Heat Project. *Large Enterprise* | Scotland | Yes | Principle contractor |
| PPSL | Design, supply and installation of pre-insulated pipes for District Heating, Cooling, Steam networks. Installed pipes in Edinburgh university, West General Hospital. *SME* | UK | Yes | Sub-contractor |
| The Purvis Group | Multi-function construction business providing civil engineering and construction services. The Purvis Group was the local contractor carrying out civil work for the Glenrothes network in Fife. *SME* | Scotland | Yes | Sub-contractor |
| WPS Water & Pipeline Services Ltd | Construction support specialising in utility installations. Contracted and subcontracted to work on heat network pipe installation due to their experience in trenching, laying steel pipes and flow and pressure testing. *SME* | Scotland | Yes | Sub-contractor |

# Conclusion

Heat Networks have been identified as strategic infrastructure needed for Scotland to meet its net-zero requirements. The density of heat demand in Scotland's towns and cities, as well as the typology of Scotland's building stock and climate, make heat networks an attractive low-carbon heating solution. The 2021 Heat Networks (Scotland) Act, the proposed Heat in Buildings Bill, government funding for new network development, and existing network improvements are anticipated to significantly grow the market and reduce barriers. This ensures the growth of heat networks and creates new opportunities across the supply chain which, with the right incentives, skills and training, Scotland is well positioned to take advantage of.

**Key Conclusions**

There are skills and competencies in the oil and gas (O&G) sector which are transferable to the heat networks sector. Specifically, welding and joining pipes, project management skills and the prefabrication of structures. Additionally, there are companies such as Weir Pumps, a global manufacturer of pumping equipment in the O&G supply chain, who have the potential to diversify into the heat networks sector.

Although most equipment is imported into Scotland, there are large, well-known manufacturers who could expand and supply the UK district heating market.

Scotland has good growth potential to build and install networks. Many Scottish companies are contracted for this work and key specialised skills such as welding exist in the O&G industry.

Scotland has world-leading engineering services and excellent research capabilities, evidenced by the presence of multinational organisations and world-leading universities. This means Scotland is well-positioned to provide engineering services for heat networks. M&E engineering design services are in high demand in the market and there are many opportunities for district heating engineers.

ESCOs in Scotland vary in size and encompass different public and private partnerships. The prevailing trend is that international firms, like Vattenfall, with extensive experience, capacity, and resources, operate larger district-scale networks. Risk appetite, experience and capital are important for ESCOs.

There are multiple opportunities for digital components to be used for heat networks, and collaboration across sectors will be key. This will be important as networks become more digital, e.g. predictive maintenance and managing demand from the grid's perspective. The UK and Scotland currently lack a framework for data sharing and interoperability.

There are market interventions which can support local content across the supply chain. For example; local content requirements, support frameworks which include capacity building, and financial support, such as subsidies for Scottish companies manufacturing components.

Ensuring Scotland has the right skills will be important to taking advantage of the growth of the supply chain. Research completed by the Energy Savings Trust into skills shortages in the heat networks supply identified that gaps in project management, heat network design, installation and optimisation, as well as technical operation and maintenance are already creating difficulties.

| Category | Scottish content | Growth potential |
|---|---|---|
| Electric boilers | Low | The market has medium growth potential because the competitors are relatively small, but well-established. |
| Large-scale heat pumps | Medium | Although the market is dominated by large firms, there is evidence of successful Scottish and UK companies manufacturing heat pumps and parts for heat pumps. Competition in this area is high, but some Scottish companies have shown to be competitive. |
| Pipework | Low | There is potential for entry of Scottish firms in standard, low-technical pipe work (e.g. for 5G networks). However, the chance of successfully competing with the market leaders for 4G insulated pipework is more difficult because incumbents are well-established. As the market grows there may be potential for direct foreign investment, particularly if the incumbents (Rehau, Logstor) could consider Scotland as a manufacturing location with the right incentives/demand. |
| Equipment manufacturers | Low | The majority of heat network equipment and components are imported into Scotland. However, Scotland has some large well-known manufacturers (Star Refrigeration, Cochran boilers, McDonald Thermal Stores) who could expand and sell their products to the wider UK DH market. Opportunities also exist for companies such as Weir Pumps, a major manufacturer of industrial pumps for the oil and gas sector, who could make pumps for the DH market. |
| Construction and installation | High | Certain phases of heat network construction work can utilise local gas engineers, plumbers, electrical and mechanical engineers, heating engineers, building management and construction companies. More specialised skills such as pipe welding and joining exist in the oil and gas industry and could transfer to heat networks. |
| Engineering services | Medium/High | Engineering services are a strength of the Scottish economy, and Scotland currently exports these skills. However, there is high competition across the engineering services market due to high demand across multiple sectors. |
| Operators and ESCOs | Medium | The ESCO market is difficult to enter due to the need for large amounts of capital, the ability to take on risk, and the need to have experience running networks. The greatest opportunities for new companies are operating smaller networks. However, at a minimum, they would require experience working in an energy-related industry. |

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# Appendix | Methodology and data collection

The methodology and analysis in this research builds on previous work undertaken by Ramboll in 2022 which identified the key components in heat pumps and heat network assemblies. Importantly, the findings of the previous study identified that the majority of components used in 4GDH are also used in 5GDHC. Where this is not the case, the report makes this distinction.

**Essential equipment**
A list of essential equipment used in 4G and 5G heat networks has been drawn up and validated internally at Ramboll and with Scottish Enterprise. Emphasis has been placed on looking at the costs of individual components, which means the results can be applied to a wide range of different contexts i.e., size of network, heat source, different types of pipes, type of buildings connected etc.

The overarching categories for which the capital costs are estimated in this study are the energy centre, distribution network, and building connections. For building connections, this study is limited to heat interface units (HIUs) and substations.

Preliminaries, contractor's cost, contingency, and consultancy fees – known as uplifts – are usually added as a percentage of the total capital cost. Estimates for equipment costs use internal industry-standard benchmark data, interviews with equipment suppliers, and existing data from relevant Ramboll reports.

**Main heat sources and seasonal energy storage**
The main heat sources considered for this study are water-source heat pumps (WSHP), air-source heat pumps (ASHP) and ground-source heat pumps (GSHP). In general, heat pumps are categorised according to which low-temperature heat source is used. ASHP and GSHP are the two most common types. Large-scale heat pumps are an increasingly important heat source for 4GDH networks. Whereas heat pumps that exploit low-grade heat from waste-water treatment plants or sewer networks are less commonly implemented, they are an interesting opportunity for 4GDH networks and are therefore included in this research.

Ideally, 5GDHC networks are balanced, meaning that at any point in time, the demand for low-grade heat or cooling is the same. In reality, it is not likely that a perfect balance will be achieved, and the network will almost always require external heat and cooling input to the system. In Scotland, the demand for heat and cooling for most buildings is highly seasonal (heat during winter and cooling in summer). This means that an excess of waste cooling will be produced during winter and an excess of heat during summer. To decrease the amount of energy added externally to the system, seasonal energy storage is required. This study therefore investigates the cost of thermal storage. There are a range of different technologies, but the most common in 5GDHC systems are borehole thermal energy storage (BTES) and aquifer thermal energy storage (ATES).

To gain a comprehensive understanding of the capital costs associated with heat pumps, Ramboll obtained quotations from suppliers and manufacturers and supplemented this information with data from Ramboll's internal database, as well as the Danish Energy Agency's technology catalogue for district heating and electricity generation.

**Costs associated with design, construction, and commissioning**
The development of district energy networks can be categorised into six distinct project phases that begin with feasibility work and end with operation and maintenance (see previous page). This study concentrates on the four middle phases; costs of feasibility, design, construction and installation, and commissioning.

Feasibility and design costs are gathered from previous Ramboll projects as well as information from heat networks that have received funding from the Low Carbon Infrastructure Transition Programme (LCITP), Scottish Heat Network Fund (SHNF), and the Heat Network Support Unit (HNSU). Ramboll prioritised gathering actual costs from heat networks that have been commissioned and constructed. Detailed cost estimations from heat networks that are currently in the design phase were also included.

**Supply chain**
Interviews with Ramboll subject-matter experts and desk-top-based research have been carried out to understand where companies within the supply chain are located, their approximate size using revenue and employees as a proxy, and their specialisms. Data was also obtained from existing networks and networks under development to understand which companies had been or are involved.

**Data collection**
This analysis has been conducted using a range of data sources. Key sources include:

- Price data from suppliers: Ramboll has collected pricing information and indicative quotes from suppliers, supplemented by publicly available information from company websites. A limiting factor in the collection of pricing data has been the fact that not all companies are willing to share their prices.
- Company information: Information on companies active in the district heating and cooling supply chain has been collected from company websites.
- Reports: Relevant reports used in this analysis include "Heat Pumps and Heat Networks Assemblies and Key Component Analysis" written by Ramboll in 2022.
- Cost data for existing networks and networks under development: Through engagement with local councils and ESCOs, Ramboll has collected data on five Scottish heat networks – the Torry Heat Network, Stirling Council, Millerhill, Glenrothes, and AMIDS.



Contents

# Appendix | Definitions of 4th generation district heating and 5th generation district heating and cooling

**Introduction**

4th generation district heating (4GDH) is well defined and understood. The viability of the concept as a low-cost and low-carbon way to supply heat has been proven across various national and local contexts. 5th generation district heating and cooling (5GDHC) on the other hand is still in its infancy. There are only a handful of small-scale existing networks, and their commercial and technical viability is not yet widely understood.

**4th Generation District Heating (4GDH)**

As in 3rd generation district heating networks, 4GDH networks consist of three main elements:

- One or multiple energy centres;
- Distribution network;
- Substations and/or heat interface units.

The energy centre is a centralised location where heat production takes place and various equipment is housed, such as pumps, water treatment, expansion vessels, thermal energy storage etc. The energy centre is connected to the various heat consumers by a distribution network consisting of insulated pipes. There is a supply pipe (to transport heat to the consumers) and a return pipe (to transport the cooled water back to the energy centre). Consumers are connected to the network via hydraulic interfaces, separating the primary network from the consumer. These can be hydraulic substations or heat interface units (HIUs).

Lund et al. define 4GDH as a district heating system providing low-temperature heat (around 60°C supply and 30°C return) largely based on renewable energy sources[1].

**Characteristics of 4GDH**

- 4GDH networks are a clear progression from generations 1 to 3 with a higher efficiency and lower temperatures in the same centralised design.
- 4GDH systems commonly use 60°C supply and 30°C return temperatures, but centralised systems with supply temperatures between 30-70°C can be classified as 4GDH. This is lower than the temperature of 3GDH systems but higher than 5GDHC systems.
- Incorporation of low-temperature waste heat and renewable heat sources as part of supply, with large heat pumps often used.
- 4GDH systems cannot provide cooling without the addition of an extra network in a 4-pipe setup[2].

**5th Generation District Heating and Cooling (5GDHC)**

5GDHC differs from the previous generations in that heating and cooling are met by the same network via decentralised energy transformation units, enabling energy sharing. These decentralised energy stations are equipped with water-source heat pumps (WSHP), thermal energy storage and if required, peak boilers and direct cooling heat exchangers. They are interconnected through an ambient network, becoming prosumers (producers and consumers) because when the WSHP extracts heat (cooling), it injects cooling (heat) back into the network. Heat is upgraded in these substations to temperatures required by the user's terminal systems. The water (or brine) in the distribution network is at ambient temperature (5-25°C).

A previous report written by Ramboll for Scottish Enterprise gave the following definition:

"5GDHC systems are defined as decentralised networks (i.e., a heat pump is located in each building) which operate at ambient temperature and are capable of supplying both heating and cooling."[2]

It is important to note that because of the novelty of the concept, there is not yet an industry consensus on the definition and the name nor what the boundaries are for economically beneficial applications compared to 4GDH.

**Characteristics of 5GDH**

- 5GDHC networks are characterised by low distribution temperatures (typically 5 - 25°C), reducing heat loss and diminishing the need for pipe insulation.
- The network connects a combination of heating and cooling capacity through the use of distributed heat pumps located in decentralised building-level plant rooms.
- The network is to be pressurised and balanced by the decentralised plant rooms. The network can have unidirectional or bidirectional mass flow depending on its topology and pumping arrangement.
- They utilise a wide variety of heat or cooling sources, including low-temperature waste heat sources, offering a demand-side response including integration of waste heat and excess heat capturing capability with storage.

[1] H. Lund, S. Werner, R. Wiltshire, S. Svendsen, J. E. Thorsen, F. Hvelplund and B. V. Mathiesen, "4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems," Energy, pp. 1-11, 2014; [2] Ramboll, "Heat Pumps and Heat Networks Assemblies and Key Component Analysis," 2022

# Appendix | Abbreviations

| Term | Definition |
|---|---|
| 3GDH | 3rd generation district heating |
| 4GDH | 4th generation district heating |
| 5GDHC | 5th generation district heating and cooling |
| ASHP | Air-source heat pump |
| ATES | Aquifer thermal energy storage |
| CAPEX | Capital expenditure |
| COP | Coefficient of performance |
| DH | District heating |
| DN | Diameter normal (internal pipe diameter) |
| EC | Energy centre |
| EfW | Energy from waste |
| ESCO | Energy services company |
| HEX | Heat exchanger |
| HIU | Heat interface unit |
| HP | Heat pump |
| kW | Kilowatt |
| LA | Local authority |
| LTHW | Low-temperature hot water |

| Term | Definition |
|---|---|
| MVA | Mega volt amp |
| MW | Megawatt |
| MWe | Megawatt electric |
| MWth | Megawatt thermal |
| M&E | Mechanical and electrical |
| OPEX | Operational expenditure |
| O&G | Oil and gas |
| TES | Thermal energy storage |
| TWh | Terawatt hours |
| WSHP | Water-source heat pump |
| WWHR | Wastewater heat recovery |
| WWTP | Wastewater treatment plant |

# Appendix | Sources

| Source | |
|---|---|
| Aquatherm | Rehau |
| Carrier | RMS |
| Clade | Solid Energy |
| Fenagy | Stirling Council |
| FES Group | Vital Energi |
| Fife Council | |
| GEA | |
| Hartwell | |
| HRS | |
| Huber | |
| Isoplus | |
| Logstor | |
| Midlothian Council | |
| Ormandy Rycroft | |
| Parat | |
| Pure Thermal | |
| Rabtherm | |
| Recirc Energy | |