Programme Area: Energy Storage and Distribution

Project: Heat Infrastructure Development

Title: Requirements, Baseline Analysis and Target Setting Report

Abstract:

The primary objective of the Heat Infrastructure Development project is to identify and then assess solutions that would deliver a substantial step change reduction in the capital cost of district heat infrastructure deployment and contribute to overall lifecycle cost reduction, focusing particularly on the upfront costs of heat network pipes and their installation, for the purposes of connecting to existing buildings. This report sets out the work carried out in Stage 1 of the project, and comprises the following main parts: a) Part A presents the system and stakeholder requirements. b) Part B presents the technology review. c) Part C presents the methodology used in creating a network cost model and the analysis of network costs. d) Part D presents the system review and target setting. Taken together, these parts assess and synthesise the current baseline practice and costs in the UK and overseas, and relevant technologies and practices from other industries which could potentially be used in future, before identifying key challenge areas for targeting of cost reduction solutions during Stage 2 of the project.

Context:

This project seeks to identify the innovative solutions needed to deliver major reductions in the capital cost of heat network infrastructure and accelerate its deployment. Examining the technical, process and system developments needed to deliver a step change reduction in the capital costs, along with cost estimates and time frames for undertaking these developments. District heat networks supply heat to homes and businesses through pipes carrying hot water. They have great potential to deliver CO2 emissions reductions and cost benefits through the use of low carbon heat, waste heat from power stations, industry and other sources, combined heat and power, and large-scale heat pump deployment.

Heat Infrastructure Development Project

Deliverable EN2013_D01

Requirements, Baseline Analysis and Target Setting Report

August 2016

This report is produced under the Heat Infrastructure Development project, commissioned and funded by the ETI

Contributions from Cowi and Loughborough University

Under the terms of the project contract between the ETI and AECOM Ltd, all information in a deliverable which is based on input from two specific subcontractors, namely COWI A/S and Loughborough University Enterprises Ltd, must be expressly identified. Users of this report should note the following:

1. In respect of information based specifically on input from COWI A/S, the intellectual property provisions in Schedule 1 of the project contract are amended by those in clauses 22.7, 22.8 and Appendix 4 of the project contract.
2. In respect of information based specifically on input from Loughborough University Enterprises Ltd, publication by the ETI is subject to additional provisions in clauses 21.1 and 31.6 of the project contract.

Specific content in this deliverable report from COWI A/S is as follows:

- A discussion was held with Cowi as part of the technology review which has been detailed in Appendix H and incorporated within the International Comparison in Section 12 and the Literature Review and Horizon Scanning in Section 13. In addition, subsequently received cost data has been included in Section 12.
- Details on costs and heat network designs in Denmark which are included in Section 20.
- Details provided on costs and heat network designs in Denmark which are included in Section 23.

Specific content in this deliverable report from Loughborough University Enterprises Limited is as follows:

- Loughborough University provided details on potential solutions which were used to support target setting in Section 23.
- Loughborough University undertook a literature review which has been detailed in Appendix L and incorporated within the Literature Review and Horizon Scanning in Section 13.

In addition, the learning arising from the contributions of Cowi and Loughborough University has been taken into account within syntheses of the work undertaken such as the Executive Summary and section summaries.

Version Control

Rev	Comments	Prepared by	Checked by WP Lead	Checked by CTO	Approved by PM/PD	Date
1	Draft for issue to ETI. This deliverable is consolidated from the draft reports from each WP reviewed previously by the ETI.	Various	TH, AC, DR	PW	MA	18.8.16
2	Revised final report for issue. Amendments made to previous version following minor ETI comments.	David Ross			MA	24.8.16

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Contents

Glossary

3-D	Three Dimensional
4DH	4th Generation District Heating, which principally includes lower distribution temperatures
4GDH	4th Generation District Heating, which principally includes lower distribution temperatures
ΔT	delta T/ delta temperature
ADE	Association for Decentralised Energy
BS	British Standard
ASHP	Air Source Heat Pump
CAPEX	Capital Expenditure
CDM	Construction (Design and Management) Regulations
CHP	Combined Heat and Power – a common heat source for DHNs linked with power generation
CIBSE	Chartered Institution of Building Services Engineers
CO_2	Carbon Dioxide
CSH	Code for Sustainable Homes
CTO	Chief Technology Officer
DEC	Display Energy Certificate
DECC	Department for Energy and Climate Change (now part of the Department for Business, Energy and Industrial Strategy)
DH	District Heating - The practice of supplying heat energy to commercial and industrial buildings, homes and other public buildings through pipes carrying hot water (or other appropriate working fluid).
DHA	District Heating Area
DHC	District Heating and Cooling
DHN	District Heat Network: A system which supplies heat energy to commercial and industrial buildings, homes and other public buildings through a network of pipes carrying hot water (or other appropriate working fluid). For the purposes of this Project, a complete DHN system will be considered to comprise (a) a distribution network and (b) the upstream generation and downstream demand components which interface with the distribution network.
DHST	District Heating Storage Tank
DHW	Domestic Hot Water supply
District Heating	The practice of supplying heat energy to commercial and industrial buildings, homes and other public buildings through pipes carrying hot water (or other appropriate working fluid)
DIY	Do It Yourself
DN	Diameter Nominal; e.g. DN300 being a pipe of 300mm nominal diameter
DNO	Distribution Network Operator
DT	Delta Temperature
DTU	Danish Technical University
Emitters	Domestic or commercial radiators or equivalent (e.g. underfloor heating)
EN	European Norm
EPC	Energy Performance Certificate
ESCo	Energy Service Company; they provide a broad range of energy solutions which can include the construction and/or management of district heating
ETI	Energy Technologies Institute
EU	European Union

EVOH	Ethyl Vinyl alcohol copolymer
FEED	Front End Engineering Design
FEM	Finite Element Modelling
FDD	Fault Detection and Diagnosis
GIS	Geographic Information System
GLA	Greater London Authority
GPR	Ground Penetrating Radar; for sub-surface surveying.
GPS	Global Positioning System
HDD	Horizontal Directional Drilling
HDPE	High-Density Polyethylene
HID	The ETI's "Heat Infrastructure Development" project under which this work was carried out
HIU	Hydraulic Interface Unit – A pre-fabricated assembly of components that forms the interface between a District Heat Network and a building's heating and/or hot water systems, and which may typically include (a) isolating valves, balancing valves, control valves and a heat meter, (b) a heat exchanger to separate the heat network from the building's heating system, and (c) a heat exchanger to produce domestic hot water. The terms "Heat Interface Unit" and, for a non-domestic property, "Heat Substation" are also sometimes used, and these have the same meaning.
HNDU	The UK government's Heat Networks Delivery Unit
HP	Heat Pump
HVAC	Heating Ventilation Air Conditioning
ICC	ETI's Infrastructure Cost Calculator
IEA	International Energy Agency
IRR	Internal Rate of Return; a financial measure to assess the viability of a district heating scheme
ITHE	Instantaneous Heat Exchanger
LA	Local Government Authority
LCA	Life Cycle Assessment
LUEL	Loughborough University Enterprises Limited
LTDH	Low Temperature District Heating
MVHR	Mechanical Ventilation and Heat Recovery
NDT	Non-Destructive Testing
NGO	Non-Governmental Organisation; not for profit, may receive public and/or private funding
OD	Outside Diameter
OFGEM	Office of Gas and Electricity Markets; the energy regulator; may have a future role in the regulation of DHN
OJEU	Official Journal of the European Union
OPEX	Operational Expenditure
PB	Polybutylene
PE	Polyethylene
PE-RT	Polyethylene of Raised Temperature resistance
PET	Polyethylene Terephthalate
PEX	Cross-linked Polyethylene
PN	Pressure Normalised
PP	Polypropylene
PUR	Polyurethane
PV	Photovoltaic
PVC	Polyvinyl Chloride
R&D	Research and Development
RAMS	Risk Assessment and Method Statement

RHI	Renewable Heat Incentive; UK Government subsidy for low carbon heat sources
RoI	Return on Investment
RP	Registered Provider of social housing
RSL	Registered Social Landlord
SBRI	Small Business Research Initiative
SCADA	Supervisory Control And Data Acquisition
SPV	Special Purpose Vehicle; legal entity set up for a specific function, e.g. a joint venture between a Local Authority and others to create a Heat Network
SUDS	Sustainable Urban Drainage System for flood mitigation; now not exclusively Urban
Supply Chain	Organisations involved in the supply of materials or direct services to a project
TOTEX	Total System Cost – CAPEX + OPEX over the project design life (Whole Life Cost)
TPL	Target Pressure Loss
TRV	Thermostatic Radiator Valve
TT	Trenchless Technology
Value Chain	All organisations with involvement in the DHN project from designers to manufacturers, clients to building control
WP	Work Package

Executive Summary

Introduction

This report is Deliverable EN2013_D01 “Requirements, Baseline Analysis and Target Setting Report” of ETI’s Heat Infrastructure Development (HID) project. This report, together with Deliverable EN2013_D02 “DHN Cost Model” which is an Excel model provided separately, comprise the results from Stage 1 of the project. This project is being led by AECOM and supported by a team comprising Total Flow, Engie, Cowi and Loughborough University.

The primary objective of this project is to identify and then assess innovative solutions that would deliver a substantial step change reduction in the capital cost and contribute to overall lifecycle cost reduction of the DH distribution system. Whilst focussing on this primary objective, the project will also consider the value of the DHN system to relevant stakeholders and the possibilities for optimising value and business cases for stakeholders, even where this may result in a slightly smaller cost reduction.

This report is presented in four parts:

- Part A presents the System and Stakeholder Requirements which is the output from Work Package 1
- Part B presents the Technology Review which is an output from Work Package 2
- Part C presents the Cost Model Methodology and Analysis which is an output from Work Package 2
- Part D presents the System Review and Target Setting which is the output from Work Package 3

Part A - Work Package 1: System and Stakeholder requirements

WP1 has made a holistic review of DHN stakeholders and their requirements in order to identify the changes necessary to achieve DHN viability from multiple perspectives. This has given a whole systems view in order to reduce the risk of focusing too early on a narrow range of target solutions.

This Part of the Deliverable includes the following key outputs which are summarised in the main body of the report, with supporting appendices providing more detail.

- **Project Scope** – Confirmation of the priority areas for future solution development.
- **Stakeholder Requirements Analysis** – A detailed review of the requirements of the important stakeholder groups and an assessment of the barriers to DHN deployment.
- **Evaluation Criteria** – Development of an approach to evaluate potential solutions and rank their potential for accelerating viable DHN delivery.

Project Scope

A project scoping workshop was held between the project team and ETI on the 12th November 2015. The aspects of DHN delivery which were confirmed as being of core importance to the project are:

- **Parts:** All components and sub-systems of a DHN which form part of the completed system.

- **Process:** The delivery phase: installation and commissioning processes.
- **Performance:** Heat system design, optimisation and through life performance.
- **People:** Resource, skills and expertise for design and delivery:
- **Systems Solutions:** The optimisation of requirements between different aspects of a DHN. Also the potential for integration with other utilities and local area services.
- **Value Proposition:** Improving the attractiveness of DHN for investors, property owners and consumers.
- **Place:** The impact of geography and topology on system design, performance and both operating and capital costs.

Stakeholder Requirements Analysis

It is apparent from stakeholders across the value chain that there is a shared ambition to accelerate deployment of DHNs in the UK. Currently the UK market is on a small scale (relative to Scandinavia and some other parts of Europe) and this gives significant opportunities for growth and improvement.

Analysis was undertaken to contrast stakeholder requirements and current DHN delivery capability. This was delivered through a combination of project team insight, stakeholder engagement and desk-based review. This analysis particularly highlighted the following for the five key stakeholder groupings.

- **Users:** Currently DHNs do not offer a compelling reason for users to change from their preferred gas boiler solution. For users to choose to change to a DHN there will need to be a significant improvement in cost, performance or reliability compared to alternatives.

- **Investors:** Currently the lack of certainty of DHN programme and cost makes an investment less attractive than alternatives. In addition the complexity of project design, delivery and associated legal contracts is a burden.

- **Value Chain:** Design, development, installation and UK manufacturing organisations are cautious about investing in additional capability and capacity whilst the market is uncertain.

- **Enabling Stakeholders:** Achieving approvals from certain external stakeholders is crucial to project success and so developing an approach to minimise their resource requirements and minimise the negative impacts is important.

- **UK plc:** For HM Government here is a desire to accelerate the adoption of low carbon heating and DHNs have the potential to contribute, ideally without major policy intervention.

There is recognition and broad agreement across stakeholders of the changes that are required, and these are summarised below. The analysis suggests great potential for improvement through industrialisation of design, delivery and operation of DHNs.

Required Changes for DHN Delivery

The shortfall against requirements has led the project team to conclude that there are nine key priorities to address to enable DHNs to succeed at scale. All aim to improve the viability of district heating in the UK, with the first five directly focussing on financial aspects and the latter covering broader issues.

- **Reducing Capital Cost:** Project capital delivery including planning and design.

- **Improving Cost and Revenue Certainty**: Capital, Operating Cost and Income.
- **Reducing Operational Cost:** Minimising the controllable through life costs.
- **Increasing Network Revenues:** Increasing income from heat or other revenue streams.
- **Reducing Time on Site:** To reduce disruption and associated additional cost.
- **Improving User Value Propositions:** Creating a compelling offering for User groups.
- **Improving Investor Value Propositions:** Enabling DHNs to become *bankable* investments.
- **Systems Architecture:** Developing a whole systems approach to identify opportunities for a step-change in DHN delivery and performance.
- **Reducing Complexity of Transactions Between Stakeholders:** Developing solutions to reduce the legal, commercial and transactional burdens of a successful DHN.

The WP1 research has enabled the Project Team to identify opportunities for improvement against these priorities (set out in sections 6 and 7, and in section 7.5 in particular) which will be used to help develop solutions during Stage 2.

Initial Assessment of DHN Viability

Stakeholder requirements and the barriers to DHN deployment have been used to develop a series of hypotheses for DHN viability at scale from each stakeholder groups' perspective, which will be used in Stage 2 to inform solution development:

- **Users** require a DHN offering which matches a combination gas boiler performance, reliability, installation and running cost; whilst offering a compelling incentive to change. This proposition needs to note most users' unwillingness to invest in their system before it fails.

- **Investors** require confidence in the DHN's capability to deliver the expected outcomes at low risk of cost and time overruns. The DHN opportunity should be no more complex to broker than similar investments.

- **Value Chain organisations** require confidence in the future market for DHN to justify investment in capability. Government policy, economic climate will influence the decision.

Evaluation Criteria for Challenge and Solution Selection

Two sets of evaluation criteria were developed to help contrast and prioritise the challenges identified in Stage 1 as well as the solutions that emerge in Stage 2.

- **Top Level Evaluation** is a high-level set of evaluation criteria. It comprises an assessment of the fit with the project scope and a qualitative Value-Effort assessment. This approach will be used to evaluate the Stage 1 challenges as well as put aside those solutions during the early part of Stage 2 that appear to hold limited or no benefit for this project.

- **Detailed Evaluation** is a more in depth review of the solutions which will be used at the end of Stage 2 to assess and contrast alternative solutions, and help select those to be taken forward to Stage 3. This comprises both a quantitative and qualitative evaluation.

Part B - Work Package 2: Technology Review

This Part of the Deliverable includes the following key elements which are summarised in the main body of the report, with supporting appendices providing more detail.

- A description of current UK practice – the approach by which DHN is normally delivered at present in the UK. This is to be used throughout the project as the baseline against which improvements are judged.

- Differences and similarities between current UK practice and those employed in other countries with more experience of DH. In particular, it looks to identify where practices from other countries might be beneficially imported to the UK. Such practices will be considered further and evaluated in Stage 2 of the project.

- Literature review and horizon scanning. This identifies potential improvements that may be forthcoming in the future from a mixture of academic literature, technical work and the outputs from International Energy Agency (IEA) Annexes. Such improvements will be considered further and evaluated in Stage 2 of the project.

In addition, a cost model has been produced in WP2 which breaks down the current costs of installing DH systems in the UK and provides an analysis of the key factors that drive these costs. This is described and discussed in Part C of this deliverable. The cost model helps inform the challenges in this project as well as assessing the cost benefits of potential solutions. The description of current UK practice in Section 11 of this report has formed the basis of the baseline costs in the cost model as described in Part C of this deliverable.

The findings in this report will help enable the identification and assessment of solutions in areas that have already been investigated by others, as well as inspiring ideas for new solutions. The findings have informed the development of a number of key challenges as part of Work Package 3 and the project's approach to solution development that will be taken forward in Stage 2 of the project. Part D of this deliverable separately describes the key challenges identified and the process for evaluating solutions for cost reduction.

The main observations from this report, which highlight areas of potential further focus for this project, are as follows.

General

- The technical solutions in Denmark and other established district heating countries are broadly similar to that adopted in the UK at present. This includes both the types of components used and installation practices. Differences identified include a trend in Europe towards using twin pipes and the approach to network design (specifically fewer heat exchangers used in Danish DHN).

- The design and installation of pre-insulated pipe systems has reached a level of technical maturity after 40 years of development and is supported by a number of European standards.

- As the components themselves are well developed, the areas with the greatest potential for cost reduction are likely to be those concerned with: completely new materials and products, new approaches to site work (e.g. trenching and reinstatement), or a more radical system design.

Business framework

- The business model and legal framework is very different in many Scandinavian countries. For example, Denmark benefits from policy support, a not-for-profit business model and open data on actual energy use which helps significantly with confidence in DH take-up, system design and cost reductions. Scandinavian DH companies are typically owned and/ or underwritten by local municipalities, which enables access to low cost financing and to local authorities' social housing and public buildings stock. These potential opportunities could be explored within the UK but it has been agreed that alternative business models and legal frameworks is outside the scope of this contract.

- There is evidently much greater experience of the delivery of DH systems in countries where the technology is established. This results in a deeper understanding of the DH systems, and a better integration in practice across delivery stakeholders which reduces problems such as uncertain responsibilities between delivery organisations.

- Linked to this greater experience, there are also more established systems in place to support design and delivery in other countries. This includes standardised methods and assumptions for carrying out assessments, design and construction. Addressing these issues, alongside workforce training for design and construction will be important for the UK where a bespoke approach is typical and the workforce is less experienced.

- The availability and use of heat demand data is another key area of difference between other countries and the UK. This is mainly focussed on improving confidence, delivering quicker design and ultimately better operational efficiency. Better demand data will enable optimised designs, more confident use of diversity factors, and less likelihood of pipes and other equipment being over-sized.

Component solutions

- The major technology shift currently proposed is a reduction in operating temperature (i.e. the transition from third to fourth generation district heating). The drive for this in other countries is to make a more effective use of low carbon technologies (particularly heat pumps) and significant reductions in heat loss and thus lower operating costs. The principal opportunity for capital cost reduction associated with lower temperature systems is the ability to make more extensive use of plastic pipes in DH systems. Although the costs of the pipes themselves are not the largest part of the total cost, and high performance plastics can be expensive, the use of plastic pipes can support a number of off-site manufacturing processes and rapid installation approaches. These have potential to reduce time and cost on site, and to reduce the trench sizes as there would be less of a need for staff to actually work in the trenches themselves as pipe-runs can be pre-assembled.

- Opportunities for non-welded pipe connections (principally in plastic) have the potential for cost reductions in more conventional site solutions, albeit the WP2 pareto analysis suggests a simple reduction in the cost of pipe connections will have limited impact on overall network capital costs.

- Significant improvements in thermal insulation of pipes are mostly constrained by the low cost, quick production and high performance of the currently widely-used polyurethane foam.

- The cost of Hydraulic Interface Units (HIUs) has been found to be a significant part of the total cost of a network, although Danish networks use fewer HIUs. No current published research was found on attempts to reduce the cost of HIUs, but they remain an important target for cost reduction, for example through standardisation which could bring economies of scale.

Civil engineering costs

- There are established options for trench-less approaches to pipe installation. These are understood to be currently more expensive and more risky than open-trench approaches, and only used where a trench is impossible or too difficult (e.g. rail or river crossing).

- Opportunities to make trenches narrower or shallower will reduce excavation volumes and associated costs. However, the application of shallow trenches can be limited in urban areas by underground obstacles.

- Reusing excavated soil as backfill reduces the need to buy and transport new material as well as landfill disposal costs. Subject to the availability of sufficient on-site space for temporary stock-piling, reductions in civil engineering costs are estimated at 10 – 20%.

- A major impact on civils costs is the uncertainty about what will be found in the ground. The greater use of improving 3D non-invasive technologies to map underground obstacles could help reduce these risks. This should result in cost savings from reduced time on site, and in lower pricing from the reduction in perceived risks which are otherwise passed on to clients by contractors.

Design and operational solutions

- A key area of change in the last few years is the rapid decrease in the cost of monitoring equipment, with more operational data now available that could assist better operation of systems e.g. real time monitoring and adjustment of key parameters to optimise performance. There is limited published evidence in this area, but there is an expectation that improved data could result in lower capital costs due to optimised management of demand (in particular peak demand) thus reducing the over-sizing of designs. Operational cost savings are also expected.

- There has been a recent trend towards more intelligent HIUs and sub-stations (i.e. digitalised controllers with significantly additional functionality) to lower return temperatures and improve operational efficiency. This trend is expected to continue.

- Because of the nature and number of components in DHN, faults are relatively common, and an active field of research for improved operation is Fault Detection and Diagnosis (FDD).

Part C - Work Package 2: Cost Model Methodology and Analysis

Introduction

This Part of the Deliverable describes the methodology underpinning the cost model developed for this project, and presents and analyses costs for current district heating systems constructed in the UK.

There are two key purposes in creating this cost model.

1. To help identify the most significant cost components to focus on in subsequent stages of this project. To achieve this, the cost estimates need to be sufficiently accurate and detailed to give confidence that the potential areas for significant cost savings have been identified. Furthermore, as district heating projects are not standardised, it is important to undertake sensitivity analysis – as discussed below a number of local heat networks designed for different building typologies have been separately evaluated.

2. To define a cost baseline to assess the impact of possible innovations to reduce costs. To achieve this, the cost breakdown needs to be sufficiently granular to assess the impact of innovations with the expectation that there may be benefit in greater resolution subsequently as areas of solution development are identified during Stage 2. Finally, given the need to evaluate the impact of potential innovative solutions, the cost model needs to be flexible to add new components in the future.

Approach to building the model

Specific heat network designs, based around five building typologies, were used as the basis for the model (with an additional typology for dense villages evaluated separately). These building typologies represent typical building types found across the UK and which represent a large proportion of the potential future heat network market. The principle aim of this study is to identify where innovation can best be used to reduce capital costs of heat networks – hence, the baseline designs in the model are based on current typical design practice using available technologies and methods.

A simple primary network has been defined which links up different typologies. This allows a representation of a large network to be created and used for the baseline cost analysis. In addition, more granular analysis is undertaken at the typology level to allow investigation of the most significant cost components and identify and assess the impact of solutions across different network designs. It is important to note that the choice of the typologies reflects the range of building types found in towns and cities, and is not intended to be well suited to a current viable heat network solution.

The heat network cost model takes the design information to produce a detailed broken down capital cost estimate of the heat networks. The model is driven by a number of cost databases which describe the various components and installation requirements associated with developing a heat network. The intention is also to reduce the operating costs of the district heat network and avoid the risk of reductions in capital and operational costs in the heat network being offset by increased costs elsewhere in the system. Hence, the model includes an assessment of the capital and operational costs of the whole district heating system i.e. including the Energy Centre. These latter costs are more approximate and less granular than the capital costs for the district heat network.

The modelling approach uses data and concepts from the ETI Infrastructure Cost Calculator (ICC), but in a spreadsheet specifically set up for the purpose of this project. However the data is managed in a way that means that the new information collected can be integrated with the ICC should ETI wish to do so.

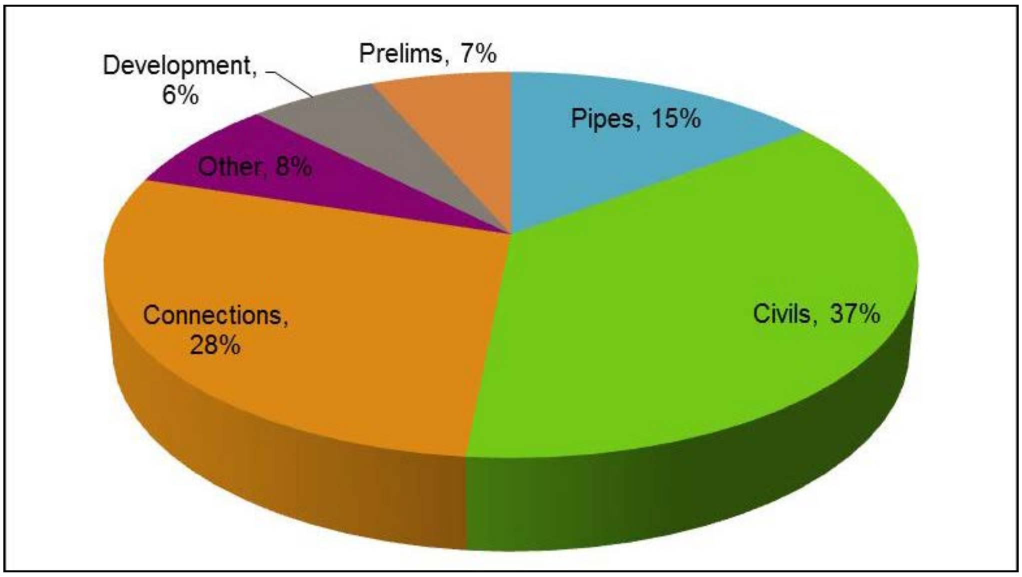
The capital cost data used in the model for the heat network has been verified in two ways. Cost data for each component has been obtained from multiple sources to enable a cross checking (and averaging where appropriate) of the inputs used. Furthermore, total heat network costs have been verified against actual costs from delivered DHN projects.

Key findings of the model

The total capital cost for the study scheme is reproduced in the table below, also shown later as Table 25. This shows that the heat network is expected to be a much larger part of the total cost than the supply of heat to it. The development costs (planning, design and legal issues) are a small percentage, but important because they take place at high risk prior to all necessary approvals being in place for the delivery of the network.

Component	Capital Cost (£k)	Percentage
DH network (including prelims)	43,200	68%
Development costs	2,700	4%
Energy Centre	17,400	27%
Total	63,600	

The split of the heat network costs is summarised in the figure below, also shown later as Figure 23. This shows that the costs of the whole network are dominated by the civil engineering and the costs of connections within the buildings. The cost of the heat network pipes and their installation is also significant but much less than these other two key items. The report also breaks down the civils, connections and pipe segments further in two ways: (i) it resolves the costs into smaller components, and (ii) it provides a percentage split of the costs by materials, labour and plant.



Where:

- Pipes includes the purchase and installation of all pipes, insulation and joints

- Civils includes the work of digging and reinstating trenches
- Connections includes the Hydraulic Interface Units (HIUs) and internal connections within buildings to the HIU
- Development includes the design and legal costs accrued before a contractor is appointed
- Prelims are costs associated with running a construction project, including site office, safety etc
- Other is any other costs, here mainly around data systems, water treatment and one-off items like rail crossings

Sensitivity analysis was undertaken to identify particularly how the relative importance of the costs varies by the type of heat network. This comprised a detailed cost breakdown of each of the five typologies and a comparison of the results. In particular, the cost for high rise flats is dominated by the connections element (i.e. HIUs and internal connections within buildings) as there is relatively little length of trench needed to reach the buildings. However, for the more suburban areas with longer pipe runs per home, there is a higher share of cost within both the pipes and civils elements. Overall, the sensitivity analysis confirmed the particular importance of the civils and connections costs, and pipes to a lesser degree, and no other costs were identified as being important under particular scenarios.

The report includes a summary of the key drivers and variability for the key cost elements. In particular, the civil engineering costs are driven by rate of progress (labour and plant together representing the majority of the cost), ground conditions (soft dig in verges or similar is much cheaper than hard dig in the road), ground uncertainty (e.g. unplanned identification of other services can cause delays and consequent costs) and trench width and depth (to install the pipes and route around other services). The variability in HIU costs is dependent on the network design in two main ways – the type of HIU to install (direct or indirect HIU) and whether every property has its own HIU or if they are shared between multiple homes.

It is useful to compare the total capital and operational costs of the heat network itself. The operational cost of the network (for pumping, heat loss and maintenance of pipes and connections) is calculated as £960k per year. This is around 26% of the capital cost of the heat network based on a net present value (NPV) calculation over 25 years with a 6% discount rate. If capital costs were to significantly reduce, say by 50%, then operational costs would become relatively higher but would still be less than capital costs.

Work Package 3: System Review and Target Setting

After the Introduction in Section 21, Section 22 identifies the key gaps between current DHN capability and stakeholder requirements, and areas of disproportionate cost and risk within the current DHN framework. This is principally a synthesis of relevant outputs from Work Packages 1 and 2.

Section 23 presents a prioritised set of five challenges to be taken forward to Stage 2 of the project, including a quantitative target for each challenge for the purpose of assessing achievability. This builds from the gap analysis in the previous section and was significantly derived through two workshops held with ETI, ETI’s review panel and the project team. The challenges can be summarised as follows.

- 10% reduction in total district heat network CAPEX from changes to System Design Architecture
- 25% reduction in Civil Engineering CAPEX
- 35% reduction in Pipe and Connections CAPEX

- 25% reduction in Internal Connections CAPEX
- New Network Income: 5% of Civil Engineering CAPEX offset from external revenue.

It is important to note that there is no specific target reduction in Stage 2 i.e. the project team should not be constrained by the values here. These targets were generated to demonstrate potential taking into account cost reductions that Total Flow has identified in previous similar projects, potential solutions already identified in Stage 1 and a comparison of UK and international costs. In total, if these target reductions are achieved, they would deliver a 33% reduction in the costs of heat networks.

These challenges are still quite broad, with more detailed opportunities already identified. The Stage 2 plans, to be presented prior to the Stage Gate Review close-out meeting, will include a work programme including those specific activities where the project team plans to focus its efforts.

Section 24 presents a standard template to capture details of solutions to be investigated during Stage 2. Its purposes are: (i) to aid evaluation of solutions in Stage 2, and (ii) to capture information that is easily accessible in Stage 2 to help enable the production of route maps during Stage 3 and avoid later duplication of effort. This in particular links to the evaluation criteria developed in Work Package 1.

1 Introduction to this Deliverable

This report is Deliverable EN2013_D01 "Requirements, Baseline Analysis and Target Setting Report" of ETI's Heat Infrastructure Development (HID) project. This report, together with Deliverable EN2013_D02 "DHN Cost Model" which is an Excel model provided separately, comprise the results from Stage 1 of the project. This project is being led by AECOM and supported by a team comprising Total Flow, Engie, Cowi and Loughborough University.

The background to this project is the need to develop cost effective ways for providing low carbon heat to buildings - by the year 2050 the UK will need to meet stringent targets requiring an 80% reduction in CO_2 emissions compared with 1990 levels, whilst still providing the end-user services that consumers require. The ETI has identified significant potential from district heating in terms of CO_2 and cost benefits. Currently, only 1-2% of UK buildings are connected to district heat networks (DHNs) and analysis by the ETI indicates that close to half of existing UK heat demand could be connected to heat networks economically. A key barrier to wider uptake of district heating is seen to be the high initial capital investment for network installation. A high proportion of this capital cost is from the DH distribution system which extends as follows: (a) on the supply side, the output terminals of generation and other heat source/recovery plant and (b) on the demand side, the output terminals of any Hydraulic Interface Units (including the HIUs themselves but excluding any consumer-side plant).

The primary objective of this project is to identify and then assess innovative solutions that would deliver a substantial step change reduction in the capital cost and contribute to overall lifecycle cost reduction of the DH distribution system. Whilst focussing on this primary objective, the project will also consider the value of the DHN system to relevant stakeholders and the possibilities for optimising value and business cases for stakeholders, even where this may result in a slightly smaller cost reduction.

The project is being delivered in three Stages and comprises seven work packages[1]. The three Stages can be summarised as follows and the structure shown also in Figure 1.

- Stage 1: Requirements, Baseline Analysis and Target Setting

  Work Package 1 defines the DHN stakeholder requirements. Work Package 2 comprises technical and cost analyses: (i) to determine the cost breakdown for the current heat network infrastructure, (ii) to understand best practice in countries with wider exploitation of DHNs, and (iii) to establish innovations that are in the research pipeline. Work Package 3 synthesises the findings from Work Packages 1 and 2 to highlight gaps between current DHN capability and stakeholder requirements and define specific challenges to be overcome in the subsequent stages of the project.

- Stage 2: Solution Development, Analysis and Selection

  Work Package 4 comprises in-depth research to identify and analyse potential solutions to address the challenges defined in Stage 1. This includes identifying and evaluating improvements to the distribution network at both a system and component level. Work Package 6 reviews the results of this analysis and determines which solutions should be taken forward into Stage 3 for more detailed analysis.

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[1] The original scope of work comprised eight work packages. During Stage 1, it was agreed with ETI to integrate Work Package 5 into Work Package 4.

- Stage 3: Route Mapping and Reporting

  Work Package 7 will determine the work required to bring the selected solutions from Stage 2 to commercial deployment. It will show the development path, including anticipated timescale, investment and technical and commercial risk. Finally Work Package 8 will present the findings from across the whole Project in a clear and succinct manner.

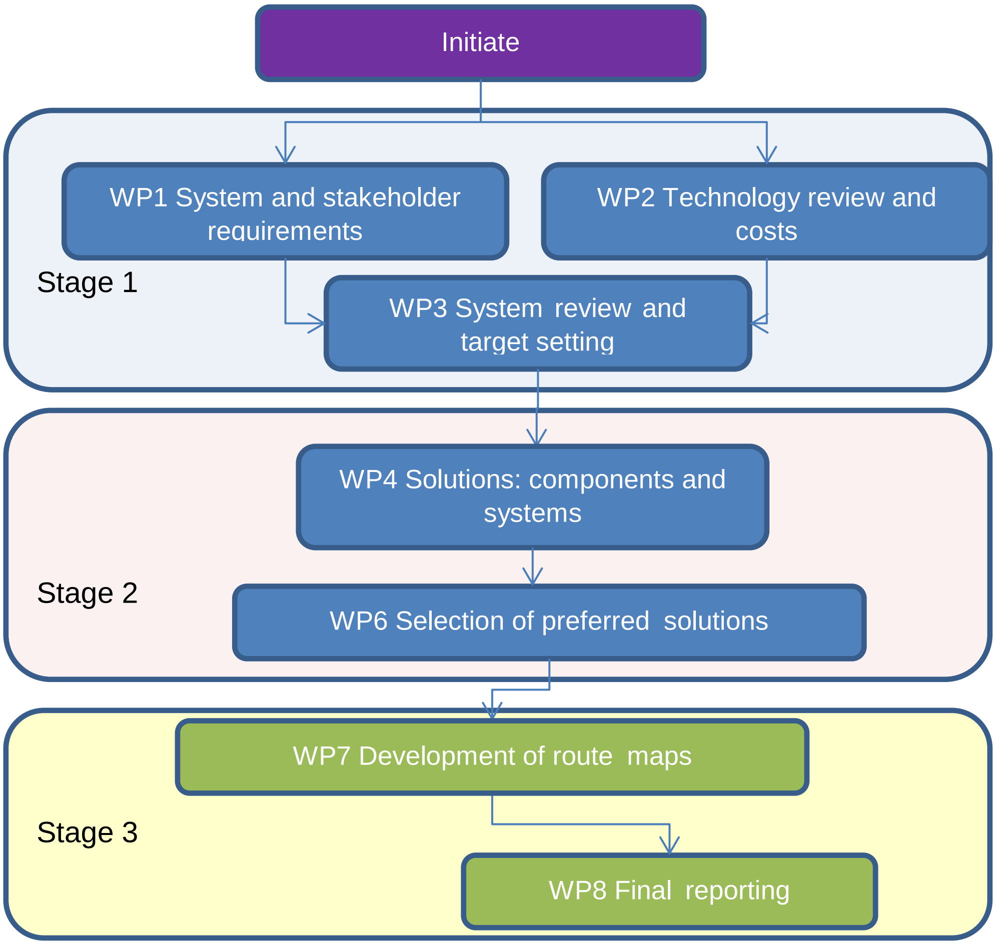


Figure 1: Overview of Work Packages

The report is presented in four parts:

- Part A presents the System and Stakeholder Requirements which is the output from Work Package 1
- Part B presents the Technology Review which is an output from Work Package 2
- Part C presents the Cost Model Methodology and Analysis which is an output from Work Package 2
- Part D presents the System Review and Target Setting which is the output from Work Package 3

Part A - Work Package 1: System and Stakeholder Requirements

2 Introduction

This report summarises the approach to, and results from, the first Work Package (WP1) of the project. It comprises three components.

- **Section 3** presents the conclusions from a **project scoping** workshop between the project team and ETI. The workshop reviewed and confirmed the scope of the project and assessed the areas which warrant particular focus and would deliver greatest value for the Heat Infrastructure Development project.

- **Sections 4 to 7** present the results of **stakeholder analysis** undertaken to help set the direction of this project. The work comprises:
  - (i) identification of key stakeholders and analysis of their requirements,
  - (ii) an assessment of the current barriers to DHN deployment,
  - (iii) prioritisation of where shifts are needed in technical performance, complexity, disruption and cost in order to overcome those barriers and better meet stakeholders' requirements, and
  - (iv) a first assessment of commercial, technical and cost conditions under which DHNs are likely to be viable.

- **Section 8** presents two sets of **evaluation criteria** both to help contrast and prioritise the challenges identified in this Stage 1 of the HID project, as well as to assess the solutions that emerge in Stage 2 (Solution Development).

3 Project Priorities and Scope

A scoping workshop formed part of the project launch event held on the 12th November 2015. The workshop reviewed and confirmed the scope of the project and assessed the areas which warrant particular focus and hence deliver greatest value for the Heat Infrastructure Development project. This activity was included in Work Package 1 as it is the first work package. However, it is effectively a distinct project management activity that informs all work packages in this project.

A broad range of elements across the DHN Value chain were considered collectively, in order to assess their relative importance to the project goals. A facilitated discussion between the ETI and Project team enabled the group to reach consensus on which aspects are **Core, Secondary** or of **Marginal** importance to the desired project outcomes. The minutes of the meeting were circulated by the Project Team to ETI to identify any final amendments.

Core aspects were selected as those most likely to achieve the target cost savings and thus accelerate and enhance the uptake of DHN. Secondary priorities are those which have a less direct impact on capital cost but still influence DHN viability. Marginal priorities were identified as those aspects over which the project can have limited influence (eg: policy) or that have limited influence on project outcomes (e.g. newbuild homes as a small proportion of the DHN target population).

It is important to recognise synergies – for example whilst the design process itself is not a core area of focus, better heat network design could enable significant reduction in the costs and process involved in the installation of the heat network which is a core area of focus.

3.1 Core Areas of Focus – The Physical Supply Chain and Installation

- **Parts:** All components and sub-systems of a heat network which form part of the completed system. This excludes both the primary heat source and the heating elements beyond the Hydraulic Interface Unit (HIU) e.g. domestic piping & emitters (radiators, underfloor heating).
- **Process:** The delivery phase: installation and commissioning processes including trenching, tunnelling and any site-enabling works. Also the design process, GPR site surveys, etc.

3.2 Core Areas of Focus – Systems Solutions

- **Performance:** Heat system design and optimisation which has a significant impact on network performance, capital and operating cost.
- **People:** Resource, skills and expertise for design and delivery: Limitations may be overcome by standardised design solutions and industrialisation of delivery to reduce skills requirement.
- **Systems Solutions:** The optimisation of requirements between different aspects of the DHN: e.g. Low cost components vs. life-span; reduced operating temperature vs. larger pipes. Also the potential for integration with other utilities and local area services to share the burden of installation costs. This could involve links to the electricity grid and other utilities.
- **Value Proposition:** Improving the attractiveness of DHN for investors, clients and consumers. Reducing the (perceived) risk of heat networks for key stakeholders to accelerate their adoption.
- **Place:** The impact of geography and topology on system design, performance and both operating and capital costs.

3.3 Secondary Priorities

- **Planning Consents:** Engaging with Local Authorities and statutory bodies to establish feasibility. If this comprises a significant time and cost burden, the investment may be a barrier to DHN adoption.
- **Plant:** Any capital equipment, machinery, jigs or fixtures used in the preparation for, and deployment of, heat networks, but which does not remain as part of the finished system.
- **Prelims:** Indirect and exceptional costs not associated with the physical network and its operation, e.g. road closure costs, permissions and wayleaves.

3.4 Marginal Areas

Examined only where change is necessary to enable solutions in core areas

- **Policy:** Changes to central or local government policy or other statutory instruments. Interactions with and permissions from NGOs (British Waterways, English Heritage etc.).
- **Procurement:** Procurement models and types of contracting for networks, sub-systems and elements - noting the cost burden of passing risk to an organisation that is unable to control it.
- **Financing:** The mechanisms and costs associated with raising the capital for DHN.
- **Newbuild:** When considering **Place** it was agreed that the core focus is on existing building stock. Improvements which are unique to new-build are marginal to this project, although HID innovations which have a positive impact on both new and existing stock will be welcome.

4 Methodology for Stakeholder Requirements Analysis

With a clear scope, the next step took a systems perspective of heat networks to identify all stakeholders and ensure that their requirements were identified and assessed. This was to mitigate the risk of improving DHN performance for a subset of stakeholders at the expense of others.

This principally comprised four activities: a literature review, stakeholder engagement, a large workshop and synthesis and evaluation of results drawing on the project team's DHN and wider infrastructure and industrial experience.

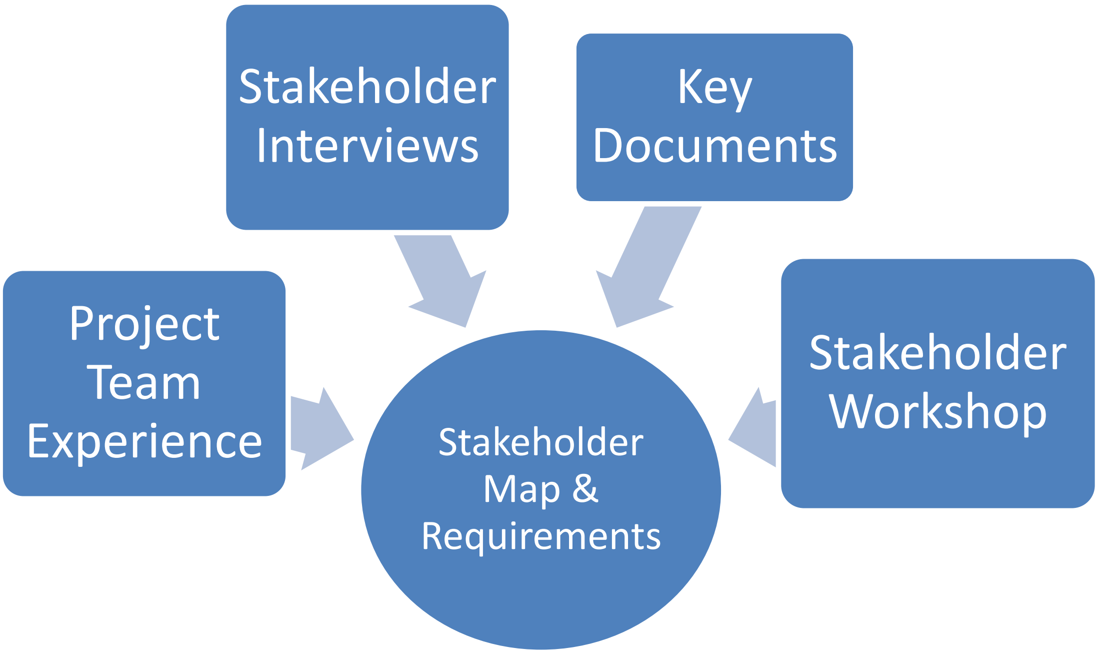


Figure 2: Sources for Stakeholder Map & Requirements

4.1 Key Document Review

To inform the stakeholder requirements analysis, a review was undertaken of documents relevant to domestic and community heating system change. This particularly focused on published research on stakeholder requirements with respect to both heat in general and, more specifically, district heat networks.

The key points are summarised in Appendix C, which also includes links to the original documents.

4.1.1 Homeowners' willingness to take up more efficient heating systems (DECC 2013)

This report is very relevant to this project. It explores through interviews and workshops the preferences and willingness to pay for more efficient heating options among homeowners (owner-occupiers) in Great Britain including heat networks. It includes details of attitudes towards current heating systems, triggers for change, the decision-making process and preferences for a replacement heating system.

4.1.2 Sustainable technologies: The experience of housing associations (NHBC Foundation, 2015)

This report summarises the results of a survey to investigate housing associations' experiences of sustainable technologies. It identifies technologies that have worked well, those that have given rise to concerns and the nature of those concerns. This includes housing associations experience of communal heating.

4.1.3 Research into Barriers to Deployment of DHN (DECC 2013)

The study investigated the barriers at each stage of setting up a heat network through a series of targeted interviews with project teams and individuals with experience of developing or planning heat networks were targeted. These themes included difficulties or uncertainties with funding arrangements, future heat demands and available heat sources, the role of local authorities and issues associated with an unregulated market.

4.1.4 Which Report – User Research (2014)

This study was intended to complement the DECC 2013 study on owner-occupiers which included little information on the experience of users already on a heat network. This study comprised a series of focus groups and telephone interviews with consumers on their experience of district heat networks.

4.1.5 Community Energy - Urban Planning For A Low Carbon Future

This guide, prepared by the Town and Country Planning Association (TCPA) and the Combined Heat and Power Association (CHPA) provides a vision of how our towns and cities can plan for the development of community-scale energy.

4.2 Stakeholder Engagement

To complement the literature review, the following stakeholder engagement was undertaken to develop a broad perspective, rather than deep analysis, across the DHN landscape. The insights collected are presented in Appendix B and synthesised in Section 6 Stakeholder Requirements Analysis. It was not intended that there would be a large-scale survey as part of this project.

- Internal discussions within the project team. In particular, Engie is a key stakeholder whose roles include investor, network developer and network operator. Furthermore, AECOM has a strong presence in the design of district heating systems.
- Discussions with registered social landlords. This comprised a group discussion with four directors and separate interviews with two sustainability managers to obtain feedback on their experience with district heat networks.
- Discussions with three Local Authority officers working on developing or delivering multiple network DH programmes.
- An interview with two commercial property companies who had significant experience of district heating
- Interviews with three householders (all with an interest in energy efficiency) to explore their perception of DHN and its potential suitability for their home in contrast to current gas boilers.
- An interview with a buy to let investor with 4 properties rented to students. This assessed investors' experience of current heating systems and attitude to a potential DHN as an alternative.
- An interview with a large insurer / pension fund to discuss the attractiveness of DHN as an investment

- Interviews with two people who had experience in related infrastructure deployment businesses (gas, water, telecoms and electricity) and a specific interest in improved infrastructure deployment.

With the diversity of the supplier base for DHN delivery there was insufficient resource to engage with manufacturers and sub-contractors representing all aspects and components of a network. Where products and processes are identified as having high potential for improvement and substantive reduction in capital cost of the DHN they will be invited to contribute during solution development in Stage 2.

4.3 Stakeholder Workshop

The stakeholder workshop was held on the 4th February 2016. It comprised 27 invitees from DHN design, development, operation and supplier organisations, plus members of the ETI review panel and Project team. Details of attendees and workshop material are included in Appendix A.

The Stakeholder Workshop was designed to be the key opportunity to gather a cross-section of DHN stakeholders and directly explore their requirements and the challenges for DHN deployment. The workshop offered an environment where assumptions and understanding could be cross-checked in real time. To minimise the risk of guiding participants to particular conclusions, the workshop was structured to build requirements, priorities, opportunities and challenges from first principles.

Following the introduction and overview of the process the workshop comprised 3 phases:

4.3.1 Stakeholder Requirements

Workshop participants were initially split into two groups to explore the requirements and desires for the two key 'Customer' groups (Users & Investors – defined in Section 5.1) against five key criteria for value propositions:

i) Performance / Specification – Features and benefits of the full DHN offering
ii) Speed – Time taken to deliver the DHN, or time to respond during service
iii) Dependability – Reliability of the offering vs. expectation or counter-factual solutions
iv) Flexibility – Ability to adapt to the potential future needs of each stakeholder
v) Cost – Whole life cost of the system (referred to as TOTEX in utilities)

Participants took the perspective of individuals or organisations in the relevant stakeholder groups, identifying distinctive subgroups and their specific requirements for heating systems or investments. Where there were gaps in representation or missing insight from significant subgroups; the requirements were supplemented with direct stakeholder discussions.

4.3.2 Challenges and Opportunities for DHN

Workshop participants were then split into two groups to explore the challenges of DHN deployment from two perspectives.

i) Physical System Challenges: Materials, labour and physical processes.
ii) Wider Value Chain Challenges: Design, legal & commercial.

The starting point was a pair of wall-charts with a first draft of the range of stakeholders / tasks / activities from the relevant end to end process. The Physical system covered components and processes from the outlet of the energy centre to the domestic HIU, whilst the Value Chain considered activities from client engagement and legal contracts to testing and commissioning processes.

This session highlighted aspects of the value chain which are considered to attract disproportionate cost or risk. In addition, this session helped refine the stakeholder map and identify alternative combinations of organisations for DHN delivery.

4.3.3 Further detailed discussion

Finally, a more detailed discussion was held with a smaller group who were able to stay in the afternoon. This provided an opportunity for further review and expansion upon the key learning points from the morning session. Some of the insights from this session are included in both Appendix A and Appendix B.

4.4 Synthesis

Following the stakeholder workshop, the Project Team synthesised the findings from all data sources to contrast with the outputs from the stakeholder workshop, highlight any contradictions and identify gaps in understanding. Further stakeholder discussions were arranged to provide additional insight and bridge significant gaps.

The requirements are presented by Stakeholder group and summarised in Section 6, using a table format where it reflects the process followed during the workshop.

User requirements are not precise metrics, nor was the research intended to be in such depth as to be able to provide an evidence based ranking. As a result the Project Team has presented all but the most specious requirements to inform solution developers of what stakeholders regard as valuable. These are then used to underpin the Evaluation Criteria as developed in Section 8.

The synthesis of sources is highlighted in each section.

Section 7 then develops the findings into a set of barriers to DHN deployment and proposes the changes required for successful DHN deployment at scale. Section 7 also presents a series of hypotheses, under which DHNs are expected to be viable.

5 Stakeholder Map and Grouping

From the stakeholder map in Figure 3 it can be seen that there is significant complexity in the number of actors involved in the delivery and operation of a DHN. There are organisations which operate in multiple boxes integrating across investor, developer and operator. However, with a shortage of technical skills it is likely to be challenging to develop a fully integrated team across all aspects.

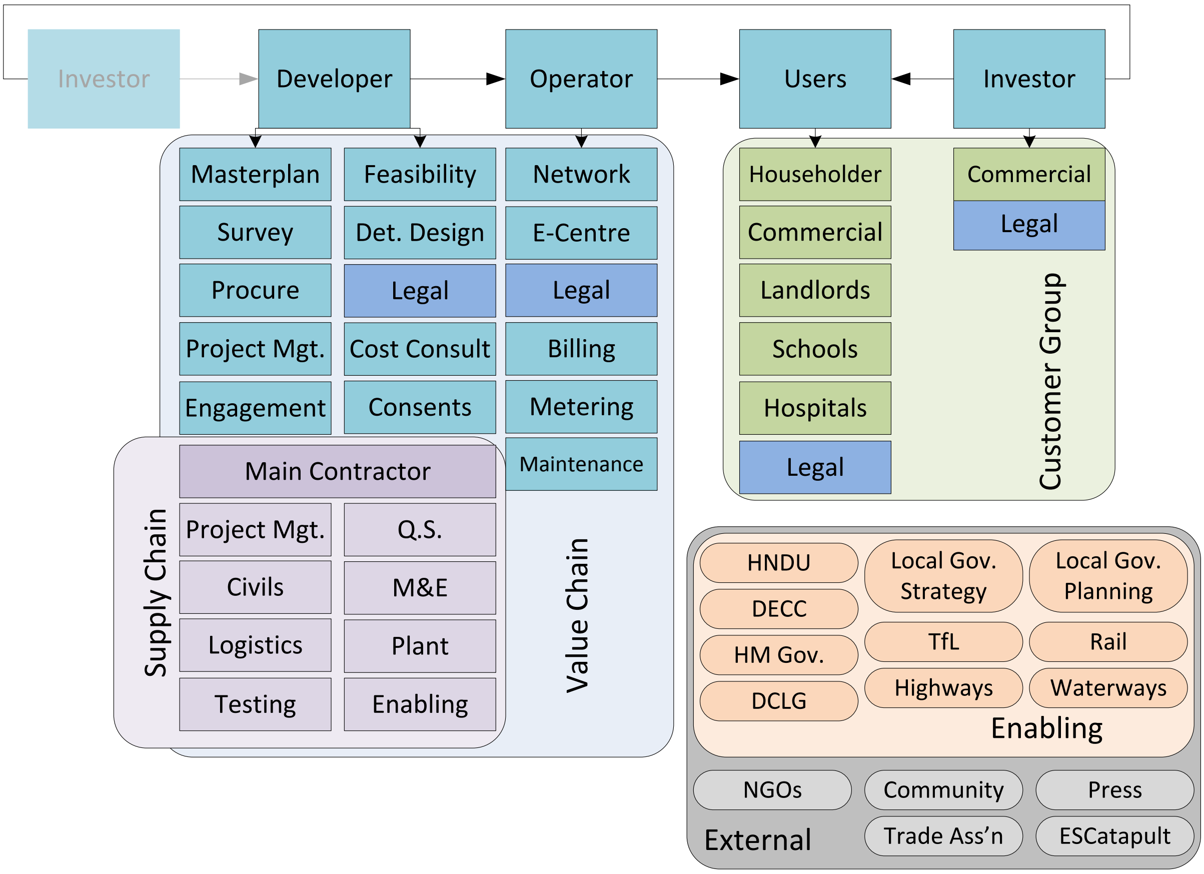


Figure 3: DHN Stakeholder Map

The legal function is highlighted in each section to emphasise the time and cost to organisations protecting their interests in an immature market. To mitigate the cost and effort of multiple legal and contractual arrangements there are alternative delivery models where organisations take on multiple roles in the value chain (as shown in the figure below). Although integration should reduce the complexity and hence legal / commercial costs, there are concerns that this leads to a lack of transparency of costs. There are multiple alternative views of the suitability and strength of organisations' roles and vertical integration across the value chain - there is no consensus around a standardised combination.

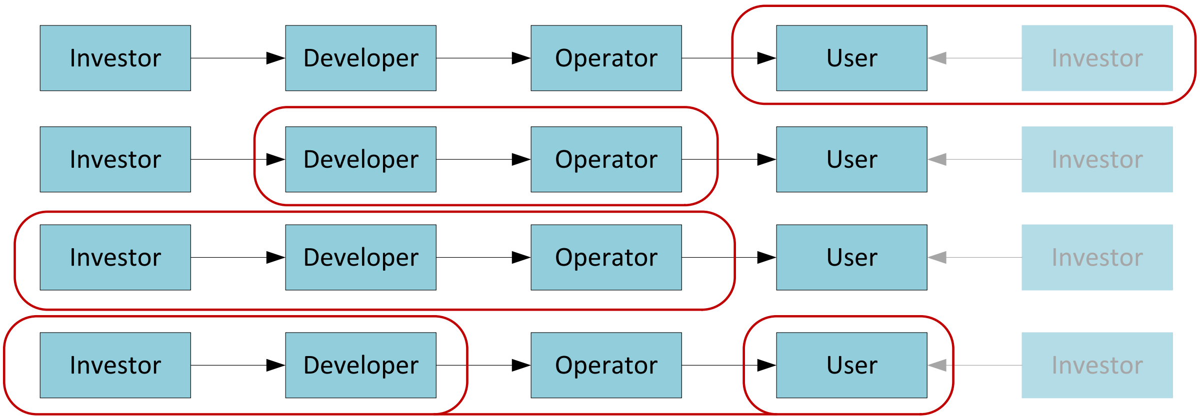


Figure 4: Alternative DHN Delivery Combinations

5.1 DHN Stakeholder Groupings

From reviewing Figure 4 and considering the challenges of DHN delivery, it became apparent that analysing the distinct requirements of each element of the stakeholder model would give more granularity of detail than is needed for this project and not be an effective use of the project resources. It was more effective to divide the landscape into 3 distinct categories of stakeholders as shown by the groupings in Figure 5. Each category has distinct perspectives of requirements for successful DHN deployment, with the customer group dividing into investors and users:

- **Investors and Users** – Potential **Customers** of Heat Networks
  Both of these sets of stakeholders need convincing that the DHN proposition is right for them. Investors have a choice where they put their investment. Consumers, Landlords and Public / Commercial customers have alternative choices for heating provision.

- For these stakeholders it is important to focus on their **requirements** and develop an attractive proposition for DHN; which is more compelling than the alternatives. This is achieved by taking stakeholder requirements and developing them into to a specification for suppliers to meet.

- **Value Chain Stakeholders**
  These are organisations with a desire to generate income and profits from DHN. They can only do so if their offering is attractive to Customers (ultimately to both the Users and Investors). If Customers are not convinced of the value, there needs to be an improvement in some combination of performance, speed, dependability, flexibility and cost. Complexity of the transaction will also have a major influence.

- **External & Enabling Stakeholders**
  These are organisations which may not have a direct interest in a specific DHN, but have the potential to enable, delay or block development. Without addressing their requirements there is a risk of DHNs failing to gain external support and routinely achieve viability.

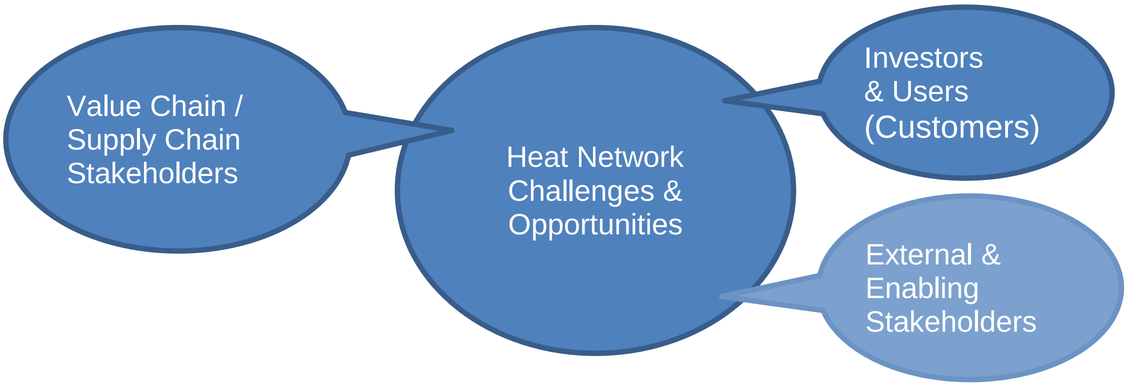


Figure 5: Identifying Challenges & Opportunities

6 Stakeholder Requirements Analysis

This section presents the synthesis of Stakeholder Requirements arising from the sources as described in Section 4 (Figure 2). By defining the desired characteristics of heat provision, across multiple stakeholders, a system level perspective can be developed identifying common requirements and those which potentially conflict.

As well as defining the benefits which the system is designed to deliver (e.g. warmth, hot water), it is crucial to identify the sacrifices (e.g. disruption to install, difficulty to use controls, cost) of both acquiring the heating system and its operation through life. If an improved DHN solution can match current system benefits, whilst reducing the sacrifices stakeholders endure, there is a greater chance of successfully accelerating DHN deployment.

The requirements set out in this Section 6 are used to identify barriers and changes required to enable wider deployment of DHN, as described in Section 7. They will also be used in Stage 2 to inform the development of solutions.

6.1 User Requirements

This section presents property owner and householder requirements for heating with a particular focus on a potential change of system. The intention is to capture key requirements and contrasts between stakeholder types, rather than provide an exhaustive analysis.

Table 1 summarises stakeholder requirements from a User perspective. The table presents the collective experience from the Stakeholder Workshop participants and additional insight from other sources. Where other sources add or contrast; they are referenced as [source] in the table. The column headings reflect the approach used in the Stakeholder Workshop as described in Appendix A. Further details of the insight and sources are provided in Appendix B and Appendix C.

Key themes drawn from this are as follows:

- Heat and Hot Water **performance** needs to be as good as the current system for all users. Households with electric storage heating may have less demanding requirements, but for DHNs to scale, performance needs to match or exceed that of gas combination boilers. These are the trusted default choice replacement; even when presented as more expensive than equivalent sustainable, but less well understood, systems [DHome].

- Energy **bills and maintenance costs** are important to all users. [Which?, DHome, Tenant].
- Eliminating the annual gas check, reducing **maintenance** cost and improving reliability would be a major benefit to regulated social and private landlords in particular [RSL, PriLL, NHBC].
- Current DHN users have mixed experience of **performance and reliability**.
- If users are to change heat provision the shift to a new system needs to be **easy to transact with confidence**. Confidence may come from a trusted brand, proven technology and /or some form of guarantees of relative pricing.
- **Fairness of pricing** from current suppliers is a concern for many households including some DHN users [Which?, RSL, NHBC, DHome]. Even so less than 25% of UK households changed provider in 2015[2] despite efforts to simplify the process and encourage switching.
- Reduced **flexibility** from a long term contractual commitment is seen negatively, particularly with the lack of regulation of a monopoly supply [Which?] and mistrust of energy providers. A long tie-in to the Network would also be counter to current advice for energy users to switch.
- Installation is required with **timing** that suits the owner and householder.
  This is a challenge for persuading owners with boilers which are not close to the end of their life to change en-masse: There may be an expectation for compensation or a need for an alternative proposition.
  Social landlords with a rolling programme may be able to link planned replacement to the DHN roll-out. Speed of installation was not a major concern [DHome]
- None of the sources indicated low carbon performance or environmental impact as a key criterion. This may be due to lack of knowledge rather than lack of environmental concern.

User	Performance	Speed	Dependability	Flexibility	Cost / Price
Common Baseline	Performs at least as well as the current system: - On-demand heat & hot water [Which?] - Controls make it easy to do what you want it to do - Compact space - Low Noise	Heats the home and water rapidly. Installed at a convenient time. No need to change radiators or other heat emitters (low disruption)	Safe operation. [RSL] As reliable as perceptions of current systems. Single point of contact for queries and problems.	Choice of time to change system. [DHome] Able to cope with changes in occupancy: - Single person - Family of 5	CAPEX ≅ Gas combi boiler. Stable pricing OPEX ≅ Current energy & maintenance [RSL, Tenant, Which?].
Tenant Social or Private	Reduce the worry of energy cost or system failure [RSL] Comfortable room temperatures Easy to control. Unlimited DHW. [Which?]	Short installation with low disruption to the property [DHome] (including garden disruption [Tenant])	Always available. No surprise costs. No maintenance visits preferred. [Tenant]	Payment options: - Direct Debit. - Pre-payment (on-line, phone) Flexible to switch technology or supplier as the market changes	No changeover cost to tenant. Stable pricing. Reduced tariff. [Tenant] Capped / index linked prices. [Tenant, Which?] Greater trust in

[2] https://www.ofgem.gov.uk/publications-and-updates/more-consumers-are-shopping-around-over-six-million-energy-switches-2015-says-ofgem

User	Performance	Speed	Dependability	Flexibility	Cost / Price
	Pre-pay (optional) Check my credit or bill status easily.				fairness than current suppliers. [Which?]
Social Landlord Local Authority or Registered Provider	Satisfied tenants (see above). [key for RSLs][NHBC] Tenant ease of use - which reduces RSL burden [NHBC, RSL] Remote support data for duty of care / diagnostics. Auto billing when tenants change.	Phased investment programme.	38% of RSLs cite maintenance cost as a priority [NHBC]. Eliminate annual gas certificate. [RSL priority] Accuracy & fairness of billing important to [RSLs] [NHBC] RSLs seek to avoid the need to collect energy revenue. Preferring it to be done by others.	Options for billing and allocating Standing charges [RSL]. Ability to connect / grow networks to create buying groups with scale. [RSL] Social landlords now see DHN as a potential revenue and profit stream [VanG]	66% see capital cost as key for heating selection [NHBC] Cost / Investment certainty for 10+ Years (ideally 30) [RSL] Only 20% decide on payback [NHBC]. Tenant bills lower and protected from energy price fluctuation.[RSL]
Private Rental Landlord (small: 1-5 properties)	Reduced maintenance burden. Satisfied tenants (see above).		Ideally more reliable than a gas boiler. Remote boiler diagnostics for operator error. [PriLL] No annual gas certificate [Engie]	Installed at a time to suit landlord and tenants. Flexible for varied occupancy. Options for heat contract with me or with tenants. Capital or lease of boiler / HIU. [PriLL]	Any change would need to be cost neutral within 5 years. [PriLL]
Owner Occupier	Good hot water supply w/o loss of space [DHome]. Enhanced asset value (proven). Comfortable and short warm up time [DHome] Remote control option [OwnO]	Installed at a time to suit me. 30% of boilers are replaced after a failure. Another 61% are due to end of life unreliability. 81% would not pre-emptively replace [DHome] Low disruption [DHome]	Trusted technology & supplier [DHome] Reliable systems – proven for some [DHome] Long system life 3rd Party taking responsibility for maintenance and cost {DHome]	I wouldn't want to have to sign up for ever [OwnO] Still want to be able to control system and supplier choice [DHome] Flexible finance for boiler replacement [DHome]	Running costs a priority 47%, capital 15%. [DHome]. Fair Billing Gas combi is the default choice even with higher cost [DHome]. System purchase driven by grant for 13% [DHome]

Table 1: User Requirements

NHBC Sustainable Technologies – [NHBC], DECC owner-occupier survey - [DHome], Social housing tenant - [Tenant], Social landlord - [RSL], Private Landlord – (PriLL], Owner Occupier – [OwnO], Which? Report= [Which?], Commercial Developer – [CD] Vanguards Network – [VanG]

6.2 Investor Requirements

The investor group is diverse encompassing Local Authorities, Social Landlords, Heat Network Developers, Energy Companies, 3rd Party investors, Property Developers and Government.

Table 2 summarises these stakeholders' requirements. Again, this combines insights arising both from the Stakeholder Workshop and additional insight from other sources. For the latter, the [source] of the information is highlighted and further details of these sources are provided in Appendix B and Appendix C.

Three key themes were identified for all investors; although the specific requirements of each investor type are very different.

- **Uncertainty:** Compared to other investment classes, DHN currently is seen as having greater uncertainty of outcomes and hence attract higher cost of capital as a riskier investment. By improving certainty of outcomes for DHN delivery, this project will improve the risk profile and reduce the cost of capital. Hence, solutions should focus on improving certainty of: CAPEX, revenue (heat and other income), project programme and operating cost.

- **Complexity:** Specialist investors [Pension] will be unlikely to invest in DHNs if commercial terms and timescales are complex. All investor groups with experience of exploring DHN funding have identified the complexity and burden of agreeing commercial and legal terms [CD, Pension, HND, RSL, CAG]. Smaller investors commented on overburden of non-expert internal resource and a need to invest in costly specialist consultants to make progress [RSL].

- **IRR / Return on investment.** Without a subsidy, DHNs will need to meet the investor thresholds for IRR. This may be low for a strategic Local Authority project (e.g. regeneration), around 3%, or as high as 18% for a third party investor who prices in risk. Broadly the IRR spectrum is expected to be: LA, RSL, Pension – 3%-5%: Network Developers - 11%-14%: Third party investors up to 18%. All are affected by source of funds; debt funding requiring a higher rate of return.

  A proportion of property developers mandated to use communal heat by the London Plan are thought to focus only on minimising CAPEX cost rather than using IRR. Longer term Developer investors [CD1,2] take an investment appraisal approach – although there may be a need to cross-subsidise the network cost [CD1].

The limited representation from the investor community at the stakeholder workshop needed augmenting to give confidence in the findings summarised in Table 2. Subsequent discussions with investors [CD1, Pension] and amongst participants confirmed that the key investor requirement is improved certainty of outcomes to attract longer term, more risk-averse investors.

Local Authorities as investors, enablers and potentially landlords within the DHN value chain have a crucial role to play to generate momentum in DHN deployment. They are able to attract investment capital and many have scale and ambition to commission large or multiple networks [LA1,LA2, LA3], although the OJEU procurement rules are burdensome. Currently DHNs require either a *Wilful Individual* LA1 (a champion of DHN to drive the programme) and/or a *Rock solid [party] council* [LA2] in order to maintain the commitment across multiple election cycles.

There is no shortage of appetite from **institutional investors** to increase their portfolio of UK property investment, both residential and commercial [Pension, CD1, LA1]. The challenge is to meet the finance communities' expectations for project certainty and simple transactions so that DHNs are ***Bankable***. Without this there are more straightforward opportunities for 3rd party funders to invest in.

Further insight from Co-operative, GIB and 3rd party investors would complete the picture, but at this stage it was decided that the project has sufficient clarity of investor requirements.

Investor	Specification	Speed	Dependability	Flexibility	Cost / Price
Common Baseline	There is little commonality between investor groups. **All value reduced uncertainty and improved IRR,** but thresholds vary greatly [Pension, CD1, LA2]. For investors the categories find expression as follows:				
	Rate of return: IRR Procurement	Time horizon: - Full investment - Revenue lag	Risk Tolerance	Exit options	Scale of investment
Local Authority	Broad range of IRR: - 3% when linked to regeneration - 12% when debt based & income required. Simple pre-packaged procurement.	Need shorter pre-contract period to overcome political cycle and up-front investment costs. [LA3] Long term investor	Medium / High for regeneration. Low when linked to debt.	Options for: - Wholly owned - Joint SPV - Spin-off new co. Future expansion needs LA leadership [LowCO2]	Historically Low £M investment. Increasing multi-site strategic schemes [LA1,LA2]
Social Landlord Registered Provider	Could be as low as LA minimum rates but very cautious investors. [RSL] Simple to specify and contract.	Short pre-contract and a clear proposition to secure funds. [RSL] Long term investor	Low appetite for risk. Improved certainty of outcomes for tenants.[RSL] Experienced contractors [NHBC]	Prefer to hold assets for the long-term [RSL]	Less than £1M until investment is well proven and understood.
Network Developer	Self-funding: [HND] 11%-14% IRR for End to End investment. Simplified planning and development.	Range of investment durations from 15 – 60 yrs	Medium: Greater certainty with internal delivery capability	Options: - Sold / returned to client LA - Convert to SPV - Spin-off new co.	Proportional to scale and access to investment. £1M - £100M
Property Developer Speculative Corporate	Interested in the planning gain. May see mandatory DHN as a tax on development [CD2]. [CD1] Contradicts: Growing corporate and technical appetite for DHN.	Early sale and exit (may put network performance @ risk). [CD2] Lengthy DHN pre-contract may extend overall project programme. [CD1]	No interest in DHN operation; aim to sell as part of the development. [CD2] Concern that DHNs are unregulated and so risk continued under-performance. [CD1]	Immediate exit sale to ESCo or other operator.[CD2] Willing to explore connection of multiple schemes; but complex. [CD1]	Proportional to minimum GLA requirement and potential planning gain.[CD2] [CD1] May be a significant part of development budget
Co-operative	Potentially low IRR expectations: 3% Limited internal resource.	Long-term community investment. Limited internal capability and funds.	Low risk from limited community funding.		
3rd Party Speculative	Medium High IRR 10%-18% [DHNB]	<15yr investment and sell stake	Risk tolerance proportional to		Not seen as core to HID project

Investor	Specification	Speed	Dependability	Flexibility	Cost / Price
	[Pension] funds invest in property @ 3.9% IRR.		potential IRR		
Corporate	Simple single tier transactions are needed to secure investment.	Long term investor in property: 60yrs [Pension]	Low appetite for risk. Improved certainty of outcomes needed.		Significant investments preferred: £100M+
Green Investment Bank	Preferential 3rd party investor. Criteria may be more favourable than other 3rd party				
HM Government Via DECC	Not IRR based: Investment linked to improved capability.		Medium/High based on accelerating deployment of DHN. [DECC]	Loan or grant for increasing capability Avoid the use of subsidy.[DECC]	Potential investment. £300M

Table 2: Investor Requirements

Barriers to DHN Deployment– [DHNB], Community Energy: Low CO2 Future – [LowCO2], Commercial Developers – [CD1 & CD2], NHBC Sustainable Technologies – [NHBC] Heat Network Developer – [HND], Social landlord - [RSL], Insurer/Pension – [Pension], Vanguards Network – [VanG], DECC HNDU – [DECC], CAG Consulting – [CAG]

6.3 Value Chain Requirements

This section is developed from project team insight and knowledge of the commercial organisations in the DHN sector. Added to this is the project team's broader understanding of the nature of achieving change in evolving markets. Further interaction with stakeholders from the wider value chain, where essential for specific solution development, will be included during Stage 2.

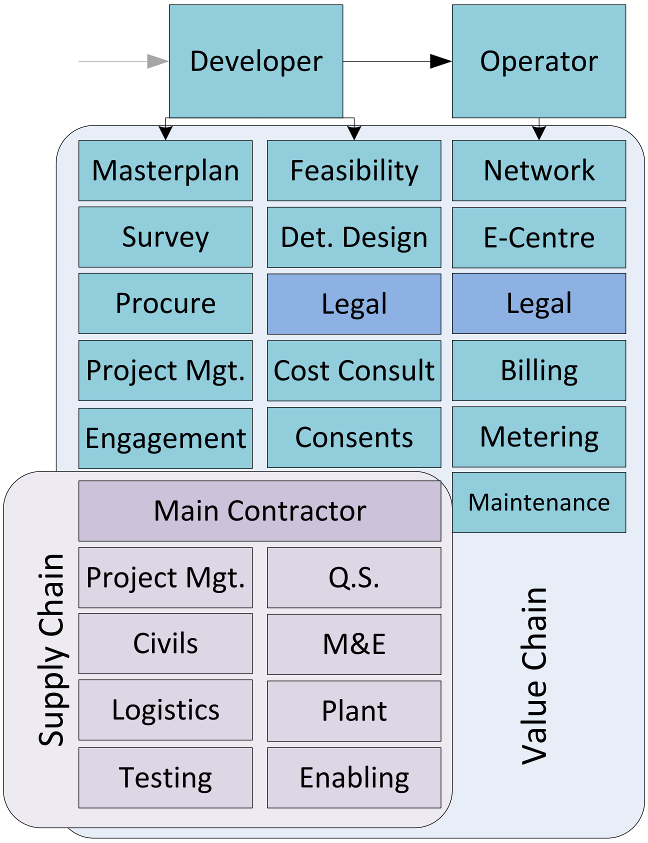


Figure 6: Value Chain Diagram (showing that the supply chain is a subset of the wider value chain)

Across the DHN value chain, and wider infrastructure and construction sector, the vast majority of organisations are commercial businesses. Whether public or private, the companies require sustainable profitability and, in many instances, growth in the sectors in which they operate
.
To achieve this, organisations will aim to:

- Maximise revenue by selling more at the highest price their clients will tolerate
- Reduce internal and external costs of providing goods and services.

In the DHN sector, for existing buildings in particular, many of the costs are uncertain:

- Civil engineering and installation costs are impacted by unknown ground and building conditions and can be subject to weather delays.
- Planning consents, project management and legal costs are influenced by the willingness of external organisations to engage and negotiate consents (planning, rail, water, etc.).

In addition, from the operators' perspective, revenues are uncertain. Heat loads for customers per building can only be estimated and in many cases customer take-up (proportion of buildings committed to joining the network) cannot be certain until after the project is in progress.

When market competition is limited there is little incentive for value chain organisations to strive to reduce prices. The temptation is to maintain current margins and volumes, rather than work to reduce costs which may expand the market.

In extreme instances this leads to cartel practices as shown in the DHN pipe manufacturing cartel of 1998[3], where fines of over ECU90M were levied against 10 European and Scandinavian manufacturers for artificially inflating pipe prices and attempting to bankrupt a new entrant.

There is a balance to be struck between:

- Encouraging competition to drive improvements in cost and performance and
- A standardisation agenda to enable common systems and scale which will also improve cost

In the electronics sector the USB cable standard is a good example of how commonality drives cost and technical improvement at scale. Even though alternatives had additional capability (Firewire / Thunderbolt) USB achieved a significantly lower system cost and mass scale with minimal sacrifice of performance. The DHN value chain is dynamic and some organisations have achieved significant improvements in capability in recent years, this has led developers (see Appendix B) to hesitate to create partnerships / frameworks while the solutions stabilise.

The EN standards developed for pre-insulated pipe have led to a general increase in quality. Further standards have been produced as new products become established in the market including twin pipes and flexible pipes[4]. The latter standard is written to define the performance of the product rather than its design which has allowed for further design development and improvements.

There are not-for-profit organisations[5] and co-operatives operating across the DHN value chain with the goal of increasing the adoption of low-carbon heating technology. These organisations aim to be technology and supplier neutral as a source of unbiased information to potential adopters of DHN.

Three key themes emerge from this:

- **Risk:** Value chain organisations need to protect themselves from exposure to losses from increased costs and the risk of litigation. Insurance and careful legal documentation will help reduce risk, but this comes at a cost. This is particularly acute when there are multiple contracting parties and each one needs to arrange bespoke legal and insurance services. Pooling risk and standardising legal or commercial documentation would reduce the burden.
- **Uncertainty:** Reducing uncertainty of technical solutions, costs and timescales through better understanding of the challenges and standardisation of approach, has a double impact: Firstly lowering the cost of capital through reduced risk and further saving project delivery costs by minimising task variability and the associated time and contingency. Place (location and building typology) has a major impact on the uncertainty; particularly of civil engineering.
- **Competition:** It would be valuable to establish mechanisms by which the DHN value chain can collaborate, whilst retaining competitive ambition to improve performance.

[3] http://europa.eu/rapid/press-release_IP-98-917_en.htm?locale=en
[4] BS EN 15698-2:2015 (Twin pipes); BS EN 15632 1-4:2009 (Pre-insulated flexible pipes)
[5] e.g. The Association for Decentralised Energy http://www.theade.co.uk/
Heat and the City http://www.heatandthecity.org.uk/about

6.4 External and Enabling Stakeholder Requirements

This section summarises the requirements of External stakeholders including those which have an Enabling role in supporting (or potentially blocking) DHN projects. They have not all been researched directly (as they are not core to the project), but it is deemed useful to summarise findings, workshop participants' experience and assumptions here as a working hypothesis.

Figure 7 gives an overview of the stakeholders which, although not directly involved in a specific DHN project, have potential to influence the deployment of Heat Networks individually and nationally.

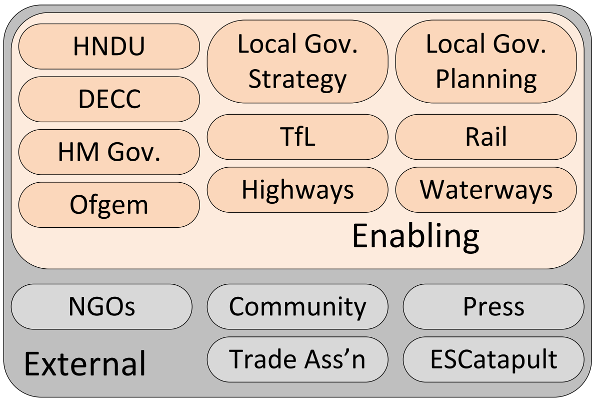


Figure 7: External & Enabling Stakeholders

Enablers:

DECC / HNDU: An objective to promote adoption of low-carbon heat generation and supply with:

- Self-sustaining, viable, open market heat supply through DHNs.
- Minimal requirement for legislation – which is costly, slow and challenging to drive precise outcomes.
- HNDU provides modest levels of financial and technical support intended as a temporary stimulus and not systemic subsidy of an unviable market.
- A secondary goal of generating sustainable economic activity for the UK and reducing fuel poverty.

The HID project will be successful from a DECC and UK Government perspective if it demonstrates solutions which meet, or contribute to, these requirements.

Ofgem

Ofgem do not at present operate in the unregulated heat market but they are looking at the need for greater regulation: not just for DH but for other heating systems. Ofgem also have a role in administering the RHI which may be used by DH schemes for biomass, deep geothermal, etc. Aligning DHN solutions with Ofgem requirements will pre-empt some of the changes of shifting to a regulated market.

Ofgem's purpose is to protect the interests of present and future energy consumers, by delivering an affordable, secure and sustainable energy system. The HID project will have added value from a regulatory perspective if it enables more sustainable energy provision without cost penalty to energy consumers.

Local Government

There are many strands to Local Government interaction with a DHN. Authorities have roles as both investors and operators of Heat Networks as described above and are also often customers for heat. Even if only involved externally with a DHN a Local Authority will have an impact across multiple departments including: planning, strategy, transport, development, regeneration, energy, environmental impact and commercial.

Our working assumptions for how DHN projects can meet the requirements of Local Authorities and similar bodies are:

- Clearly present DHN project proposals and full implications – using standard formats and data
- Understand the specific requirements for each department and structure information in such a way that it makes it easy to come to a decision
- Minimise the effort required to process plans within stretched Local Government resource
- Demonstrate a breadth of value to the wider local community.

Third Party Consents

There are a number of other organisations who may need to give consent for the path of the network or temporary access. These include:

- Network Rail
- Canals and Rivers Trust
- Highways England
- Transport for London
- Private landowners

These organisations are unlikely to benefit directly from the DHN and so their requirements will predominantly focus on minimising the burden of reaching mutual agreement of the consent. The DHN project will meet the requirements of these bodies if it has a focus on making it as straightforward as possible to arrive at a positive consent decision; consuming minimal resource.

External

More widely, local communities and the media have interest in the implications of DHNs for the public. Keeping such stakeholders informed minimises the risk of negative public reaction to proposals. To maintain the wider community support DHN teams should ensure:

- Consistent message and regular communication to external stakeholders
- Unambiguous information and data
- Full disclosure of successes, challenges and plans to improve

The value of addressing the requirements of external and enabling stakeholders is to smooth the path of applications through bodies which have the potential to delay, block or adapt a DHN proposal.

7 Barriers and Required Changes for DHN Deployment

This section summarises the barriers to DHN deployment by contrasting where they fall short of the stakeholder requirements in the previous section. To overcome these barriers, priority changes and improvements are proposed to improve technical performance, whilst reducing complexity, disruption and cost.

Barriers are reviewed and presented by stakeholder group as in sections 5 and 6:

- Users – Householders and Building Owners
- Investors
- Value Chain
- External Stakeholders

Required changes are presented as priority challenges for the DHN value chain to address. As a summary, a first (qualitative) assessment is then proposed (in section 7.6) to present the conditions under which DHNs are likely to be viable.

7.1 Barriers to Users Adoption of DHN

For users of existing properties to connect to a DHN, the crucial requirement is to establish a compelling reason to change from the current heating provision in the building.

There are three underlying commercial drivers of such a change:

- **Reduced cost** - compared to the current and alternative heat provision
- **Additional benefits** - improved performance - actual or perceived
- **Reduced sacrifices** - easier transactions, fewer quality failures for product or service delivery

A fourth option is that change could be mandated through regulation or another external driver. However, the intention of this project is to identify non-mandated solutions.

By blending these attributes there is the potential to raise the profile of DHN and generate interest and momentum. The following sub-sections summarise the DHN barriers and concerns by user grouping with the required changes proposed at the end. Sources other than the Stakeholder Workshop are referenced to Appendix B and Appendix C.

7.1.1 Tenants and Owner Occupiers

At the household user level the key requirement is how a DHN performs compared to the current or other alternative heating systems.

Although tenants do not generally choose the heating system in their property their experience of the heat provision will have influence on the landlord, as it will affect the attractiveness of the property to future tenants and perhaps the rental value.
Barriers have been identified by existing DHN tenants and private Owners with DHN connections in relation to performance and heat charges.

Performance:

- AECOM has experience, through post-occupancy evaluation and discussions with others in the industry, of the poor operation of heat generation plant within the energy centre. Causes range from poor design, installation and commissioning (including the plant itself) and its control systems. This issue appears more prevalent across the smaller communal heating schemes developed in recent years in London. This may well reflect the feedback of a lack of hot water from the Which? survey.

- In a similar manner, AECOM has direct knowledge and anecdotal evidence from others of high heat losses in apartment buildings from poorly designed and insulated pipework in the communal areas. This leads to instances of overheating in the summer as a result of heat loss from hot water being continuously circulated to feed domestic hot water systems. The issue of overheating was also identified by both the Which? survey and two of the RSLs surveyed.
- To help address these issues, A Heat Networks Code of Practice has recently been developed by the Chartered Institute for Building Services Engineers (CIBSE). It sets minimum design standards that aim to avoid some of the issues that have been identified in poorly performing heat networks and can be used as a design specification for new projects. It is too early to know how effective this will be in improving performance across the industry.

Heat Charges:

- AECOM is aware of concern by some DH residents about being subject to a long-term contract tie-in from a monopoly DH provider and confirmed by feedback from Which?
- The Which? survey also found that a number of heat networks are delivering heat at a similar or lower total cost to residents (taking into account maintenance and replacement costs) compared to installing conventional gas boilers or electric heating to each property. However, the report also showed that the price that residents pay ranges significantly, by around a factor of three (from 5.5 to 14.9 p/kWh). As a result, many residents on the worst performing heat networks are not benefitting from lower fuel bills and, indeed, may well be paying more than they would with a more traditional heating system. Similar concerns of higher bills were expressed by two of the RSLs surveyed for this project.
- Both the Which? survey and feedback from an RSL highlighted a lack of understanding / transparency / trust of heat charges.
- The Heat Trust has introduced a standard set of requirements for contracts between heat providers and consumers. This is to tackle issues around customer service standards and customer protection, and aims to deliver a similar regulatory framework which exists for other utilities. It is too early to know how effective this will be in improving consumer confidence.

General feedback from owner-occupiers and tenants who did not currently have district heating was that there is **no compelling reason to choose a DHN** upon replacement of the heating system. As highlighted in the DECC report [DHome], this was particularly the case for owners who currently have a gas combi boiler. Without a compelling proposition, there will be a need for regulation or incentives to shift the market. There was an expectation by two tenants and one owner-occupier surveyed for this project that **low carbon solutions should lead to cheaper energy bills** – although this was not identified in the DECC report. There were a number of issues identified as currently putting potential future consumers off switching to heat networks. In general, the DECC study [DHome] particularly highlighted that in choosing a heating system, there is the need for **a trusted supplier** and **confidence in the heating system's performance and reliability**, which was echoed from tenants surveyed for this project – a potential challenge for DH in its infancy with a limited track record. Furthermore the DECC study highlighted that most owner-occupants only change heating system towards the end of their current boiler's life – hence demonstrating **strong resistance to pre-emptive boiler replacement which has major implications for DHN rollout.**

The DECC report also highlighted more specific barriers to switching around DH systems. This included **concerns about disruption when installing DHN** in existing buildings and images of a large power station being built in the neighbourhood. Whilst the **transfer of**

maintenance responsibility was seen as a plus point, it raised concerns for a few who foresaw a loss of control and worried that this might mean problems were not promptly fixed. The report also highlighted **concerns about DHN billing** as an obstacle to a move to district heating (also highlighted by a tenant and an owner-occupier surveyed; both anxious that a long-term contract tie-in would give best value). Some respondents wanted to know who would run the network (e.g. a private company or local authority) and whether they (tenants) would have **control of the timing and temperature** of the heating. A more general concern, expressed at the WP1 workshop and by owner occupiers and Landlords, is the potential negative **impact of DHN on the value of the home when it is sold**. Many of these concerns may be as a result of a lack of understanding; rather than a poor DHN proposition.

7.1.2 Social and Private Landlords

Barriers to DHN identified from Social Landlord interviews were significantly greater than anticipated – including from sustainability leaders. The majority of experience was from communal rather than large scale DHN, but the [RSLs] perception is that they have very similar characteristics. The feedback was of **performance and billing issues** as described above for tenants: even those without direct experience agreed that both communal and district heating suffered from **poor reputation in operating performance and bill costs**.

Research with 185 RSLs by NHBC Foundation [Appendix C] shows poor performance is most closely associated with biomass aspects of communal heat systems. Even so DHNs need to overcome negative perceptions of reliability and cost if social landlords are to adopt DHNs at scale.

The NHBC Foundation survey found that communal heating (without biomass) was **rated relatively highly (in comparison with alternative sustainable technologies** – conventional gas boilers were not included as a comparator in this study) in terms of all categories evaluated including installation, maintenance and resident feedback and engagement. **Some found it cheaper for residents,** improving efficiency and reducing maintenance costs. **Eliminating the need to visit individual properties for annual gas servicing and certification** was seen as a major cost and logistics benefit. However, some respondents spoke of problems with **unevenly distributed heat and heat loss** through lengthy distribution networks coupled with complex maintenance regimes. Resident **satisfaction has suffered in some instances with the loss of ability to choose their own energy supplier**. Challenges in ensuring accurate metering of individual usage has led to billing difficulties, which has resulted in **some housing associations relying on estimates of consumption, or failing to recover costs at all.**

A key issue highlighted by social landlords who instigated projects is the **complexity and resource requirements of specifying and project managing** the delivery of community heat provision. [RSLs] proactively raised this as a burden. They cited conflicting guidance from suppliers and advisors and **time consuming difficulty in agreeing the system specification**.

7.2 Investor Barriers

For DHNs to succeed at scale, as a low carbon heating technology, there is a need for significant investment in the network and energy centre infrastructure. For investors to choose to put their money into DHN projects they will need confidence in the return on investment and for the process of investing to be straightforward. A number of barriers exist which impact investors of all types:

- Contractual complexity across the development process and in the pricing of heat to customers [HND, CD1, CD2, Pension, RSLs, DECC].

- There are easier ways to get a more certain return on investment than via a DHN [CAG]
- DHNs have a history of underperformance against design. [RSLs, CD1]
- Most projects require very technical resource which is in short supply [CD1, HND].
- Approximately 15% of Capital cost is invested at risk – before project contracts are signed.
- Concerns about a lack of transparency and best value from the DHN value chain.
- Investors [CD1, RSLs] concerned that heat is an un-regulated sector (unlike other utilities)
- With high capital cost it is not unusual to need to cross-subsidise the cost of the residential heat network from the broader development funding [CD1].
- Selling power from CHP units has technical and pricing issues making the process difficult [CD1, HND, VanG].
- Development takes too long: 6 months to agree design and 6 months to get to contract. [CD1]

From an investor perspective the key barriers are a lack of certainty of outcomes (cost, programme and return) and the resource requirements burden for a DHN project compared to other investments.

7.3 Value Chain Barriers

As described in the Stakeholder Workshop overview (and Appendix A) participants made a focused review of both the physical supply chain and the wider DHN value chain. The priority was to highlight areas which attract disproportionate time, effort or cost.

The barriers presented are those arising from the Stakeholder Workshop and, where other sources support; they are referenced [*source*] and any contradictions noted. Sources other than the Stakeholder Workshop are referenced to Appendix B and Appendix C.

The diversity of the barriers identified across the value chain demonstrates that there are significant opportunities to improve DHN delivery, but also that there is no single area of improvement that will deliver the required change. Key barriers highlighted are:

- **Capital Cost:** There are a number of elements of both the physical system and supply chain which have been identified as attracting disproportionate cost (HIU, Pipe joints). [HND, Engie]
- **Complexity:** Complexity of engagement (legal / commercial) across the value chain. Higher cost from multiple layers of margin. Duplication of effort from additional levels of design.
- **System Architecture:** DHN Systems are bespoke with a high risk of over-engineering. A strong system integration role and standardisation of componentry will improve performance.
- **Collaboration:** Significant potential for improved outcomes from collaborative system and process design rather than linear contracting.
- **Resource:** Requirement for skilled resource (design / installation) and shortages of capability: both scarce resource and lower UK productivity (compared to Europe & Scandinavia).
- **Quality:** Variable performance and quality in design and delivery. Significant cost and time in testing & commissioning to inspect in quality.
- **Clarity of Offer:** Landlords and developers are unclear how to translate their requirements into a DHN specification for their suppliers or a clear offer to end consumers: The value chain is frustrated by their lack of understanding, but could offer more product based solutions.

Many of these barriers were highlighted from organisations within the value chain and recognition of a need and potential to improve is a good starting point. Details are set out in Table 3.

Barriers	Specification	Speed	Dependability	Flexibility	Cost / Price
Design Feasibility Masterplan Detail Survey	Systems are **over-engineered** and inefficient. Lacking industry standards resulting in design inefficiencies from poor network design. [HND, CD1, CD2, Engie]	System design is long-winded (and can still result in over-engineered systems) Low **collaboration** between parties extending design programme	Errors arise from interface **complexity** between contributors **Uncertainty** of project outcomes (heat revenue, time, cost and performance)	Costly to include flexibility for future expansion (who will pay) [Engie] [CD1] disagrees: An extra connection point is not a major cost burden, but larger pipe may be.	15% of Project Cost Committed in Design and Procurement [CD1] **Duplication** of survey and design adding to costs
Procurement Legals Cost Consulting	Legal **complexity** and cost is a barrier to investors & users [RSL DHNB,LA1,HND, CAG]	No standard frameworks for faster procurement [CD1]	Uncertain heat demand and its longevity [DHNB]	Challenges of pricing heat and power for external use [LowCO2]	Off-loading risk to sub-contractors inflates costs [VanG]
Supply Chain					
Civils	Insufficient data on underground obstacles – increases risk, work content and cost of schemes. [Engie, ETI, AECOM]	Faster approaches available with early contractor engagement [Civils] Hard-dig has a major impact on time and cost [AECOM, Civils]	Disruption for property occupiers and locality during installation [NHBC]	Opportunity to share civils cost with other utilities [Civils, HND,CD1, NGrid] Tunnelling; though effective is a prohibitively expensive solution. [AECOM]	Added cost from lack of specialist civils involvement in design [Civils]
M&E Install	Insufficient number of capable installers in the UK [DHNB] Suppliers not involved early to save cost [Civils]	Pipe laying is slow UK productivity lower than Scandinavia	Disruption for property occupiers and locality during installation Finding capable contractors [NHBC]		Shortage of skilled resource & premium rates.[DHNB] Ridiculous variability of pipe costs [DHNB]
Materials	Overly complex systems must add cost without standardisation [DECC]				HIUs & Pipe connections costs out of proportion [HND,AECOM,Engie] UK pipe prices are inflated [VanG]

Barriers	Specification	Speed	Dependability	Flexibility	Cost / Price
Testing			Defects at testing & commissioning add excessive time and cost [Engie, HND]		High cost to repair.
Logistics	No issues raised				
Plant	No issues raised				
Operation Billing Metering Maintenance	System controls are immature [HND]		Uncertain head load demand (commercial in particular) [DHNB CD1,CD2,HND,VanG]		
Clients	Clients & system users have little experience of DHN & can't define what they require [HND]				Client project management is a long-term cost and commitment [LA1, LA2, CD1]
Consumers	Poor consumer awareness of heat network's benefits 69% never heard of DHN [DHome]	Market / user engagement is a time and cost challenge for existing buildings			
External Government Utilities Rail Highways TfL	Combined utility trenching is a logical approach but incredibly difficult in practice.	Complex consents for interactions with rail, power, canal, road and other utilities [Engie]			Cost of commercial interactions with rail, power, water bodies.

Table 3: Value Chain Barriers

Barriers to DHN Deployment – [DHNB]**,** Community for Energy Low CO2 Future – [LowCO2], NHBC Sustainable Technologies – [NHBC], DECC Homeowners Study – [DHome], Heat Network Developer – [HND], Commercial Developers – [CD1 & CD2], Social landlord - [RSL], Vanguards Network – VanG, DECC/HNDU – [DECC], Pipeline Civil Engineering Specialist. - [Civils], National Grid Infrastructure Upgrade - [NGrid], Local Authorities – [LA1,2,3], CAG Consulting – [CAG], Global Energy Group – [Engie]

7.4 External Stakeholder Barriers

The majority of the external stakeholders have no shared interest in the successful creation of a DHN. For the likes of Highways and Rail there is in fact a negative impact from two angles:

- Resource requirements needed to process, review and approve applications for DHN.
- Disruption during the delivery phase and any future need for access.

Achieving approvals from such external stakeholders is crucial to project success and so developing an approach to minimise their resource requirements and minimise the negative impacts is important.

7.5 Required Changes for DHN Delivery

With a clear picture across DHN stakeholders of both stakeholder requirements and barriers to DHN delivery, these can be summarised into the priorities which need to be tackled for DHN deployment at scale. These priorities are reflected in both the HID project evaluation criteria (Section 8) and also form the basis for Work Package 3 System Review and Target Setting, which in turn sets the challenges for solution development in stage 2.

7.5.1 Financial Viability

There are a number of areas in the HID project which directly focus on the financial viability of the scheme.

- **Improving Cost and Revenue Certainty** (Capital, Operating Cost and Income)
  Greater cost certainty and reduced risk will attract a greater range of investors. Furthermore, cost certainty has a major impact on the required rate of return and the viability of a scheme. For example, in a simple illustrative calculation for a DHN the capital cost available for a scheme at 18% is only a quarter of that available based on an IRR of 3% for the same scheme to be viable (Appendix D).
  Operating cost and revenue uncertainty also have a major impact on scheme returns.
- **Reducing Capital Cost**
  The absolute level CAPEX is a key hurdle for investors and developers.
  As a simple illustration, a 40% reduction in CAPEX can more than double the IRR from 3% to 7% for a 40 year investment (see Appendix D).
  Capital cost focus should look at capital equipment, material, labour, plant and all overhead including contingency and margins.
- **Reducing Operational Cost**
  System running cost, OPEX, also effects DH system viability. It is dependent on the cost of primary fuel, heat losses, pumping energy, staff cost, repairs and maintenance.
- System design has a key role for fuel efficiency as well as for reliability and maintenance.
  Understanding the trade-off between CAPEX and OPEX is a crucial challenge for the project as both impact viability.
- **Reducing Time on Site**
  Installation time impacts project cost in three ways at the same time (in addition to the direct impact on the core capital cost, such as labour and plant for civil engineering):
    - Prelims costs for site management and plant etc. are proportional to construction time.

    - o Road closure is charged by the day; even if waived this is a cost to the community.
    - o Extended programmes reduce project cash flow and add interest cost to the project.
- Site time is heavily influenced by ground conditions and topology: A city centre location for the network will involve much more ‘hard-dig’ excavation in streets vs. faster cheaper ‘soft-dig’ in verges and greenfield sites.
- **Increasing Network Developer & Operator Revenues**
  Reducing revenue uncertainty, by adding alternative revenue streams, improves viability. Such additional revenue could arise from, for example, sharing cost of civil engineering works with those of other utilities to installing new infrastructure (e.g. data, heat storage, SUDS – Sustainable Urban Drainage systems).

7.5.2 Wider Priorities

There are other priorities which fundamentally affect the viability of the scheme but focus on other aspects of DHN delivery.

- **Systems Architecture**
  Integrated systems design provides a significant opportunity to assure DHN performance and optimise system cost; avoiding over-engineered components. Options to be explored for innovative network design including: elimination of network elements or combining them with other infrastructure, challenging current concepts of heat transfer and containment / storage.
  For DHNs to get beyond the Social Housing and New-build sectors will likely mean identifying mechanisms to deliver DHNs with low levels of initial take-up from owner occupiers. A technical and commercial model is needed to allow other users to connect at a later date (at boiler end-of-life or when convinced of the proposition), whilst keeping the early connectors well served and network operating costs manageable.
- **Improving the User Value Proposition**
  Create a compelling offering for user groups and a reason to switch to a new DHN solution. The analysis of stakeholder requirements and current barriers particularly identifies difficulties to overcome resistance to pre-emptive boiler replacement. This is likely to be crucial to wider deployment and viability. There is a need for greater confidence in the supplier, confidence in the performance and reliability of district heating, fair pricing throughout the contract and minimal disruption. Market / user engagement is a major barrier for existing buildings in particular given limited knowledge and reputation of district heating.
- **Improving Investor Value Proposition**
  Create a compelling offering for Investors (including those Developers who invest in projects) to attract lower cost finance. In addition to challenges of reduced costs and improved cost certainty, there is the need to reduce the legal & commercial complexity. Standardised solutions and/or improved skills to address the complexity of project leadership and greater integration of the design and delivery teams.
  Streamline master-planning and design to reduce the at risk cost pre-contract (≈15% of CAPEX)
  Ensure risk is held at the appropriate level: not off-loaded to sub-contractors thus inflating costs.
- **Reducing Complexity of Transactions Between Stakeholders**
  Identifying cost & delay across the Value Chain and engagement with Enabling Stakeholders.
  Identifying opportunities to simplify and standardise transactions across all stakeholders. Complexity is recognised by potential Users and Investors as a barrier

to their involvement in DHN, but also highlighted as a burden from stakeholders already working in the sector.

7.5.3 Summary

There are nine priority areas which encompass the range of success factors for DHN. Improvement is needed against most, if not all, these criteria if acceleration of DHN deployment is to be achieved. Cost is a crucial enabler, but the proposition in the round also needs to appeal more effectively to the market it seeks to serve.

7.6 First Assessment of Conditions under which DHNs are Viable

With the range of requirements across multiple stakeholders the viability of DHNs is a complex system and does not lend itself to an algorithm or model. At this stage the review of requirements, barriers and priorities has been used to develop a series of hypotheses for DHN viability. These are developed from each of the stakeholder groups' perspectives. It is also worth exploring how the viability of DHNs might evolve over time.

7.6.1 User Viability

These are hypotheses for User adoption of DHN system as either a householder and / or a property owner.

Firstly Users need to know what a DHN is and its benefits: currently only 16% report that they understand what a district heating system is [DHome].

To change to a district heating system Users will need confidence / guarantees that:

- It will perform at least as well as current systems for heating and hot water.
  - For DHNs to deliver at scale this must include matching performance of gas combi-boilers.
- Capital cost equivalent to the default alternative [gas combi boiler]
- Reliability is proven; assuring users that the system provides heat and hot water as needed.
- It will cost the same or less to run and maintain.
- Consumers are protected from unfair monopoly supplier pricing.
- The DHN installation and contract will not have a negative impact on the property value.

For Landlords the incentive to change may come from:

- A significant reduction in the cost and admin burden of boiler maintenance and tenant support

For Owner Occupiers a compelling reason to change will be needed to replace an existing boiler; particularly to get consumers to switch ahead of a boiler failure or increasing unreliability.

Crucially consumer markets have significant inertia to change from the status quo. Even when householders can save around £200 per year by switching energy supplier, less than a quarter do so. Hence the need for significant incentives to switch. If this cannot be achieved with an improved heat or service offering; a direct financial incentive may be needed. As an example (not tested), Users connecting early might benefit from free HIU and connection, with no heat charges for the first winter, or from reimbursement of boiler residual value.

7.6.2 Investor Viability

Hypothesis for Investors to provide funding for DHN investment at a target 4% IRR.

- Confidence in the DHN to meet or outperform its budgeted rate of return
- An easily investible proposition: without additional complexity above equivalent investments.
- Ability to take credit corporately for the Carbon savings and sustainability aspects of DHN.

For investors with a property or development stake in the DHN there will be other benefits which will support the viability of the network investment:

- Potential additional revenue from network expansion to private customers.
- Ability to attract additional funding for regeneration linked to a low carbon development plan.
- As a focal point for a commercial development which supports a favourable planning decision.

7.6.3 Value Chain Viability

For the value chain to be viable, developers, suppliers and advisors need confidence that:

- There is a potential pipeline of DHN network delivery backed by investment
- There is an opportunity to build a sustainably profitable business based on customer price / performance expectation and the organisation's ability to develop its offering at the right cost.

Initially there may be a need for investment to outweigh revenue as value chain organisations develop solutions and capability ahead of market requirement. Without this, or other stimulus, the DHNs may remain a niche market, only viable in certain locations and building typologies.

The value chain is highly dependent on successfully negotiating the risk factors of location (Place / Topology). One reason developers are more attracted to New-Build, is because of the much lower likelihood of uncharted services or archaeology which adds to the cost of city centre DHN installation. To overcome this, new or improved approaches of de-risking network delivery would be valued to reduce the uncertainties and costs associated with civil engineering where there may be underground obstacles. Three-Dimensional GPR Surveys have been suggested as having a role in this area, although it is not yet clear whether this is a viable solution for further evaluation in this project.

The nature and distance to a reliable heat source has significant impact on the Value Chain viability. Low temperature, remote heat sources need to compete with a gas CHP solution as the default.

7.6.4 External Stakeholders

Without a direct interest in the outcomes of DHN, the external stakeholders need to be persuaded to support rather than inadvertently delay DHN proposals. To be viable the DHN offer needs to be:

- Clear and easy to review and make a decision on the way forward
- Minimal burden on staff time and any other resource
- Minimal disruption during installation and through life

7.6.5 Phasing

The conditions for the viability of DHN propositions will change over time. At the early stage the lack of User and Investor experience and proven value of DHN means there is likely to be a need for incentive mechanisms to encourage adoption.

Achieving this first tranche of Users is vital to get correct if DHNs are to accelerate. In the Owner Occupier space this is unlikely to happen with sufficient Heat User density to justify a DHN. So there is a crucial challenge to either incentivise a mass switch or develop a proposition which performs well while potential users gradually migrate at boiler failure. The third alternative is to mandate a switch.

As the number of DHNs increases, confidence in the systems' value and benefits will increase. When the proposition is correct, uptake will grow to reach a tipping point and DHNs will become in demand rather than needing promoting. A corollary is the combi-boiler market: which took time to build confidence (installers and householders) but is now the default option without needing incentives. Another parallel is the Solar PV Feed in Tariff where early systems were heavily subsidised, but as market confidence and supply chain capability increased, supported by rapidly reducing product costs, the need for incentives diminished.

This project's goal is to identify mechanisms by which we can encourage DHN adoption with the minimum of external incentives and rapidly arrive at the tipping point for adoption. The core focus will be to address the prime requirement of reducing capital delivery cost, but also consider wider aspects which could improve the likelihood of wider DHN delivery.

8 Evaluation of Challenges and Solutions

The evaluation process is in two distinct stages; directly linked to Stages 1 and 2 of the Project.

- Stage 1, Work Package 3 (WP3) assesses and selects the broad challenge areas for which solutions will be developed in Stage 2.
- Stage 2: Then at the end of Stage 2, Work Package 6 (WP6) takes the solutions developed in Work Packages 4 & 5 and evaluates them for further development in Stage 3. In addition, during Stage 2, some initial filtering takes place in Work Packages 4 and 5 (WP4 & WP5) to focus resources on the more attractive solutions.

Two levels of evaluation criteria have been developed. These provide complementary approaches for assessing project challenges and solutions. There may be some minor refinement upon further use.

- **Top Level Evaluation** tests the challenge or solution's fit with the Project Scope and completes a qualitative Value-Effort assessment. This approach was taken to evaluate the challenges defined in Work Package 3 and select the optimum set of challenges to be taken forward to Stage 2. In Stage 2 the Value-Effort assessment will be a coarse filter for solutions.
- **Detailed Evaluation** provides a more detailed review of the solution or idea using criteria previously agreed as important to the ETI and additional criteria revealed by the key stakeholder requirements analysis. This is to provide a balanced review of each solution's impact across key parameters. Many of these criteria are appropriate to solutions and are not relevant to the evaluation of challenges (e.g. the impact on health and safety).

The criteria were developed over a number of iterations; at each step reviewing whether the insight gained in the previous research had been given sufficient emphasis and weight.

8.1 Top Level Evaluation

8.1.1 Fit With Project Scope

The first part of this evaluation is to confirm the alignment of the challenge or solution with the project scope as reviewed in Section 3. Challenges deemed to be **core** to the project are given highest priority at this stage. Those that are **secondary** will need to score highly on other criteria. Challenges **marginal** to the scope, although they may be important to the overall success of DHNs, would need a strong case to be included in future work.

8.1.2 Value Effort Analysis

This is a qualitative evaluation of the value and effort associated with a challenge or a solution.

- The anticipated potential value of improvement (the value that addressing a challenge or delivering a particular solution would bring): Based on the project scope and from earlier stakeholder analysis, the key drivers of value are deemed to be a reduction in capital cost and an improvement in certainty of outcomes.
- The relative effort to make the improvement (the effort involved in bringing a challenge or solution to market deployment): This includes items such as capital investment, research and development and elapsed time.

Figure 8 shows a simple Boston Matrix which was used to evaluate value and effort at the WP3 workshop in Stage 1. There was no quantification of value and effort in WP3, but there was testing of the relative value / effort for pairs of challenges to confirm the relative ordering.

It may be necessary to filter out solutions during WP4 and WP5 to focus on those which appear most attractive to the project. If this is the case, the current intention is to use a simpler two-by-two matrix to filter out those solutions in the quadrant that appear to have low-value and high-effort. The need for this will be clearer once Stage 2 has commenced and the choice of what is of low-value and high-effort may need to be tailored to the challenge area. Note; it is important to regularly review filtered solutions as they may be of more benefit in combination with, or as an enabler of, other solutions.

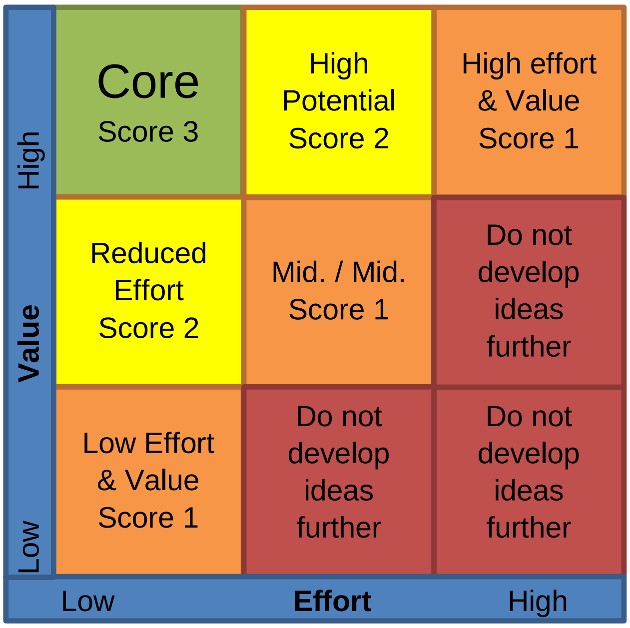


Figure 8: Value Effort Grid

8.2 Detailed Evaluation

The criteria previously agreed important to the ETI and additional key stakeholder requirements have been combined to create an evaluation tool. It is important to have a sufficiently broad range of evaluation criteria. At the same time, the criteria need to be focused towards the most important aspects such that we can easily evaluate the benefits and detriments of each solution and contrast the solutions with each other. The evaluation criteria particularly drive the information to be collected for each solution during Stage 2 (see the WP3 report for more detail).

8.2.1 ETI identified criteria

The provisional evaluation criteria from the project contract provide an initial set of requirements to use as the basis for the detailed evaluation. A full description of these requirements is given in Appendix E. In summary, these comprise the following.

- Impact on capital and through-life costs
- Impact on the operation, performance and reliability of the DHN
- Impact on the general benefits of heat networks as a method of heat supply (Flexibility)
- Opportunity for use at scale or constraints on deployment by location, housing type, etc.
- Technical feasibility and any implications for commonality of technical standards
- Health, safety or environmental impacts
- Synergies with other sub-surface infrastructure

- Assessment of the relative difficulty of installing DHNs (vs. other network infrastructure)
- Suitability for deployment in the UK

8.2.2 Additional Stakeholder Criteria

The stakeholder requirements and priorities developed in Sections 6 and 7 respectively reinforce many of the deliverable criteria listed above. However, some others have not been included in this list and the following additions have been made:

- **Certainty of Outcomes:** As highlighted previously, certainty of cost and time is particularly important to Investors. Performance and reliability issues are covered by the previous list.
- **Improving Value Propositions**: Users and Investors in particular do not yet have a compelling reason to choose a DHN compared with current alternatives. Some of the attributes of the value proposition are covered by the original list. However, it is important to evaluate solutions against the value proposition as a whole to ensure that all relevant factors are considered and a more holistic evaluation undertaken.
- **Increasing Network Revenues**: This is not explicitly covered in the initial list and additional revenue has therefore been linked with "synergy with other sub-surface infrastructure".
- **Reducing Time on Site**: Time is a proxy for cost in many instances, but in DHN delivery also has a major impact on the disruption to the locality which is not explicitly dealt with elsewhere. This can be combined with improved propositions for users and investors.
- **Reducing Complexity of Transactions:** Complexity of transactions will be a burden to all stakeholders, including those which enable DHN through consents etc. If complexity can be significantly reduced, there will be a corresponding reduction in cost as well as reduced barriers to new users and investors. Impact on Complexity aligns with the 7th Criterion (Table 4) with a wider scope.
- **Improved Outcomes for UK plc:** Taking HM Government and UK plc as an overarching external stakeholder, it includes the potential impact on the UK's ability to achieve Climate Change Commitments and economic growth whilst being mindful of the burden of adding policy change to enable DHNs to deliver.

8.2.3 Combined set of criteria

The combined list of criteria is shown in the table below which forms the basis for evaluation. For qualitative evaluation, a five-point scale will be used (major positive impact to the value of DHN deployment, limited positive impact, minimal impact, limited negative impact, significant negative impact). The project team will strive to ensure consistent use of the scale by contrasting solution scores and using common descriptors in the assessment. The individual criteria will not be weighted as there is little value in a single total score and as the ETI have identified that they may wish to select a range of solutions for Stage 3 based on different attributes.

Criteria		Measurement
1	Impact on capital cost	Quantified using the cost model
2	Impact on certainty of outcomes	Qualitative
3	Impact on operational and whole life costs	Quantified using the cost model
4	Impact on the operation, performance and reliability of the DHN	Qualitative
5	Impact on the flexibility of heat networks as a method of heat supply at scale	Qualitative
6	Impact on the attractiveness of the DHN proposition for Users and Investors	Qualitative
7	Impact on transaction complexity and the relative difficulty of implementing DHNs	Qualitative
8	Health, safety or environmental impacts (consideration of likelihood and impact)	Qualitative
9	Opportunity for use at scale or constraints on deployment across the UK	Qualitative
10	Increased revenue and value from synergies with other sub-surface infrastructure	Qualitative
11	Benefit to UK plc from improved CO_2 and economic performance	Qualitative
12	Technical feasibility and any implications for commonality of technical standards	Qualitative
13	Effort, including consideration of: • Investment capital and research required • Present level of technological innovation (uncertainty), technology readiness level • Anticipated timescale to the point where the solution is delivering value. • Likelihood of success – qualitative assessment.	Qualitative

Table 4: Evaluation criteria

There is significant detail underpinning each of the 11 qualitative criteria and this makes a numeric score difficult to assess with rigour and consistency. As a result two approaches have been developed to ensure a consistent evaluation across the project team:

- An initial checklist is shown in Appendix F to help evaluators assess the impact of each solution. This also helps steer thinking during solution development.
- Creation of more precise qualitative scales (e.g. “Likelihood of Success” component within Criterion 13 (“Effort”): Certain, Probable, Likely, Possible, Unlikely) where they assist a consistent evaluation.

This was considered a more robust approach to evaluation than to artificially create quantitative assessments which are not supported by evidence, or are less valuable for the evaluation.

During Stage 2 the Solutions Management Group (SMG) will act as the core project team and will review / refine the evaluation rationale as solutions are tested.

Within the Evaluation Criteria Checklist a five point colour scale (From Red to Green) is used to visually present the assessed impact of solutions. It has been agreed with ETI that this colour coding is not appropriate for the Effort evaluation (Time, Investment & TRL) because long-term or high investment solutions should not be seen as less valuable in the plans to achieve the overall goal.

9 Conclusions

This section draws together the insight from the WP1 research to summarise scope, challenges and the approach to evaluation which will be taken forward in to Work Package 3: System Review and Target Setting. This then steers Stage 2 of the project which focuses on Solution Development.

WP1 has made a holistic review of DHN stakeholders and their requirements in order to identify the changes necessary to achieve DHN viability from multiple perspectives. This has given a whole systems view in order to reduce the risk of focusing too early on a narrow range of target solutions.

9.1 Project Scope

The aspects of DHN delivery which were confirmed as of core importance to the project are:

- **Parts:** All components and sub-systems of a heat network which form part of the completed system.
- **Process:** The delivery phase: installation and commissioning processes.
- **Performance:** Heat system design, optimisation and through life performance.
- **People:** Resource, skills and expertise for design and delivery:
- **Systems Solutions:** The optimisation of requirements between different aspects of a DHN. Also the potential for integration with other utilities and local area services.
- **Value Proposition:** Improving the attractiveness of DHN for investors, property owners and consumers.
- **Place:** The impact of geography and topology on system design, performance and both operating and capital costs.

9.2 Insight from Stakeholder Requirements Analysis

It is apparent from stakeholders across the value chain that there is a shared ambition to accelerate the deployment of DHNs in UK. Currently the UK market is on a small scale (relative to Scandinavia and Europe) and this gives significant opportunities for growth and improvement.

The stakeholder and gap analysis has particularly identified the following.

- **Users:** Currently DHNs do not offer a compelling reason for users to change from their preferred gas boiler solution. For users to choose to change to DHN there will need to be a significant improvement in cost, performance or reliability compared to alternatives.
- **Investors:** Currently the lack of certainty of DHN programme and cost makes an investment less attractive than alternatives. In addition the complexity of project design, delivery and associated legal contracts is a burden.
- **Value Chain:** Design, development and installation organisations are cautious about investing in additional capability whilst the market is uncertain.
- **Enabling Stakeholders:** Achieving approvals from such external stakeholders is crucial to project success and so developing an approach to minimise their resource requirements and minimise the negative impacts is important.
- **UK plc:** For HM Government there is a desire to accelerate the adoption of low carbon heating and DHNs have the potential to contribute, ideally without major policy intervention.

There is recognition and broad agreement across stakeholders of the changes that are required. This suggests great potential to improve through industrialisation of design, delivery and operation of DHNs.

9.3 Required Changes for DHN Delivery

This has led the project team to conclude that there are nine key priorities to address to enable DHNs to succeed at scale. All aim to improve the viability of district heating in the UK, with the first five directly focussing on financial aspects and the latter covering broader issues.

- **Reducing Capital Cost:** Project capital delivery including planning and design stages.
- Improving Cost and Revenue Certainty: Capital, Operating Cost and Income
- **Reducing Operational Cost:** Minimising the controllable through life costs.
- **Increasing Network Revenues:** Increasing income from heat or other revenue streams.
- **Reducing Time on Site:** To reduce disruption and associated additional cost.
- **Improving User Value Propositions:** Creating a compelling offering for User groups.
- **Improving Investor Value Propositions:** Enabling DHNs to become *bankable* investments.
- **Improving Systems Architecture:** Developing alternative systems design approaches which enable a step-change improvement in DHN cost, delivery and performance.
- **Reducing Complexity of Transactions Between Stakeholders:** Developing solutions to reduce the legal, commercial and transactional burdens of a successful DHN.

The WP1 research has enabled the Project Team to identify opportunities for improvement against these priorities which will be developed into solutions during Stage 2 (Solution Development).

9.4 Initial Assessment of DHN Viability

Stakeholder requirements and the barriers to DHN deployment have been used to develop a series of hypotheses for DHN viability at scale from each stakeholder groups' perspective:

- **Users** require a DHN offering which matches a combination gas boiler performance, reliability, installation and running cost; whilst offering a compelling incentive to change. This proposition needs to note most users' unwillingness to invest in their system before it fails.
- **Investors** require confidence in the DHNs capability to deliver the expected outcomes at low risk. The DHN opportunity should be no more complex to broker than similar investments.
- **Value Chain:** Requires confidence in the future market for DHN to justify investment in capability. Government policy, economic climate will influence the decision.

9.5 Evaluation Criteria for Challenge and Solution Selection

Two sets of evaluation criteria both to help contrast and prioritise the challenges identified in Stage 1 as well as the solutions that emerge in Stage 2.

- **Top Level Evaluation** is a high-level set of evaluation criteria. It comprises an assessment of the fit with the project scope and a qualitative Value-Effort assessment. This approach will be used to evaluate the Stage 1 challenges as well as put aside those solutions during the early part of Stage 2 that appear to hold limited or no benefit for this project.
- **Detailed Evaluation** is a more in depth review of the solutions which will be used at the end of Stage 2 to assess and contrast alternative solutions, and help select those to be taken forward to Stage 3 (Development of Route Maps). This comprises both a quantitative and qualitative evaluation.

Part B - Work Package 2: Technology Review

10 Introduction

This Part of the Deliverable presents the technology review undertaken as part of the second Work Package (WP2) of the project.

The content of this report is summarised as follows.

- Section 11 describes current UK practice – the approach by which DHN is normally delivered at present in the UK. This is used through the project as the comparison with which improvements are judged. It is intended to be typical of good UK practice around 2016. It is also used as the basis of the baseline costs which are presented in a separate report.

- Section 12 identifies significant differences between current UK practice and those employed in other countries with more experience of the use of DH. This part of the work aims to identify where practice from other countries might be beneficially imported to the UK.

- Section 13 presents a review of the literature. This identifies potential improvements that may be forthcoming in the future from a mixture of academic literature, technical work and the outputs from International Energy Agency (IEA) Annexes. The aim here is to identify ideas that are already invented, but still in development, which could be adopted to achieve cost reduction in the UK.

11 Current Practice

11.1 Introduction

The purpose of this section is to capture to an appropriate level of detail the process of design and construction by which district heating schemes are currently delivered in the UK. It describes what is judged by the project team to be typical of present installations in the UK, but it is recognised that there is variation in practice by different suppliers and in different locations.

This work is being used in a number of ways:

- To inform the development of the Work Package 2 (WP2) cost model to ensure that all significant components are accounted for in the model and that the baseline cost represents current UK practice.
- As the basis for comparison with practice in other countries.
- To underpin subsequent work in Stage 2 which will evaluate changes from the baseline.

This analysis is structured in terms of the typical chronology of a DHN project. There are differences in the specific work needed on projects of different scales, but in general the following stages will be required.

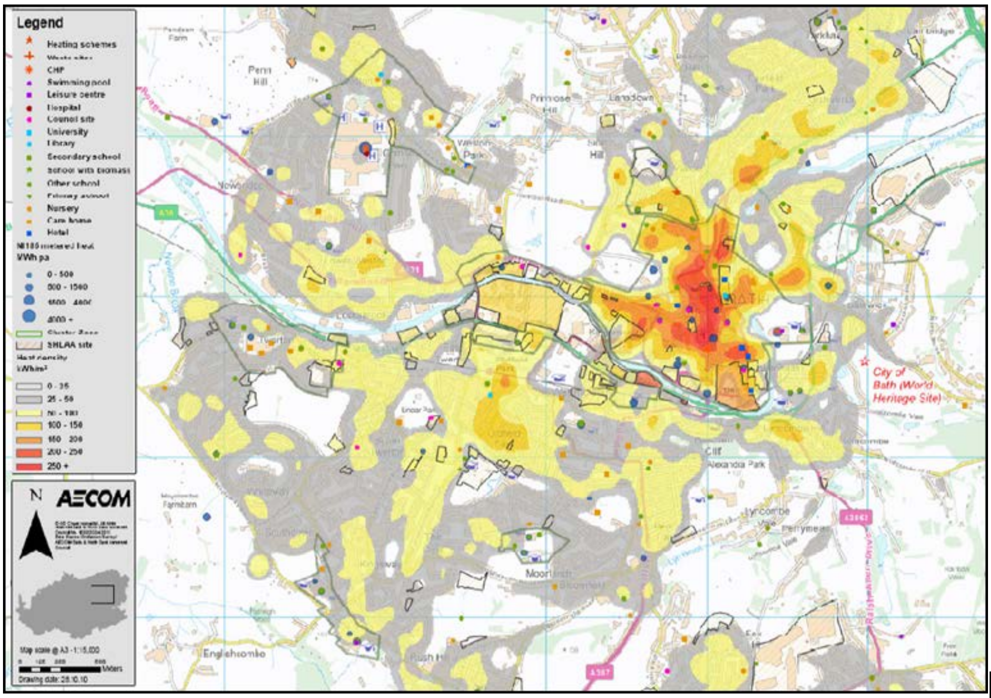
1. Energy Masterplanning.
2. Feasibility and outline design.
3. Consents – planning, wayleaves, etc.
4. Tender and contract award.
5. Detailed design (Front End Engineering Design, FEED).
6. Enabling works.
7. Site establishment – prelims.
8. Excavation of trench.
9. Installation – main pipes.
10. Installation – building connections.
11. Backfilling of trench and reinstatement of ground.
12. Managing connections.
13. Testing, Commissioning and Setting to work.
14. Operation and maintenance.

Note that in the text that follows the stages are presented as consecutive, but in reality a number of them overlap and some aspects may take place in a different order.

11.2 Stages of Delivery of a Project

11.2.1 Energy Masterplanning

In the energy masterplanning stage of a project, a wide area of a town or city will be reviewed with a view to establishing which districts will be most appropriate for the installation of district heating. This work is normally delivered by the creation of a heat density map, as shown below.



These heat maps are prepared by gathering information at an appropriate level of detail about the buildings in the area of analysis. This will typically mainly be based on a simple knowledge of what the building uses are, their locations, floor areas and the application of standard benchmark rates for the energy demands of the buildings.

Energy consumption data is rarely available directly and has to be derived from a range of sources including: DECC Lower and Middle Super Output Area data on historic gas consumption[6]; DEC / EPC certificates or benchmarks. Direct contact with energy users is necessary to obtain real metered data. Local Authorities often have information on their own non-domestic and communal domestic buildings. Data for commercial non-residential uses can be more difficult to obtain as Lower Super Output Area boundaries are designed to avoid revealing data for large individual users. Data is generally difficult to obtain and this is an important part of the cost of early stage work. It would benefit the process significantly if information were more easily available.

Emerging from this study will be an initial appraisal of the relative attractiveness of different parts of the town for district heating, in order to inform the second stage of the process.

This stage corresponds to the first part of work required by the funding from the Heat Networks Delivery Unit (HNDU) within DECC. For a typical study, this energy masterplanning work would take 2 or 3 months to complete. If there were more information in the public domain about energy use of buildings then this stage would be both quicker and easier to complete. In Denmark this information is available and so it does not need to be estimated as is usually the case in the UK.

This work is generally carried out by one of a number of engineering consultants who maintain their own tools for supporting the work. The client for this type of work is usually a Local Authority. It could in principle be funded privately, but at this stage the risk of no viable scheme emerging makes this much less likely to be attractive to a private sector company.

[6] https://www.gov.uk/government/statistics/lower-and-middle-super-output-areas-gas-consumption

11.2.2 Feasibility and outline design

The energy masterplanning stage identifies the areas of a town or city where networks are expected to be most cost-effective. The feasibility stage takes this one step further and develops a design to a sufficient extent to allow the technical and financial feasibility to be established.

The key stages of this work are to:

- Establish more information about the buildings that may connect, including measured energy use where possible.
- Engage with the building operators to understand the likely appetite for connection to the network.
- Propose a potential network route(s).
- Determine any significant barriers (e.g. railways, canals), their implications, and how to resolve them.
- Develop an estimate of the capital cost of the installation, including connections.
- Develop an energy and financial model for income and expenditure for the installation.
- Decide on a preferred option.
- Prepare a business case for the scheme, including identifying potential customers and routes to market.

There is often a break point in this work when a smaller investment in time has resulted in a scheme that is judged to be feasible. Work will then continue on outline design to develop the solution sufficiently to bring the project to a stage where it can proceed to tender. The split of work between these stages will vary between providers.

This stage of work is typically delivered by the same type of consultant as the first stage, but with additional input from those with expertise on cost and business modelling who may come from a different organisation.

11.2.3 Consents – planning, wayleaves, etc.

Where planning permission is required, applications are often undertaken by the client (currently, typically, a Local Authority) so that the tender process is carried out on the assumption that the necessary permissions have been granted. This is due to the high level of risk perceived to exist with planning in terms of both whether permission is granted or not and in the costs associated with obtaining planning permission. Contractors are however often made responsible for discharging aspects of conditional permissions as these cannot be determined until the installation is complete.

While planning permission may not always be required as such, planning authorities, the Environment Agency, Building Control and other authorities will still have an interest in the project. Although case specific, it may be necessary to:

- Obtain permission to dig in highways from the Highways Authority.
- Provide environmental plans for the pipework installation phase such as flood risk, tree protection.
- Carry out environmental surveys such as bat, bird or reptile surveys with agreed plans being developed where protected species are found.
- Ensure central plant meets noise and emissions limitations where additional plant is added to serve the new heat network.

Where planning permission is needed for an energy centre this will typically take 6 to 12 months to secure with a cost of around £50-200k, but much of the work will be needed anyway as part of the design. The cost of other permissions will depend entirely on the nature of the project, but could be six to 12 months depending on the extent of the project and the range of surveys to be undertaken.

Where the pipe route crosses private land, agreements for installing pipes and for continued access for maintenance will need to be put in place. A wayleave style agreement would be preferred to protect the asset going forward and to provide the right to access the pipes at any time.

11.2.4 Tender and contract award

Within the client organisation, usually a Local Authority at this stage, a decision must next be made as to whether and how to proceed with the proposed scheme. The client must decide on how much to invest themselves, which of their own buildings to commit to connect to the scheme, and how to engage with other stakeholders including owners of existing buildings or developers of future new buildings. From all of this they can then prepare the project to go out to tender for a supplier to build the network, and probably also to (part) fund it and operate it.

Tenders are normally put out based on anchor loads that form a basic minimum heat demand for the system. Local Authorities will usually commit buildings under their control for connection in the location of the proposed network. Other major clients such as universities or hospitals could also offer a level of commitment. Usually there is an ambition to grow a larger network from this basic anchor scheme.

To support this work tender documents and contracts will be required, taking time of both in-house staff and also typically hired in support from lawyers, engineers, quantity surveyors and project managers.

The tender documents will need to include:

- Details of the tender process, what bidders are required to provide, arrangements for site visits, interviews, how bidders can ask questions and how these will be responded to and the method of tender assessment.
- A technical proposal that shows the intended physical extent of the scheme, buildings that have committed to being connected, the standards to which the scheme should be built to and any information gathered on site constraints. This will use information produced as part of the feasibility study, which may be supplemented by additional work if thought of any value. Up to a point the greater the level of detail, the more bidders are able to reduce the level of contingencies for risk mitigation from their offer.
- A contract stating who investors, designers and operators will work for and what terms and conditions will apply. Typically where a third party Energy Services Company (ESCo) is being procured, a concession period to develop and operate a heat network will be granted within a specific area for 20-40 years. The contract should also set out standards of service to end customers and heat price setting rules. Typically a heat price formula will be proposed that indexes the price of heat to a mixture of fuel, labour and materials costs, with the overall tariff being required to be lower than obtaining heat from an alternative system when taking into account all costs on a lifetime basis.

Note that not all DH developments need to appoint an ESCo, and some local authorities may choose to develop and or operate their own networks. Nevertheless similar standards of service and customer protection will need to be defined.

11.2.5 Detailed design (Front End Engineering Design, FEED)

Once the project has been awarded to a contractor, detailed design will commence. This is generally delivered by the contracting organisation that is contracted to build the project; these firms are often referred to as Energy Services Companies or ESCos.

The ESCo will design the network in detail, size the pipes and connections, design the energy centre equipment and any other pumps, valves, sensors, controls and metering that will be needed. As noted above, other procurement options are used by some clients – for example directly procuring the system design, construction and operation through one or more organisations or through design and build contractors. In these cases the appointed design consultant or contractor will be responsible for design.

As part of the design process:

- Plantroom surveys will be undertaken to allow customer connections to be designed.
- Topographic and utility surveys will be undertaken around the pipe route to identify obstacles that need to be avoided or require special care when installing the pipework.
- Noise surveys may be required where new plant is to be added to the energy centre to set a baseline against which the plant design can be carried out.
- Emissions from any additional heat generating plant will need to be assessed to meet local air quality objectives potentially using dispersion modelling.
- Other surveys may be needed e.g. ecology, archaeology, etc.

Next a detailed project cost will be built up, and equipment ordered. Where an ESCo route is being followed typically the ESCo will contract out some or all of the installation work. There may be an additional tender process at this stage or the ESCo may have pre-agreed sub-contractors.

11.2.6 Enabling works

In many schemes there will be a need to deliver works in advance of the main scheme to enable it to proceed - hence the term ‘enabling works’. These could cover many things which are needed but are not a core part of the intended scheme, and may be able to be delivered in advance of the main scheme.

Particular examples include:

- Preparing buildings to connect to the network:
    - Removal of asbestos in plant rooms where works are to be carried out.
- Removing known obstacles to the route:
    - Vegetation clearance or pruning to avoid problems with nesting birds or other wild life that could stop installation of the heat network.
    - Demolition or removal of disused assets on the proposed pipework route or within plantrooms.

Clearly these are very scheme specific, but will always occur and can bring a significant cost.

11.2.7 Site establishment – prelims

The general term 'prelims' covers all of the costs associated with the operation of the installation that are not part of what is left behind. There are typically costs to set up the site, costs per week of use, and costs to clear the site. Items covered include:

- Protective barriers to site works.
- Traffic management equipment.
- Staff facilities (toilets, site office where needed).
- Secure storage space for equipment and pipes.
- Site management.
- Public engagement.

The cost of these is dependent on the extent of the scheme, and how long the works last for. Unlike building projects, there is a need for a 'mobile' site as the works progress through the different streets involved.

11.2.8 Excavation of trench

In current practice most pipes are laid within trenches in the ground, usually dug within the road. It is generally cheaper if the trench can be dug in soft ground (e.g. road verge), but this is only possible in some streets and where other services allow it. The assumed solution is that the trench is dug in the road.

Typical excavation involves:

- Where digging in road, a diamond cutter is usually used for cutting the trench line, followed by breaking up the road surface with a pneumatic drill / hammer.
- Digging out the sub-surface layers with a mechanical digger of the appropriate size for the work:
    - A minimum trench width will be required at weld points to enable safe working. For smaller pipes this may mean special weld pits are dug where required.
    - Welding can be undertaken outside the trench and the pipes lowered in. This takes up more room outside the trench that must be segregated from the public to provide room for pipes, welding and lifting machinery but reduces the width of the trench. The base case is for welding in the trench.
- Where there are other services in the ground, then digging by shovel / hand will be needed.
- Some excavated materials can be stored locally for re-use, but some must be disposed of away from the site.
- Where the depth is greater than c1.2m, or the ground conditions unhelpful, the sides of the trench must be supported to provide a safe environment in the trench:
    - Where digging in unpaved areas, battered sides can be used, i.e. trench side is sloped and compacted to reduce risk of collapse. It requires more trench excavation but it avoids the cost of shuttering material and bracing equipment.
- Smaller trenches will be dug to connect to each building on the network.

The likely methods of trenching (above) are reflected in the costs built into the cost model database which have been used to establish baseline costs and which provide varying costs linked to the diameter of the pipe. Costs will for example assume that larger heat transmission mains are typically at depths of greater than 1.2m to assist in avoiding existing services and hence typically require support, while smaller connections to homes will require narrower shallower trenching which depending on ground conditions may not require support.

Trenches must be kept free of water, and so pumps for dewatering are generally needed.

Where pipes are laid in areas used by the public, it is generally the case that the length of open trenches needs to be kept to a minimum in keeping with efficient installation.

The digging of trenches is one of the more dangerous activities involved in construction as unstable ground can collapse, particularly when it becomes wet and existing services pose a hazard. A high standard of health and safety is required which is delivered by preparing a detailed Risk Assessment and Method Statement (RAMS) for each aspect of the project.

11.2.9 Installation – main pipes

The standard solution for the main transmission network at present in the UK is for pre-insulated steel pipes (to EN 253[7]) to be used for the network. The pipes are pre-insulated using rigid polyurethane foam and an outer casing of high density polyethylene. The pipes are manufactured in standard lengths (16 m / 12m / 6m), and therefore some will need to be cut on site to match the lengths needed. The flow and return pipes are normally laid horizontally adjacent to each other.

The smaller pipes connecting to individual buildings, for example connections to houses in a terrace, are increasingly made using plastic carrier pipes – either cross-linked polyethylene (PEX) or polybutylene (PB). Where plastic pipes are used PB pipes can be fusion welded. PEX pipes cannot be welded so require the use of mechanical couplings similar to a compression joint in standard plumbing. There are two types of mechanical fittings for Plastic: ‘Press Coupling’ or ‘Compression Coupling’. ‘Press Coupling’ should be used for DH networks. The baseline assumption for the cost model is that plastic pipes would be used for pipes up to 50mm diameter. Plastic pipes are normally delivered pre-insulated and are more flexible than steel pipes allowing a quicker process of installation.

The main pipes are laid on prepared sand bag supports on the base of the trench in order to ensure the pipes are level and stay in position through their life.

Joints are made either when needed by the length of the pipes, for installation of valves or bends or for each building connection to be made.

The steel pipe lengths are welded together. Typically arc welding is used for larger diameters and gas welding for smaller diameters. This process is critical to avoiding leakage in operation and so must be monitored carefully. EN 13941[8] indicates the proportion of welds that should undergo radiography or ultrasonic testing, depending on the class of project. All welds should be pressure and leak tightness tested using either air and a marker, or water. Plastic pipes are also usually welded, although other jointing methods are starting to be used.

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[7] BS EN 253:2009 District heating pipes. Pre-insulated bonded pipe systems for directly buried hot water networks. Pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polyethylene

[8] BS EN 13941:2009 Design and installation of pre-insulated bonded pipe systems for district heating.

The insulation must be cut in order to achieve the joints, and so this must be reinstated using a joint sleeve once the welding has been tested. The process involves:

- Connect leak detection wires across joint.
- Install joint outer casing – this is either a heat shrinkable sleeve using a sealant and adhesive or a casing which can be fusion welded to the pipe casing.
- Carry out an air pressure test of the joint to prove the joint is correctly sealed or welded to the pipe casing.
- Fill joint void with insulation – normally a two pack mix that is pre-weighed for the pipe size and joint type to ensure complete fill without excessive waste.

Pre-insulated isolating valves are installed at suitable intervals to enable sections of the system and individual connections to be isolated. Typically pre-insulated valves also include facilities for venting and draining. Pre-insulated valves are accessed using valve chambers which are fully drained. Conventional valve pits are not used as there is a risk of flooding and corrosion.

When pipes are first filled with hot water they will expand which can cause stresses on pipes and joints. Different approaches are adopted for dealing with this which are referred to as "cold-laying" or "hot-laying". Most systems within built up areas will use 'cold-lay' techniques in which the pipes are connected and reburied before being heated up. This is because it is not possible to keep long lengths of trench open to allow expansion which is the procedure where pre-heating is needed. With the current trend towards lower operating temperatures the benefits from using pre-heating are limited.

11.2.10 Installation – building connections

To complete a connection to the building from the trench to its outside will require different work depending on the system within the building and its location.

For an unbuilt plot, the pipe will typically be brought to an agreed point on the site and capped off in a way that makes it easier for later connection to the building.

For existing buildings, there will need to be a specific design for each connection. In individual homes it is normal to install a Hydraulic Interface Unit (HIU) that separates the district heating water from that in the home. In the UK it typically contains a heat exchanger that transfers heat to the space heating circuit inside the home, and means that the dwelling's heating system is separated from the DH system and will not be subject to the DH system pressures. The water quality and condition of the building's heating system will also be less critical. Domestic hot water is typically generated from a second plate heat exchanger in parallel with the first. The HIU also typically contains a heat meter and controls to enable the system to be managed in terms of temperature and flow rates to meet the occupier's demands. This type of HIU is referred to as an "indirect" HIU because of the separation between the heat network and the individual building's space heating circuit.

An equivalent solution to that for domestic buildings is adopted at a larger scale for other building types. For apartment blocks it will be typical to have a main heat substation at the main building connection, which will then serve individual indirect HIUs serving each apartment. The baseline assumes homes typically have instantaneous heat production rather than local storage cylinders.

Works in the buildings may also include:

- Modifications to the heating system to work at the temperatures best provided by the network (typically either larger heat emitters that can operate at lower temperatures, or the addition of insulation to the building to allow the existing emitters to be used at lower temperatures. Alternatively, if there is sufficient radiator surface, the heating system may be rebalanced to achieve lower return temperatures.

- Removal of existing systems (unless these are retained as back-up).
- Modifications to systems and controls to enable district heating connection to be prioritised and to ensure low flow return temperatures for efficient network operation.
- Making good of finishes.

Ensuring that secondary networks and services systems on the consumer's side of the HIU are designed or adapted to minimise heat losses and return low flow return temperatures is critical for efficient network operation but is not the focus of this project, (although significant impacts of potential solutions on secondary networks will be assessed).

11.2.11 Backfilling of trench and reinstatement of ground

When the system is installed, tested and insulated, the pipe trench is initially backfilled with sand and the pipes covered by 100mm to help protect them from damage from large stones. The trench is then backfilled to the underside of the road construction layer. This could be done with excavated material, but it is normal practice to use new imported material. This ensures a consistent quality and avoids the need to store the excavated material on site. The aggregate is compacted back into the trench and then the road surface is reinstated. Highways Authorities will set the standards for both the road construction and the allowable difference in levels from trench to undisturbed road level. Warning tapes are placed 200mm above the crown of the pipe during backfill.

It is typical for a length of trench of around 100m to be open at one time; a key aim is to minimise the length of trench open to reduce accident risks to the public.

11.2.12 Managing connections

<u>Heat source</u>

The new network must also be connected to the heat source. It will depend on the design of the heat source how this is achieved. It may be quite simple where the energy centre was designed with this in mind, but can also involve considerable extra work.

There may also need to be modifications to the energy centre to absorb the extra connections. This would cover both the provision of additional heat (e.g. a larger CHP or more boilers) and changes to pumps and hence energy used for pumping. All of these issues are not core to this ETI project, but are noted for completeness.

<u>Additional connections</u>

Connection points are sometimes included in district heating network to reduce the cost of the future expansion of the network. This tends to be the case where there is a clear expectation of expansion and for larger pipe sizes (it would not be possible to use hot tapping to add a connection point later for a larger pipe branch and so there would be a significant cost for a major excavation, shutdown, use of temporary boilers). It involves an additional t-piece with valves, with an end-cap in case the valve leaks. There may also be over-engineering of the system (e.g. larger pipes etc) dependent on future expansion plans. There are disadvantages in including connection points in the district heating network. in particular: (i) they can act as a weak point in the system, resulting in stagnant water in the capped off branch and increasing the potential for corrosion of pipe work, (ii) when subsequently planning the expansion of the system, the connections may not be in the most appropriate location and (iii) if the expansion does not take place, the additional upfront costs and over-sizing negatively impact both CAPEX and OPEX.

In the modelled network, no connection points have been assumed. Our assumption is a scenario in which there is planned construction of DH schemes across the region (or the UK). The provision of connection points to cope with the uncertainty of market expansion is not deemed justified.

11.2.13 Testing, Commissioning and Setting to work

Once the system is connected, it must be commissioned to enable it to be set to work efficiently. The key elements of this process are to:

- Flush the system (not always done for large systems as it uses too much water, although this carries a risk of debris being left in the pipes so “Pigging” is used instead. Pigging involves blowing a plug of material (often polyurethane) down the pipe to remove any debris. Pigging with ice slurry can also be used).
- Fill the system with water (Large systems will need special arrangements to fill in a reasonable time. They may also need temporary plant to treat water before fill as plant used for normal water treatment in operation is not designed for this level of water throughput).
- Pressurise the system and hydraulic pressure test. Depending on the operating temperature, there may be a need to pressurise the system before heating.
- Heat the system. This needs to be controlled to allow the controlled expansion of water and pipework.
- Disposal of excess water as the system heats up (normally achieved using the Energy Centre pressurisation plant).
- Check that differential pressure control valves or pressure independent control valves are maintaining system flows.
- Proving of control and monitoring signals.
- Test correct operation of safety systems.
- Test cause and effect of controls.
- Test and commission surveillance system.
- Creating record information containing as-installed drawings and all test results.
- Issuing record drawings to the Highways Authorities.

Surveillance systems should comply with BS EN 14419[9]. They typically consist of measuring wire(s) embedded in the pipe insulation joined to form measuring sections. Connection points are provided to the measuring sections and instrument(s) are used to detect deviations in the electrical properties such as resistance or impedance that indicate moisture ingress due to defects or bad workmanship. A system designed to good practice would be expected to be able to locate a fault to within 1m. Tests should be carried out on both the individual pipe components and each measuring section to prove the continuity of the wire(s) and that there is no contact with the metal pipe.

[9] BS EN 14419:2009 District heating pipes. Pre-insulated bonded pipe systems for directly buried hot water networks. Surveillance systems.

11.2.14 Operation and maintenance

The operation and maintenance of the scheme are not part of the capital cost, but they are important to consider at the design stage such that the whole life cost of the scheme can be optimised.

The maintenance requirements on a network include:
- Monitoring and testing the water quality.
- Chemical dosing of water.
- Cleaning of filters – side stream and in-line.
- Checking valves are operational by operating them every 6-12 months.
- Checking and re-calibration of meters as required.
- Monitoring of the leak detection system.
- Monitoring of water consumption.
- Monitoring of system temperatures.

On measurements, it is normal to measure return and flow temperatures to customers and at any major heat interfaces (i.e. if a block of flats say has a building heat exchanger and individual HIUs at each flat, then temperatures are likely to be measured at the building level.) Systems are also monitored at the energy centre.

Recording and monitoring of temperatures is a matter of choice / contract requirements for the operator, so often they will not record the data but use it for operational adjustments. The Heat Network: Code of Practice for the UK[10] states under best practice for Objective 5.1 that "A check on the average temperature difference achieved across any circuit can be achieved by the use of a heat meter that records volume and energy."

Key technical operating costs for the network are:
- Heat losses – the baseline assumes level 2 insulation and flow and return temperatures of 85-90°C flow and 60°C return.
- Pumping energy – the baseline assumes variable volume control and pressure drops of c200Pa/m.
- Water treatment.

There are also costs associated with:
- Contracts.
- Metering.
- Billing and
- Debt management.

Failures requiring repair may include:
- Leaks due to internal erosion / corrosion (if water quality is not kept to the necessary standard).
- Leaks due to corrosion caused by external water ingress, through poorly installed joints.
- Damage to pipes caused by other road works.
- Failed valves and other equipment on the HIU.

[10] Heat networks: Code of Practice for the UK – Raising the standards for heat supply. CP1. Chartered Institution of Building Services Engineers (CIBSE) & The Association for Decentralised (ADE). 2015.

These are included to allow consideration of the costs of repairs and how alternative solutions may affect these.

11.3 Summary of Key Assumptions for Current UK Practice

The following summarises the key assumptions made in the current UK practice base case within the cost model:

a. Topographic and utility surveys required.
b. Pipes – steel pre-insulated to EN 253[7].
c. Two pipes laid horizontally.
d. Temperatures of 85-90°C flow and 60°C return.
e. Trench backfilled with sand and imported backfill.
f. Trench located in roads.
g. Level 2 insulation.
h. Fusion welded or shrink sleeve joints that are tested with air.
i. Surveillance system to EN 14419[9].
j. Isolation valves assumed 10 no. per km plus on each customer connection.
k. 5 tees provided for future connections.
l. 10% Non-Destructive Testing (NDT) on welds.
m. Welding carried out in the trench.
n. Trench fenced on both sides.
o. Traffic management required, assuming one lane closure.
p. Trench reinstatement only for width of trench, but with imported material.
q. Indirect connection of buildings and dwellings and instantaneous domestic hot water heat exchangers for individual dwellings; commercial buildings to have plate heat exchangers and buffer tanks for DHW.
r. Pumping energy based on pressure drops of 200Pa/m on average.

12 International Comparison

The purpose of this section is to identify differences between current practice in the UK and that in other countries with more developed traditions of district heating. Such learning could be introduced to the UK to reduce costs and improve viability of DHN.

The following activities have been undertaken to provide the international comparison.

- An international questionnaire survey was completed by a total of seven academic or industry experts from Denmark, Finland, Sweden and Germany. The results of the survey are presented in further detail in Appendix G.
- A face-to-face discussion was held between AECOM and Cowi in Denmark. Cowi are consultants who are active across the countries that have the most experience of District Heating. AECOM shared with Cowi the previous section on current UK practices and discussed differences across each of the stages of delivery of district heating systems. The key observations from this comparison are presented in this Section, with further detail included in Appendix H.
- A review of the book, *Advanced District Heating and Cooling (DHC) Systems* [11] (referred to as the "Advanced DHC Review" in the proceeding text) which was published in 2015 and for which Robin Wiltshire is editor. It details both current international practice (captured in this section) as well as potential future innovations currently undergoing research (captured in the next section). This review is presented in more detail in Appendix K.

It was originally agreed with the ETI that a key part of the international comparison would be based on the work of the IEA District Heating & Cooling programme and that of the 4GDH (4th Generation District Heating) Centre in Denmark. However, upon initial review, much of this work is more relevant to the state-of-the-art and is therefore principally captured in Section 13 Literature Review and Horizon Scanning.

These sources covered similar themes and the key conclusions are synthesised and integrated together below.

12.1 History of District Heating

The Advanced DHC Review provides a useful introduction to the historical development of district heating (Paul Woods was a joint author of this section). Modern DH systems began in the late 1870s with the introduction of steam distribution systems. However, the major growth of district heating in Europe began during the 1970s, when oil rapidly increased in price, and countries moved to the use of district heating particularly using waste heat from coal power stations or the use of combined heat and power generation (CHP) for improved efficiencies. It has led to Denmark becoming the leading DH country in Europe. The Danish, Swedish and Finnish DH industries in particular spent time and money on research and development – whereas the USSR and Eastern Europe did not see the same technological progress. As a result, the DH schemes in Denmark, Sweden and Finland are regarded as state-of-the-art technologies and are being increasingly adopted by Eastern Europe and the former Soviet republics, as well as South Korea and China which are both seeing significant expansions of district heating.

[11] Advanced District Heating and Cooling (DHC) Systems. Edited by Robin Wltshire. Woodhead Publishing Ltd. Sept. 2015. ISBN: 978-1-78242-374-4

As a result of this development since the 1970s, the technology in its current form can be considered mature. This is also reinforced by the availability of EN standards which are written around the typical pre-insulated products available. This has not necessarily restricted development as additional standards have been produced to cover twin pipes and flexible pipes as these products became more widespread. This background and, as discussed later in this section that the technologies used in the UK are fundamentally the same as those used in Scandinavia, does indicate that there is likely to be limited scope for cost reduction based on incremental improvements in the basic technologies and more radical ideas may need to be investigated to achieve a significant cost reduction.

12.2 Organisational Issues

Client and business model

The most fundamental difference identified in the international comparison is the business model. This affects issues such as the capital cost and delivering an attractive price to consumers.

District heating is widespread in Scandinavian countries such as Denmark, Sweden and Finland. Traditionally, these have been instigated by and the resultant energy companies owned by a local cooperative or the local authority, albeit in at least some of the countries (e.g. Sweden), a number of these municipal energy companies have been sold in recent years to large national (and international) energy companies[12].

The municipal company approach brings cost benefits for the following reasons:

- By the schemes being underwritten by the municipality, it means that they have access to low cost finance for establishing schemes and any subsequent expansion.
- The municipalities have been able to include their significant stock of social housing and public buildings (e.g. schools and hospitals) to drive larger scale district heating schemes and economies of scale.
- Public acceptance is high as profits are seen to benefit the community.
- Heat prices are regulated and minimised by being on a not-for-profit basis.

Furthermore, heat supply is regulated in these countries. As a result, social or commercial developers enjoy privileges alongside regulatory obligations – such as an easier permit process for rights to carry out trench works in streets. If implemented in the UK this would reduce uncertainty and save time for the process of delivering schemes on site. The cost element of this is not large, but the impact on timing and uncertainty is likely to be more significant.

In the UK, if the pipes are located in the roads, obtaining consent is typically straightforward and limited cost. Costs can be more significant if, say, the route goes over or beneath a railway crossing or a river. The costs in this case can be up to £100k (or even more in complex cases) which covers both internal costs and external legal fees. Note that these costs are included in the legal component in Table 18 from the WP2 Cost Model Methodology and Analysis. By comparison, other utilities benefit from national agreements and statutory powers which include compulsory purchase rights so they generally will find it easier to negotiate crossings and have lower costs.

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[12] http://www.res-h-policy.eu/downloads/Swedish_district_heating_case-study_(D5)_final.pdf

The Advanced DH Review highlights also that to counteract concerns that DH is a monopoly provider, the model in Scandinavia has been for the municipality DH owner to have a board of elected representatives and customer representatives who take decisions on energy prices and investment.

Although such countries do not generally force residential and commercial building owners to connect to DH networks, it is strongly encouraged by local planning policies, and generally the price of district heating is attractive to consumers compared to the price of alternative heating solutions, which may be subject to higher taxes. It is worth noting that these prices are not necessarily lower than typical UK heating prices. There are a number of drivers for the *relatively* attractive DH heating prices.

- The heat price is regulated. For example, in Denmark, DH systems are operated on a not for profit basis and they have to match prices to their costs whereas in Norway, there are market-based tariffs fixed in relation to the main alternative supply[13].
- As the DH schemes have traditionally been run by municipalities, they have been willing to accept much longer payback periods (afforded by the relatively low cost of capital) than would typically be the case with a commercial organisation.
- The competing fuels (for much of Scandinavia this has been oil rather than gas) were often subject to high energy taxes making DH prices (for example, using more efficient CHP schemes) more attractive.

A study published by DECC in 2013[14] identified the significant role that local authorities could play in the wider development of district heating in the UK - setting the strategic context for, and initiating the development of, district heating networks within the UK's towns and cities. Furthermore, their local knowledge, capacity for organisation, and key functions as planning authorities and service providers, puts them in a unique position.

However, the study identified a number of barriers for local authorities of which a lack of funding was the principal one. This included capital funding, but also funding for in-house staff resources, feasibility work, legal advice, and procurement. Several of those who had received grant funding pointed out that the scheme would not have proceeded without it. Linked with this need for resources, the internal lack of knowledge and skills in all aspects of district heating was also identified as a significant barrier, as was the difficulty in aligning all the stakeholders from the outset. The need for a stronger planning framework within which to take schemes forward was also highlighted. In addition, other barriers included the need for suitably qualified consultants, the need to ensure transparency in heat pricing, and a lack of generally accepted contractual arrangements.

For the purposes of Stage 2, it is noted that this study also suggests enablers and possible types of support to facilitate the growth of district heating in the UK. Some of the proposed solutions appear to be being implemented such as the setting-up of the Heat Networks Delivery Unit (HNDU) to provide funding and guidance to local authorities in England and Wales.

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[13] Webb, J (2015). Improvising innovation in UK urban district heating: The convergence of social and environmental agendas in Aberdeen. Energy Policy, Volume 78, March 2015, Pages 265–272

[14] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191542/Barriers_to_deployment_of_district_heating_networks_2204.pdf

It is worth also highlighting the experience in Germany as a contrast. As shown by Euroheat statistics[15], Germany is the largest user of district heating (by MWth) in Western Europe. Whilst the percentage take-up is relatively low compared to Scandinavian countries (Germany serves around 12% of its people through district heating compared to around 60% in Denmark), it is the largest provider in Western Europe simply because of its significantly greater population. In the main, the district heat network system has been in place for many decades with much of it originating from the former East Germany (albeit significant systems were constructed in the former West Germany e.g. one of the earliest being the large network in Hamburg). The ambitious goals of the German government relating to climate change, security of supply and energy efficiency have led to a beneficial environment for District Heating and the DH market has started growing particularly for new buildings with a representative of the AGFW (the German Energy Efficiency Association for District Heating and Cooling and CHP) reporting a 21% share of new buildings which is higher than the national average. However, Germany does not benefit from, say, the heat planning legislation that Denmark introduced which required all local authorities to define zones for district heating which brought about a rapid increase in the percentage of the country connected to district heating. Finland’s expansion was more market led, but it benefited at the time from the price of DH being more competitive than competing fuels (for much of Scandinavia this has traditionally been oil rather than gas) in an environment of high energy taxes.

<u>Supply chain issues</u>

In the UK, it is sometimes the case that several different organisations carry out the work for the different stages of DHN development, particularly for the heat supply to new build housing schemes. A different company may be used for: energy masterplanning, detailed design, construction and operation. It is considered that this leads to solutions which are not well integrated. By contrast, within Scandinavia, most of the DH system will be designed by a single DH company using in-house resources, resulting in a much more unified design process. The design organisation is frequently responsible for the long-term operation. Similarly, either the DH company or a main consultant has overall responsibility of the delivery and will manage the subcontractors. This helps reduce the problems sometimes seen in the UK with split responsibilities and lack of clarity of individual organisation’s roles.

12.3 Design

There are a number of important differences in place in the design of networks.

<u>Standardisation</u>: For countries where district heating is a more established method for delivering heating, there is a set of standards for the design of networks, and these are widely known and understood. In Denmark, there are prescribed methods for the delivery of feasibility studies, with specific tools in place to be used by all designers and standard assumptions for inputs to the models. This means that feasibility studies are carried out in a consistent way, saving time and providing more comparable outcomes. Most DH companies supplying a single city will have developed their own standards and procedures suitable for their particular scheme and the local supply chain will have had many years’ experience of working to these standards.

<u>Data availability</u>: Although this varies between countries, there can be very good data available about building energy use. In Denmark there is a database publicly available of the

[15] http://www.euroheat.org/wp-content/uploads/2016/03/2015-Country-by-country-Statistics-Overview.pdf

energy use of all buildings. This removes the time-consuming need in the UK to estimate energy use, and provides greater confidence in the design as actual energy consumption data is used. It also helps ensure the appropriate allocation of diversity factors for space heating and hot water.

Experience of building services designers: A key difference between the UK and countries more experienced in district heating is that, for the latter countries, their building design teams are more familiar with DH systems. This means that buildings are more likely to be delivered in a way that suits connection to the DH network, which is not always the case in the UK.

Engineers in the UK typically oversize systems to avoid the risks associated with under-sizing. This can result in high capital costs for the network and substations and inefficient operation including higher heat losses. Where the oversizing involves pipework within the building this can contribute to overheating in summer. In particular, Germany confirmed that oversizing was an issue – it was noted that there is a lack of building heat demand monitoring and optimisation and simulation of complex non-residential buildings to be able to consistently make optimal sizing decisions. The Scandinavian countries appeared to have fewer problems around oversizing systems as a result of poor design. The question is more around whether, and how much, to oversize the system to reflect long-term flexibility of connecting additional heat loads to the network. In some cases, the system has been oversized to reflect future expansion which has not taken place.

12.4 Components

General

The components that make up DH systems are broadly the same in each country – it is a global industry and market-place. UK contractors have adopted the systems used in other countries and buy components from the same end-suppliers. However, the lack of current market scale in the UK means that suppliers may not stock all of the components in the UK; Cowi reports that one supplier representative to the UK market had no knowledge of a product that the same supplier organisation sold in other parts of Europe.

This globalisation was also confirmed at the WP1 workshop. A DH company highlighted that they had compared their practices against those in Scandinavia – one of the drivers for this benchmarking exercise being the suggestion that the costs are significantly lower in Scandinavia. However, the components used (and the methods of installation) were similar.

Pipes and fittings

In principal, plastic pipework[16] offers significant benefits over steel pipework. Plastic piping (at smaller sizes) is flexible, it is laid directly from a roll, and it is not at risk from corrosion damage. Pipe joints can be installed above ground and the pipe can be lowered into the trench. Part of the trench width for steel pipes is to allow space for welding and consequently trench width can be reduced for plastic pipes. Reduced internal friction means smaller plastic pipes can be used to achieve the same flow as traditional steel pipes (reduced friction can also help lower pumping loads). Longevity of plastic pipes is not fully known yet, but there can be fewer joints than for steel pipes, joints being the most vulnerable part of a network. However, currently, the use of plastics is limited as they degrade at high temperatures. The

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[16] Currently used materials are described in Section 11.2.9 and the possibilities for the future are discussed in Section 13.4.

international review showed that there is limited use of plastic pipes across Europe. There is almost no use in city networks which tend to operate at high temperatures, with several countries reporting increased use in smaller networks which may operate at a lower temperature. Furthermore, if the existing networks could be operated at a suitably lower temperature, the respondents suggested that they would replace steel pipes with plastic pipes when the existing steel pipes needed to be replaced.

One more recent practice identified from several sources is the increasing use of twin pipes (either steel or plastic), where the flow and return pipes are both placed inside the same outer casing. The heat losses from twin pipes are lower than from single pipes with the same dimensions. Furthermore, twin pipes are also usually cheaper to install as the trench width is narrower and there is only one outer casing joint, although, with the pipes so close to each other, a more skilled welding technique is needed. A representative at the WP1 stakeholder workshop suggested that the use of twin pipes can be difficult to implement in practice in the UK where the use of separate pipes for supply and return makes it easier to navigate around existing utilities in the ground. However, given the increasing use internationally and their potential to save costs, the project team propose to consider the use of twin piping further in Stage 2, even if it is only appropriate for particular ground conditions.

Hydraulic Interface Units (HIUs)

Significant differences were identified around the use of hydraulic interface units (HIUs) at both the component and overall design level. DH systems in the UK tend to have a HIU in each property. Furthermore, these tend to be indirect units which have two plate heat exchangers, delivering domestic hot water and heating so that there is full hydraulic separation between the network and the customer system. An alternative is to use a direct HIU, where space heating is delivered directly from the district heating system but a plate heat exchanger is provided for domestic hot water. An indirect system adds capital cost because there is an additional heat exchanger, as well as the need to pump the space heating water through the radiator or underfloor heating circuit. Furthermore, the addition of the heat exchanger results to some degree in greater losses and higher network operating temperatures. An indirect approach is often used due to concerns about, say, burst pipes and resultant impact of a direct system on the safety and performance of the wider network and the potential for damage within the dwelling or apartment block.

Furthermore, Cowi report an alternative approach used commonly in Denmark which is worth considering for Stage 2. It is typical to have a single heat exchanger for space heating for several blocks of flats or a group of terraced housing. Similarly, high density housing or flats are more likely to have a common hot water system running from a single heat exchanger than individual HIUs for each property. This potentially saves significant costs from the avoidance of individual HIUs although additional pipework is needed and metering is more complex. This approach has been adopted in Denmark as traditionally high density housing has used communal heating. Hence when changing heating systems to district heat networks, this design was the most appropriate, the lowest capital cost, and the residents were already aware of the need to avoid damaging the pipework given the implications for neighbouring properties and not just their own.

Prices

Anecdotally, the prices of some components (particularly pipes) are being reported as being much higher (as much as 100%) in the UK. One reason proposed is that some components are imported from other countries, such as Denmark, which results in additional costs (e.g. transport costs). Another reason suggested is less purchasing power in the UK, and thus higher prices, due to smaller number and sizes of schemes and associated components. This is not easy to prove in detail, as although prices of components are widely available, most suppliers operate a discount that is commercially sensitive and results in large price reductions for significant orders. As a result actual sale prices are less easy to obtain. An impact due to the increasing UK market size is expected, with lower costs emerging if / when more work is delivered in the UK.

It was not originally the intent to do an international price comparison in Stage 1. However, given the previous anecdotal comments and to help develop plans for Stage 2, a simple high-level comparison of prices was undertaken between those in Denmark and the UK. It is intended that a benchmarking exercise will be held with Cowi, particularly around civils processes, in Stage 2.

Table 5 compares UK prices (used in the WP2 cost model) with benchmark information provided by Cowi from Denmark. Note that price data for pipes includes both the supply of components and the laying of the pipes. There is evidence that the greater experience of installation, and potentially also the market size, is resulting in lower installation costs. There is considerable uncertainty in these comparisons, due to the impact of assumptions around ground conditions and difficulty of installations. However, the comparison indicates that both pipe and civil costs are generally lower in Denmark.

Table 5: Comparison of price data for installed pipes

Pipe size	**Cowi**			**Cost model**			**Difference**
	Pipes	**Civils**	**Total**	**Pipes**	**Civils**	**Total**	
mm	**£/m**	**£/m**	**£/m**	**£/m**	**£/m**	**£/m**	
100	120	180	300	191	320	511	170%
300	529	353	882	646	455	1104	125%
450	764	509	1,273	798	496	1294	102%

The price of an indirect HIU (supply and install) in the UK is £2100 with a typical variation of ± 10% (the WP2 Cost Model Methodology and Analysis provides further details). In discussion with Cowi, indirect HIUs are typically used for single family homes in Denmark (e.g. a detached house of 130m^2). The prices vary from £1500 to £2500 (supply and install). District heating companies can usually obtain a better price via economies of scale and will therefore be at the lower end of the scale, whereas the individual purchase from a supplier of a single HIU by a resident is expected to be at the higher end of the scale. Hence, overall the prices are similar in the UK and Denmark, albeit the best prices in Denmark may be 10-20% lower. Cowi noted that Scandinavia tends to operate as a single market i.e. the price for HIUs (at least for the supply of the unit itself which comprises most of the cost) is expected to be fairly consistent across Scandinavia.

In Cowi's experience, the price of a direct HIU (supply and install) has previously been less than half of that of an indirect HIU (i.e. they could be as low as £500). However, several recent rules have been implemented for the connection of individual dwellings, which includes the installation of weather compensation[17] on every connection. This may be increasing the prices, as Cowi have recently seen prices for direct HIUs coming in at only slightly less than indirect HIUs as a circulating pump and control valves are now required. Direct HIUs are only offered by the district heating company, and not something that a user would be able to purchase and organise installation themselves, so economies of scale apply to the prices.

[17] Weather compensation controls measure the temperature outside of a building, and vary the temperature of the water pumped into the heating system accordingly.

12.5 Installation

Civil engineering

The review suggests that the overall process of civil engineering is similar in all countries. The conventional approach of excavation, the purchase and use of backfill material, and the subsequent surface reinstatement is the norm. There can be similar challenges around the location of buried services for older service installations.

Compared with conventional construction, the trenchless drilling techniques involve a higher risk (e.g. of hitting underground services), which can however be kept small if there is careful planning and implementation. It offers advantages in that potentially building times can be considerably shortened and roads need only be opened up at the launching and target trenches. However, a key obstacle is still that trench construction is cheaper due to the high cost of the equipment hire. As in the UK, trenchless drilling is used where open trenches are undesirable or impossible e.g. road, rail or river crossings.

As noted earlier, in countries where heat is regulated, there is generally easier access to the roads to carry out works. This is equivalent to how utilities, such as water, gas and electricity, work in the UK.

Pipe laying

There are different approaches used across Europe to control the compressive longitudinal stress that occurs when the steel pipe that is constrained in the ground is heated. For schemes in Europe operating at temperatures up to 120°C, pre-heating prior to backfill is often used. However, cold laying appears more prevalent in the UK partly as lower temperatures are used and partly as there is a pressure to minimise the amount of trench open at any one time. It was suggested by a UK DH company that the pre-heating of systems is only relevant for transmission lines with long straight lengths of pipes. Typically in the UK there is often a need to include bends in the pipe run to avoid obstacles, and these allow the heat-induced stresses to be managed effectively.

Skills

There is more experience of installation within the countries with a longer tradition of district heating and this means that there is a larger pool of skilled staff available. Furthermore, there are standardised ways of working and those in the different disciplines know their roles.

AECOM is aware from its experience of at least some of the DHN schemes in the UK employing contractors who are not specialists in district heating (including detailed design, installation and commissioning), can subsequently lead to problems of performance and the need for additional work (which may help rectify some problems but not all as they may be too embedded in the scheme and not considered cost-effective to address). It will therefore be necessary to initiate a widespread training programme if there is to be a major expansion of installations in the UK.

12.6 Operation

Heat Metering

In many Danish networks, for example, the cost of heat billed to clients is based on floor areas rather than measurements. This approach for billing is simpler to implement but provides a reduced incentive for the individual to save energy. This approach will be affected over time by the recent EU Directive on energy efficiency which requires individual dwelling metering in new buildings and the appraisal of retrofit of metering in existing buildings.

Time of use

In discussion with Cowi, it is normal in Denmark to leave the heating on for most of the time, rather than allowing the home to cool during the day if unoccupied and at night. This may be linked to a colder climate. This approach uses slightly more energy in total, but smooths the demand for heat which reduces the peak load and affords, for example, more efficient system operation.

The survey interviewees were also asked whether heating should be turned off during times of the day to save pumping cost. For example, whilst in most countries there is no night setback, there may be a case to do this in a relatively benign climate like the UK's. It was suggested that night setback only makes sense for buildings with low (short) time constant (lightweight building construction with poor insulation or high ventilation losses). For modern buildings with a good insulation level, the temperature drop during night is relatively small and the potential heat loss and pumping cost savings from night set back are also relatively small. Where night setback is used, care is needed with the high peak load once the heating starts again. This high peak load can cause problems with the DH system operation and may require additional peak load boilers. The peak can be avoided by a "slow" ramp up of the load. It was suggested that it may be better to make improvements to the insulation and air tightness than adopt night setback (which would also have additional benefits such as reduced heat generation required).

Monitoring

The leading DH systems have increasingly sophisticated monitoring and operational systems in place to optimise the performance of the networks. This includes real time monitoring of many aspects of the performance of the network, with this information being fed into a model of the system allowing real-time adjustment of key parameters. Cowi support many DH systems in this way, and this is more developed than is the norm in the UK. This is understood to reflect the better developed market for DH in Denmark, with larger, longer established networks, and many more of them in place. This may well change with expanding UK networks, as well as the rapid decrease in the cost of monitoring equipment in the last few years, delivering potentially both reduced operational costs as well as reduced capital cost through more optimised design.

Network temperature and heat sources

Although there has been a great deal of discussion around low temperature DH systems, in practice these are rare at present, and most built networks have to operate in the manner in which they were originally designed. Lowering return temperatures by good design and control of building heating systems remains a target for all DH schemes. Recent developments have been mostly in terms of sources of heat, with a greater range of lower carbon solutions being added in, for example energy from waste, large heat pumps and even direct electric when excess wind power is available.

12.7 Summary

In summary, the key learning points from this section are as follows.

- Client: A key contributor to the rapid expansion of district heating in Scandinavian countries has been the ownership of the DH company by a local municipality. This approach has resulted in lower capital costs both through the schemes being underwritten by the local municipality and thus gaining access to low cost finance, and that the municipalities have been able to incorporate their significant stock of social housing and public buildings. By comparison, UK local authorities suffer from a lack of funding, knowledge and skills to take DH projects forward and increasingly fewer buildings under their control especially housing.
- DH supply chain: In the UK it is typical, especially for smaller new-build housing schemes, for several different organisations to carry out the work for the different stages of DHN development. This can lead to split and uncertain responsibilities between organisations and solutions which are not well integrated. By contrast there is greater integration in Scandinavian countries both in the design and the delivery of the scheme which reduces such problems.
- Skilled workforce and standardisation: There is a greater skilled workforce in Scandinavian countries to deliver district heating – issues of poor performance, for example, have been highlighted in the UK, particularly for smaller DH schemes where non-specialist designers and contractors have been used. There is also greater standardisation of roles and processes for Scandinavian DH schemes, including both design and construction, as opposed to UK schemes which can be more bespoke. Furthermore, given that building design teams are more familiar with DH systems in Scandinavia, it means that buildings are more likely to be delivered in a way that suits connection to the DH network, which is not always the case in the UK.
- Design stage: Within the UK, the heat load is often based on estimated energy use. In contrast, in Denmark, the actual energy use of all buildings is publicly available providing greater confidence of the capacity requirements of the DH system. Furthermore, engineers in the UK typically oversize systems to avoid the risks associated with under-sizing. Whilst Germany confirmed that oversizing was also an issue, Scandinavian countries appear to have fewer problems as a result of greater experience, the use of better energy data at design stage and more confident use of diversity factors.
- Components: The components that make up DH systems are broadly the same in each country reviewed – it is a global market-place. One area of potential interest is the trend towards using twin pipes in Europe, where the flow and return pipes are placed in the same outer casing, which affords narrower trenches, cheaper installation, reduced heat loss and thus operating cost. Another potential area of interest is that in Denmark it is typical to have a single heat exchanger for space heating for several blocks of flats or a group of terraced housing, whereas within the UK a heat exchanger (HIU) is typically located in each property which increases the number of heat exchangers and associated costs.
- Installation: Similarly the installation practices are similar in each country reviewed. It is noted that it is common practice in the UK to cold-lay pipework. In some larger schemes in Europe pre-heating of the pipe is used to reduce operating stresses. However, it was suggested by a UK DH company that the pre-heating of systems is only relevant for transmission lines with long straight lengths of pipes and it is not often practical in the UK as there is the common need to include bends in the pipe run to avoid obstacles and pressure to limit the length of an open trench.

- Operation: The leading DH systems have increasingly sophisticated monitoring and operational systems in place to optimise the performance of the networks. This includes real time monitoring of many aspects of the performance of the network, with this information being fed into a model of the system allowing real-time adjustment of key parameters. Cowi support many DH systems in this way in Denmark, and this is more developed than is the norm in the UK.

13 Literature Review and Horizon Scanning

A review was undertaken to identify where new ideas are already available through research and other work. The aim of this is to collect ideas that have potential to contribute to meeting the challenges that are likely to emerge from Work Package 3 to reduce the cost of district heating.

The following sources were used for this work.

- A review was undertaken of the work supported by the International Energy Agency under its Implementing Agreement on District Heating and Cooling including Combined Heat and Power "IEA DHC". The IEA work on district heating and cooling has been taking place over the last 30 years and has covered to some extent all of the issues that concern this project. A review was undertaken of published reports of completed projects and, where available, progress reports of on-going projects. Some further insight was provided by Robin Wiltshire, the UK representative and chair of the Executive Committee. This is presented in more detail in Appendix I which focusses on the most recent completed and on-going work, where information is more relevant to the project.
- A review of the work of the 4DH centre in Denmark. This comprised a review of material available on its web-site (http://www.4dh.dk/) and a research paper on the future of district heating around 4th Generation District Heating of which Robin Wiltshire (project team member) is one of the authors. This is presented in more detail in Appendix J[18].
- A review of the book, *Advanced District Heating and Cooling (DHC) Systems* (referred to as the "Advanced DHC Review" in the proceeding text)" which was published in 2015[11] and for which Robin Wiltshire is editor. It details both current international practice as well as potential future innovations currently undergoing research. This is presented in more detail in Appendix K.
- A literature review was undertaken by academic staff from Loughborough University. The review was structured around key topic areas such as trenchless technologies, plastic pipes, in-situ jointing, control measures, etc. The literature review was not focussed on the district heating industry, but most of the publications reviewed addressed aspects of DH. The results of the literature review are presented in more detail in Appendix L.
- A review of the research projects in District Heating sponsored by DECC under the Small Business Research Initiative (SBRI).

13.1 The Adoption of Lower Network Temperatures

There is considerable interest internationally in a move to what is termed "4th Generation District Heating (4GDH)", where district heating systems operate at significantly lower temperatures e.g. supply and return temperatures even as low as 50°C and 20°C

[18] In addition, Andrew Cripps (AECOM) had a meeting with David Connelly in Denmark who is an Assistant Professor at Aalborg University in Denmark. Part of his role comprises working with the 4DH centre in Denmark on the role of 4th generation district heating in future renewable energy systems. Details from this meeting repeated information collated elsewhere and hence are not separately reported. The intention is that David Connelly (and other international experts) may provide useful input when identifying and assessing innovative solutions within Stage 2 of the project.

respectively (reduced from 85/90°C and 60°C respectively in the baseline model). This is seen as being the forward direction of travel with much of the research within the DH community focussed around innovation to deliver the changes required in the DH system architecture.

There are two key international drivers for lower temperature district heating [19].

- As the building stock becomes more thermally efficient, and the heat density reduces, network heat losses need to reduce such that the system remains commercially viable. Lower operating temperatures in the network will result in lower network losses.
- The ability to recycle heat from low-temperature sources using heat pumps and integrate renewable heat sources such as solar and geothermal heat.

These drivers are relevant to the UK with its aims for improved energy efficiency and energy security and a low-carbon economy. Furthermore, reduced network heat losses would also potentially help enable district heating to be deployed more widely in the UK, outside of high heat-density urban areas. However, it is not clear that 4DH will result in lower capital costs as the emphasis is more on gaining efficiency and additional CO_2 savings in a future energy scenario where thermal power stations are being phased out.

There are a number of related research activities currently in progress (including a dedicated 4DH Research Centre in Denmark set-up to investigate the potential for and develop 4th Generation District Heating). For example[20]:

- Research is being undertaken to assess alternative approaches to heating existing buildings (with poorer insulation) through the use of low-temperature district heating. It may be that some buildings need to be modified (e.g. insulation improved) in order that lower temperatures can be used in heat emitters and thermal comfort for the occupants is achieved.
- The heat exchange systems and services system design in buildings need to be designed carefully to meet the needs of a lower temperature system.
- Work is on-going on how best to manage the risk of legionella in different low temperature domestic hot water systems. A low supply temperature of say 50-60°C can deliver hot water at acceptable temperatures of say 45°C and the legionella risk is considered low if the water is not stored and very small volumes of water are kept warm as is the case with instantaneous hot water heating.
- There are multiple ways being investigated to minimise losses in the district network. Low-temperature DH affords a significant reduction in the distribution heat losses. Other additional measures being explored include the use of smaller pipe dimensions, drag reducing additives, new materials for pipes and insulation, pulsed operation, and supply and return pipes provided in a loop layout designed to enable circulation in the supply pipe only during lower load summer periods. Intelligent controls and metering of network performance are also being explored with the aim of minimising temperatures whilst meeting customers' demands.

Whilst the cost focus is particularly around reducing the operational costs, there are potential benefits for capital costs as well, especially where the use of advanced controls and variable flow temperatures can minimise the pipe sizing and avoid oversizing for short duration

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[19] Lund H, Werner S, Wiltshire R et al. 4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems; Energy 68 (2014), 1-11.
[20] http://www.4dh.dk/projects

peaks. Lower operating temperatures and variable flow temperatures enable a wider range of pipe products to be used and they will also permit direct connection with potential for lower component costs as a result.

There are currently a number of low temperature pilot projects and small DH schemes. For example, Cowi highlighted that it is currently working on a low temperature scheme with a supply temperature of 50°C, and providing hot water directly at 45°C, with legionella being managed by reducing the amount of water stored. It results in less than 3 litres stored at the heat exchanger and 5 litres in the pipes to the tap. This approach is more difficult to apply with storage tanks, but direct electric heating could be used to boost the temperature on occasions to control legionella growth. It was also noted that most Danish homes do not have local storage so this is less of an issue than for the UK. This system includes a special Danfoss heat exchanger to work at these temperatures. The solution used still has steel pipe in the street, with plastic pipes to homes in ducts to allow easier replacement. Cowi noted that there would be resistance to the use of plastic for major pipes because of the trusted tradition of using steel for the main pipes. The boards of the DH companies make these decisions and they would be likely to continue with the conventional steel approach.

13.2 Civil Engineering and Installation of Pipework

Reducing excavation volume

Advanced DHC Review discusses potential strategies to make the trench narrower which would have the benefit of reduced volume of excavation and speeding up the installation of the DH system. This includes using a milling technique more commonly used for the installation of broadband cables and narrow gas pipes [21, 22, 23]. However, it is noted that the studies quoted in this review are over a decade old and these processes have not been introduced into common practice within the DH industry. As noted in the international comparison, there is a move towards the greater use of twin pipes which affords narrower trenching. There have also been trials in the past with so called ‘piggy-back laying’ with the flow and return pipes arranged vertically resulting in a narrower trench [24], but this creates difficulty should the lower pipe need to be repaired in the future.

The Advanced DHC Review highlights research undertaken on shallower burial of pipes [25, 26]. This similarly has the benefit of reduced volume of excavation and speeding up the installation of the DH system. The depth of burial under a road is mainly determined by the need to protect the pipe from surface loads from vehicles. Perhaps more important is the

[21] Claesson, C. et al (2004). A new method of laying district heating pipes. In: 9th International Symposium on District Heating and Cooling, Espoo, 30-31 August.
[22] Lindmark, A. (2004). Ecotrench läggning av fjärrvärmerör [Ecotrench laying of district heating pipes]. Report/Swedish District Heating Association 2004:114.
[23] Dahlgren, M. (2005). Fräsning av fjärrvärmespår i småhusområden [Milling of district heating trenches in detached house areas]. Report/Swedish District Heating Association Värmegles 2005:22.
[24] Schmitt, F. and Hoffmann, H-W. (1999). New ways of installing district heating pipes. Netherlands agency for energy and the environment. IEA District Heating and Cooling, 1999: T3.2.
[25] Sällberg, S-E. and Nilsson, S.F. (2008). Shallow burial of district heating pipes. In: 11th International Symposium on District Heating and Cooling, Reykjavik, August 31 - September 2.
[26] Fransson, A. and Sällberg, S-E. (2010). District heating pipes 200 mm below surface in a street with heavy traffic. In: 12th International Symposium on District Heating and Cooling, Tallinn, September 5-7.

laying-depth requirements set by the road owner whose main objective is to ensure a well-functioning road structure and avoid uneven surface settlements. In the case of steel pipes, the depth the pipe is buried is also determined by the need for a sufficient overburden pressure on the pipe to prevent vertical upwards buckling of the pipe caused by thermal expansion stresses.

This research has evaluated the damage risk for pipes and pavement from shallower burial. It showed that any pipe deformation from vehicle use was negligible and actually that this technique is better for preserving the road surface as less soil is disturbed and requires settling afterwards. The Advanced DHC Review highlights that further research is required around the risks in reducing the overburden pressure on the vertical stability of the pipes. Furthermore, shallower burial should be used with caution when there is a risk for frost heave, i.e. where pipes are laid in frost-susceptible soils.

Reusing excavated material

As highlighted earlier, current practice after the pipework is installed and tested, is for the trench to be backfilled. This could be done with excavated material, but it is normal practice to use new imported material. This ensures a consistent quality and avoids the need to store the excavated material. However, significant cost savings can potentially be achieved from reusing excavated existing soil as backfill by not needing to buy and transport large quantities of gravel material as well as not paying landfill costs which are particularly high in London. The Advanced DHC Review summarised research into the impact of reusing excavated material on the pipes themselves and joints e.g. the impact of subjecting the pipe wall and joints to point loads from stones [27, 28, 29, 30, 31]. The Review suggests that coarse grained / unspecified soil poses no significant damage risk – albeit noting this technique has not broken through into use. Reductions in the capital costs for civil engineering works have been estimated as being between 10 and 20% for small and large pipes respectively. However, such savings have been questioned for urban areas in particular due to the lack of space for stock-piling excavation soil on-site and thus the necessity for some level of transportation and storage off-site.

Trenchless techniques

An alternative approach to installation is to use trenchless drilling. There are many methods of trenchless digging to suit different installation types and dimensions [32,33]. For example, Horizontal Directional Drilling (HDD) is a common trenchless technique which is used for

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[27] Molin, J. et al (1999). Laying of district heating pipes using existing soil material – economic motivations and results from field trials. In: 7th International Symposium on District Heating and Cooling, Lund, May 18-20.
[28] Schmitt, F. and Hoffmann, H-W. (1999). Re-use of excavated materials. Netherlands agency for energy and the environment. IEA District Heating and Cooling, 1999: T3.3.
[29] Göhler, T. and Hoffmann, W. (2004). Construction of DH pipelines by reuse of excavation material. Euroheat Power IV, 54-59.
[30] Selle, O. and Theile, R. (2003). Erdverlegte Druckrohrleitungen aus Kunststoff – Untersuchungen zu verlegebedingten Beanspruchungen. Leipzig Annual Civil Engineering Report, 8.
[31] Bergström, G. and Nilsson, S. (2001). Stone indentations in district heating pipes caused by lateral displacement of the pipeline – experimental studies. Electron J. Geotech. Eng 6.
[32] Allouche, B.E.N. et al (2000). Horizontal directional drilling: Profile an emerging industry. J. Constr. Eng. Manag., vol. 126, no. FEBRUARY, pp. 68–76, 2000.
[33] Kramer, S. (2012). An introduction to trenchless technology. Springer Science & Business Media.

district heating. A pilot hole is first drilled between the entrance and receiving pits. This is followed by reaming which consists of using an appropriate tool to open the pilot hole to a slightly larger diameter than the carrier pipeline. The entire pipeline length is then typically pulled in one segment through the reamed-hole pathway.

As highlighted in the international comparison, trenchless drilling has currently limited use – tending to be applied where open trenches are undesirable or impossible e.g. road or river crossings. Trenchless digging is relatively expensive compared to the use of open trenches. As highlighted in Section 12, modern burial techniques have been designed to control pipe movement in the ground, and compensate for the expansion and contraction of a steel pipe during operation, which are not currently available when drilling and as a result will require older methods of securing the pipe (e.g. through the use of anchors and expansion joints) and a greater risk of problems with joints. Care also needs to be taken to avoid damage to the pipe casing and joints when pulled through the ground, as well as frictional forces fracturing the service pipe/insulation interface, which can be addressed through using appropriate sliding supports and fusion welded joints. A greater risk is unknowns with drilling underground (e.g. the presence of unknown underground services) – a key reason for the initial pilot hole. There are also greater maintenance costs associated with trenchless digging as they are normally relatively deep to ensure that they go under all the services.

It would be expected that with advances in trenchless technologies and practices tailored for use with DHN, the use of trenchless drilling will increase. It is likely to be most competitive in urban environments where hard dig is required (soft dig is significantly less expensive) and where there is greatest need to minimise disruption. Further work would be necessary to better understand whether there are opportunities for the costs and risks to be reduced and achieve greater levels of deployment.

It is noted that civil engineering costs can be reduced through better planning by placing ducts in key new infrastructure roads/works where there are DH schemes planned for at a later date. This secures the connection at low cost/risk with minimal disruption. In discussion with a DH developer, with prior experience as a contractor, he noted that he has worked on many projects where he has had to go back in after major works have been completed and had to dig it all back up again, even where it was intended to install a DH scheme at a later date.

13.3 Non-Invasive Techniques to Identify Underground Objects

There are issues in the UK (and internationally) around accurately determining the presence of and depth of underground utility lines and other buried objects. These may be, for example, water supply, sewage system, electrical grid, gas network, telecommunications etc. Information can be obtained from utility companies but it can be inaccurate and/or incomplete, particularly for more historic infrastructure. This can lead to problems and additional expense associated with installation of a DH network.

There are a number of non-invasive techniques to map underground objects [34, 35, 36, 37, 38, 39, 40]. For example, ground penetrating radar (GPR) is a relatively well

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[34] Peters, L et al. (1994). Ground Penetrating Radar as a Subsurface Environmental Sensing Tool". In IEEE: 1994, vol. 82, no. 94055.
[35] Olhoeft, G.R. (2000). Maximizing the information return from ground penetrating radar. J. Appl. Geophys., pp. 175–187, 2000.
[36] Costello, S.B. et al. (2010). Underground asset location and condition assessment technologies" Tunn. Undergr. Sp. Technol., vol. 22, no. 2007, pp. 524–542, 2010.

established and developed technology. It is widely used due to it being able to detect a wide range of different types of asset materials (although it cannot distinguish between them) and is able to provide a determination of the depth of buried assets. There is a variety of different approaches to asset locating that in certain circumstances can be better suited and/or can provide more information on the buried asset. These technologies include electromagnetic line locators (appropriate for sensing metal utility pipes and cables), infrared thermography, and acoustic techniques.

From a market review, all of these techniques are being implemented into the latest products available [41, 42, 43, 44, 45, 46, 47]. Indeed, some technologies have multi-sensor capabilities. Services mapping surveyors have the option of using one or more type of technology for a given mapping project depending on their relative advantage.

In practice, the use of such mapping techniques is taken on a project by project basis. It can be of benefit but it is expensive over the large area of a DH network and it cannot be fully relied upon (e.g. accuracy tolerance is relatively high). It is particularly focussed on high risk projects and/or where a client has asked for this which is normally on their new developments where correct space planning is good upfront work with all the new services. However, it is seen as being no substitute for trial holes on existing high risk areas/services.

It may seem sensible for the DH developer to carry out the mapping work upfront and pass this information on to the contractor to potentially reduce their risk and cost. In practice, the developer tends to pass the detailed design risk to the contractor and it is then their choice whether to do mapping or allow in their contract price the risk of potentially uncovering underground obstacles and the need to, say, increase the depth of the trench or modify pipe layout.

A further area for consideration is the way in which the data collected is managed and shared. Mapping equipment already available provides a link through geographic information systems (GIS) that should allow data collected to be added to a database in a way that enables the information to be captured and made available to others. Underground data can also be collated and integrated from other utilities. This should help enable an accurate 3-D model of below ground utilities in the city and reduce the need for surveys whilst improving design co-ordination.

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[37] Metje, N et al. (2007). Mapping the Underworld – State-of-the-art review. Tunn. Undergr. Sp. Technol., vol. 22, pp. 568–586, 2007.

[38] Rashed, M. and Atef, A. (2015). Mapping underground utilities within conductive soil using multi-frequency electromagnetic induction and ground penetrating radar. Arab. Jounral Geosci., pp. 2341–2346, 2015.

[39] Fuchs, H.V. and Riehle, R. (1991). Ten Years of Experience with Leak Detection by Acoustic Signal Analysis". Appl. Acoust., vol. 33, pp. 1–19, 1991.

[40] Hao, T. (2012). Condition assessment of the buried utility service infrastructure," Tunn. Undergr. Sp. Technol. Inc. Trenchless Technol. Res., vol. 28, pp. 331–344, 2012.

[41] http://www.rpsgroup.com/UK/Services/S/Surveying.aspx

[42] http://www.groundpenetratingradar.co.uk/ground-penetrating-radar-surveys/utility-surveys/site-utility-surveys.html

[43] http://www.centara-ltd.com/solutions/utility-mapping.htm

[44] http://www.lincenergysystems.com/linc-energy-blog/entry/what-are-the-common-underground-utility-location-methods#.VpkN2ssny5s

[45] http://www.gasleaksensors.com/brochures/sensit_ultra_trac_apl_brochure.pdf

[46] http://www.geophysical.com/utilityscan.htm

[47] http://multimedia.3m.com/mws/media/487162O/3mtm-dynateltm-advanced-pipe-cable-locator-2220m-data-sheet.pdf

13.4 Piping Technologies and Connections

Heat distribution pipes are normally designed as a bonded pre-insulated piping system suitable for burying directly in the ground. This typically consists of a steel carrier pipe with polyurethane (PUR) insulation and a high-density polyethylene (HDPE) casing all bonded together. The Advanced DHC review discusses future improvements to this technology.

- The high density polyethylene (HDPE) casing pipe has not developed in any significant fashion over recent years with the exception of the introduction of a diffusion layer barrier and a reduction in wall thickness. Incremental progress is being made to improve its mechanical properties.
- Incremental progress is being made to the thermal insulation in that polyurethane (PUR) foam insulation is being continually improved with regard to thermal properties. Potential improvements investigated over the last decades comprise, for example, Polyethylene Terephthalate (PET) foam insulation, casing free pipe configuration and various types of new blowing agents for optimising PUR foam properties. One recent development highlighted is a new hybrid, PUR/vacuum insulation, where recent laboratory tests demonstrate a 30% reduction in thermal conductivity [48, 49].

A limiting factor for achieving a step change in thermal insulation technology is seen to be the production cost. PUR foam is seen as an excellent thermal insulator, inexpensive and quick to produce. A shift towards any kind of advanced hybrid structure will also require innovation in production technology to make it commercially viable. A possible option could be some type of PUR composite, with additives reducing the thermal conductivity further but which would still be possible to manufacture using existing production lines.

Plastic pipework is also available for district heating. Unlike standard steel pipes which are rigid, plastic pipework at small diameters is flexible which can potentially reduce installation costs: they can be coiled and hence delivered in long lengths which reduces or eliminates the need for buried joints, and do not require straight trenches and can more easily go around obstacles. However, they cannot support as high a pressure or supply temperature as steel pipes. Cross-linked polyethylene (PEX) is the standard plastic material of choice for high (up to 90^{o}C) temperature applications. When originally introduced no diffusion protection was used which resulted in some corrosion problems and consequent poor reputation. At present, plastic pipes are protected against oxygen diffusion by a vapour barrier, e.g. EVOH (ethyl vinyl alcohol copolymer), or an aluminium layer. One drawback of PEX is that it cannot be welded due to its thermoset properties and therefore couplings are required. As noted in section 11.2.9 press compression couplings are used for PEX pipes in DH networks. Another option is to use polybutylene (PB) which is weldable and various such systems have been produced. It has a similar maximum operating temperature as PEX[50]. In terms of thermal insulation, often polyethylene (PE) foams or mineral wool are used which are flexible, but there is also a semi-flexible PUR foam variant.

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[48] Adl-Zarrabi, B. and Berge, A. (2012). Högpreseterande fjärrvärmerör [High performing district heating pipes]. Report/Swedish District Heating Association 2012: 16.

[49] Adl-Zarrabi, B. and Berge, A. (2013). Hybridisolerade fjärrvärmerör [Hybrid insulated district heating pipes]. Report/Swedish District Heating Association 2013: 23.

[50] http://www.iea-dhc.org/index.php?eID=tx_nawsecuredl&u=855&g=3&t=1465109746&hash=e15838d9b82a95b05c6f6b25dc1ef5f5eda186a2&file=fileadmin/documents/Annex_V/8DHCT99-06LR.pdf

The literature review highlighted early research in altering the properties of PE and PB type plastics for greater impact strength, heat distortion temperatures and resistance to rapid crack formation. A further paper[51] describes the potential use of cross-linked PE pipes, reinforced with carbon nanotubes, to be more resistant to thermal decomposition in comparison to ordinary PEX pipes. Another potentially useful study[52] describes a novel series of ring-chain polymers that show good thermal stability at DH operating temperatures. However, such research is in its early stages and whilst increased resistance to thermal degradation has been identified, further work would be needed to assess the long-term performance of these plastics at DH network operating temperatures.

An alternative is to use other plastics that are able to operate at higher temperatures. There are many thermoplastics that are thermally stable at district heating operating temperatures i.e. stable at temperatures exceeding 120°C. Common examples include Polyether ether ketone (PEEK) and Polytetrafluoroethylene (PTFE) as well as other fluoropolymers. Thermoplastics are already used for higher temperature operation in other industries. For example, they are frequently applied in applications such as: sliding/friction-stressed mechanical parts in mechanical engineering/textile/office technologies and the automobile industry; heat- and shock-resistant products in the glass/aerospace industries; highly insulating heat-resistant components in electrical engineering, sterilization and hydrolysis-proof medical devices, radiation-resistant components in vacuum, x-ray and nuclear technologies; and various components for the chemical industry and chemical transportation[53].

However, the main reason that such thermoplastics have not been used for district heating pipes to date is one of cost. The highly processed plastics are at least several times more expensive than the most basic alternatives, such as PE and PB, as well as steel. Furthermore, the key benefit of the flexibility of plastic is only really realised for the smaller connections off the main distribution network in larger DH schemes (larger diameter plastic pipework is intrinsically less flexible). In addition, the future demand for high temperature plastics is unclear given the current drive for lower network operating temperatures.

Joints are a potential weak link of a DH pipe system. Straight pipe sections, for example, are virtually never damaged in normal use. Joints, on the other hand, are fairly sophisticated constructions, with high demands on workmanship and good conditions on-site at installation, and they are sensitive to thermally induced movements and frictional forces from backfill. However, advanced research on the design of joints for steel pipes appears to be limited. The Advanced DHC Review reports that there have been attempts to devise physical coupling-like connectors for steel pipes, which could result in quicker and less expensive installation work, but there has been limited success. The literature review observed that in-situ jointing is not a topic of great interest in academia - it is mostly the R&D departments of industrial companies that are competitively investigating and developing such technologies. From the limited success to date in reducing the cost for steel pipes joints, and the pareto analysis in the WP2 Cost Model Methodology and Analysis identifying that joints comprise a

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[51] Roumeli, E. et al. Carbon nanotube-reinforced crosslinked polyethylene pipes for geothermal applications : From synthesis to decomposition using analytical pyrolysis e GC / MS and thermogravimetric analysis. Polym. Degrad. Stab., vol. 100, pp. 42–53, 2014.
[52] G. Yu, C. Liu, J. Wang, X. Li, and X. Jian, “Heat-resistant aromatic S-triazine-containing ring-chain polymers based on bis (ether nitrile) s : Synthesis and properties,” Polym. Degrad. Stab., vol. 95, no. 12, pp. 2445–2452, 2010.[53] Ensinger, “High temperature plastics.” [Online] Available at: http://www.ensinger-online.com/en/materials/high-temperature-plastics/
[53] Ensinger, “High temperature plastics.” [Online] Available at: http://www.ensinger-online.com/en/materials/high-temperature-plastics/

relatively small part of overall network capital cost, it appears better to focus solution development on looking to eliminate on-site welding rather than reducing significantly the cost of welding steel pipes. There are alternative jointing technologies for plastic pipes. Fusion welding and push-fit coupling connections are both available. Indeed, this can be pre-fabricated and speed-up installation on-site with some recent innovative application of plastic pipes being supplied in a coil combining both the main pipeline and individual building connections. It is envisaged that there will be a greater role for plastic pipework as network temperatures reduce.

As noted in Section 12, there is an increased use of twin pipes. Original twin pipe solutions were for smaller pipe dimensions. Currently pipe manufacturers are working on increasing their size range to deliver twin pipe solutions of larger diameter.

13.5 Hydraulic Interface Units (HIUs) and Sub-Stations

HIUs are used in dwellings to exchange heat between the DH system and the dwelling's space heating and/or domestic hot water. Larger systems, used for groups of housing or larger commercial buildings, are known as sub-stations.

The Advanced DHC review notes that, in general, there has been little development in the composition of such units. The heat exchangers have been miniaturised and the systems pre-fabricated rather than being built on-site. Furthermore, in some designs the control systems are now electronically operated instead of using direct acting valves.

However, as highlighted in the WP2 Cost Model Methodology and Analysis, there is still significant variation in the units being requested and supplied. The Advanced DHC Review highlights that opportunities given by miniaturisation and pre-fabrication to standardise such units have not been embraced by the DH community (internationally, as well as the UK). This provides an opportunity to reduce capital cost. For greater cost reductions, given that the UK operates in a global marketplace, it would be better for such standardised specifications to be agreed at an international level, and not just in the UK to maximise the benefits of volume production. Different control strategies may be necessary to handle differences in schemes related both to the DH network and the connected buildings.

13.6 Improved Measurement and Control Systems

In recent years there has been a trend towards more intelligent HIUs and sub-stations to improve operation and lower return temperatures. The required heat flow is calculated and governed rather than regulated based on feedback control. By measuring temperatures and flows in the sub-station, the required flow is continuously computed. The result is a smoother control that can reduce the energy usage by avoiding overheating. The Advanced DHC Review provides further methods for more efficient operation for an individual building or group of buildings that could be implemented.

With good communication between substations, coordinated control approaches can deliver greater energy and financial savings. To reduce the overall heat usage in general and, in particular during high-load periods, load-balancing methods could be employed where sub-stations are co-ordinated to switch off, or set to reduce their power transfer, during limited periods of time in order to limit their overall usage. The energy must be returned to maintain balance in such a way to avoid creating a new peak e.g. increase the heat supply during a period of lower heat demand. Energy demand management technology and expertise exists today and has been research and applied in other sectors e.g. the electricity industry [54, 55].

A large DH system can include many thousands of HIUs and sub-stations. Faults in components, such as flow meters or temperature sensors, will be relatively common given the nature of the components and the number of HIUs and sub-stations. The Advanced DHC Review highlights that Fault Detection and Diagnosis (FDD) is an active field of research both in general and in the heating of buildings [56, 57, 58, 59].

Whilst this discussion has focussed on the HIU and substation, there is clearly opportunity for real time monitoring of many wider aspects of the performance of the network and the DH system as a whole, with this information being fed into a model of the system allowing real-time adjustment of key parameters. The ability and functionality is anticipated to increase over time. Several of the current DECC funded Small Business Research Initiative (SBRI) projects around district heat networks are looking at using sophisticated data gathering to optimise DH systems.

Whilst, in general, this work appears to focus on reducing the operational costs, it would be expected that the learning will aid future improved design which may lead to lower capital cost as well. For example, if loads and diversities are better understood, network size can be optimised driving down pipe sizes, civils costs and connection costs. Ideally, information is shared across DH professionals to benefit the DH community as a whole.

13.7 Heat Emitters

The heat emitters (e.g. radiators) in buildings are not part of the district heat network per se. However, it is important that they work well with a district heating system such that the occupants are thermally comfortable. Hence, it is worth noting that Advanced DHC Review discusses current research on radiators. This includes reference to a new radiator control method based on the control of both the supply temperature and flow rate in the radiator system which aims to continually adapt to provide the lowest possible return temperature [60]. There is also the suggestion that existing radiators could function effectively at lower supply temperatures through the use of increased means of convection (e.g. through the use of retrofitting of radiator fans) [61,62].

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[54] http://innovation.ukpowernetworks.co.uk/innovation/en/research-area/demand-side-response/
[55] https://www.flexitricity.com/en-gb/solutions/dnos/
[56] Isermann, R. (2006). Fault-diagnosis systems – An introduction from fault detection to fault tolerance. Springer, Berlin/Heidelberg, 475 p.
[57] Isermann, R. (2011). Fault-diagnosis applications. Springer, Berlin/Heidelberg, 354 p.
[58] Katipamula, S. and Brambely, M.R. (2005). Methods for fault detection, diagnostics, and prognostics for building systems – a review, part I. Int. J. HVAC&R Res. 11 (1), 3-25
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[60] Lauenburg, P. and Wollerstran, J. (2014). Adaptive control of radiator systems for a lowest possible district heating return temperature. Energy Build. 72, 132-140.
[61] Johansson, P-O. (2011). Buildings and District Heating – Contributions to development and assessments of efficient technology, Doctoral Thesis, Lund University.
[62] Ploskic, A. (2013). Technical solutions for low-temperature heat emission in buildings. Doctoral Thesis. KTH Royal Institute of Technology, Stockholm.

13.8 DECC Small Business Research Initiative

In 2015 DECC funded a number of research projects in the field of district heating. Several feasibility studies were funded and some of these ideas were taken forward into demonstration projects. A number of these were focused on developing renewable heat sources but some were aimed at improving control and operation of systems. The latter contain ideas that could be pursued within this project in the area of system design architecture.

13.9 Summary

In summary, the key learning points from this section are as follows.

- Lower temperature networks: There is considerable interest internationally in a move to what is termed "4th Generation District Heating (4GDH)", where district heating systems operate at significantly lower temperatures e.g. supply and return temperatures of 50°C and 20°C respectively. This has the advantage of allowing the use of a wide range of low-carbon heat sources and significantly reducing heat losses. It may also have the potential to reduce capital costs through the greater use of plastic pipes and direct connection of heating systems.
- Civil engineering and installation of pipework: Research is presented around opportunities to make trenches narrower or shallower to reduce the volume of excavation required – noting particularly limitations to shallower burial in more urban areas given potential underground obstacles. Research is also presented on the opportunity to make cost savings from reusing excavated existing soil as backfill by not needing to buy and transport large quantities of gravel material as well as not paying landfill costs which are particularly high in London. Reductions in the capital costs for construction works have been estimated as being between 10 and 20% albeit such savings may be limited where there is a lack of space for stock-piling excavation soil on-site and thus the necessity for some level of transportation and storage. It would be expected that with advances in trenchless technologies and practices tailored for use with DHN, the use of trenchless drilling will increase – however further work is necessary to better understand and generate solutions to maximise its potential given relatively high current costs as well as increased risks compared to open-trench digging. It is noted also that civil engineering costs can be reduced through better planning by placing ducts in key new infrastructure roads/works where there are DH schemes planned for at a later date.
- Non-invasive techniques to identify underground objects: There are multiple techniques to identify underground objects and these are being implemented into the latest products available. Indeed, some multi-sensor products are available to complement the strengths and weaknesses of individual techniques. Given the cost of such techniques, and limits of accuracy from previous generation of equipment, they are particularly used on high risk projects and/or where a client has particularly specified their use. This is an area where contractor's factor in risk within tender pricing and more accurate information on buried services together with 3-D modelling would reduce these risk margins.
- Piping technologies and connections: Plastic pipes have advantages over traditional steel, such as greater flexibility to go around underground objects, and can reduce installation costs. However, they cannot carry as high pressure or supply temperature as regular steel pipes. Hence, plastic pipework currently has limited usage. The literature review highlighted early research in improving the thermal stability of plastic piping at temperatures traditionally used in city-wide district heating schemes (up to 120°C) – albeit it is questioned whether such solutions will be viable in the longer

term given that highly processed plastics are not intrinsically cheap unlike their more basic alternatives and the expectation of further lower temperature networks which would support current plastics such as cross-linked polyethylene (PEX). Joints are a potential weak link of a DH pipe system and are fairly sophisticated constructions, with high demands on workmanship. Advanced research on the design of joints for steel pipes appears to be limited and not a topic of great interest in the academic literature. Mechanical coupling connectors already exist for plastic pipes, which results in quicker and less expensive installation work. Incremental progress is being made to thermal insulation – a limiting factor for achieving a step change is likely to be the production cost given that polyurethane (PUR) foam insulation is seen as an excellent thermal insulator, inexpensive and quick to produce.

- Hydraulic Interface Units (HIUs) and Substations: As highlighted in the Part C of this Deliverable, there is significant variation in the units being requested and supplied. There is opportunity for cost reduction through standardisation and assembly-line produced units. Such standardised specifications would ideally be agreed at an international level to achieve greatest economies of scale.
- Improved measurement and control: In recent years there has been a trend towards more intelligent HIUs and sub-stations to improve operation and lower return temperatures and this is expected to continue. Furthermore, it is envisaged that with good communication between substations, coordinated control approaches can deliver greater energy and financial savings e.g. demand-side control of energy usage during periods of peak demand. A large DH system can include many thousands of HIUs and sub-stations. Faults in components are relatively common given the nature of the components and the number of HIUs and sub-stations, and an active field of research is fault detection and diagnosis (FDD). Finally, there is a more general opportunity for real time monitoring of many wider aspects of the performance of the network and the DH system as a whole, with this information being fed back to continually adjust and optimise the system. Whilst, in general, this work appears to focus on reducing the operational costs, it would be expected that the learning will aid future improved design especially to manage peak demands which would lead to lower capital costs as well.

Part C - Work Package 2: Cost Model Methodology and Analysis

14 Introduction

14.1 Overview

This Part of the Deliverable forms part of Work Package 2. It describes the methodology underpinning the cost model, and presents cost results and analysis for current district heating systems constructed in the UK.

There are two key purposes in creating the cost model:

(i) To help identify the most significant cost components to focus on in subsequent stages of this project.

To achieve this, the cost estimates need to be sufficiently accurate and detailed to give confidence that the potential areas for significant cost savings have been identified. However, there is a limit to the precision necessary, particularly for those components of lowest cost.

Furthermore, district heating projects are not standardised and the breakdown of costs between projects can vary significantly. Hence, it is important to undertake sensitivity analysis of the results of the cost model to ensure that the most significant cost components are captured for different project scenarios. In particular, as seen later, a number of local heat networks designed for different building typologies have been separately evaluated.

(ii) To define a cost baseline to assess the impact of possible innovative solutions on reducing costs.

The cost breakdown needs to be sufficiently granular to assess the impact of innovations. There needs to be a balance here as the innovative solutions are not known in advance. For example, there are many hundreds of components and activities involved in the construction of district heat networks and it is unknown at the outset of the project which of these will be targeted during solution development. Hence, it is expected that the cost model may become more granular in areas of most interest during latter stages of the project.

The cost model needs to be flexible, such that new innovative components can be introduced as the project progresses to assess their impact on capital and lifecycle costs.

In practice, as noted above, baseline costs do vary significantly by project e.g. civil engineering costs are very dependent on ground conditions, other utilities and surface reinstatement requirements. For this project, it is not necessary or practical to have a distinct baseline model for each of the many scenarios for a DH system. It is more important to understand the cause of the variability in cost and the underpinning cost drivers for consideration in solution development stages.

As agreed with the ETI, the focus of the model is on the capital cost of the district heat network itself. Hence, this is where the Project Team have focussed their efforts. However, the intention is also to reduce the operating costs of the district heat network and avoid the risk of reductions in capital and operational costs in the heat network being offset by increased costs elsewhere in the system. Hence, the Project Team has agreed to include within the cost model an assessment of the capital and operational costs of the whole district heating system i.e. including the Energy Centre. These latter costs are more approximate and less granular than the capital costs for the district heat network.

The spreadsheet based cost model developed for this project comprises two main components:

- Heat network design: This specifies the various elements which make up a heat network.
- Heat network costing: This takes the heat network designs and provides a detailed cost breakdown estimate.

The combination of these two elements allows a detailed understanding of the cost breakdown for different heat network designs, and therefore where the greatest costs currently reside. Within this report, the methodology is initially presented, followed by the results from the model and cost analysis to evaluate the most significant cost components.

14.2 Heat Network Design

Specific heat network designs were used as the basis for the costing exercise and represent the types of networks which may be developed across suitable areas of the UK. By basing the costing on specific designs, the range of components, installation requirements, and other cost elements can be identified and quantified. This also allows sensitivity analysis of the most significant cost components across different network designs.

The principle aim of this study is to identify where innovation can best be used to reduce capital costs of heat networks, and not to optimise a particular design. The designs in the model are based on current typical design practice, using available technologies and methods. This means that any cost reduction will arise as a result of adopting best international practice, employing state-of-the-art technologies and processes being introduced into the market as well as introducing more innovative approaches and improved design approaches.

The designs of the heat networks are based around five building typologies. These building typologies represent typical building types found across the UK and which represent a large proportion of the potential heat network market. The typologies are based on analysis of actual locations in the UK so that the representative characteristics can be taken into account. These typologies can be aggregated to represent larger areas made up of different building types.

14.3 Heat Network Costing

The heat network cost model takes the design information to produce a detailed broken down cost estimate of the networks. This is driven by a number of cost databases which describe all of the various components and installation requirements associated with developing a heat network.

The cost model also calculates lifecycle costs by using a discounted cash flow model. Whilst the emphasis of this study is on capital investment reduction potential, the lifecycle costs need to be considered to ensure that innovation in reducing capital costs does not result in higher lifecycle costs, or that it might provide a lifecycle cost benefit. As an example, a cost reduction innovation could be to use cheaper insulation on pipes, but this would be offset by increased heat losses from the network.

The cost model also considers development stage costs which cover items required before investment in the installation of the network. These include items such as design fees, surveys, legal and commercial fees, and feasibility studies. Whilst the cost for these elements is relatively small in comparison with the capital investment, their up-front nature prior to project approval means that they are a high risk and can often form a significant barrier to networks being brought forward. Based on the prioritisation agreed in WP1, the study should not focus on investigating solutions to reduce these costs, but it is important to identify where innovation may impact on these costs. For example, an innovation resulting in standardised components and networks could reduce the design costs. However, to reduce the capital cost of the civil engineering, one solution may be to put a greater emphasis on improved design or better surveys and route proving.

15 Scope of analysis

15.1 Overview

Heat networks can form complex items of infrastructure linking a number of energy sources to many customers. It is therefore important to define which parts of the infrastructure are included in the analysis and which are excluded. This section provides a description of the scope of the analysis split into three main elements:

- Core. These are items central to the analysis and included as direct costs in the modelling.
- Secondary. These are items which are not of central importance but which may be impacted by the design of networks and innovation in the design, installation, and components.
- Marginal. These are items which may be partially influenced by the network costs and innovation, but which are likely to be more influenced by other factors.

The following sections describe these in more detail.

15.2 Cost Elements

15.2.1 Core elements

The definition of the heat network components on which this study is based can be defined as:

“all elements of a heat network from the output of the heat source to the output of the final customer interface unit”

The following components are therefore included in this study:

- All heat network pipework, both above ground and below ground including junctions and valves
- Internal pipework where required to distribute heat within a building to final customer connections (for example, in a block of flats)
- Individual customer heat interface units at the final point of supply
- Heat substations (for example in a multi-customer block or commercial building)
- Water treatment equipment
- Pumping equipment
- Leak detection system
- Control system

Thermal stores are excluded from the baseline heat network costs, since these are more closely aligned in terms of capacity and operation with the heat source and the operation regime of the heat source. However, if the need for additional thermal storage arises as a consequence of innovative approaches to heat network design and construction, the relevant costs will need to be accounted for.

15.2.2 Secondary elements

There are a number of elements which may be impacted by the design of the core heat network (described above), but which are not included in the core elements. They are therefore considered as secondary elements since any impact needs to be considered in the overall cost model, but it is not of central importance.

Secondary items may include:

- Customer heating systems. Innovation in heat networks could result in modifications or replacement of existing customer systems. An example is where heat networks operate at lower temperatures, and customers require larger heating emitters.
- Heat sources. Innovation in heat network design may have an impact on the heat source and associated thermal storage, and the physical energy centre building.
- Plant and capital equipment. Innovation in heat network installation may require new forms of plant to be developed. These may provide cost reduction in civils works, but require additional investment in terms of development and manufacture. For example, tunnelling may reduce installation time and disruption, but requires the use of a tunnelling machine.
- Exceptional and indirect costs. It is likely that many networks will have highly specific costs which may be regarded as exceptional or indirect. An example may be the construction of a tunnel or pipe bridge to cross a railway.

It will be important that the analysis identifies these secondary elements, especially where the costs are likely to be significant. These costs will be considered outside of the core cost model and at a high level such that their significance can be understood and accounted for based on any impact by changes in the core heat network design.

15.2.3 Marginal elements

Marginal elements can be considered as those on the periphery of heat network costs and design. They are factors which could both influence the cost of heat networks, and which may be influenced by heat network innovation. However they are sufficiently disconnected, and more heavily influenced by other factors, such that they are considered marginal. These will not be explicitly costed for in the project.

Examples include:

- Central or local government policy. The lack of supportive policy and regulation has often been identified as a barrier to heat networks in the UK. The development of suitable policy could help support heat network development, and effectively reduce the risk cost often allocated to schemes.
- Procurement models. There are a large number of procurement models available, and the immature UK market often means that a large amount of effort and resources are required to proceed through the procurement process. The development of standardised procurement processes could help reduce the cost of delivering networks and reduce the early stage barriers.
- Financing. Investment in heat networks can provide a long term return which limits the sources of potential funding. Improving the availability of funding could help reduce this barrier and increase the number of networks proceeding.
- New build schemes. The largest potential for heat networks in the UK lies in the existing building sector. This represents the greatest proportion of buildings and includes the least thermally efficient buildings. The focus of the study is therefore on

the existing and not the new build sector. However any cost reductions achieved though innovation may also be applicable to the new build sector. Currently much of the heat network construction at least at a small-scale is in the new build sector and although the learning from this work will be captured through stakeholder meetings it is recognised that supplying existing buildings will offer different challenges.

15.2.4 Grouping of costs

Within the analysis that follows the costs are grouped as identified in this section, and set out in the diagram below.

The category ‘connections’ includes the cost of the Hydraulic Interface Unit (HIU) and pipes within the building.

The category ‘pipes’ includes the cost of the pipes and their installation to the wall of the building, and so including the heat main and the link to the customer. The category ‘civils’ covers the works needed to dig the trenches and reinstate afterwards, including works in the street, pavement and gardens if any. The diagram below shows a terraced street, but the same principles apply to all cases.

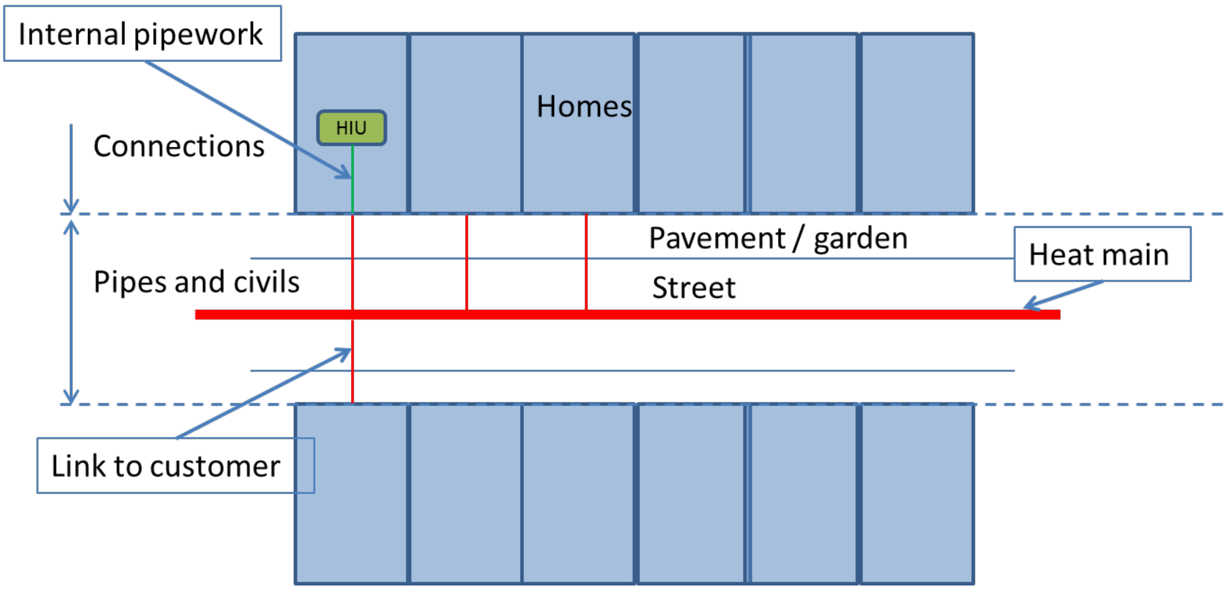


Figure 9: Schematic of street layout to show where different elements are costed

16 Typologies

16.1 Overview

This section provides information on the building typologies selected to form the basic building blocks of the model and how these are incorporated into the network design. A typology represents an area and includes the local distribution network and a number of similar or identical customers.

The five building typologies selected are:

- City Centre - commercial / institutional non-domestic buildings
- High density residential – flats
- High density residential – terraced housing
- Medium density residential – semi-detached housing
- Low density residential – semi-detached / detached housing

These building typologies have been selected for the following reasons:

- They represent a significant proportion of the potential heat demand in areas which may be suitable for heat networks, and therefore provide a useful basis for understanding the cost reduction potential for heat networks.
- They exhibit particular characteristics in relation to heat network design, so that alternative design measures and systems can be explored. For example, semi-detached housing and detached housing differ in that shared connections could be used in the former, but not the latter.

16.2 Defining Networks

16.2.1 Overview

Typologies are used as the basis of the cost model to assess how innovation may be used to reduce heat network costs, and what the overall cost impact is. To do this, the model allows the construction of networks using the following inputs:

- Specification of local distribution networks, each comprising the configuration of buildings of a single typology.
- Specification of wider primary network between the energy centre and one or more local distribution networks.
- One-off costs to reflect specific situations (such as crossing a railway)

The aim of this process is not to model a specific area of the UK in detail resulting in an accurate heat network design, but to represent typical areas so that the impact of the various types of cost reduction can be assessed in a realistic fashion for various heat network designs.

The concept of the complete network is shown in the schematic in Figure 10. The schematic shows:

- Five local distribution networks each based around one of the five typologies identified above.
- The primary network which links together the five local networks to the heat source at the energy centre (EC).
- A railway crossing.

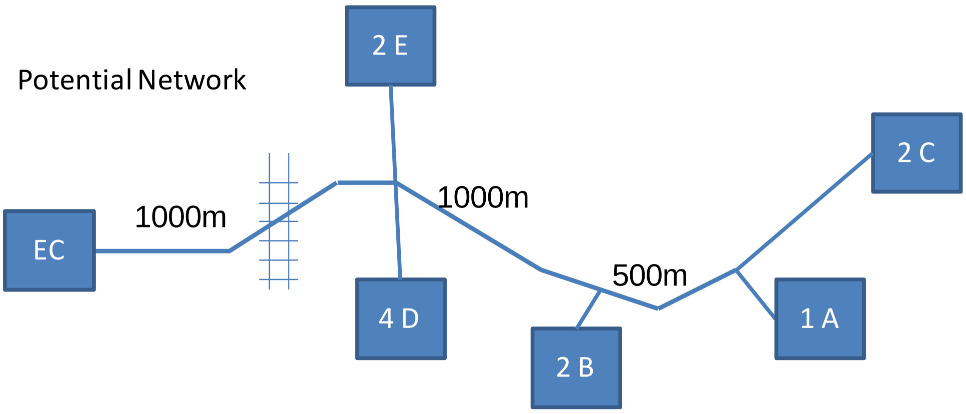


Figure 10: Schematic showing network construction concept for the cost model

16.2.2 Modelling typologies

The typologies are described later in this section and each typology is defined by a number of metrics which determine the network sizing and length. A typology is based around a standard "block" which represents a sample area and, in the case of housing, this will be limited to a set number of houses. A simple hydraulic model is used within the network typology calculator[63] (see 18.4.2) to simulate the local distribution network and provide pipe diameters.

Where an area to be modelled is larger than the limit set for a typology (for example, 500 terraced houses rather than 200), then it is assumed that two of the same typologies are neighbouring each other, with a section of primary pipework used to connect the two. This means that the basic network design and hierarchy for each typology area is unchanged.

16.2.3 Modelling the primary network

The primary network links together the different geographic areas represented by the typologies. A hierarchy of pipework is defined based around the location of each typology connection and the heat source, and then a simple hydraulic model is used to calculate the pipe diameters.

Each typology area acts as a point load based on the diversified peak demand of its individual heat customers.

[63] AECOM's network typology calculator is a pre-existing AECOM tool that it used to size pipework

16.3 Typology A: City Centre - Commercial / Institutional

16.3.1 Description

This typology is used to represent a broad range of non-domestic areas where heat networks may be developed. There are no “standard” non-domestic building types or area types, and therefore the metrics used to describe this typology are correspondingly broad. However the broad characteristics are that the buildings are reasonably large with a single connection point associated with each. Examples could include commercial offices, public sector buildings, hotels, large retail stores or complexes, etc.

This typology represents the typical locations where heat networks are currently used in the UK, or where feasibility studies (such as those commissioned under the Heat Networks Delivery Unit – HNDU) are being conducted. It is considered one of the more economically viable typologies due to the high heat density, large customers, and ability to coordinate a relatively small number of potential customers. Public sector involvement in both delivery and heat customer is also a common feature, with local authority offices, hospitals, and universities often featuring as they may be able to sign a long-term heat supply agreement to underpin the financing of the scheme. It is evident that every specific project would be different, but the basic principles would apply in most cases.

16.3.2 Example areas

These areas can be found in the commercial centres of most large UK towns and cities. For this study, Manchester City Centre Civic Quarter is used as the basis for a typology, based on a feasibility study conducted by AECOM. A schematic of the network is shown in Figure 11. Customers include the Manchester Town Hall, Central Library, Manchester Central (a conference centre), the Midland Hotel, Bridgewater Hall (concert hall), Art gallery, a new office block (St Peters Square), and Heron House (an office block used by the City Council). The scheme also includes a crossing of the tramway which requires major civil construction works.

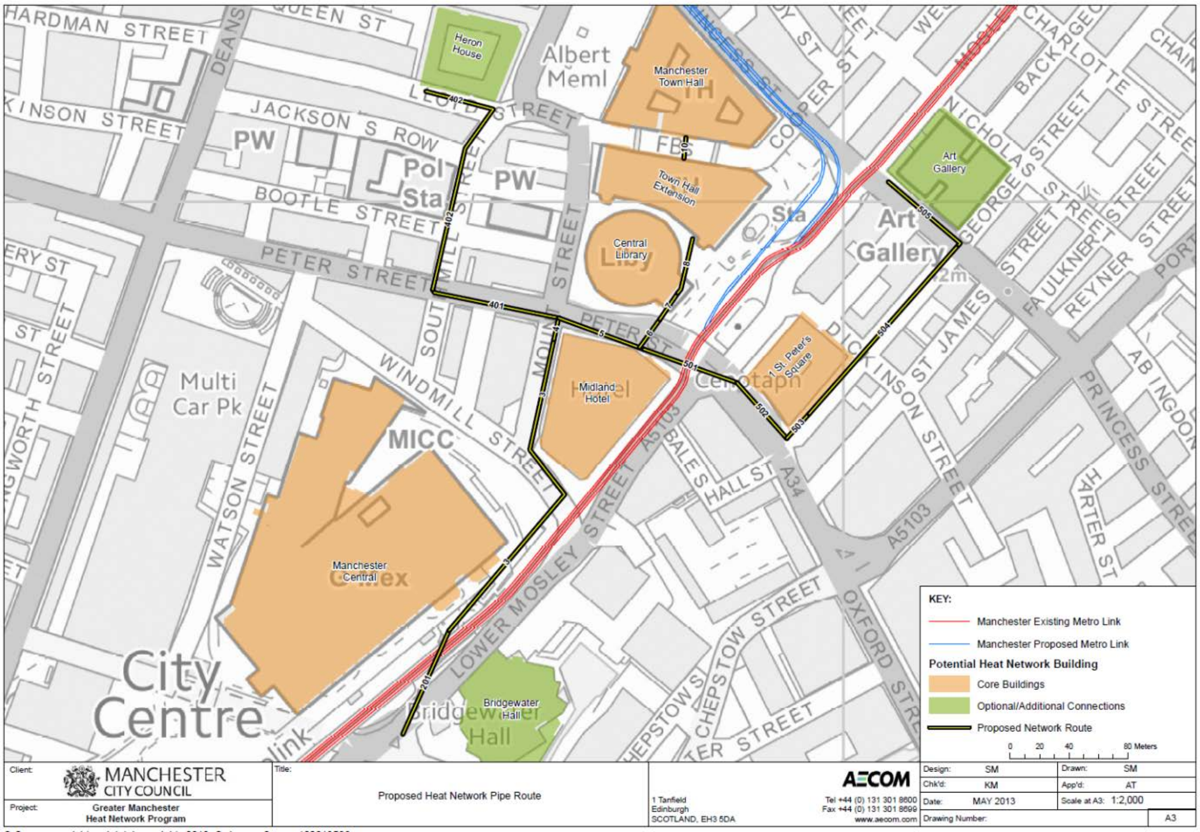


Figure 11: Schematic of Manchester Civic Quarter Heat Network (CQHN).

16.3.3 Potential variants

Due to the generic nature of this typology, there are no specific variants. However the following variations could be investigated:

- Density and spacing
- Road vs non-road (soft ground) installation

16.3.4 National importance

This form of heat network could be developed in most large towns and cities in the UK as there is normally a concentration of large public sector and commercial buildings in the central business district.

16.3.5 Typology specific metrics

The linear heat density of the network is a useful indicator of the nature of an area, and is the only metric used for this typology, as each scheme is bespoke and varies greatly from scheme to scheme. The linear heat densities for all typologies are presented in section 16.8.1. Manchester Civic Quarter Heat Network (CQHN) has been modelled in the tool as a "typical" viable scheme.

It is assumed that all customers have a single bulk supply point per each building to an existing plant room equipped with a heat exchanger, and that any internal building distribution is through the existing internal building system.

16.4 Typology B: High Density Residential – Flats

16.4.1 Description

This typology represents higher density flats, often found in town and city centres. They fall into two main types:

- High rise. Often with a common core to each building with a number of flats on each floor. In some areas, the blocks of flats are often widely spaced with landscaped areas between, as common in the 1960s / 70s developments. However they can also be closely spaced.
- Medium rise. Typical of the mansion-type blocks found around London, or newer medium rise developments. The buildings often have more than one core.

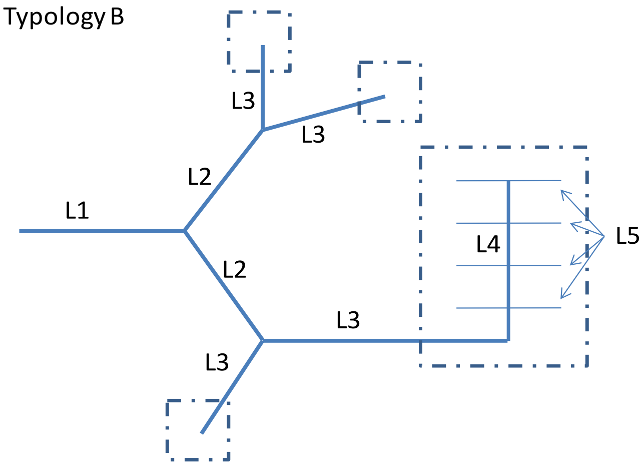
16.4.2 Example areas

There are many examples of high and medium rise flats around the UK.

- Examples of high rise include the Birmingham Newtown area, and Aberdeen (which are connected to a heat network).
- Medium rise flats can be found in most towns and cities, and are typified by the London mansion block, but, also in lower density areas with greater spacing.

Figure 12: Examples of high rise flats.

Figure 13 below shows an example area, and the schematic layout based on this area.



Level Descriptions:

L1 = Main pipe from wider DN

L2 = 1st Branch

L3 = 2nd Branch

L4 = Risers

L5 = Laterals

Default Branch Length Calculation Rules/Assumptions:

L1 = User input from wider scheme

L2 = User input

L3 = User input – average distance from L3 pipe to centre of flat block

L4 = Given by (Avg. # Risers) x (Avg. # Storeys) x (Avg. Storey Height) x (# Flat Blocks)

L5 = Given by (Width of unit) x (# Storeys) x [(# Units per floor) – (# Risers)] x (# Flat Blocks)

Figure 13: Example area and network schematic used for typology B.

16.4.3 Potential variants

This typology will be used for modelling all forms of purpose-built multi-residential buildings. The metrics used allow the following variants to be simulated:

- Height of building (eg high rise vs low rise)
- Density and spacing
- Bulk supply and secondary system versus single system.
- Direct and indirect customer connections.
- Internal pipework layouts (laterals vs risers)

16.4.4 National importance

According to previous analysis for the ETI, flats account for around 18% of residential CO_2 emissions, although this covers all forms, and the higher density flats which are of interest for this typology will be a smaller percentage [64]. They are of importance in the context of heat network viability because:

- They are often of sufficient density to enable heat networks to be viable
- They can be difficult to retrofit with individual dwelling low carbon systems
- There is often a high proportion of social tenants in high density flats and fuel poverty can be a driver for improvement

16.4.5 Typology specific metrics

The selected typology metrics, and typical values based on the area shown in Figure 13 are given in Table 6 below.

Table 6: Typology B metrics used for baseline modelling.

Metric	Value
Number of flat blocks	4 blocks
Average number of units per block	64 dwellings
Average distance from the centre of the block to connection (L3 distance)	30 m
Average number of storeys	8 storeys
Storey height	3 m
Number of risers	2 per block
Average unit width	6 m
Internal pipework length per unit	6 m

[64] The CO_2 emissions data is taken from the ETI Thermal Efficiency Project - Stock Types, 2010. The data in this report is based on analysis of the English House Condition Survey and the English Housing Survey, and conducted by the BRE.

Each individual unit has an HIU for instantaneous Domestic Hot Water (DHW) and space heating. A main heat substation is also provided for each block to provide separation between the primary network and internal distribution systems.

The assumption for the flats is that they are not electrically heated but have some form of wet heating system in place, risers run within the building and no substantial works would need to be carried out within the flats for the installation of district heating.

16.5 Typology C: High Density Residential – Terraced

16.5.1 Description

Terraced housing is characterised by long runs of identical homes, often with a regular grid pattern. The majority date from pre 1919 and were built to house workers across the UK through the industrial revolution. However there are a range of forms, and whilst small terraced homes are often considered the predominant type, large terraces can also be found (especially in large cities including London) dating from the Georgian era and Victorian era. These are often split into converted flats by floor.

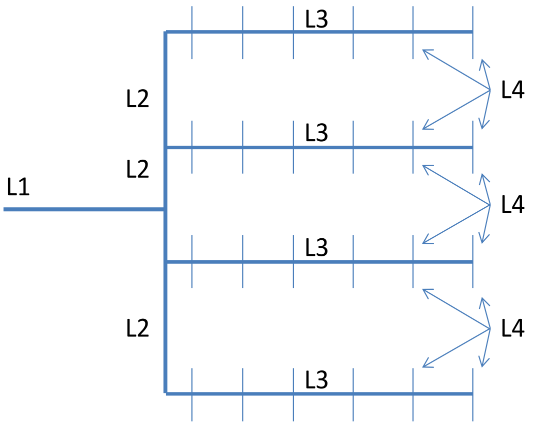
16.5.2 Example areas

Terraced housing can be found in all towns and cities across the UK.

Figure 14: Examples of terraced housing demonstrating variability.

Figure 15 below shows an example area, and the schematic layout based on this area.

Typology C



Level Descriptions:

L1 = Main pipe from wider DN

L2 = 1st branch (spacing between L3)

L3 = 2nd branch (serving residential terraced street)

L4 = Street to Unit(s) – this level can serve individual units or multiple units

L5 = Internal pipework (either for an individual unit, or connecting a series of units depending on the L4 connection)

Default Branch Length Calculation Rules/Assumptions:

L1 = Assume as 1 branch spacing (can be edited to reflect actual scheme)

L2 = User Input – Terraced Street Spacing. Number of L2 lengths given by (Total Unit #)/(2 x Unit # per L3 branch)

L3 = Given by (Pipe length per unit [USER INPUT]) x (Total Unit #)

L4 = Given by (Centre of road to edge of unit [USER INPUT]) * (Unit # per L4 branch)

L5 = [(Unit # per L4 branch minus 1)/(Unit # per L4 branch)]*(Unit width [USER INPUT])*(Total Unit #)

Figure 15: Example area and network schematic used for typology C

16.5.3 Potential variants

Potential variants covered by this typology include:

- 2 / 3 storey single customer terraces
- Large multi-customer terraces which have been split into flats or commercial premises
- Different house widths, street widths and setback from the street

16.5.4 National importance

Terraced housing represents around 30% of UK housing CO_2 emissions, and pre-1919 mid terraced homes are the largest housing category in the UK representing around 11.2% of residential CO_2 emissions (assuming the inclusion of pre 1919 end terraces).

Terraced housing presents an important target customer type for district heating:

- It represents a large proportion of UK housing CO_2 emissions
- It is often 'hard-to-treat' with solid walls.
- It is predominantly high density and in towns and cities, and therefore one of the more cost effective non-flat typologies
- The contiguous nature of buildings could provide opportunities for innovation in heat distribution

16.5.5 Typology specific metrics

The selected typology metrics, and typical values based on area shown above, are given in Table 7 below.

Table 7: Typology C metrics used for baseline modelling

Metric	Value
Pipe length per dwelling (L3 level) Assuming dwellings on both sides of the road	2.5 m
Branch separation average (L3 level)	60 m
Centre of the road to the dwelling site boundary	6 m
Dwelling site boundary to building	0 m (i.e. no front garden)
Width of dwelling frontage (average plot width)	4.1 m
Internal pipework length	6 m

Each dwelling is assumed to have a separate pipe connection to the street branch, and is equipped with an HIU for instantaneous DHW and space heating.

16.6 Typology D: Medium Density Residential – Semi Detached

16.6.1 Description

Semi-detached housing is the second most common housing format in the UK, and found across many towns and cities. It perhaps best typifies suburbia and the rapid expansion of towns and cities in the inter-war period.

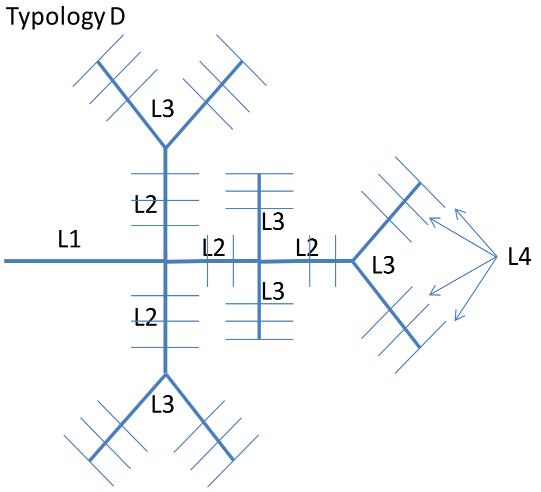
Semi-detached homes mostly date from the interwar and post war periods, although the format dates from late Victorian times as a mass-market design.

16.6.2 Example areas

There are many examples of semi-detached housing across the UK.

Figure 16: Examples of semi-detached housing demonstrating variability

Figure 17 below shows an example area, and the schematic layout based on this area.



Level Descriptions:

L1 = Main pipe from wider DN

L2 = 1st branch

L3 = 2nd branch (serving residential streets)

L4 = Street to Unit(s) – this level can serve individual units or multiple units

L5 = Internal pipework (either for an individual unit, or connecting a series of units depending on the L4 connection)

Default Branch Length Calculation Rules/Assumptions:

L1 = Assume as 1 branch spacing (L2 length) (can be edited to reflect actual scheme)

L2 = User Input – Residential Street Spacing. Number of L2 lengths given by (Total Unit #)/(2 x Unit # per L3 branch)

L3 = Given by (Pipe length per unit [USER INPUT]) x (Total Unit # - Unit # served directly at L2)

L4 = Given by (Centre of road to edge of unit [USER INPUT]) * (Unit # per L4 branch)

L5 = [(Unit # per L4 branch minus 1)/(Unit # per L4 branch)]*(Unit width [USER INPUT])*(Total Unit #)

Figure 17: Example area and network schematic used for typology D

16.6.3 Potential variants

This typology will be used for modelling all forms of semi-detached housing. The metrics used allow the following variants to be simulated:

- Width of street
- Width of houses
- Separation between pairs of semis
- Setback from street
- Size of house

16.6.4 National importance

Semi-detached housing represents around 26% of the UK residential CO_2 emissions and is the largest sector after terraced housing. Interwar (1919 – 1944) and post war (1944 – 1964) periods each account for around 8% of the residential CO_2 emissions[65]. Thermal performance is unlikely to vary significantly during this period since building regulations governing thermal efficiency were introduced after this date. Around one third of the interwar semi-detached houses had solid walls, whilst the remainder are predominantly of cavity wall construction, many now with cavity wall insulation as a retrofit.

The lower density of semi-detached housing over terraced housing means that it is often viewed as a less viable typology for district heating. This is offset by the higher heat losses from gable walls and generally the larger size of the buildings. As a result, some semi-detached streets can have a higher linear heat density than terraced houses. The size of the sector means that it presents an important target if a reduction in heat network costs would enable economically viable networks in these areas.

16.6.5 Typology specific metrics

The selected typology metrics, and typical values based on area shown above, are given in Table 8 below.

Table 8: Typology D metrics used for baseline modelling

Metric	Value
Pipe length per dwelling (L2/L3 level) Assuming dwellings on both sides of the road	5.5 m
Branch separation average (L3 level)	60 m
Centre of the road to the dwelling site boundary	12 m
Dwelling site boundary to building	2.5 m
Width of dwelling frontage (average plot width)	5.75 m
Internal pipework length	6 m

[65] The CO_2 emissions data is taken from the ETI Thermal Efficiency Project - Stock Types, 2010. The data in this report is based on analysis of the English House Condition Survey and the English Housing Survey, and conducted by the BRE.

Each dwelling is assumed to have a separate pipe connection to the street branch, and is equipped with an HIU for instantaneous DHW and space heating.

16.7 Typology E: Low Density Residential – Semi / Detached

16.7.1 Description

The low density typology is predominantly made up of detached housing and semi-detached housing. This typology is often seen on the outskirts of towns and cities, and often consists of newer homes built in housing estates. Post 1965 detached housing accounts for around 11% of residential CO_2 emissions and post 1965 semi-detached a further 7.5%. There is often a mix of semi-detached and detached homes in the estates which typify large scale house building during this period.

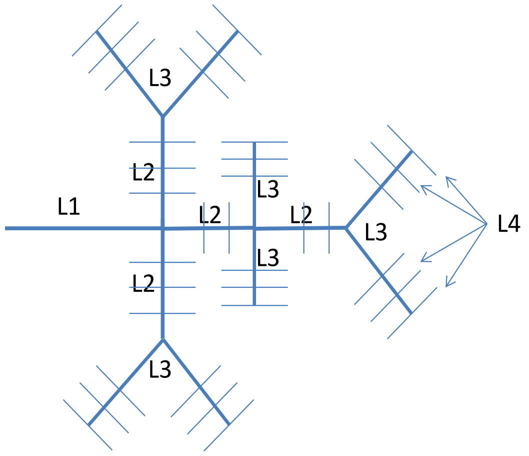
16.7.2 Example areas

There are many examples of low density estate housing across the UK.

Figure 18: Examples of detached-detached housing demonstrating variability.

Figure 19 below shows an example area, and the schematic layout based on this area

Typology E



Level Descriptions:

L1 = Main pipe from wider DN

L2 = 1st branch

L3 = 2nd branch (serving residential streets)

L4 = Street to Unit(s) – this level can serve individual units or multiple units

L5 = Internal pipework (either for an individual unit, or connecting a series of units depending on the L4 connection)

Default Branch Length Calculation Rules/Assumptions:

L1 = Assume as 1 branch spacing (L2 length) (can be edited to reflect actual scheme)

L2 = User Input – Residential Street Spacing. Number of L2 lengths given by (Total Unit #)/(2 x Unit # per L3 branch)

L3 = Given by (Pipe length per unit [USER INPUT]) x (Total Unit # - Unit # served directly at L2)

L4 = Given by (Centre of road to edge of unit [USER INPUT]) * (Unit # per L4 branch)

L5 = [(Unit # per L4 branch minus 1)/(Unit # per L4 branch)]*(Unit width [USER INPUT])*(Total Unit #)

Figure 19: Example area and network schematic used for typology E

16.7.3 Potential variants

This typology will be used for modelling all forms of low density housing, comprising semi-detached and detached housing. The metrics used allow the following variants to be simulated:

- Density and spacing: distances between the homes along the street and lengths of front gardens are the main variables

16.7.4 National importance

Post 1965 detached housing accounts for around 11% of residential CO_2 emissions and is therefore an important sector to target for emissions reductions [66]. The addition of post 1965 semi-detached housing brings this to almost 20% of UK residential emissions. The estate formats which were developed during the 1960s – 1990s are often relatively low density and with non-uniform street patterns (short streets in the form of cul de sacs) which will increase the costs of heat network connections. However there may be more opportunities to use grass verges to install pipes and a lower density of buried services making the installation easier. Later developments from the 2000s often have higher densities (due to planning

[66] The CO_2 emissions data is taken from the ETI Thermal Efficiency Project - Stock Types, 2010. The data in this report is based on analysis of the English House Condition Survey and the English Housing Survey, and conducted by the BRE.

requirements), but with complex, and often inefficient street layouts, which may also make heat network layouts more costly and inefficient.

This sector represents potentially the least viable urban typology for district heating. However the proportion of emissions means that improvements to viability through heat network cost reductions could significantly increase the national potential for heat networks.

16.7.5 Typology specific metrics

The selected typology metrics, and typical values based on area shown above, are:

Metric	Value
Pipe length per dwelling (L2/L3 level) Assuming dwellings on both sides of the road	8.2 m
Branch separation average (L3 level)	60 m
Centre of the road to the dwelling site boundary	9 m
Dwelling site boundary to building	4 m
Width of dwelling frontage, (average plot width)	9 m
Internal pipework length	6 m

Each dwelling is assumed to have a separate pipe connection to the street branch, and is equipped with an HIU for instantaneous DHW and space heating.

16.8 Primary Network

16.8.1 Description of network

A simple primary network has been defined which links up different typologies. This allows a representation of a large town centre network to be created and used for the baseline cost analysis. A schematic of an example primary network is shown in Figure 20, with the number of each typology (A to E) included, where they are connected and the Energy Centre. A railway crossing is included as something which is likely to be encountered in a typical town or city centre scheme.

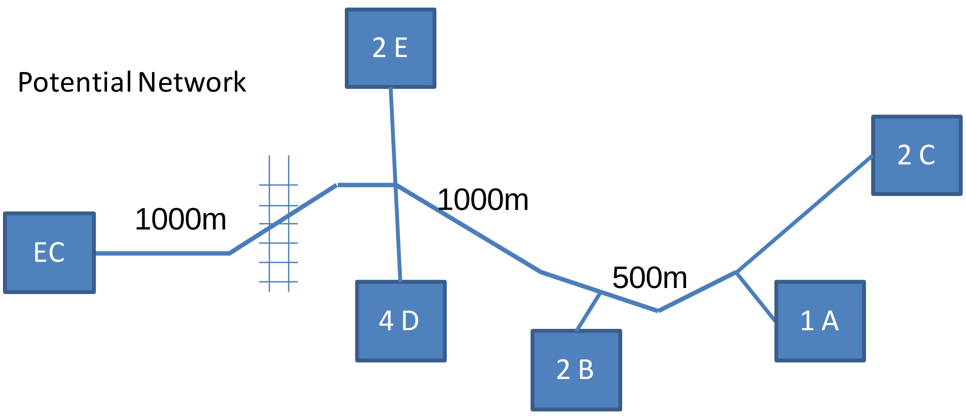


Figure 20: Schematic of primary network

For simplicity, the typologies connect to the main primary network at the same point where multiples of a typology are included. In reality, different connection points may be used (for example, where a large area of one typology is located alongside the primary network), but this approach is used to simplify the modelling and will have a negligible impact on the primary network sizing and costs.

It is evident that by changing the lengths of the connections between the typologies the resulting costs will change. However, this is not significant as the future innovations will be compared on the same basis.

Table 9 gives the linear heat densities of the different typologies and the combined network. As a rule of thumb a linear heat density over 3000 kWh/m/year is a level where systems are likely to be attractive with current costs. Only the densest typologies A and B are seen to be in this category and this aligns with current practice as these are largely the typologies where district heating is currently applied. Any area under around 1,000 kWh/m is considered to be of low heat density. Note that the detached case of Typology E is similar to Typologies C and D as, although they are further apart than the other housing types, their individual energy use is higher due to significantly greater space heating use. This will clearly not apply for a less dense area of detached housing.

Table 9: Linear heat densities of the different typologies

Typology	**Linear Heat Density (kWh/m/year)**
A	12,200
B	4,200
C	950
D	780
E	1,100
Combined	1,200

The combined share of the types of homes included in the typologies represents around 55% of the total national residential heat load. This is spread across the house types as shown in Table 10.

Table 10: House types and share of energy use across UK stock[67]

Type of home	**% of number**	**% of load**	**Typology**
Flats	15.3	8.5	B
Pre-1919 terrace	10.6	11.5	C
1919-1964 semi	15.2	15.7	D
Post 1965 detached / semi	18.8	19.1	E
Total	59.9	54.8	

[67] ETI (2011). Segmentation of UK Housing Stock, Deliverable D2.1b, ETI project - Optimising Thermal Efficiency of Existing Housing (OTEoEH)

Typology A is intended to represent reasonably large non-domestic building types located in city centres e.g. commercial offices, public sector buildings, hotels, large retail stores or complexes, etc. To provide a simple indicator of the percentage of heat load that this Typology comprises of the non-domestic building stock, the ratio of floor area of buildings of 5000m^2 or greater has been compared to the total floor area for public and commercial non-domestic buildings [68]. In doing this, the building types less likely to be present in city centres have also been excluded from the numerator only; thus the numerator includes commercial offices, education, local Government, hospital, hotel and retail categories, but excludes categories such as warehouses which are also included in the denominator. This is calculated to be approximately 60%. In practice, this is on the higher-side as some of these buildings will not be in the city-centre e.g. out of town retail. Hence, it is estimated that 30-50% as a more reasonable indicator.

16.9 Dense Villages

The English Housing Survey (2011-12) data showed that approximately 6% of dwellings in the English (not UK) housing stock sit in the category defined as "village - less sparse". The other major items are 80% in "urban >10k - less sparse" and 9% in "town and fringe - less sparse", which are currently the main focus of DH schemes.

Reviewing the housing types in the English Housing Survey associated with "villages – less sparse", it includes a large proportion of detached housing. It is therefore expected that some of these villages are therefore not dense enough to allow for DHN roll-out.

Examples of dense villages include some of the mining villages round Durham city (e.g. New Brancepeth) and round Merthyr Tydfil (e.g. Aberfan). A less dense example might be Sawbridgeworth near Harlow, whilst others are more akin to small towns than villages (e.g. Blaenavon).

Based on visual examinations using Google Earth, the denser village examples appear to have very little detached housing, being mainly terraced and semi-detached, in varying proportions. Because of this variation a notional 50:50 split of terraced:semi has been proposed to represent a dense village. This is appropriate as the denser end of these options probably represents a more appropriate target for DHN roll-out than the less dense with significant amounts of detached housing, thus providing better learning about potential roll-out.

In the work going forward dense villages are therefore modelled, for the purposes of the project, as a 50:50 mixture of terraced and semi-detached housing. This will be modelled as a separate, simplified, stand-alone typology to model capital cost of the typology (only).

Taking this work forward in the most efficient way, the dense village is being represented by a combination of 1 of Typology C (terrace) with 0.5 of Typology D (semi-detached) making a total of 200 homes of each type, and therefore 400 homes in total. This would represent a population of around 1000 people. It is noted that in doing so the assumptions of pipe size in the model are too high and would need to be reduced in practice. However, this would be a small percentage of the costs of the whole DH network for the dense village typology.

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68 http://webarchive.nationalarchives.gov.uk/20120919132719/www.communities.gov.uk/archived/publications/planningandbuilding/regulatoryimpactenergyperformanc"

17 Heat Network Design

17.1 Introduction

The heat network design model specifies the various elements which make up a heat network. The design of heat networks for the purposes of baseline costing in this study are based around the use of conventional materials and practices which are typically used currently in the UK.

17.2 Design of Typologies

Each typology is provided with an indicative network layout as presented in section 16 based on an analysis of existing areas containing that building type. This analysis includes estimates of typical branch lengths, number of dwellings in a street, and factors governing the length of connections such as set-back of buildings.

Whilst the exact layout of the networks is not important for the purposes of this project, the layout must ensure that there is sufficient pipe work to allow connection to the individual customers and be reasonably representative of real schemes. The Network Typology Calculator is used to calculate the network sizing and component requirements for each typology.

Each typology is defined by a hierarchy of pipes labelled L1 to L5 which describe each level of pipework. The incoming pipe is labelled L1 and carries the total diversified load of the typology area. The downstream branches carry the diversified heat load of customers connected directly to them, or via further downstream branches. The diameter of each branch is calculated in the network typology calculator based on typical flow rates (see section 17.5) and it is assumed that each branch has the same diameter along its length.

Connections are included in the typologies as follows:

- Individual dwellings are provided with a Hydraulic interface unit sized for instantaneous DHW and space heating.
- Blocks of flats include a heat substation for each building to provide hydraulic separation between internal and external systems. This may often be required in high rise blocks to reduce the pressure requirements on the main network through separate pressurisation of the internal building distribution system.
- Non-domestic buildings are assumed to require a heat substation sized for the building's peak heat load.

For the domestic typologies, the network typology calculator has a range of inputs based around the typology metrics, which are used to calculate the pipework requirements automatically. An automated pipe sizing routine is then used to calculate the diameters for each level of the network hierarchy.

For the non-domestic typology (A) and the primary network (denoted as typology T), the potential variability and lack of repetition in network layout means that an automated procedure is not possible. Inputs for these network layouts were therefore calculated manually and required pipework sizing to be conducted outside of the model framework.

17.3 Selection of Components and Grouping into Assemblies

Once the network layouts are defined in the network typology calculator, the components which make up the networks are selected and grouped into assemblies (see section 18.2.1 for a description of how assemblies are used). The assemblies are defined for each hierarchy of pipework (from L1 and up to L5), and other elements such as customer connections. The baseline modelling framework allows for up to 10 assemblies to be defined for each specific typology area.

17.4 Calculation of Peak Loads

17.4.1 Domestic hot water peak loads and diversity

Diversity in domestic hot water (DHW) demand is an important factor to consider when sizing the network, both within the local distribution networks, and for the primary network. Diversity reflects the fact that it is unlikely for all customers' peak DHW loads to exactly coincide, and as a result, the overall peak load is less than the sum of the individual peaks. The diversity factor is the ratio of the peak load really used versus the sum of the individual peaks. For a heat load of 1MW, a diversity factor of 0.7 means that you only need a 700 kW plant.

This study uses the Danish DS439 standard for diversity factors which is illustrated in Figure 21. This provides a reduction in peak DHW demand to around 20% for 10 homes and 10% for 50 homes. Whilst there is no formal adopted standard in the UK, standards such as DS439 are commonly used and is the approach taken in the CIBSE Code of Practice for Heat Networks.

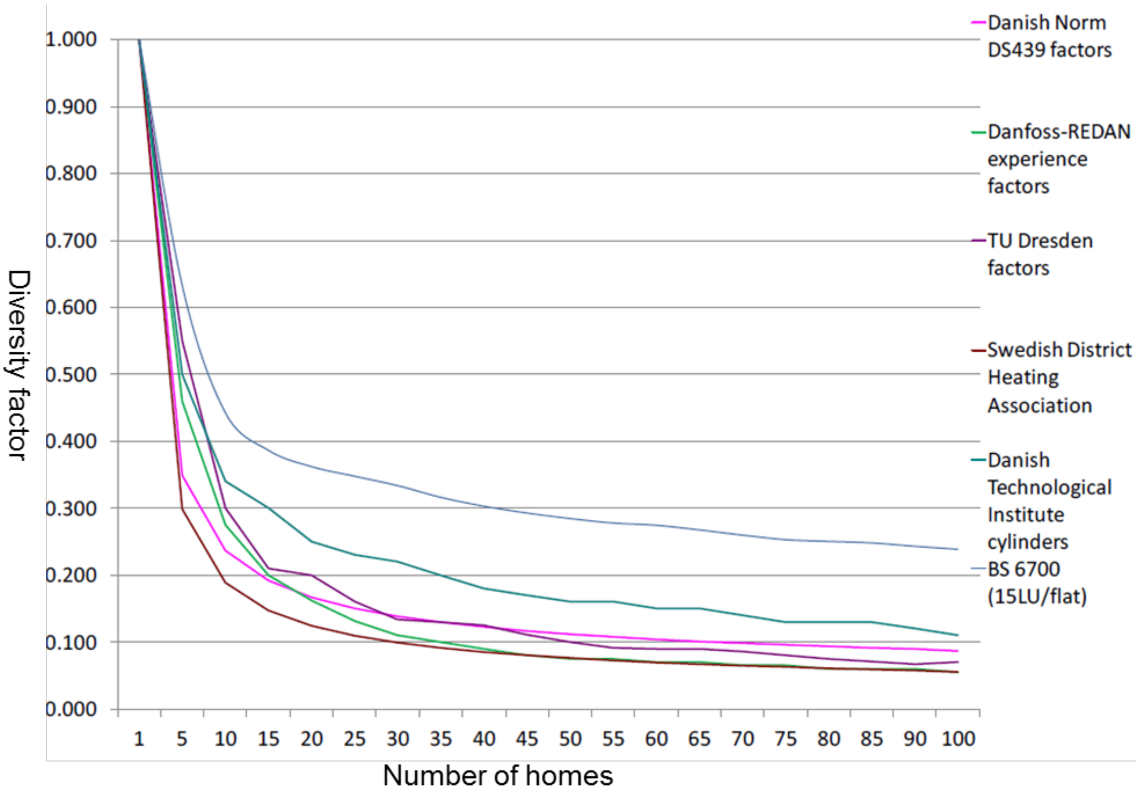


Figure 21: Instantaneous domestic hot water diversity factors (from CIBSE Code of Practice for Heat Networks – image acknowledgement to SAV Ltd).

The formula used to calculate the DHW diversity is given below:

$P_{max} = 1.19 \times N + 18.8 \times N^{0.5} + 17.6$

where N is a ‘normal’ dwelling defined as having 3.5 residents. The resulting peak load for a single dwelling is around 38 kW.

17.4.2 Space heating peak loads and diversity

Space heating demands are incurred over a longer period and so the potential for reducing the peak through diversity is much less than with DHW. To reflect the potential for some diversity in the modelling, a diversity factor of 0.9 is assumed for sections of networks connected to more than 50 dwellings. As with DHW diversity, there are no formally adopted standards, but the inclusion of a small amount of space heating diversity represents good practice.

Peak loads for dwellings are based on the peak heat loss parameter for indicative dwelling types (representing flats, terraced, semi-detached, and detached homes) modelled in the Cambridge Housing Model, and assuming a pre-heat margin factor of 1.2 [69].

17.5 Operation Parameters

17.5.1 Pipe sizing

The network typology calculator includes simple pipe sizing algorithms which calculate the pipe diameter required for each hierarchy of pipework. For the baseline heat network designs, a temperature difference (delta T) between flow and return of 30°C is assumed.

The sizing algorithm makes use of flow rates taken from the CIBSE Code of Practice for Heat Networks. The resultant pressure loss is also calculated to ensure that the pressure loss is reasonable, and for use in pumping calculations. Note that the pressure drop for the plastic pipes is a little higher than for the steel pipes primarily due to an assumed higher velocity.

[69] The Cambridge Housing Model (CHM) has been developed for the UK Government and simulates the UK housing stock using a SAP (Standard Assessment Procedure) calculation, and using data from the English Housing Survey. For this project, the defined dwelling typology datasets have been constructed from average geometry and performance values for those building types in the CHM. More information is available from https://www.gov.uk/government/statistics/cambridge-housing-model-and-user-guide.

Table 11: Summary of flow velocities and pressure loss for each pipe diameter

	Typical velocity (m/s)	Pressure drop (Pa/m)
Steel pipes diameter (mm)		
32	0.72	167
50	0.85	129
80	1.06	109
100	1.20	105
150	1.60	109
200	1.90	107
250	2.20	108
300	2.50	110
450	2.50	69
Polymer pipes diameter (mm)		
32	1.00	298
50	1.30	278
80	1.50	205

17.5.2 Pipe material selection

For the baseline network design, the following pipe selection criteria are used:

- Pipes of 50mm diameter or less: Plastic twin pipe is selected. This provides lower heat losses than single pipe for small diameters and ease of installation over steel pipe due to reduced joints and the flexibility of the pipe. The small internal diameter means that the overall twin-pipe external diameter is not excessive and trench widths can be smaller than for a single pipe solution. The heat losses used in this study assume a bonded polyurethane (PU) foam typical of good practice. The use of plastic pipework can limit the network lifetime at higher temperatures, and therefore implies that the modelled schemes will operate at temperatures of 80°C or less with higher temperatures used only at times of peak demand [70]. Current typical practice favours the use of variable flow and temperature regimes such that peak flow and temperature are only used when required in peak heating periods.

- Pipes of 80mm diameter or more: Pre-insulated single steel pipes are selected. At these larger internal diameters, single pipes have a much smaller external diameter than a twin pipe solution, and therefore are easier to manoeuvre and install. Whilst steel pipes require welded joints and come in relatively short sections (typically 6 or 12 m), they have a longer lifetime than plastic pipes and can take higher water pressures (typically up to 16 bar operational). Series 2 insulation is assumed for all pipework and fittings as per current typical practice in the UK. There are three series of insulation with different thermal performance.

[70] The network is designed to work at 90°C at peak demand. However, it will operate much of the time at temperatures of 80°C or less and thus allow plastic pipe to be used.

The use of steel pipes for larger diameters allows a greater range of temperatures and pressures to be used with an estimated lifetime of up to 50 years. This provides greater flexibility over areas of the network which are likely to be more strategic and subject to future changes in demand. Conversely there is likely to be less variation in future heat demands on smaller branches and lower pressures can be used, therefore twin plastic pipework offers benefits in terms of installation and heat losses.

17.5.3 Network layout assumptions

The network layouts assume the following:

- All layouts are based on a single main and branch structure. There are no ring mains used in the modelling.
- All customers have a single connection to the local branch. This means that every dwelling has a separate tee from the branch which runs along a street.
- Valves are included in the network layouts to allow isolation of a group of customers. For dwellings, this is typically at a street level.
- Each branch (labelled L1 to L5) has a single diameter along its length (although each branch will typically have a different diameter). An optimised network design may result in a reduction in diameter along the length of the branch, but this level of design detail is considered unnecessary for the purpose of baseline costing.

17.6 Key Summary Data

The baseline primary network model has the following key characteristics:

- 36,700 m of hard dig (roads);
- 14,300 m of soft dig (verges and front gardens);
- 9 non-residential connections;
- 3,300 Heat Interface Units (HIUs) in residential properties; and
- annual heat supplied 62,400 MWh, of which: 44,600MWh residential, 17,800MWh non-residential.

18 Heat Network Cost model

18.1 Introduction

This section provides an overview of the heat network cost model framework and calculation processes. The original plan was to use the existing ETI Infrastructure Cost Calculator (ICC) and carry out additional modelling for this work. However as the project developed it became clear that this was not operating fast enough and a more direct approach was used instead. However the approach is still based in terms of data structure on that within the ICC, and the data collected can be put into the ICC at a later date.

This chapter retains the summary of the ICC tool as it still forms the reference of the structure used.

18.2 ETI's Infrastructure Cost Calculator

The ICC tool has been developed for the ETI to provide high level cost estimates for a range of large infrastructure projects covering gas, electricity, hydrogen and heat networks. The tool comprises a large database of individual components and has flexibility for additional items to be added as needed, and for a range of projects to be simulated.

The ICC is a complex model and has associated documentation describing the functionality in detail. The following description is therefore at a high level to provide the reader with an understanding of how the model can be used in this project.

18.2.1 Structure

The ICC is constructed in Microsoft Excel and has the following basic structure:

- **Cost database**. This spreadsheet is the main 'control panel' which draws together information from each of the separate components described below, and conducts the overall cost calculations and sensitivities.
- **Component datasheets.** The model contains over 800 component datasheets. These contain information describing each individual component including a unique component name, baseline costs split into labour, materials, and plant, and cost adjustment factors to describe locality, ground conditions, and scale. All of the inputs for a component are based on a unit of measure, for example, per metre of insulated pipe.
- **Assembly datasheets.** These are used to combine one or more components into an assembly which forms a commonly understood unit. For example, an assembly could be a 100m run of buried insulated pipe. The constituent components could include pre-insulated pipe, pipe fittings and connections, and trench digging and re-instatement. Assemblies are also defined by a unit of measure.
- **Projects datasheets.** A project is constructed from one or more assemblies which describe all the elements of a system. For example a heat network may be constructed from assemblies describing different pipe sizes and assemblies describing connections to buildings.

A simple schematic of this is shown in Figure 22.

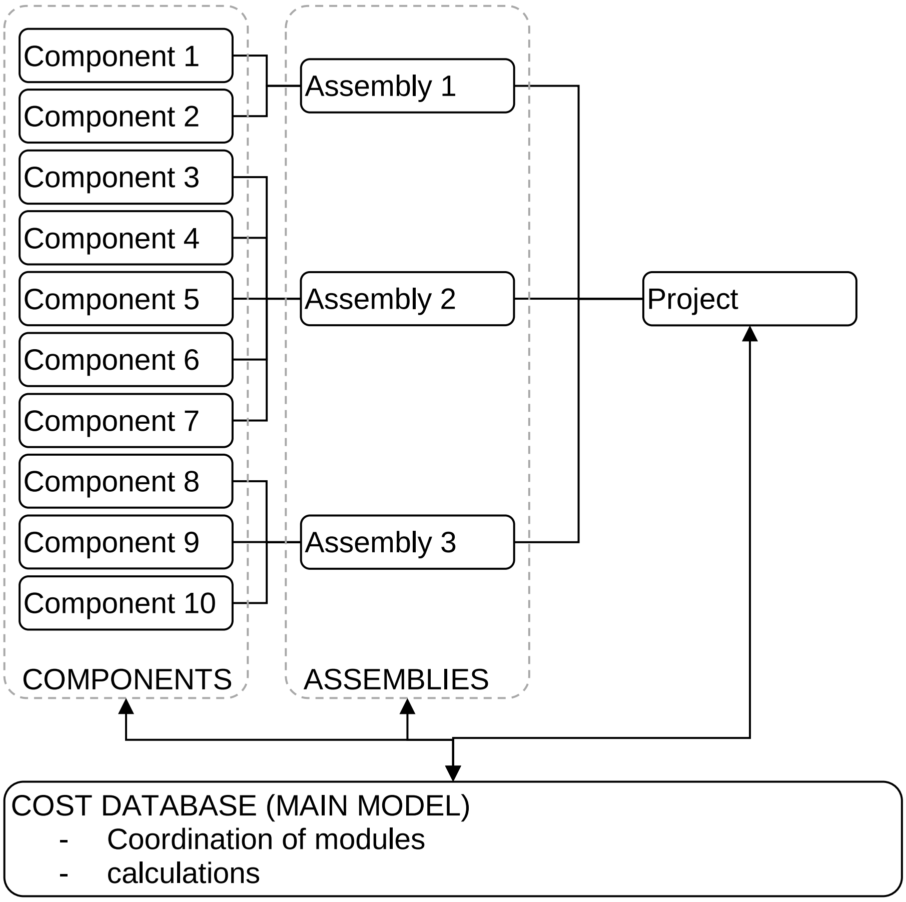


Figure 22: Basic structure of the ETI Infrastructure Cost Calculator

18.2.2 Calculations

The ICC's cost database acts as the control panel which coordinates the inputting of data into component, assembly, and project datasheets, and then extracts the relevant data to conduct the cost calculations.

Quantities of each component are calculated based on the unit of measure specified. For example with heat network pipes, a component may be per metre, an assembly a 100m length, and a project requires 1.5 km. In this case, 1,500 component units are required for the project. It is possible that the same components feature in different assemblies and therefore the total quantity needs to sum over all relevant assemblies.

Costs are calculated in a similar manner by aggregating over assemblies and projects. However the cost calculations are more complex through the use of adjustment factors to represent locality, ground conditions, and scale. For example, component 1 may have a rural installation in assembly 1 (with a reduction in baseline cost), but an urban installation in assembly 2 (with an increase in baseline cost).

During the calculation of project costs, the model uses a Monte Carlo approach to simulate the sensitivities around costs (using upper and lower bounds) to identify the probabilistic cost profile of a project. Outputs from the model include overall project costs, and also a breakdown of costs by constituent assemblies and components to identify where the main cost elements lie.

The ICC also includes inputs to describe project-wide costs such as prelims and engineering design. These are expressed as simple percentages of the overall cost value.

18.2.3 Approach taken

Early in the project it was intended to work with the ICC model. However, as the work developed it became clear that it was too slow for the purpose intended, at least with the approach planned. However the general approach in terms of data structure has been retained.

The main areas for work to meet the needs of this project were as follows:

- Inclusion of new component datasets to provide the level of detail required to interrogate heat network costs.
- Inclusion of assemblies to construct the required heat network major elements.
- Specification of projects, built around the area typologies described in this report
- Analysis of the capital cost of the network, lifecycle cost of the network, and capital and lifecycle cost of the DH system.

The new model is implemented in a single spreadsheet, which combines all the different elements to give the different outputs required. Further details of the approach used are provided in the cost model spreadsheet.

18.3 Cost Data

The ICC tool currently had high-level capital cost estimates. For the purposes of this project additional capital costs have been included in the model to enable: (i) more granular breakdown of cost data, and (ii) a wider size range of components for better tailoring to the typologies modelled.

The cost data is presented and discussed in section 19.

18.4 Modelling Framework

The framework elements are:

- Component database
- Network typology calculator
- Other capital cost inputs
- Lifecycle cost inputs
- Data extraction and analysis module

These are described in more detail in the following sections.

18.4.1 Component database

The component database is a single dataset containing all component data. This single database format allows for easy input of new component data and cross checking between components. A list and description of fields within the dataset is shown in the table below.

This structure was created to work with the ICC tool. The data structure has been retained to allow data to be transferred into the ICC tool at a later date should ETI wish to do this.

Table 12: Description of component dataset fields

Field	Description
Filename	This is used as the filename of the ICC component datasheet. It supersedes the ICC file naming convention of date and time.
Main data source	This designates the data as ETI (from the ICC) or AECOM (from this project).
Uniclass	The Uniclass allocated to each component as per the ICC data structure. Uniclass is a system linked to Building Information Modelling (BIM) and groups similar types of items together in a consistent way. It contains nested levels, for example ‘Heat networks’ – ‘Installation civils – trenching’ – ‘excavate trench for F&R 450 mm pipework’.
Description	A unique description of each component.
Unit	The unit of measure for each component as per the ICC data structure.
Base cost	Summation of the materials, labour, and plant baseline costs.
Source reference	Description of the data source.
Quality	A measure of data quality as per the ICC model.
Notes	Additional supporting information.
Site context	Cost adjustment from the baseline cost for different localities. Split into: • Sub-urban *(this replaces the ICC rural category)*. Representative of suburban areas which are of lower density, typically residential, and network installation is likely to be less constrained. Low levels of utilities congestion and traffic on roads. Some opportunities for off-road installation. • Light-urban *(this replaces the ICC semi-urban category)*. Representative of town centres and lower density city areas. Some Congestion of existing utilities and traffic on roads. • Dense-urban *(this replaces the ICC urban category)*. Representative of dense city areas with a large number of installation constraints, and congestion of existing utilities and traffic on roads.
Material costs	Cost input for materials per unit measure. Split into: • Baseline. Central cost assumption. • High. Upper bound expected in normal circumstances. Expressed as a % of the baseline. • Low. Lower bound expected in normal circumstances. Expressed as a % of the baseline. • Future cost trend. Selection of future cost trends as per ICC model. ‘Flat Price’ is selected for all modelling in the baseline cost analysis.

Labour costs	Cost inputs for labour per measure. Sub categories as per material costs.
Plant costs	Cost inputs for plant per measure. Sub categories as per material costs.
Installation scale	Adjustment factors to alter costs based on the scale of the component. Split into: • Cost adjustment % factors (Baseline, large small). These are used to multiply the baseline costs based on the scale selected. • Scale capacities (Baseline, large, small). These are used to provide the range of capacity for the cost adjustment % factors. Intermediate capacities have their relevant cost adjustment % factors pro-rated. Any capacities which are under or over the minimum or maximum capacities respectively have the small or large cost adjustment % factor applied.
Ground conditions	Adjustment factors used for modifying the costs based on prevalent ground conditions. Split into: • Excavation difficulty. • Ground contamination. • Ground water. Cost adjustments for three levels of each can be specified. The baseline modelling assumes low levels of excavation difficulty, ground contamination, and ground water.

18.4.2 Network typology calculator

The network typology calculator is used to define the individual typologies and the overall primary network connecting different areas of each typology. The network typology calculator is used to identify the range of components which make up the individual networks and group these into assemblies for modelling.

Further information on the network typology calculator is provided in section 17.2.

18.4.3 Other capital cost inputs

In addition to the core capital cost elements of the DH network itself, there are additional costs associated with the project as a whole. These costs are generally incurred before the project starts on site. These costs therefore include all aspects of feasibility studies, design and gaining planning permission where needed, and contractual negotiations. Many of these costs will not appear in the 'capital cost' reported as they may be funded in a different way, and some of the costs will be internal to the client organisation. However, they are real costs and are at-risk, as these costs need to be spent before the scheme is approved to go ahead. Section 19.2.2 provides information on these as part of the development costs.

As part of the model, cost data has also been included for wider system costs. This includes consideration of upstream costs associated with the energy centre as well as building-related costs downstream of the HIU, see sections 19.2.4 and 19.2.5.

18.4.4 Lifecycle cost inputs

The modelling framework includes a discounted lifecycle costing tool to allow the lifecycle impacts of heat network innovations to be understood. The lifecycle model uses a 25 year operational lifecycle, preceded by a year for development costs and a year for initial capital expenditure.

In addition to the initial capital costs, the lifecycle cost calculation includes the following:

- asset lives (and replacement costs) for the components;
- operating costs;
- maintenance costs during operation; and
- heat revenues.

18.4.5 Data extraction and analysis module

The final part of the cost model is set up to collate different aspects of the cost information in ways which support the analysis process. The tables and figures provided in this report are generated in this part of the tool. The key elements are:

- breaking down the total cost into key single components;
- preparing the results for the different typologies;
- combining cost elements in appropriate ways as needed (e.g. all civil engineering costs); and
- identifying the impact of simple changes in inputs on the total result.

This part of the tool will necessarily develop further in Stage 2 of the project as alternative solutions are tested through the model, to understand better how an idea may affect the total cost.

19 Cost Data

19.1 Introduction

This section presents a summary of the cost data used in the model. The model itself provides the actual cost data, with more detailed references to the sources of the data and any key assumptions made.

Given the project's focus on DHN capital costs, the model includes a breakdown of capital costs for all of the key network components. Network operational costs have been included at a less granular level.

It is also important to evaluate the impact of a DH network solution on wider system costs – both capital and operational – to ensure that network savings are not significantly offset by changes elsewhere. At this stage of the project only a simple estimate of these costs has been included as without knowing the proposed cost reduction solutions, it is not possible to know what specific wider system costs would be affected, and where more granular baseline data would be beneficial (if at all).

19.2 Capital Costs

19.2.1 Heat networks

To inform the model it has been necessary to source cost data on a range of elements of the system. The costs have been built up (and validated) by combining multiple sources of data. As many companies deem their cost data commercially sensitive, in general the organisation names have been removed within this report and in the accompanying cost model, such that it is not possible to identify the source of such commercially-sensitive information. Furthermore, where possible and appropriate, we have combined data from multiple sources, e.g. including stating averages only, which both helps protect the data providers and provides more accurate input data.

The sources collated for the key capital cost components of the network are summarised below.

All below-ground pipes and related components (materials only)

- Four suppliers
- A district energy contractor
- Multiple supplier tenders (for a DH scheme that AECOM is closely involved with)
- ENGIE

Installation of pipes and related components

- ENGIE
- A contractor
- A pipe supplier
- Multiple supplier tenders (for a DH scheme that AECOM is closely involved with)
- ETI Macro DE project

HIU (equipment and installation)

- Giocomini and two other HIU suppliers
- ETI Macro DE project
- ETI ICC
- DECC report on “Assessment of the Costs, Performance, and Characteristics of UK Heat Networks”[71]

Commercial substations for non-residential buildings (equipment and installation)

- ENGIE
- ETI ICC
- DECC report on “Assessment of the Costs, Performance, and Characteristics of UK Heat Networks”

Above ground pipes (equipment and installation)

- SPONS (Industry-standard construction price information for the UK which is updated throughout the year and compiles data from multiple sources)

Civil engineering

- Two contractors
- ENGIE (averaged contractor data from recent tendering exercise)
- Multiple supplier tenders (for a DH scheme that AECOM is closely involved with)
- ETI ICC
- ETI Macro DE

Prelims
- ENGIE (averaged contractor data from recent tendering exercise)

A summary of the data used in the model is provided in the tables below. This is not intended to be fully comprehensive – more details are provided within the cost model itself (e.g. reflecting a wider range of pipe and trench sizes). It is worth noting that from discussions with civil contractors, they do not tend to build-up costs in a bottom-up manner that could be particularly helpful to this project. They estimate costs based on experience of staff / plant needed and the expected time length of the project and an uplift is included based on the likely difficulty of the project.

Table 13: Pipes (supply and lay) – Costs per metre

Pipe		**Size (mm)**	**Materials**	**Labour**	**Plant**	**Total**
Pre-insulated S2 Steel, single length	Smallest	DN32	£16	£53	£0	£69
	Typical	DN300	£151	£178	£0	£329
	Largest	DN450	£205	£350	£0	£555
Pre-insulated Plastic twin pipe	Smallest	DN32	£13	£15	£0	£28
	Typical	DN50	£23	£15	£0	£38
	Largest	DN75	£39	£15	£0	£54

[71] Assessment of the costs, performance and characteristics of UK heat networks. DECC. 26th March 2015.

Table 14: Connections (supply, fitting and insulation) – Costs per unit

Pipe		Size (mm)	Materials	Labour	Plant	Total
Pre-insulated S2 Steel, single length	Smallest	DN32	£150	£184	£0	£334
	Typical	DN300	£948	£467	£0	£1,415
	Largest	DN450	£4,421	£535	£0	£4,957
Pre-insulated Plastic twin pipe	Smallest	DN32	£109	£600	£0	£709
	Typical	DN50	£263	£600	£0	£863
	Largest	DN75	£595	£600	£0	£1,195

Table 15: HIUs and building connection – Costs per unit

	Materials	Labour	Plant	Total
HIU (indirect)	£1,710	£330	£50	£2,090
Internal pipes	£1,000	£650	£50	£1,700

Table 16: Civil engineering works – Costs per metre[1]

Ground	Trench width (m)	Materials	Labour	Plant	Total
Soft dig	0.25	£22	£65	£59	£146
	0.5	£22	£65	£59	£146
	0.75	£30	£91	£82	£203
	1.0	£34	£103	£92	£229
	1.5	£51	£138	£111	£300
Hard dig	0.25	£114	£72	£101	£287
	0.5	£114	£72	£101	£287
	0.75	£162	£102	£143	£406
	1.0	£175	£109	£154	£438
	1.5	£209	£130	£182	£521

[1] This is further broken down as follows: Excavation 58%, Backfill 19%, and Reinstatement 23%.

19.2.2 Preliminaries costs

In addition, site preliminaries (or prelims) is a term which includes a large number of different costs. Contractors typically estimate these by adding a percentage of the cost of their part of the work. In the model, an average figure of 11% of the total capital costs of the heat network (but excluding building connections) has been used to represent all of the prelims cost. Some projects report a higher percentage than this, but taken only against the civils part of the costs, making comparison of different headline figures difficult. The main components of the prelim costs are listed below.

- Mobilisation (prior to site commencement)
- Main Site works (including office / welfare / fencing / generators and skips)
- District heating Site Works
- Traffic Management

- Site Management (staff)
- Documentation and Support
- Other Prelims / Premium Costs

One supplier did provide a more detailed breakdown of the components that comprise prelims which is included in Appendix M. The project team's understanding is that the most significant cost components are typically those associated with site staff and accommodation.

Another confidential tender contained the following breakdown of prelim costs. This made up a total of around £500k, representing 18% of a relatively small tender (<£3 million) to supply and install pipes, and including both the civil and mechanical works. This scheme seems not to have costs for site accommodation and it is not known why, but the split is provided here.

Table 17: Split of prelim costs from a confidential tender

Item	**Share of cost**
Project Engineer	32%
Assistant Project Engineer	32%
Visiting Head office assistance (CM, QS)	10%
Establish site set up	2%
Maintain site set up	2%
Demobilise site establishment	2%
Skips	1%
Considerate Constructors Certificate	0.2%
Design	18%

19.2.3 Development cost inputs

Development cost inputs for a typical current scheme of around £10 million are shown in the table below. These are based on AECOM's experience of costs for typical schemes of the type that HNDU are currently supporting. On this basis the development cost is therefore taken within the cost model to be 10% of the capital costs of the network (excluding the HIUs), and this has been supported anecdotally by others.

It is noted that negotiations and legal agreements comprise a significant component of these costs and can vary significantly in practice. These costs are dependent on both the number and complexity of the tasks needed. Whilst the table shows typical costs, the project team are aware that legal costs have exceeded £1million for a very complex scheme.

Table 18: Development cost inputs

Component	**Range (£k)**	**Typical (£k)**
Masterplanning	30-70	50
Feasibility	30-70	50
Business planning and negotiations	50-250	150
Legal agreements	50-500	200
Procurement	20-200	150
Detailed design	300-500	400
Total pre-commencement		1000

19.2.4 Energy Centre

The data for the capital costs of the energy centre was based on a combination of AECOM experience and data from SPONS. It is based on gas CHP engines and gas boilers in a central energy centre. Sizing calculations estimated a peak load of 44,543kW and delivered assuming the gas CHP thermal capacity was 30% of peak load.

Table 19: Energy Centre cost inputs

Component	Heating system information	Total cost
Gas CHP	£700 per kWe; 12.1MWe capacity	£8,500,000
Boilers	£50 per kW; 44.500MW capacity	£2,230,000
Energy Centre Building and other ancillary plant		£6,680,000
Total		£13,800,000

19.2.5 Existing buildings

No costs have been included for any additional modifications to the existing building. It has been assumed that the heat network is installed during an intended replacement of the heating system, and that any works to upgrade the home are funded by another mechanism. This may need to be revisited depending on the solution proposed. In particular, a low temperature heating solution may require either improved insulation or larger heat emitters in dwellings. It is also noted that if the heating system (e.g. gas boiler) is replaced before the end of its life, there may be some residual value in the asset which would be lost.

19.3 Lifecycle Costs

19.3.1 Asset lives

The following asset lives were included in the model. These were based on the experience of AECOM staff and typical assumptions used in other work.

In addition, the asset lives associated with the energy centre were: (i) 15 years for gas CHP, (ii) 25 years for gas boilers and (iii) 50 years for the energy centre building.

Table 20: Asset lives

Component types	Years
Steel pipes and fittings	50
Plastic pipes and fittings	30
HIU	20
Commercial connections	25
Pumps	25
SCADA	25
Water treatment	25
Leak detection	50

19.3.2 Operational and maintenance costs

There are ongoing costs in maintaining the physical system. A normal figure proposed by a network operator was for 1% of the capital costs of the network to be set aside for maintenance each year. This covers inspection of system, monitoring leak detection, carrying out water treatment, operating isolating values regularly and building up a pot for responsive maintenance. This percentage has been calculated based on the total cost of the heat network less the cost for the building connections.

Within AECOM modelling, and based on informal discussions with suppliers and operators, the following costs have been used in the model for maintenance costs:

- Domestic HIU maintenance: £150 per year
- Domestic customer, billing and metering: £100 per year
- Commercial connection maintenance: £1 per kW per year
- Commercial billing: Absorbed within heat price

For this work, AECOM has estimated additional operational costs associated with heat losses and pumping energy which were not explicitly provided by schemes in the DECC report. These costs were estimated using an internal sizing tool based on standard calculations and manufacturer data.

- Heat losses: £25 per MWh of heat lost. This equates to £141,574 per year.
- Pumping energy: £75 per MWh of pumping energy. This equates to £56,128 per year.

Note that the value of heat losses is lower than that of heat sales as it reflects the marginal cost of a unit of heat production at the supply point, and not the value to the customer.

Within the simplified cost model for the energy centre, the cost for gas has been taken to be £15 per MWh. Furthermore, the maintenance costs for the energy centre have been assumed to be around £50 per kWe per year (based on a large gas CHP).

19.3.3 Revenue

A range of rates of income were reported in the DECC report as referenced above, and given in the table below.

Table 21: Data from DECC study on costs of DH

Heat prices from schemes	All schemes	Bulk schemes	Non-bulk schemes
Mean average (p / kWh)	6.43	5.77	7.52
Minimum (p / kWh)	4.64	4.94	4.64
Maximum (p / kWh)	9.88	6.89	9.88

Table 11: Summary of heat prices from the heat network schemes.

Based on this, the model assumes a heat revenue of £55 per MWh delivered for domestic customers. A typical cost for a commercial customer is around £35 per MWh.

In addition most systems include a standing charge per connection. These are applied as:

- Residential: £55 per MWh variable + £250 annual standing charge per dwelling.
- Commercial: £35 per MWh variable + £17 per kW per annum collected load.

There is additional revenue from the sale of electricity generated in the energy centre, assuming that it is a gas CHP source in the energy centre. The value of electricity sales is assumed to be £50 per MWh. The CHP is assumed to be 40% efficient thermally, and 36% electrically, with an average of 60% of heat delivered by CHP. The remaining 40% is assumed to be provided by gas boilers.

20 Results and Analysis

20.1 Introduction

This section of the report presents findings from the baseline cost model. This particularly includes the following:

- High-level capital costs at a network and typology level.
- Comparison between capital and operational costs.
- Capital cost breakdown to identify the dominant components and underpinning drivers and cost variability.
- Details of the validation of the model.

20.2 Capital Costs

20.2.1 Capital cost by typology

The total capital costs for each individual typology are shown in Table 22 below. These costs are the core costs associated with constructing the heat network and building connections for each area. A further 11% is added to these costs to account for prelims.

Table 22: Breakdown of capital cost for each typology (excluding prelims)

	Typology A	Typology B	Typology C	Typology D	Typology E
Capital cost (£1000s)					
Total capital cost	£1,869	£1,378	£1,795	£4,362	£4,479
Labour	£676	£425	£552	£1,400	£1,411
Material	£846	£889	£960	£2,139	£2,213
Plant	£347	£65	£283	£823	£855
Capital cost breakdown					
Labour	36%	31%	31%	32%	32%
Material	45%	64%	54%	49%	49%
Plant	19%	5%	16%	19%	19%

20.2.2 Capital cost of example whole network

The total scheme capital costs for the network and building connections are shown in Table 23 below. These costs represent the whole network as described in section 16.8, which contains 1 or more of each typology. The costs cover the main study topics for this project, namely the pipes and their installation, the civil works and the connection to the building to the point of the customer HIU. In addition it includes the development costs to plan the project and contractor prelims in delivering the network. The “Baseline Cost of DH Distribution Systems” is the total capital cost in the final column.

Table 23: Breakdown of capital costs for overall network

Typology	A	B	C	D	E	Primary network	Total
Number of typologies in baseline scheme	**1**	**2**	**2**	**4**	**2**	**1**	
Capital cost (£1000s)							
Total capital cost	£1,869	£2,757	£3,589	£17,449	£8,958	£6,476	£40,170
Labour	£676	£850	£1,104	£5,601	£2,822	£1,761	£12,540
Material	£846	£1,778	£1,921	£8,555	£4,426	£3,848	£20,744
Plant	£347	£129	£565	£3,293	£1,710	£867	£6,885
Capital cost breakdown							
Labour	36%	31%	31%	32%	32%	27%	31%
Material	45%	64%	54%	49%	49%	59%	52%
Plant	19%	5%	16%	19%	19%	13%	17%

Note that the total cost is slightly less than the sum of the typologies as the scale of the whole network triggers an assumption of a 5% reduction in the cost of HIUs.

The capital cost for a typical dense village has also been calculated using the definition in section 16.9. The results are given in Table 24. Note that the dense village is not a part of the overall network for the purposes of the project.

Table 24: Capital costs for dense village

	Capital cost (£1000s)
Total capital cost	£3,980
Labour	£1,250
Material	£2,030
Plant	£690

20.2.3 Capital cost of whole system

The capital costs for the whole system are as below. This cost includes the network costs as shown above, but also a typical cost for the construction of an energy centre to supply heat to that network. The “Baseline Cost of Complete DH Systems” is the total capital cost in the table.

Table 25: Summary of capital costs

Component	Capital Cost (£k)	Percentage
DH network (including prelims)	43,200	68%
Development costs	2,700	4%
Energy Centre	17,400	27%
Total	63,600	

20.2.4 Comparison of the capital and operational costs of the heat network

It is useful to compare the total capital and operational costs of the heat network itself (including building connections).

Element of network cost	Annual cost	NPV over 25 yrs
Heat loss	£113,000	£1,370,000
Pumping	£56,000	£677,000
Network maintenance	£274,000	£3,300,000
Connection maintenance	£518,000	£6,620,000
Total	£961,000	£11,967,000

The operational cost of the network (for pumping, heat loss and maintenance of pipes and connections) is calculated as £960k per year. This is around 26% of the capital cost based on a net present value (NPV) calculation over 25 years with a 6% discount rate. If capital costs were to significantly reduce, say by 50%, then operational costs would become relatively higher but would still be less than capital costs.

It is also informative to review the annual operational costs and income for the whole system as shown in Table 26. It is important to note again that the scheme is not one that is being currently constructed as it includes typologies with a relatively low heat density. Where heat networks are constructed in areas of lower heat density, the heat revenues will reduce within a given geographical area but the operational costs will reduce by a lesser proportion (e.g. still have a significant heat network to maintain but with, say, less branching to individual buildings). This is currently being recognised in Scandinavia where their concern is that with existing buildings being retrofitted with improved thermal insulation, falling heat revenues will not be matched by falling operating costs (similar issues will apply in the UK as well). This is one of the key drivers for fourth generation district heating whereby a lower temperature heat network will result in lower heat losses to help balance lower heat density and revenue.

Table 26: Operational Costs and Income Summary

Item	Cost	Income
Gas cost	£1,980,000	
Maintenance of network	£270,000	
Maintenance of connections	£520,000	
Customer billing costs	£330,000	
Maintenance in energy centre	£580,000	
Electricity Income		£1,820,000
Heat Income		£4,260,000
Operational cost margin		£2,390,000

20.3 Pareto Analysis of Capital Costs

In terms of the overall breakdown across the whole model network, the following chart summarises the main components.

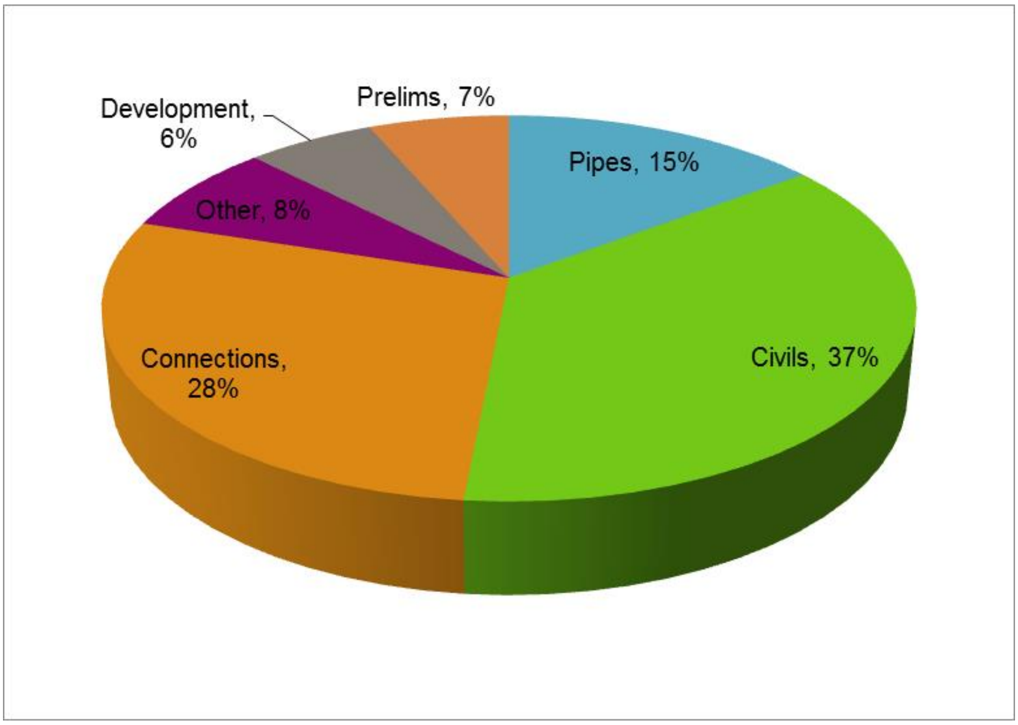


Figure 23: Whole network, breakdown of costs into key elements

Where:

- Pipes includes the purchase and installation of all pipes, insulation and joints
- Civils includes the work of digging and reinstating trenches
- Connections includes the Hydraulic Interface Units (HIUs) and connections within buildings to the HIU
- Development includes the design and legal costs accrued before a contractor is appointed
- Prelims are costs associated with running a construction project, including site office, safety etc
- Other is any other costs, here mainly around data systems, water treatment and one-off items like rail crossings

These main headings can be broken down to a further level of detail, as shown in the table below. This excludes prelims and development costs.

In particular, the following is highlighted.

- The civil costs are dominated by hard dig which comprise roughly 40% of the costs. Excavation costs form the majority of these costs, although backfill and reinstatement comprise a significant minority. As shown in Section 19.2.1, the hard dig civils cost comprise similar breakdown of material, labour and plant.
- The connection costs are dominated by the residential sector (30%), particularly due to their volume. The HIU and associated pipework connections both significantly contribute. As shown in Section 19.2.1, the material costs dominate but labour still comprises a significant minority.

- The costs associated with the pipework together comprise 17%. However, there is no single dominant cost component.

Table 27: Key cost groups, whole network

	Cost group	
Civils – hard dig	Excavation	21%
	Backfill	7%
	Reinstatement	8%
Civils - soft dig	Excavation	3%
	Backfill	1.0%
	Reinstatement	1.3%
Valve pits		0.3%
Connections	Residential HIU (supply and fit)	17%
	Residential pipework connection	13%
	Commercial substation	1.3%
Pipes	Pipes steel	4%
	Pipe fittings – steel	3%
	Pipes plastic	4%
	Pipes fittings - plastic	6%
Crossings		3%
Pumps, controls, water treatment		6%

The information can also be broken down in a further way. The following chart comprises raw data from the cost model. It shows the dominance on the whole scheme for the civil engineering associated with the smaller diameter parts of the pipework (because of their greater length) and the HIUs because of their number.

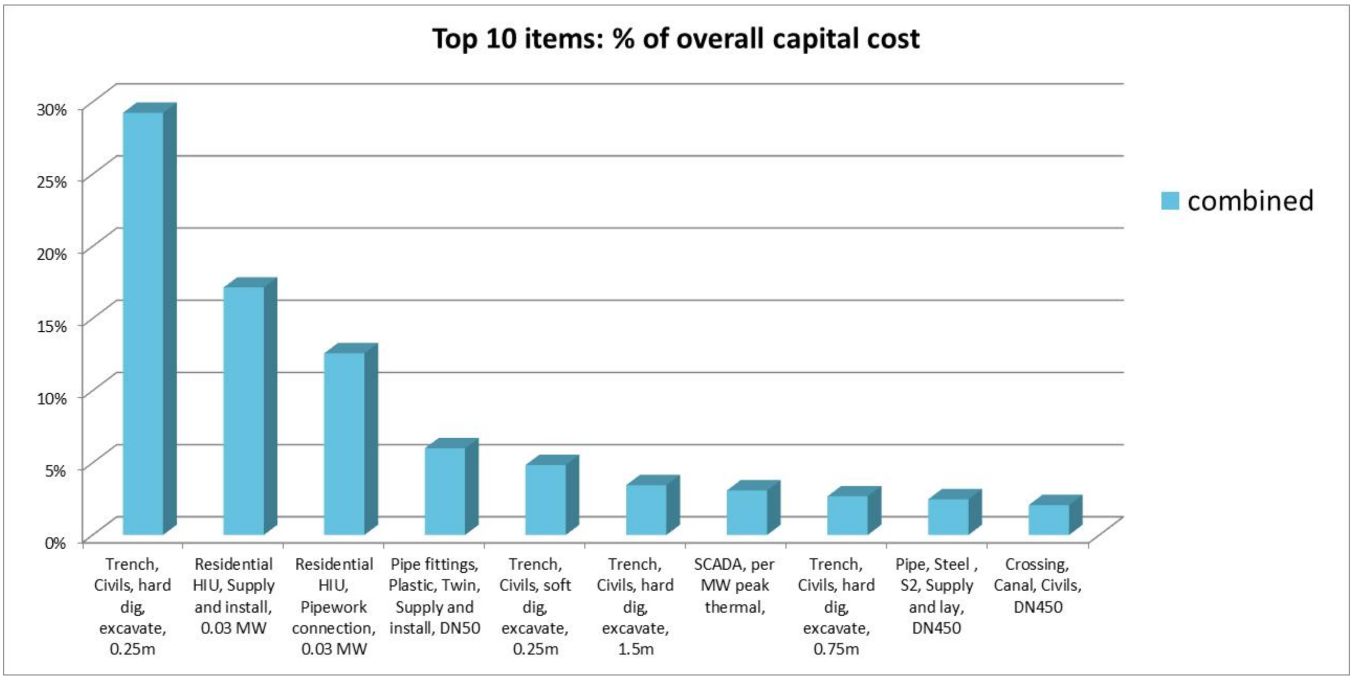


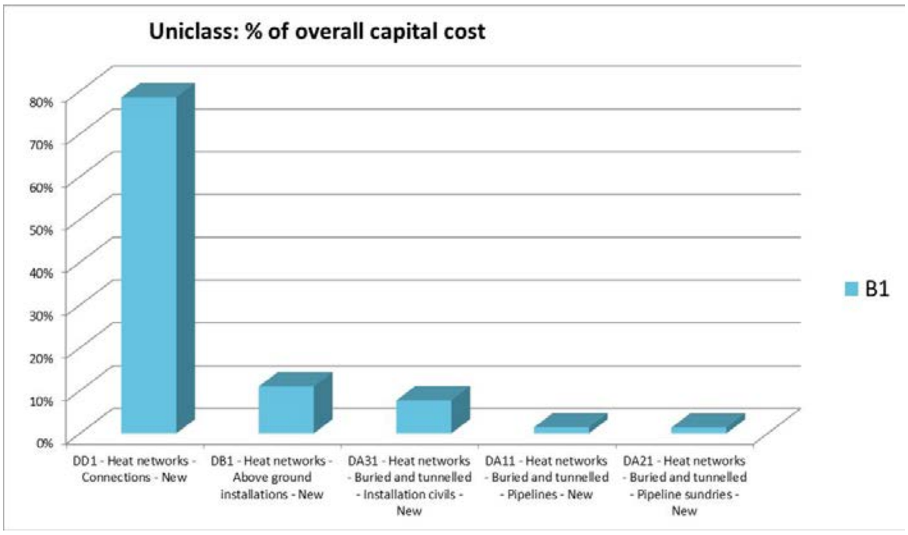
Figure 24: Leading components, whole system

Sensitivity analysis was undertaken to compare the cost breakdown for each of the typologies in the baseline scheme. In practice, a network may differ in make up to the overall baseline network and it is useful to identify how this might affect the key cost breakdown, and any significant impacts.

In particular, the results showed that the relative importance of the civil and residential HIU costs depend on typology.

- The first figure below shows typology B, which comprises high rise flats, where the cost is almost entirely for the internal connections (which includes HIUs).
- The second figure shows typology D, which comprises semi-detached homes, where the civils costs are highest due to the relatively long network length, but connection costs are still high.

One key further difference was identified in reviewing the results for typology A. It comprises non-residential buildings only and hence commercial sub-stations comprise a significantly higher percentage of these costs (18% of the total for this typology).



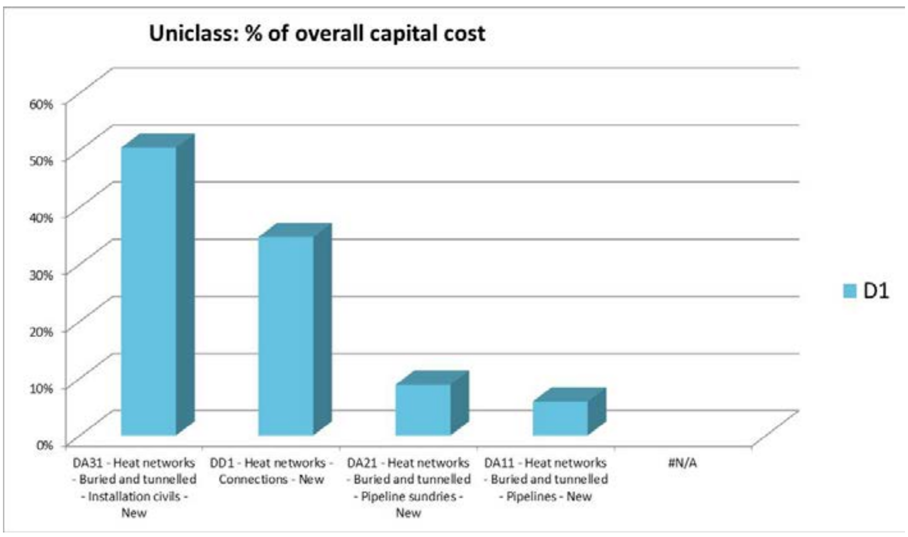


Figure 25: Leading components cost breakdown, comparing Typologies B and D

The cost for each component will also vary depending on other factors such as the size of scheme and negotiations with the supplier. However, it is clear that overall both civils costs and the costs of HIUs dominate. Varying them by, say, ± 30% at the extreme would not vary their relative level of importance to this project.

20.4 Cost Drivers and Variability

This section discusses the key factors that affect the costs of key elements within the whole system.

<u>Civils costs</u>

The cost of civils works, and their variation, is driven by many factors.

- Rate of progress: With labour and plant together representing the majority of the cost, the speed of delivery is important. This is affected by many factors to be investigated further in Stage 2, but including problems found in the ground, availability of staff and weather conditions.
- Ground conditions: As shown earlier, soft dig in verges or similar is much cheaper than hard dig in the road. Furthermore, contaminated soils add significantly to the cost.
- Ground uncertainty: There is uncertainty as to what will be found in the ground when excavating, especially other services. This can cause delays and consequent costs. Advance planning and surveys are important here.
- Trench width and depth: the wider and deeper the trench, the higher the civils cost. Width is defined by pipe size, and also the need to work in the trench to weld pipes and make joints. Increased depth may be required to avoid other services, where it may often be necessary to go deeper to find an acceptable route.
- Space for excavated material: There is typically a lack of space for excavated material. This is a key driver for the normal practice to simply replace all the excavated material rather than reusing it for backfill. In addition to replacement costs, there is a cost to take the original excavated material away to landfill. Landfill costs are region dependant and particularly high in London where there is a greater distance to transport to a landfill site.

To explore this further, a discussion was held with a civil engineering contractor who has been involved in district heating and utilities installations for over 30 years. The costs for civil engineering are significantly impacted by the number of metres that you can dig in a day. This is related to factors including the presence of underground services, traffic sensitive roads (e.g. which may limit the days of the week and/or the time of day that work can take place and the ability to only work on half of the road at any given time to allow traffic flow) and the availability of a lower-cost dig such as parkland. It was suggested that at best 15-20 metres can be excavated on average per day (little or no services), 10 metres per day on average is a more typical best but it can go down as low as 3 metres on average per day. The reduced output rate from identification of underground services is due to delays whilst the route is re-designed, time to obtain the necessary pipe and joints (which is ordered directly from the supplier as there is no central store) as well to re-route around obstacles and/or excavate a deeper trench. The impact on cost is principally around labour costs. As an indication, for a 100mm pipe route, reducing output from 10m to 5m per day can increase the cost per metre of civils (excluding prelims) by 50%. Given that the earlier pareto analysis shows that civils contribute around 40% of the total DHN costs, it does highlight the importance in this work of identifying solutions to increase output (metres per day).

HIUs

It is most typical in the UK to have a HIU in each property. Furthermore, these tend to be indirect units which have two plate heat exchangers, delivering domestic hot water and heating so that there is full hydraulic separation between the network and the customer system. A variation is to use a direct unit, where space heating is delivered directly from the district heating system but a plate heat exchanger is provided for domestic hot water. An indirect system adds capital cost because there is an additional heat exchanger, circulation pumps and pressurisation unit. Furthermore, the addition of the heat exchanger results to some degree in greater losses and higher network operating temperatures. An indirect approach is often used due to concerns about, say, burst pipes and resultant impact of a direct system on the safety and performance of the wider network.

Feedback from manufacturers suggests that the upfront capital cost of indirect systems can be 10-20% more expensive than direct units. This does suggest the potential for a reduction in costs. However, it is important to consider impacts on the wider system performance and costs. The WP2 technology report highlights that it is not clear that indirect systems result in higher costs overall when all differences in direct and indirect approaches are accounted for in the whole system design. However this is a key area to investigate further as some of the disadvantages of a direct connection could be overcome by innovations.

In Denmark, for example, an alternative design is used and something worth exploring further in Stage 2. It is typical to have a single heat exchanger for space heating for several blocks of flats or a group of terraced housing. Similarly, high density housing or flats are more likely to have a common hot water system running from a single heat exchanger than individual HIUs for each property. This approach has been adopted in Denmark as traditionally high density housing has used communal heating. Hence when changing heating systems to district heat networks, this design was the most appropriate and lowest capital cost (relatively few HIUs), and the residents were already aware of the need to avoid damaging the pipework given the implications for neighbouring properties and not just their own.

Another variable is the size of the HIU required, with a smaller unit possible where there is local domestic hot water storage within the home, as this reduces the peak rate at which heat may need to be delivered.

In discussions with manufacturers, it was highlighted that there are many HIU products in the UK market, with customers routinely requesting changes to configuration and thus non-standard products. A member of the ETI review panel added further detail suggesting that there are now over 40 HIUs on the UK market, many made in relatively small runs of 15-30 units per day, with customisation in terms of control valves, control units, interface points and metering selection.

The comparison with costs in Denmark is informative here. The costs are broadly similar there (Cowi suggest that costs range from £1500 to £2500 including supply and installation, with the costs of buying centrally from the DH supply company coming towards the lower end). It has been expected that the costs may be significantly lower in Denmark due to economies of scale. However, it is possible that this may be tempered by the fact that, as above, an HIU is not typically installed in every home. Cowi did also note that Scandinavia tends to operate as a single market i.e. the price for HIUs (at least for the supply of the unit itself which comprises most of the cost) is expected to be fairly consistent across Scandinavia.

Pipes

The selection of pipes sizes (and operating temperatures) is based on an optimisation to minimise lifecycle costs. The diameter of the distribution pipes can be decreased to reduce capital costs and heat losses, but these lead to higher pressure drops requiring more pumping energy and higher running costs. AECOM used a pipe sizing tool to determine appropriate dimensions for this work.

The market for pipe is well established and so the basic pricing is fairly consistent. There will be variations in cost based on the scale of order placed and the location of the site affecting delivery cost. There are also small differences due to the thickness of insulation material used. The quality of pre-insulated pipe is defined by the EN standards, EN253 and associated standards.

The cost model assumes separate supply and return pipes for pipe sizes of 80mm diameter or more. The WP2 technology review does highlight the increased use of twin-pipes internationally, where both the supply and return pipes are contained within the same casing. Whilst the pipe can cost more, it benefits from slightly lower heat losses and, more importantly, it should be possible to have a narrower trench and therefore less excavation work. At the WP1 workshop, one stakeholder said that it is difficult to implement twin pipe solutions in practice in the UK as the use of separated pipes for supply and return makes it easier to navigate around existing utilities in the ground. Twin pipe is beginning to be more widely used in the smaller diameter pipes, and the solution is applied to both steel and plastic options. Plastic twin pipe solution is used in the baseline cost model for pipe sizes of 50mm diameter or less.

Prelims

There are two major issues that affect the stated prelims cost: (i) the real significant differences between projects, and (ii) the variation in what is included in the prelims cost.

Prelims are generally stated based on a percentage of the network cost, but it varies as to whether this is based upon the civils cost only or the civils and mechanical costs. Further there are a range of issues that are included under the banner of prelims (for examples aspects of design and then site supervision) which in other projects may be reported differently. This makes comparison of reported figures difficult if the basis is not made clear.

The more important differences that drive the prelims cost are the nature of the site and the project, and therefore the elements that are needed within it. There may be large or small requirements for traffic management, a site compound, safety fencing, staff accommodation, etc. It is therefore inevitable that there will be significant variation in the costs for different projects.

An important element is reported to be the role taken on under the Construction (Design and Management) Regulations (CDM) - the main set of regulations for managing the health, safety and welfare of construction projects. It was suggested that the prelims cost could be around 15% if supplying all CDM (and Safety, Health, Environmental and Quality – SHEQ) functions. This could be lowered to around 10% if the contractor has less of a role with respect of CDM. It is noted that in this case someone else would need to carry this cost.

The contractor would go through each project individually, once they have built up a programme, to allocate the appropriate prelim allowances.

From discussions with contacts in Denmark, it was noted that prelims tend to be lower there because there is more upfront design and survey work done reducing time on site. Heat networks also have a formal status in Denmark as they are a Regulated system, making road management quicker to organise.

20.5 Validation

As part of this work, there has been both bottom-up validation of the individual components and top-down validation of the overall cost. This section provides initial discussion of the validation of the key cost components prior to then reviewing the top-down validation.

20.5.1 Civils

A set of civils costs was provided by a major contractor. Data was provided for London, Midlands and Scotland. Midlands was selected as being a central location. It is interesting to note that London costs were 23% higher and Scottish costs were 4% lower. (It was also noted that for pipe laying, the prices were 10% more expensive in London and around 10% cheaper in Scotland). These costs were then split into materials, labour and plant by applying the same ratio available from the existing ICC data.

The costs were then validated and amended based on price schedules that have been received from ENGIE. These were based on a recent tender process carried out and are an average of prices from 4 or 5 contractors.

One contractor provided an indicative breakdown of the civil costs to be 58% excavation, 19% backfill and 23% reinstatement. This was seen as being appropriate by a second contractor, but recognising that there are many variables associated with the civils work for each job and the split will be different.

20.5.2 HIU and internal connections

The model has included the original costs from the ICC which have previously been validated. This includes around £2,100 per installed HIU unit and £1,700 for pipes and other work within the dwelling.

We note that the HIU cost is a little higher than both the ETI macro DE project and the DECC study of “Assessment of the Costs, Performance, and Characteristics of UK Heat Networks” which both report a HIU cost of around £1700 per unit. The latter also suggests a connection cost of around £1200. However, taking into account inflation, these values are broadly in line with the cost data in the model. The modelled prices are in line with current prices obtained from a manufacturer whose products ranged from £1,300 to £2,100 for equipment supplied only (the model assumes a HIU price of £1,710 for the equipment only).

20.5.3 Pipes and connections

The main suppliers provide published list prices for pipes and connections. The differences in these costs are relatively small, with differences of less than 5% being typical. However, in practice, it is more complex with suppliers offering deep discounts (50%+) to contractors. Scale is an important part of this variation; a leading supplier referred to an increase of 35% for a scheme of less than 100m in length.

As part of this work, the project team were able to obtain confidential information on discounts from suppliers. All costs included in the model were averages of information provided from two or three suppliers.

20.5.4 Prelims

As noted before, prelims costs are complex because of a lack of consistency from different sources about what is included within the prelims cost, and what is within other cost elements. The validation of the numbers is therefore difficult. However a range of sources present values in the range 10-20% of the civils costs. Therefore because of the expectation in this project of a focus on larger projects, the decision was made based on ENGIE experience to work with 11% of the civils and mechanical cost (excluding design and building connections).

20.5.5 Whole network

In order to validate the model, we have also compared the final predictions of the model with overall network cost data. The costs were compared with anonymised costs within the DECC study on “Assessment of the Costs, Performance, and Characteristics of UK Heat Networks”. This study reported actual cost data (i.e. actual costs rather than design-stage estimates) from seven schemes that commenced operation (or extended) in the last decade and that were in the main a mixture of residential and commercial buildings, with at least 500 dwellings/units connected. The costs per metre of network and the costs for connections were applied to the three typologies most relevant to the schemes reviewed in the DECC study.

Table 28: Validation of whole model costs with DECC (AECOM) report - £millions

	Typology A	**Typology B**	**Typology C**
min	£1.71	£0.92	£2.22
ave	£2.52	£1.15	£3.03
max	£3.10	£1.32	£3.55
Project cost model	£1.87	£1.38	£1.94

It is important to note that the single typologies in this study are not the same as the whole schemes in the data available, so they would not be expected to correspond to any exactly. In practice Typology A, for the urban area with a small number of large energy connections is the most attractive of the set, and we would expect to see that it has a relatively low cost in comparison to other schemes. For Typology B (blocks of flats) the cost is dominated by the HIU cost; we have used the data from the ETI Infrastructure Cost Calculator (ICC) which is roughly a third higher than quoted by DECC in its study (for HIU and internal connections), and this is the main reason for the higher cost. For Typology C (terraced homes) the cost predicted is low on a per metre of pipe basis, and this is likely to be because the DECC benchmarks are for an average network with a range of pipe sizes, but Typology C mainly consists of small diameter and therefore much lower cost pipes and associated trench sizing.

Part D - Work Package 3: System Review and Target Setting

21 Introduction

This Part of the Deliverable summarises the insights from the WP3 workshops and research, and it describes the process by which the Project Team agreed the key challenges to be addressed in Stage 2 “Solution Development” and the improvements targets for each challenge.

The content of this report can be summarised as follows:

- Section 22 identifies the key gaps between current DHN capability and stakeholder requirements, and areas of disproportionate cost and risk within the current DHN framework. This is a synthesis of relevant outputs from Work Packages 1 and 2.
- Section 23 presents a prioritised set of challenges to be taken forward to Stage 2 of the project, including a quantitative target for each challenge. This builds from the gap analysis in the previous section and was significantly derived through two workshops held with ETI, ETI’s review panel and the project team.
- Section 24 presents a standard template to capture information necessary: (i) to aid evaluation of solutions in Stage 2, and (ii) to capture information that is easily accessible in Stage 2 to help enable the production of route maps during Stage 3 and avoid later duplication of effort. This is a distinct piece of work to that presented in the other sections.

22 Findings from WP1 and WP2

22.1 Results of Gap Analysis between Current DHN Capability and Stakeholder Requirements

Part A of this Deliverable presents the methodology and results of a gap analysis between the current DHN capability and stakeholder requirements. Key information has been summarised here.

The WP1 research identified three distinct categories of stakeholders. Each category has distinct perspectives of requirements for successful DHN deployment.

- **Customers (comprising both Users and Investors):** Users are building residents and owners. Investors are those providing capital to a district heating scheme. Both of these sets of stakeholders need convincing that the DHN proposition is right for them – hence can together be viewed as customers of DH schemes. Investors have a choice as to where they place their investment. Consumers, Landlords and Public / Commercial customers have alternative choices for heating provision. For these stakeholders it is important to focus on their requirements and develop an attractive proposition for DHN which is more compelling than the alternatives. This is achieved by taking stakeholder requirements and developing them into a specification for suppliers to meet.
- **Value Chain Stakeholders:** These are organisations with a desire to generate income and profits from DHN. They can only do so if their offering is attractive to Customers (ultimately to both the Users and Investors). If Customers are not convinced of the value, there needs to be an improvement in some combination of performance, speed, dependability, flexibility and cost. Complexity of the transaction with the associated products and services will also have a major influence on the attractiveness to the Customer.
- **Enabling and External Stakeholders:** These are organisations which may not have a direct interest in a specific DHN, but have the potential to enable, delay or block development. Without addressing their requirements there is a risk of a DHN becoming unviable. Enabling stakeholders include national and local Government plus other organisations that may need to give consent to the path of the network or temporary access. External stakeholders include local communities and the media who have an interest in the implications of DHNs for the public. Keeping such stakeholders informed minimises the risk of negative public reaction to proposals.

Analysis was undertaken of the various stakeholder requirements to identify nine key improvements necessary to both address barriers to and incentivise wide-scale commercial DHN deployment.

22.1.1 Financial Viability

There are a number of areas for improvement which directly focus on the financial viability of the scheme. These can be summarised as follows.

- **Reducing Capital Cost**
  The absolute level of CAPEX is a key hurdle for Investors. Capital cost focus should look at capital equipment, material, labour, plant and all overheads including contingency and margins.
- **Reducing Operational Cost**
  System running cost, OPEX, also affects DH system viability. It is dependent on the

cost of producing the heat, heat losses, pumping energy, staff cost, repairs and maintenance. Understanding the trade-off between CAPEX and OPEX is a crucial challenge for the project as both have an impact on viability.

- **Improving Cost and Revenue Certainty (Capital, Operating Cost and Income)**
  Greater cost certainty and reduced risk will attract a greater range of Investors with lower hurdle rates. Furthermore, cost certainty has a major impact on the required rate of return and the viability of a scheme.
- **Reducing Time on Site**
  Installation time impacts project cost through the direct impact on the core capital cost (such as labour and plant for civil engineering) but is also a measure of impact on the community. For example, road closure is charged by the day and is disruptive to the community.
- **Increasing Network Developer & Operator Revenues**
  Reducing revenue uncertainty, by adding alternative revenue streams, improves viability. Such additional revenue could arise from, for example, sharing cost of civil engineering works with those of other utilities installing new infrastructure.

22.1.2 Wider Priorities

There are other priorities which fundamentally affect the viability of the scheme but focus on other aspects of the DHN delivery.

- **Systems Architecture**
  Integrated systems design provides a significant opportunity to assure DHN performance and optimise system cost, avoiding over-engineered components. Options to be explored for innovative network design include: elimination of network elements or combining them with other infrastructure, challenging current concepts of heat transfer and containment. For DHNs to get beyond the social housing and new-build sectors may mean identifying mechanisms to deliver DHNs with low levels of initial take-up from owner occupiers. A technical and commercial model would therefore be needed to allow other users to connect at a later date (at boiler end-of-life or when convinced of the proposition), whilst keeping the early connectors well served and network operating costs manageable.
- **Improving the User Value Proposition**
  There is a need to create a compelling offering for User groups and a reason to switch to a new DHN solution. The analysis of stakeholder requirements and current barriers particularly identifies difficulties to overcome resistance to pre-emptive boiler replacement. This is likely to be crucial to wider deployment and viability. There is a need for greater confidence in the heat supplier, confidence in the performance and reliability of district heating, fair pricing throughout the contract and minimal disruption. Market / user engagement is a major barrier for existing buildings in particular given current limited knowledge and reputation of district heating. In some sectors – commercial buildings and the private rented market – the owner of the heating system installed is not the user and this makes the decision making more complex. This is the case with other energy efficiency improvements – the landlord is required to invest but the tenants gain the benefit.
- **Improving Investor Value Proposition**
  Creating a compelling offering for Investors. In addition to challenges around reduced costs and improved cost certainty, there is the need to reduce the legal and commercial complexity, the need for skills to address the complexity of project leadership and greater integration of the design and delivery teams. There is the need both to reduce the risk and to ensure risk is held at the appropriate level and not simply off-loaded to sub-contractors as this may inflate costs.
- **Reducing Complexity of Transactions between Stakeholders**
  The complexity of the process is recognised by potential Users and Investors as a barrier to their involvement in DHN, but it is also highlighted as a burden from

stakeholders already working in the sector. There is the need to better identify costs and delays across the Value Chain and through engagement with Enabling Stakeholders, and determine opportunities to simplify and standardise transactions.

22.2 Elements which attract Disproportionate Cost or Risk

To support the gap analysis, further consideration was made to better understand which elements attract disproportionate capital cost or risk. These act as barriers to commercial deployment.

22.2.1 Disproportionate Cost

The findings of Work Package 2 highlight the most significant elements of capital cost and how they can vary depending on the characteristics of the network. These findings are included in Part C of this Deliverable and are summarised here.

The capital cost breakdown for the baseline heat network (excluding prelims) is shown in Table 29. Some particular points are noted.

- The civil costs are dominated by hard dig which comprise roughly 36% of the total costs. More detailed breakdown shows that typically excavation costs form the majority (21%) of these costs, although backfill and reinstatement make up a significant portion (15%). The hard dig civils cost comprise similar breakdown of material, labour and plant – demonstrating the significant benefits of reducing time on site which will reduce both labour and plant costs.
- The connection costs are dominated by the residential sector (30%), particularly due to the number of buildings by volume. The HIU and associated pipework connections both significantly contribute. The material costs dominate but labour still comprises a significant minority.
- The costs associated with the pipework together comprise 17%. However, there is no single dominant cost component.

The relative importance of these costs will vary depending on the type of network. In particular, the following were noted from sensitivity analysis on capital cost.

- The capital cost for a network comprising principally high rise flats will be dominated by HIUs and internal connections given the high housing density.
- For networks comprising a lower housing density, the relative contribution of civil costs increases.
- A greater component of non-residential buildings will increase the percentage of capital cost for commercial sub-stations.

The WP2 Cost Model Methodology and Analysis also compared the total capital and operational costs of the heat network itself (including building connections). The operational cost of the network (for pumping, heat loss and maintenance of the pipework and HIUs) is calculated as £960k per year. This is around 26% of the capital cost of the heat network based on a net present value (NPV) calculation over 25 years with a 6% discount rate.

Table 29: Cost breakdown for total network (based on HN1 model)[72]

	Cost group	
Civils – hard dig	Excavation	21%
	Backfill	7%
	Reinstatement	8%
Civils – soft dig	Excavation	3%
	Backfill	1.0%
	Reinstatement	1.3%
Connections within buildings only (HIU / substation and internal pipes only)	Residential HIU (supply and fit)	17%
	Residential pipework connection	13%
	Commercial substation	1.3%
Pipes	Pipes steel	4%
	Pipe fittings – steel	3%
	Pipes plastic	4%
	Pipes fittings - plastic	6%
Crossings		3%
Pumps, controls, water treatment		6%
Other (principally monitoring)	Other	1.4%

22.2.2 Disproportionate Risk

Investors and Users are both key customers necessary to create a significant market for DHNs and particularly need convincing that the Value Proposition is right for them – Investors have a choice of where to invest and Users have a choice of energy supplier. For both of these groups, there are significant perceived or actual risks which limit engagement.

For Investors, the costs of a project are closely linked to a consideration of risk. If a project is considered a high risk, the return on capital will need to be higher than for a similar project where the risks are lower. Hence reducing the risk of the project has a similar impact to reducing the absolute cost of the project in terms of project viability. For Investors, the areas of particular risk are set out below. The areas of risk identified are based on feedback from the WP1 workshop plus further details provided by ENGIE and E.ON.

- Uncertainty of cost
  There are significant pre-contract costs at the commencement of a scheme which may be abortive if the scheme does not go ahead. A scheme will be dependent on reaching agreement with customers for the heat, being financially viable and on obtaining appropriate consents and authorisation, for example by local planning authorities (feedback was that the greatest take-up of district heating is where it aligns with local planning policy). Furthermore, there is the distinct perceived risk of changes to

[72] These costs are for the baseline district heat network model (HN1) detailed in the WP2 Cost Model Methodology and Analysis. These costs are not intended to reflect figures for the UK as a whole.

Government policies which impact on operation but especially in the planning phase as district heating has a long development period and so is more likely to be impacted by policy changes. These pre-construction activities have a significant cost (around 10%-20% of the district heat network) and at the same time are perceived as a high risk. For example the Bunhill project in London Islington took about 12 months to construct but this was preceded by two years of feasibility, planning and procurement activities.

Furthermore, during the construction period there are a number of significant unknowns – for example, trenching work which is uncertain due to lack of information on existing underground utilities and other ground conditions and obstructions. The costs and risks are likely to be higher when retrofitting to supply existing properties – likely to need hard dig in the streets and greater uncertainty of ground conditions. It is difficult to modify the scheme half way through if the costs are higher than expected.

- Uncertainty of time
  Given the uncertainty of time for construction works due to unforeseen ground conditions, constraints imposed by local planning or traffic management issues, this has a number of implications for Investors. In addition to the impact on core capital costs it has other key impacts e.g. (i) costs associated with prelims (e.g. site management, plant and machinery are proportional to construction time), (ii) road closure is charged by the day; even if waived this is a cost to the community, and (iii) the time for installation reduces project cash flow and adds interest cost to the project. Note that whilst this risk was reported from the WP1 workshop, it was not highlighted particularly in the subsequent feedback from ENGIE and E.ON.

- Uncertainty of performance
  Areas of uncertainty in terms of project performance include efficiency and availability of central plant producing the heat, and return temperatures achieved from the network which is a function of the building services design. Again, whilst this risk was reported from the WP1 workshop, it was not highlighted particularly in the subsequent feedback from ENGIE and E.ON.

- Uncertainty of revenue
  The Investor needs to be confident of the revenue stream to achieve a return on the substantial upfront capital investment. This particularly relates to volume of chargeable heat sold rather than price per unit of heat. For this reason, major UK schemes to date have been instigated by Local Authorities that have direct control, or have the influence, to commit the necessary core load to a long-term heat supply agreement. For wide-scale DHN deployment with diverse customers it will be unlikely that long-term heat supply agreements will be possible in all markets. There may have to be greater reliance on maintaining a competitive heat supply price and delivering good customer service so that there is no incentive for customers to switch back to gas. However, in practice, Investors may need regulation to mandate customers to be confident in future revenues required to offset upfront capital costs.

  Furthermore, current models of heat revenue from existing buildings are based on estimates of energy use. It is noted that in Denmark, say, Investors can determine heat revenue based on actual energy use data for existing buildings.

  Even if the customer base is secure, heat revenues in the future will still depend on the degree of energy efficiency improvements and any future impact of local climate change.

The general consensus in WP1 is that potential Users (i.e. those not currently connected to DHN) have little or no knowledge of DHN. Hence if the User is approached to connect to a

DHN system, there is significant perceived risk for them to change to an unknown system. At the very least the consumer needs confidence that the new system will overall match the running costs (energy bills and maintenance) and the performance of current heating system alternatives, as well as limiting disruption in the changeover to the new heating system. The consumer also needs a compelling reason to change to the DHN alternative to make it worth the effort of engaging in the decision-making process and implementing the change, as well as overcoming other personal and social factors which can discourage change, such as trust in the heating provider and approval of the decision by peers.

More specifically, this work has highlighted two risks expressed by current Users of district heating.

- The certainty that the User will have, and continue to have, a fair price for heat consumption, given that they are entering into a long-term contract with a monopoly heating provider.
- Given that heat provision is currently unregulated, Users are concerned that customer service standards and customer protection requirements will not be comparable to the quality and performance standards required for regulated utilities, such as gas and electricity supplies. The voluntary Heat Trust73 scheme has been set up to address this concern.

A number of stakeholders who could be described as enablers were also identified during the course of the WP1 and WP2 work. As discussed above, these have significant influence on whether and how a district heating scheme proceeds. These stakeholders are as follows:

- Local Authority departments such as Highways, Planning and Environmental Health. These departments are not directly concerned with energy supply and are not customers for heat. The Highways department has a role to ensure co-ordination of the DHN installation with other work in relation to both the roads themselves and the work of other statutory authorities. They will issue licences to allow the DHN installation to go ahead and will be responsible for approving traffic management and suspension of car park spaces. The Planning and Environmental health departments are likely to be involved in granting planning permission for the construction and in evaluating environmental impacts especially from dust and disturbance during construction and from the Energy Centre during operation.

- The second stakeholder category is owners of other infrastructure that may present a barrier to routes for DHNs, especially railway/tramway companies, Network Rail, Transport for London, other utilities including water, drainage, electricity and gas and the Canal and River Trust. These stakeholders will often need to provide information on the extent of their existing equipment and ownership boundaries, and where appropriate grant easements or wayleaves for the crossing of their land. In some cases these may have onerous liability provisions for example for damage to the equipment or service that may be impacted.

[73] http://www.heattrust.org/

23 Evaluating the Technology and System Challenges

23.1 Identification of Challenges

An initial list of 28 challenges was derived by the project team. This was informed by the nine key priority areas from WP1, plus early learning from WP2. For completeness, some additional analysis was compiled comparing the DHN proposition against the counterfactual alternatives and is provided in Appendix N. The list of the 28 challenges is given in Appendix O.

This initial list of challenges was reviewed and refined at the first of two WP3 workshops. This workshop was held on the 1st March 2016 and comprised representatives of the project team, ETI and ETI's review panel[74]. The findings from WP1 and WP2 were first discussed and the initial list of challenges presented. Based on the workshop discussions, some of the initial challenges were grouped together where it was considered that there were affinities between challenges for managing solution development, and new challenges were also included.

The workshop resulted in a refined set of 16 challenges. These challenges are listed and described in Appendix P. This table includes an evaluation of each challenge made at the workshop according to the following criteria[75] [76] (the best challenges are those of core scope, higher value and lower effort).

- Scope – Whether the challenge was deemed to be core, secondary or marginal to the scope of this project.
- Value – The anticipated potential value of the improvement. This was rated as low, medium or high.
- Project Effort – The relative amount of work necessary in this ETI project to investigate solutions. This was rated as low, medium or high.
- Expected Delivery Effort – The relative cost (e.g. capital investment, research & development) and effort in time required to deliver the improvement. This was rated as low, medium or high.

At the end of the first WP3 workshop, the challenges were separated into four categories based on this initial evaluation. This categorisation is also shown in Appendix P.

- "firm selection"
- "probable selection"
- "unlikely"
- "rejected"

The expectation was that the "firm selections" would be taken through to Stage 2 and "rejected" challenges would not as their evaluations were quite clear. It was anticipated that the "probable selections" would also be taken through to Stage 2 and the "unlikely" challenges would not, but these may benefit from further consideration. In general, it was

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[74] Attendees comprised the following: ETI (Nick Eraut, Liam Lidstone and Alex Buckman), ETI Review Panel (Peter Mildenstein, Natalie Miles, Grant Tuff, James Welter and Alasdair Young), Project Team (Andrew Cripps, Tim Hall, David Ross and Paul Woods)
[75] Based on feedback from workshop attendees, post the two WP3 workshops, 'effort' has been split into two distinct components for clarity.
[76] These criteria are described further in the WP1 report – in particular describing core, secondary and marginal aspects of this project.

considered that key elements of the challenges not taken through to Stage 2 can be covered by those challenges taken through, but with less individual focus.

A prioritised list of eight challenges was agreed at a second WP3 workshop held on the 15th March 2016. This similarly comprised representatives of the project team, ETI and ETI's review panel77. These challenges were those categorised as "firm selection" or "probable selection" from the first WP3 workshop. These are listed below.

i. System Design Architecture
ii. Civil Engineering CAPEX
iii. Materials & Equipment CAPEX
iv. Labour and Installation CAPEX
v. Network OPEX
vi. New Network Income
vii. Value Proposition Design
viii. New Legal / Commercial / Risk Models

Following further feedback from the ETI outside of the workshop, the eight challenges were reduced to six challenges. The two challenges of "New Legal / Commercial / Risk Models" and "Value Proposition Design" were removed from this list. The ETI considered that these two challenges were not core to the scope of the original work and the project team was not best-suited to addressing the former challenge and it was identified by ETI that another ETI project was already undertaking relevant work around the latter challenge. The issues surrounding these two challenge areas are still important and will be considered when defining the evaluation criteria to identify and develop solutions.

As highlighted earlier, network OPEX is small compared to network CAPEX. Hence, it was agreed with ETI that the challenge of "Network OPEX" is treated as a secondary challenge. This issue will still be considered in the evaluation criteria to identify and develop solutions (e.g. a solution which delivers a 20% reduction in CAPEX and a 20% reduction in OPEX would be evaluated more favourably than a solution which delivers a 20% reduction in CAPEX and no reduction in OPEX, assuming all other attributes are similar).

The project team has reframed two of the remaining challenges. Challenges (ii) and (iii) have been amended to one challenge around internal connections and a separate challenge around pipework. This better manages and focusses the challenges around components of the DH systems i.e. in reviewing improvements to HIU design, the project team will consider together improvements both to reduce capital cost and to make it easier and cheaper to install.

A final list of five challenges is given in Table 30.

- [77] ETI (Nick Eraut, Liam Lidstone, Rebecca Sweeney and Alex Buckman), ETI review panel (Peter Mildenstein, Grant Tuff, James Welter (by telephone) and Alasdair Young), Project Team (Andrew Cripps, Tim Hall, David Ross and Paul Woods)

Table 30: Final list of five challenges

1.	System Design Architecture
2.	Civil Engineering CAPEX
3.	Pipes and Connections CAPEX
4.	Internal Connections CAPEX
5.	New Network Income

To support this understanding, Figure 26 shows the scope of challenges 2 to 4. The diagram below shows a terraced street, but the same principles apply to all typologies.

- “Internal connections” includes the Hydraulic Interface Unit (HIU) and pipes within the building.
- “Pipes and Connections” includes the pipes and their installation, downstream from the Energy Centre to the wall of the building. Hence, this includes the heat main and the link to the customer.
- ‘Civil Engineering’ covers the works needed to dig the trenches and reinstate afterwards, including works in the street, pavement and gardens if any.

Figure 26: Schematic of street layout

These challenges are still quite broad. The Stage 2 plans, presented prior to the Stage Gate Review close-out meeting, will highlight those activities where the project team initially plans to focus its efforts, a resource plan and timetable.

Targets for each challenge are set out in Section 23.2, with initial estimates of resource allocation in Section 23.3.

23.2 Target-Setting for the Stage 2 Challenges

There is no specific target for capital cost reduction in Stage 2. However, as requested by the ETI, some indicative values have been produced to indicate achievability. Targets were proposed for the challenges at the second WP3 workshop and subsequently refined further by the project team. The values and rationales for each target are set out in Table 31. The impacts on the capital costs of the DHN (excluding prelims[78]) can be seen in Table 32.

[78] This analysis of cost reductions excludes prelims. However, those solutions which reduce time on-site are also expected to significantly reduce prelims given that key components include staff and site accommodation which are both time-based.

Table 31: Targets for each Challenge

Challenge	Target	Justification
1 System Design Architecture	10%	The design of district heating has developed over a number of years and is generally seen as a mature technology and so the scope for radical improvements from the overarching design concepts that are covered by the term 'system design architecture' are likely to be limited. However, there are a number of ideas that have already been identified in the literature and research review that are relatively recent and could be significant, especially where they eliminate components entirely. For example: • The term 4th Generation DH covers a range of solutions that are leading to a radical rethink of system design, including aiming for very low temperatures and the use of local micro heat pumps at buildings and a lowering of domestic hot water supply temperatures. • In the UK DECC has funded research into advanced controls to reduce peak demands and hence enable lower flow rates to be used. • Various research projects have shown that there is scope to design with much higher pressure drops and smaller pipes than typical guidance would recommend. This in turn leads to a re-assessment of how pumps are used within the system. • Finally more radical solutions for some types of housing where the DH pipes can be installed externally along the walls, through the roof space or at shallow depth in front gardens could eliminate much of the civil engineering costs. With the wide range of solutions that might be possible under this heading it is difficult to set a suitable target. Although there are some radical ideas that would have a large impact in certain situations this needs to be balanced by the recognition that overall this is a mature technology and so a 10% target has been selected.
2 Civil Engineering CAPEX	25%	**Relevant Total Flow experience** The two examples below highlight the significant potential cost reduction in this space. The first is particularly relevant for civil engineering and the second for the installation of pumping stations or similar network assets. These examples are from more mature industries in the UK than district heating and suggest the potential for similar or greater cost savings for district heating.

Water Company

As part of a pipe laying improvement project for a major UK Water Company, Total Flow helped their client establish that on-site processes were much more complex than the project management team imagined or intended, and on average only 26% of site staff time was adding value to the process.

Collaborative teams, involving engineering and sub-contract site crews, created a current state value stream map and identified opportunities to streamline processes, eliminate waste. The teams developed localised planning and performance monitoring tools.

Within 6 months the teams had achieved an average installation time reduction of 50% and a corresponding 28% reduction in out-turn cost.

Distribution Network Operator

Total Flow was commissioned by a UK Distribution Network Operator (DNO) to establish how “The end to end process of brown field substation design, preparation, construction and commissioning could be improved cost effectively through industrialisation”. Within this context industrialisation was defined as the process of creating a capable, robust, repeatable, sufficient and standardised process to enable value to flow waste-free to customers. The project team identified opportunities to reduce the time on site by up to 60% and the total cost of capital by 25-30%; with significant savings coming from the reduction in city centre road closures.

Work Package 2 technology review

The technology review highlighted a number of areas of further consideration. The cost impacts of these potential areas of solution have not been quantified as yet but they focus on key areas of cost. In particular, these included the greater use of twin pipes which could potentially reduce costs through narrower trench requirements, reusing excavated existing soil as backfill and thus saving cost through not needing to buy and transport large quantities of granular material as well as pay landfill fees, and the use of shallower trenches. Whilst there is some merit in exploring innovation trenchless digging technologies, in combination with real-time, 3D location of the boring tool and its position with respect to installed assets/obstacles, its use may be limited due to issues around costs, design and risks.

Comparison of UK vs Cowi costs

Pipe size	Cowi			Cost model			Difference
	Civils	Pipes	Total	Civils	Pipes	Total	
mm	£/m	£/m	£/m	£/m	£/m	£/m	
100	180	120	300	320	191	511	170%
300	353	529	882	455	646	1104	125%
450	509	764	1,273	496	798	1294	102%

From a comparison of costs with benchmark information provided from Denmark, there is evidence that the greater experience of installation, and potentially also the market size, is resulting in lower installation costs. There is considerable uncertainty in these comparisons, due to the impact of assumptions around ground conditions and difficulty of installations. However the comparison indicates that both of civils and pipe costs are generally lower in Denmark.

Comparison with other utilities

Although the installation of district heating pipes is not dissimilar to the work to install other buried piped services such as gas and water there are important differences. As two pipes are needed with insulation and with spacing between for access, the trench widths are significantly larger. This often means that lane closures are necessary and traffic management costs increase. The additional trench width also means that it is difficult to find a clear route that avoids other services. This in turn means that the pipes have to be laid at a greater depth to find a route below other services increasing costs significantly because of the need for trench supports. Finally for the steel pre-insulated systems welding is needed to join the sections together and in most cases this welding needs to be carried out in the trench and additional access space is needed around the pipes at this point to enable the welder to work. This is in contrast to say polyethylene (PE) gas or water mains where the pipe is flexible, far fewer joints are required and a much narrower trench can be used. These considerations have led to the development of plastic carrier pipes and twin pipes with the aim of providing more flexibility and a narrower trench. However plastic carrier pipes are themselves more costly especially for larger diameters and generally for the smaller diameters they also have a higher heat loss due to the requirements for flexible insulation. Whilst we expect there is some learning from other utilities and that we can explore some techniques such as micro-tunnelling and

			vacuum excavation which are less frequently seen in district heating, the specific issues that arise with district heating may mean that direct transfer of approaches is not easy to achieve.
3	Pipes and Connections CAPEX	35%	**Relevant Total Flow experience** Both of the examples given for Challenge 1 are also relevant here. The first example is explicitly around pipe laying. The second example is around benefits in reducing time on site. **Work Package 2 technology review** This is the area that the technology review provided the least insight. Potential benefits from lower system temperatures and the greater use of plastic pipework (e.g. 4th generation district heating) are included in Challenge 4. There is the potential from improved joints but this appears led by confidential industry research rather than academics. It is likely that value engineering of the installation process will be a key focus here e.g. reviewing opportunities both to save time and use a multi-skilled labour force. **Comparison of UK vs Cowi costs** Challenge 1 discussion above is also relevant to this Challenge.
4	Internal Connections CAPEX	25%	**Relevant Total Flow experience** These two examples highlight the significant potential cost reduction in this space. The first is particularly relevant for existing building retrofit and the second for HIU manufacture. ***Housing energy efficiency retrofit*** Total Flow have reviewed existing housing property retrofit/installation processes and shown these to have less than 35% productive labour time. The project has demonstrated that the adoption of standard work would achieve a 25% productivity increase and has identified opportunities for a 30% further productivity increase with product and process innovation. Conceptual designs have shown that full product and process innovation could potentially reduce time and labour on site by ~50%. ***Combi boiler manufacturer*** Total Flow conducted operations reviews in several factories belonging to an internationally-known

		combi boiler manufacturer. These identified significant waste in direct labour activities and the conclusion was that elimination of waste through adoption of lean manufacturing principles could improve productivity by 25%. Inventory was reduced by 97% and throughput times went from 6 weeks to same day in assembly. **Work Package 2 technology review** The international comparison particularly highlighted alternative architecture around the use of HIUs (cross-over with Challenge 4). The approach often taken in Denmark and Sweden is to have centralised domestic hot water for a block(s) of apartments or a group of terraced housing, rather than an HIU per individual house as is the case in the UK. Direct connection is also more prevalent in Denmark and one challenge here is to find a solution to the perceived risks of wider damage if leaks occur within the building heating system. The review also particularly highlighted many relatively small HIU suppliers, each providing tailored solutions to clients. There are benefits around standardisation of technology and components across industry. Other key innovations highlighted particularly focus around the improved control of HIUs. These are particularly focussed around operating costs but could impact on capital costs through, for example, reduced system capacity required and thus smaller pipes and/or smaller sized heat generation plant. **Comparison of UK vs Cowi costs** The prices are broadly similar between the UK and Denmark. The price of the HIU used in the cost model is around £2100 (supply and install). Cowi suggests that equivalent prices range from £1500 to £2500, with the price of buying centrally from the DH supply company coming towards the lower end. Allowing for ±10% price variation for the UK, it may be that the best Danish prices are 10-20% lower. This could be explored further in Stage 2, noting the need to allow for currency fluctuations and differences in standards of living and thus labour costs. It had been expected that the costs may be significantly lower in Denmark due to economies of scale. However, it is possible that this may be tempered by the fact that an HIU is not typically installed in every home. Cowi noted that Scandinavia tends to operate as a single market i.e. the

		price for HIUs (at least for the supply of the unit itself which comprises most of the cost) is expected to be fairly consistent across Scandinavia.
5 New Network Income Estimated potential for 5% CAPEX saving based on reduced civils cost through shared trenching and reinstatement.	5%	It is envisaged increasing network revenues may be achieved in three ways: 1. Achieving higher than expected consumer take-up from the original network or small scale expansion It would be speculative to estimate a potential increase in network take-up beyond the launch, but in Stage 2 the Project Team can assess the typical potential un-utilised capacity in existing networks and the cost implications of making additional connections. 2. Offsetting capital cost by shared civil engineering; linked to new infrastructure or renewal of existing sub-soil utilities (gas, electricity, water, sewerage, data, Sustainable Urban Drainage Systems – SUDS) Total Flow's past work with Water companies reveals that 80% of pipe laying and renewal cost is in the trenching and reinstatement. The opportunity to defray some of these costs through shared civil engineering would be highly attractive commercially for Water, Gas, Electricity and Data infrastructure providers. There are technical and commercial challenges for combined trenching but worthy of investigation. To quantify the potential: Identifying opportunities to share the cost (50%) of the trenching work across 10% of the main pipe network would reduce total civil engineering cost by 5%. This is a realistic target once a relationship can be established between the development organisation and local Water Companies, Distribution Network Operators and Telecoms/data providers. Where there is a requirement for flood risk mitigation and plans for Sustainable Urban Drainage System (SUDS) there is a significant opportunity for innovation and civils cost sharing. 3. On-going rental of installed ducts to third parties. At this stage of the project the team is aware of cabled data and telecoms providers who pay on-going fees to install their systems in existing sewerage pipes and other ducts. There is potential interest in linking with a DHN roll-out to provide high-speed data to residences and businesses on a 'duct rental' model. This is worthy of further exploration, but there is insufficient detail or breadth of insight to be able to identify the scale of application or

		potential revenue levels.

Table 32: DHN capital cost reductions from achieving the targets

Challenge	Target	Saving
System Design Architecture	10% reduction of total cost	10%
Civil Engineering CAPEX	25% of civil engineering CAPEX. Civil engineering CAPEX forms 41% of total CAPEX from Table 29 To avoid double counting, reduce total CAPEX by 10% from system architecture first	90% x 25% x 41% = **9%**
Pipes and Connections CAPEX	35% of pipes and components CAPEX. Pipes and components CAPEX forms 17% of total CAPEX from Table 29 To avoid double counting, reduce total CAPEX by 10% from system architecture first	90% x 35% x 17% = **5%**
Internal Connections CAPEX	25% of internal connections CAPEX. Internal connections (including HIU) CAPEX forms 31% of total CAPEX from Table 29 To avoid double counting, reduce total CAPEX by 10% from system architecture first	90% x 25% x 31% = **7%**
New Network Income	Offsetting CAPEX with shared trenching and other civils works. 50% saving across 10% of the network pipeline length or equivalent. Note that the new revenue streams themselves are conservatively not included here.	90% x 35% x 5% = 1.6%
	Total Saving =	33%

23.3 Resource Allocation for the Stage 2 Challenges

The following is initially allocated:

- 10% of resources are focused on “New Network Income”
- The resource allocation for the remaining four challenges is proportional to the percentage projected cost savings in percentage projected cost savings in Table 31.

This allocation will be refined based on the work programme and resources plan being prepared for Stage 2 and to be circulated in advance of the Stage Gate Review close-out meeting. ETI is to make the final decision on the distribution of resources across challenges.

24 Template to capture details on solutions

24.1 Full set of information to be captured in the solution template

The solution review needs to capture information both to record key learning as well as to enable the solutions to be assessed and ranked.

- Solutions will initially be assessed and filtered during WP4 and WP5 to focus resources on the most promising solutions. Solutions will then be assessed in more detail in WP6 to determine those to be taken forward to WP7.
- It is useful to record information in Stage 2 that will be necessary for the route-mapping of solution development in Stage 3 to save duplication of effort. However this needs to be limited to capturing information that is readily available during Stage 2 activities, rather than employing resources on any additional investigations, as the majority of solutions considered during Stage 2 are not anticipated to be progressed to Stage 3.

The template is shown in Table **33**. Text in *italics* is for information only to aid completion and will not be included in the completed template. It builds from (and should be read together with) the evaluation criteria list from Part A of this Deliverable. Part A also includes a checklist to support the evaluation.

In practice, it is expected that many solutions will be quite specific and the information recorded will focus on only a few items only in the template. A redesign of the network system architecture, say, is likely to result in greater impact throughout the template.

24.2 Evaluation during Stage 2

Solutions will be assessed and filtered during Stage 2 to focus resources on the most promising solutions. This will be based on early information captured in the template, but the full template will not need to be completed at this stage. This early evaluation will be based on judgements of value and effort as described in Part A of this Deliverable.

It is intended that those solutions filtered out, will be captured in an Excel spreadsheet for regular review as to their potential benefits that might arise from synergies with other solutions. For example, solutions put aside may be more attractive when combined together with other solutions or may enable other solutions to gain greater value. The spreadsheet will include a description of the solution as well as the value and effort of evaluation.

Table 33: Solution Template

Solution Title Name of evaluator(s):	Solution ID: X/YY (X relates to the Challenge Number and YY to the particular solution)	Evaluation Rating
General		
Description of solution	A sufficient description of the solution to support its evaluation below.	
How the solution was identified	Any specific inspirations, triggers, discussions, pieces of analyses, comparisons with other industries etc	
Capital cost		
Change relative to baseline CAPEX	Costs of the DH **Network** • This should include description of significant changes in cost. It should also include quantitative details of cost changes and how they were calculated. Costs of the DH **System** • This should include description of significant changes in cost. It should also include quantitative details of cost changes and how they were calculated.	Costs generated by cost model
Certainty of outcomes		
Certainty of outcomes	This should consider changes in certainty based on • Improved confidence in capital cost • More certain and/or shorter programme • Increased confidence in user take-up • Greater certainty of revenue This would be expected to be a qualitative description, contrasting differences to current DHN systems.	Qualitative evaluation (-2, -1, 0, +1, +2)
Operational cost		
Change relative to baseline	Costs of the DH **Network** • This should include description of significant changes in cost. It should also include quantitative	Costs generated by cost model

OPEX	details of cost changes and how they were calculated. Costs of the DH **System** • This should include description of significant changes in cost. It should also include quantitative details of cost changes and how they were calculated.	
Lifecycle costs		
Change relative to baseline lifecycle costs	Costs of the DH **Network** • This should include description of significant changes in cost. It should also include quantitative details of cost changes and how they were calculated. Costs of the DH **System** • This should include description of significant changes in cost. It should also include quantitative details of cost changes and how they were calculated.	Costs generated by cost model
System performance		
Impact on DHN performance	This should capture the potential impact on the operation, performance or other aspects of the DHN. This includes (i) thermal efficiency *(ii) system reliability (i.e.* change in time between failures & mean time to repair) (iii) potential to be effective at lower system temperature (iv) Ability to assure supply at times of peak demand (v) Responsiveness to demand This should be a qualitative description with quantitative estimates where relevant and available. This is in contrast to current DHN systems.	Qualitative evaluation (-2, -1, 0, +1, +2)
Future flexibility	This should capture the potential impact on the future flexibility of heat networks. This would be expected to include: (i) adaptable to a range of input heat sources (ii) capacity for reduced or variable temperatures (iii) options to extend and interconnect This would be expected to be a qualitative description, contrasting differences to current DHN systems.	Qualitative evaluation (-2, -1, 0, +1, +2)

Attractive to Users & Investors		
Attractiveness to Users and Investors	This should capture the change in attractiveness of district heating to users and investors. This includes factors such as: (i) heat / hot water cost & maintenance vs. current (ii) confidence to switch: Attractive Simple, low risk (iii) installation / changeover disruption (iv) heat / hot water capacity and responsiveness vs. current (v) additional value for users and investors. This would be expected to be a qualitative description, contrasting differences to current DHN systems.	Qualitative evaluation (-2, -1, 0, +1, +2)
Reduced Complexity		
Complexity	This should capture the impact on transaction complexity and the relative difficulty of implementing DHNs, giving an improved proposition for Investors. For example, reduced complexity could include: (i) product - shift from bespoke design towards product (ii) procurement - Simple transactions for consumers and investors	Qualitative evaluation (-2, -1, 0, +1, +2)
Health, Safety and Environmental Impacts		
HSE	This should consider both the likelihood and impact of issues around health, safety and environment associated with this solution. This would be expected to be a qualitative description, contrasting differences to current DHN systems.	Qualitative evaluation (-2, -1, 0, +1, +2)
Opportunity to scale		
Scope of opportunity	This should capture where the solution is particularly well-suited or where there are constraints. It includes consideration of suitability to different types of DHN, location, environment, ground condition, geography, application, building type, etc. This would including considering the suitability for the five typologies: (i) Typology A - City Centre Commercial Buildings (ii) Typology B - High Density Flats (iii) Typology C - High Density Terraced Houses	Qualitative evaluation (-2, -1, 0, +1, +2)

	(iv) Typology D - Medium Density Residential (v) Typology E - Low Density Residential This should include any relevant differences between the UK and other countries which affect its suitability for deployment in the UK or export solution to other countries This would be expected to be a qualitative description, contrasting differences to current DHN systems.	
Increased Revenue		
Potential for synergies	This should capture potential synergies with other sub-surface infrastructure (such as gas, hydrogen and electricity networks) and recommendations as to how these synergies could be exploited. This could include reductions in capital cost or additional revenue streams. For example: (i) Shared Civils - Offset Capex with shared civils / trenching (ii) Trench Revenue - Revenue from installed pipes, ducts, wires or fibres (iii) Electricity sales - External electricity sales and demand side response (DSR) (iv) New service offering - Additional revenue opportunities This would be expected to be a qualitative description.	Qualitative evaluation (-2, -1, 0, +1, +2)
UK plc external Stakeholder Value		
Value for the UK	This should capture the benefit to the UK from improved CO_2 and economic performance. Issues to consider include the following. (i) CO_2 Budget Impact – Will this solution save significant amounts of CO_2? (ii) Policy Impact – Will this solution require minimal policy change? (iii) UK benefit for jobs – Will this solution result in a significant increase in jobs or job security? (iv) Potential for export - Might this solution enable increased UK Export? This would be expected to be a qualitative description.	Qualitative evaluation (-2, -1, 0, +1, +2)
Technical feasibility		
Technical feasibility	This should capture issues around the technical feasibility of the solution and any implications for commonality of technical standards.	Qualitative evaluation (-2, -1, 0, +1, +2)

	This should include: (i) Technical feasibility - How near market is the solution? (ii) Standards - Any implications for commonality of technical standards? This would be expected to be a qualitative description.	
Effort to Implement Solution		
Effort	• Effort, including consideration of • Investment capital and research required (<=£500k, £500k- £5M, £5M+) • Level of technological innovation (uncertainty), technology readiness level (TRL 10-7, 6-4, 3-1) • Anticipated timescale to the point where the solution is delivering value (<=2yrs, 2-5yrs ,5yrs+) • Likelihood of success – qualitative assessment (probable, possible, unlikely) • • This would be expected to be a qualitative description.	Qualitative evaluation (+1,+2, +3, +4, +5)
Other		
Any additional equipment required	Based on what is known at this stage, highlight any new equipment that may be required to deliver the innovation (e.g. specific innovation to drilling equipment). This would be expected to be a qualitative description.	
Barriers	Bullet point list of other potential barriers identified at this stage not addressed above. This includes highlighting any known potential IPR issues. This would be expected to be a qualitative description	

25 Conclusions

This section summarises the insights from the WP3 workshops and research, confirming the challenges and potential improvement to take forward to Stage 2 of the project: Solution Development.

25.1 Findings from WP1 & WP2

The review of findings from WP1 and WP2 has identified key gaps between current DHN capability and stakeholder requirements, including areas of disproportionate cost and risk within the current DHN framework. This gives a baseline of cost and performance to select the key challenges which, once addressed, would have a significant impact on DHN costs and viability.

WP2 identified a number of potential areas for solutions that could be applied to help reduce the capital cost of networks. These are based on a combination of a comparison with practice in other countries, recent academic research work and activities within the industries that support DH.

25.2 Challenges

Through the workshop process and additional research, the Project Team and ETI stakeholders have identified five key challenge areas for reducing capital cost of DHNs. Each challenge has an indicative target based on results achieved in similar projects, or based on the identified potential:

- 10% reduction in total district heat network CAPEX from changes to System Design Architecture
- 25% reduction in Civil Engineering CAPEX
- 35% reduction in Pipe and Connections CAPEX
- 25% reduction in Internal Connections CAPEX
- New Network Income: 5% of Civil Engineering CAPEX offset from external revenue.

In addition to the capital costs the Project Team will target savings in Operational cost which can be delivered in parallel.

Whilst the challenges are still quite broad further detailed opportunities have already been identified and these will be developed in Stage 2: Solution Development.

The challenges have been set out to reduce the risk of the approach to solutions being too narrow or siloed. This results in having a broad challenge on e.g. civil engineering costs rather than a specific, ‘e.g. finding a solution to breaking the road surface at lower cost’. The project team will work on a range of possible solutions to this overall challenge. In addition, the work on the different challenges will be integrated to ensure that the solutions in one area do not cause problems in another, and that whole system solutions are not ignored.

25.3 Solution Details and Evaluation

Section 24 has presented a standard template to capture details of solutions during Stage 2. This will support the:

(i) evaluation of solutions in Stage 2, and
(ii) capture information that is easily accessible in Stage 2 to help enable the production of route maps during Stage 3

This also links to the evaluation criteria developed in Work Package 1.

25.4 Summary

This report has described the process by which the Project Team has agreed the key challenges to be addressed in Stage 2. Whilst there is no specific target reduction, indicative targets have been identified for each challenge area based on results achieved in similar projects, or based on the identified potential to date, and together total a 33% reduction in the costs of heat networks.

26 Appendix A: Stakeholder Workshop

The stakeholder workshop was a half day event on the 4th February 2016 with 27 invitees from DHN design, development, operation and supplier organisations, ETI, members of the ETI review panel and the Project team.

With the emerging challenges arising from the desk based and direct research, it was important to minimise the risk of pre-empting results and guiding participants to particular conclusions. To achieve this, the workshop was structured to build requirements, priorities, opportunities and challenges from first principles.

Following the introduction and overview of the process the workshop was split into 3 phases:

- Assessment of User and Investor stakeholder requirements: as described in Section 6.
- Challenges and Opportunities for DHN: as described in Section 7.
- Physical System & Supply Chain Challenges: Materials, labour & physical processes.
- Wider Value Chain Challenges: Design, legal, commercial & consumer engagement.
- More detailed discussion with a smaller group able to commit time in an afternoon session.

Workshop Attendees

Details of workshop attendees are provided in the table below.

Role	Name
DECC – Heat Networks Delivery Unit	Charlotte Large
Battersea Power Station Development Company - Technical Director	Gary Edwards
E.On - Principal City Design Engineer	Connell McNelis
Options Energy	John Flannery
Pinnacle Heat	Peter Mildenstein
Buro Happold	Alasdair Young
DECC – Heat Networks Policy	Natalie Miles
Ramboll	John O'Shea
Vital Energi - Group Sales & Strategy Director	Nick Gosling
Vital Energi - Services & Design Director	Paul Kaye
Vanguards Network	Michael King
CAG Consulting	Bill Kirkup
ETI – Smart Systems Senior Analyst	Grant Tuff
ETI – Strategy Manager	Liam Lidstone
ETI – Programme Manager	Nick Eraut
AECOM Associate	Robin Wiltshire
Engie (Cofely) Head of Energy Partnerships - East London	Paul Woods
Engie	Andrew Simms
AECOM Regional Director	Andrew Cripps
AECOM Regional Director Sustainability	Peter Concannon
AECOM	Lucy Pemble
Total Flow	Ian McDuff
Total Flow – Project Chief Innovation Officer	Tim Hall
Total Flow - Consultant	Simon Box
AECOM	Miles Attenborough
AECOM	Andrew Turton
AECOM	David Ross
Total Attendees:	27

26.1 Workshop Agenda

- Scene Setting, Introductions
- Background - Nick Eraut, ETI
- Introduction to the Workshop Approach - Tim Hall, Total Flow
- Stakeholder Requirements Analysis - split into 2 groups:
- Users – Tenants, Landlords, Owner Occupiers
- Investors – Local Authorities, Network Developers, 3rd Party Investors
- Challenges & Opportunities for DHN - split into 2 groups:
- Physical System – Pipes, Pumping, Civil engineering, Controls
- Value Chain – Design, Planning, Consents
- Plenary Feedback and Discussion.
- Next Steps and opportunities for further engagement.
- Afternoon session covering additional detail for a smaller group.

26.2 Distilled Workshop Outputs

User Requirements

One group reviewed the requirements of Users (consumers and landlords) :

- Occupiers (Tenants)
- Owner Occupiers (owners)
- Social Landlords (Domestic) - Split into: Local Authority and Housing Trust
- Private Landlords (domestic)
- Private Landlords (Large Domestic 30+)
- Landlords (commercial)
- Commercial Tenants
- Other Commercial – Public Sector

User requirements were analysed using five key aspects of a value proposition:

- **Performance / Specification** – Features and benefits of the full DHN offering
- **Speed** – Time taken to deliver the DHN, or time to respond during service
- **Dependability** - Reliability of the offering vs. expectation or counter-factual solutions
- **Flexibility** - Ability to adapt to the potential future needs of each stakeholder
- **Cost** – Whole life cost of the system (referred to as TOTEX in utilities)

Points to note:

- What is the selling point of DHN? Why change? Comfort? Control? Make it do what you want it to do?
- No disruption is wanted. Avoid the need to replace all radiators and plumbing in house.
- Local Authorities want the flexibility to join up networks.
- Be flexible in the heat supplier.
- Heating should maintain property value, not erode it.
- Choice: whole street or individual? Clusters?

Investor Requirements

A second group reviewed the requirements of the Investor group. The first task being to identify the different types of investors associated with DHNs:

- Local Authorities
- Heat Network Developers

- Self-Funders
- Third Party Investors
- Green Investment Bank
- Housing Developers
- Housing Associations / Registered Social Landlords
- Co-operative Networks – Not for profit, possibly community groups
- The UK Government

Investor requirements were analysed using five key aspects of a value proposition with adapted definitions to suit their particular requirements:

- **Specification** for investors includes: Return on Investment (RoI) & Investment duration:
- **Speed** is reflected in the time necessary to generate positive cash-flow (impacting risk).
- **Dependability** is the risk of the investment: lower risk projects will support a lower RoI or IRR
- **Flexibility** is reflected in the ability to expand the network & investment – without penalty. Investors want options to expand networks but are unwilling to increase upfront investment.
- **Cost / Price** are the relative scales of investment (e.g.: 3rd party investors are looking for larger scale investments than self-funders)

Points highlighted during the discussion:

- The priority of cost reductions should be around CAPEX and extending design lifetimes.
- Investors are often too focussed on CAPEX.
- For Local Authorities carbon saving is regarded as less of a driver for DHNs than fuel poverty and regeneration
- Permissions – utility rights and obtaining licenses is a challenge.
- Averaging about 2 years development time before the project starts. This time is spent going over the legals which attracts disproportionate cost, especially on small projects.
  3 years before work starts on site is not uncommon – this should be simplified.
- Commercial contracts that are standardised to a certain extent could help reduce cost.
- There is no one size fits all DHN; therefore costs are not as low as with mass production.
- Investors don't always want options for future connections to their DHNs because this is seen as increasing cost and risk.

Challenges and Opportunities

The second section of the workshop was to review the Challenges and Opportunities of the DHN Supply Chain and Value Chain: focusing on areas which attract disproportionate cost or risk.

System & Supply Chain

One group reviewed component and process groups for DHN delivery comprising:

- Main Pipeline (straight, bends, joints, Ts)
- Pumping
- Manifolds
- System Controls
- Metering
- Civils: Trench
- Branch Pipe
- Valves
- Building Risers
- Heat Storage
- HIUs and Consumers
- Civils: Reinstatement

- Tunnelling and Boring
- Civils: Other Utilities
- Bedding and Backfill
- Operation and Maintenance

General Points to Note:

- There is a high cost of connections compared to that of pipes.
- Twin pipes which are being increasingly used outside of the UK may be problematic here due to underground services. Easier to route separate supply and return pipes around obstacles.
- One DH company highlighted that they had undertaken a benchmarking exercise of their practices with those of Scandinavia to look to identify the potential for cost reductions. However, the practices and technologies reviewed were similar to the UK.
- The cost of prepayment is disproportionate
- Risk appetite – total system view? Makes it difficult to compare different bids.
- The image of DH should be better
- It should be easier to switch suppliers
- DH should not have a negative impact on property value

Value Chain Challenges and Opportunities

The second group reviewed the wider Value Chain which includes:

- Engagement, Marketing and Site ID
- Concept
- Masterplanning
- Feasibility
- Legal Advice, Governance
- Detailed Design
- Consent and Planning
- Tender and Contract
- Prelims & Site Overhead
- Enabling Work
- Testing and Commissioning

General Points to Note:

- Sharing trenches should in theory reduce cost, but no stakeholders seemed to have seen proof of this. In some cases, having to liaise with different trench users added unnecessary complexity.
- Problems in testing and commissioning tend to be caused by the diversity of buildings being connected – as each one is different there are additional complexities with retrofitting.
- In the early stage of a project, costs are less certain and less tightly controlled as a result of many variables in topics and insufficient data.
- Heat supply contract templates would be welcome – any standardisation would reduce costs.
- Improved data at the detailed design stage is an opportunity to reduce uncertainty and cost, as currently a margin of fee is added to cover estimations of risk.
- Information on energy usage should be made readily available to reduce the time and effort involved in gathering the building user's data (commercial property). DECC have this data but they are unable to pass on to network developers.
  In Denmark all the data is freely available.
- The heat mapping element of feasibility studies could be fulfilled with software if it was further developed. This would reduce cost and duplication and also the role (& fees) of consultants.

Close

- To some extent cost changes with the temperature of the DH network.
- There's a general lack of trained (and expert) installers.
- Systems are over-engineered in an attempt to lower risk – this adds cost.
- The whole image of DH needs to change, so that we can better sell it
- Why is it that UK DH pipe costs 2.5 x the price of that in Denmark? Research is in process.
- Feedback: It was good to have a diversity of stakeholders in today's meeting
- Feedback: Some straying off topic in today's discussions, but that hasn't always been a bad thing.
- Feedback: good to have a broad collection of people
- Feedback: Discussions were general, examples and photographs would've been good aids of discussion and would've encouraged me to contribute more
- Feedback: We are reducing the cost by 40% but what is the baseline cost? How do we define this?

Post lunch discussions

Attendees:	Tim Hall (Total Flow)	Simon Box (Total Flow)
Andy Simms (Cofely/Engie)	David Ross (AECOM)	Robin Wiltshire (AECOM Associate)
Andrew Turton (AECOM)	Andrew Cripps (AECOM)	Lucy Pemble (AECOM)
Natalie Miles (DECC)	Nick Eraut (ETI)	John Flannery (Options Energy)

- Suppliers in Scandinavia are waiting to join the UK market when the time is right. Therefore the cost of pipes might be lowered at one point.
- Pipe products are made in Poland, shipped to Sweden – UK costs should not be higher.
- The diverse roles of stakeholders at this workshop may have limited participants' willingness to be candid about the challenges and opportunities: competitors & clients in the discussion.
- EnergyPath software from the ETI works with maps and models of buildings and their energy demand to help optimise energy networks locally.
- UK skills shortages: installers (civils & installing pipes), designers, specifiers. Do we need these skills? Should it be industrialised vs craft based?
- Aim for a standardised product not a bespoke engineering project.
- Over-engineering exists to de-risk system performance at the expense of increased cost. Should there be a penalty for over-engineering rather than just guidance?
- Clients have little knowledge of what they want and what they can buy - therefore there is higher legal and procurement cost.
- What does the customer need to know? And want to know? In simple layman's terms.
- Limited supplier base and competition means higher cost.
- The size of the market is unclear. Annual spend is uncertain.
- More communication needs to be in place to eliminate lots of changes throughout DHN delivery and therefore cost e.g. between the civil workers and the designers of the scheme
- Lack of flexibility in pipework routing with steel pipework, particularly when it meets another service underground.
- Legal standards, commercial standards
- Water treatment (affects pipe lifetime), important to get right. Scandinavia has the opportunity to carry out bits of system design, and lessons learnt, to use on new

works.
Common elements and components are the way to go. Standard designs + modular designs.

- Who's in control of the overall process? Big question
- Off-the-shelf answers would be cheaper
- Programme Management is crucial.
- There is significant difference in understanding of different DHN stakeholders
- The client doesn't really know what he wants, making it difficult for the contractor to deliver
- Perceived value: people will pay more where they think something is worth more.
- Difficult to justify why DHNs are so much more expensive than water networks.
- BIM type model for DH: RFID tags in components enabling effective Kanban of material to site and ease of future maintenance.
- What would enthral DECC to fund testing an innovative idea? Natalie Miles to feed back.
- There is a challenge to get communities to collaborate en-masse to join a DHN.
- Setting up a small network and scaling gradually would have a greater chance of consumer success in take-up. Is this technically feasible?

Close

27 Appendix B: Stakeholder Feedback

Householders

Three occupants (all with an above average interest in energy efficiency and participating in other energy efficiency research) were interviewed to explore their perception of DHNs and the suitability for their home. Two were social housing tenants and one was an owner-occupier.

Key points identified from discussions.

- All thought that Heat networks were ideas from the past rather than the future – hence not a positive brand image. However, having had the principles outlined, they were happy to consider the proposition.
- All assume a low-carbon solution is more energy efficient and will work out cheaper.
- There would need to be a guarantee that any new heating system would have the same or cheaper cost, particularly if connecting required a long term commitment.
- There should be minimum disruption to the residents.
- Ease of access for maintenance (for tenants)
- Ideally, looking for a solution where water from the hot tank never ran out.

Some key quotes as follows

Dartford **Social Housing Tenants**: Retired Couple, Interviewed during property Retrofit. [Tenant]

‘It’s the Housing Association which decides the heating, but if they changed it, the bills would have to be guaranteed the same or cheaper or I’m not having it.’

‘If you’ve got to install a new pipe it had better not disrupt my front garden. That’s taken years’

Gloucestershire **Social Housing Tenants**: [Tenant]

Interviewed as a family interested in energy efficiency. Extended Family, 2 adults, 2 young adult children + 1 partner + 1 toddler.

‘We’re happy with the system we’ve got – It’s never broken down. We sometimes run out of hot water if all the family is at home and has a shower; it would be good if the hot tank never ran out. If it’s more energy efficient – that would mean our bills would be cheaper, wouldn’t it? How can you prove it? The Association is really picky about getting the boiler serviced every year and I have to make sure one of us is at home.’

Yorkshire **Owner Occupier** Family: 2 Adults, 2 Young adults, [OwnO]

Interviewed during property Retrofit.

‘This insulation has made the house more cosy and our bills are a bit lower. Would this district heating make it cheaper still? I wouldn’t be happy signing up for ever – we were being ripped off on gas and electric by [Big 6 Company] until we switched. It would be good if I could turn the heating down from my phone – the girls keep setting it ridiculously hot’.

<u>Registered Social Landlords</u> [RSL]

A discussion was held with 4 Directors (as a group) and interviews with 2 sustainability managers. The social landlords represented Catalyst, East Thames, Circle, Peabody and Genesis.

The key insight from these discussions is that the current requirement for London housing associations to include Communal Heat or District Heat within their housing developments is seen as a major burden and a blockage on development. The underlying reasons are:

i) A lack of credible and cost-effective providers to support the specification, design and construction of community level heating.
ii) The major technical under-performance of existing DH schemes, leading to tenants being burdened by excessive bills for heating.
iii) Disproportionate time and effort required to specify and procure heat networks, when compared with individual household boilers.
iv) Difficulties in operating systems leading to high operating costs

Some key quotes as follows

- “We are putting a paper together to resist the London requirement for district /communal heating in our properties, because it disadvantages our tenants with higher bills and damages our reputation.”
- “Maintenance of heating and electrics is the biggest proportion for Asset Management budgets and getting property access to service boilers is a significant cost and problem. Not to mention the no-fault call outs for engineers.”
- “Tenants tell us that their neighbours (off the network) are paying a lot less per month than they are.”
- “The metered bills through the ESCO are considerably higher than we expected”.
- “If we could piggyback on a larger scheme I still think there is value in district heat, but we just don’t have the resource.”
- “The Biomass boiler was a disaster; it never ran successfully and managing pellet delivery was a challenge and so we have decided to switch it off permanently. I can’t believe I’ve back-tracked on my sustainability plan – but it just didn’t do what we needed.”
- “There was virtually no insulation in the risers causing huge heat losses almost warming the cold supply! Even after retrofitting lagging the tenants complained about the heat in summer.”
- “Getting advice for the [communal heating] system design was costly and time consuming.”

<u>Private Landlord</u> [PriLL]

A buy to let investor with 4 properties rented predominantly to students. His perception was that DHNs were an unsuccessful experiment from the era of communist Eastern Europe.

- Heating systems tend to cause the greatest problems in all properties.
- When the tenants are new there is frequently a need for multiple visits to help when they can’t work out how to operate the controls.
- Once a boiler starts proving genuinely unreliable it is best to bite the bullet and replace it; costs of gas fitter call-out and unhappy tenants are a higher price to pay.
- Gas safe certification is not difficult with students as the properties are often changing tenants in September and I can get multiple tests done at the same time more cost effectively.

- It would be brilliant if I could provide a remote diagnosis when tenants have a problem.
- Changing to a district heat system might be appealing if it had less to go wrong and there was an all-inclusive lease option – *but I'd have to be sure of the numbers over a 5-year period.*

Local Authorities and Commercial Network Developers

County Local Authority embarking on a Countywide DHN Partnership [LA1]

- Our initial thought was to test the water with a single scheme in the County Town, but the lack of internal expertise would have involved a disproportionate advisor / consultant costs.
- We decided to tackle a full OJEU process and tender for a residential / industrial County wide programme and framework including some off gas-grid communities in fuel poverty.
- We have chosen a partner that we believe is both capable and understands our needs. It is a risk putting all our eggs in one basket, but better that sitting on our hands and doing nothing, or spending time and money exploring multiple options which we are not expert to evaluate.

London Borough preparing a 3 DHN Regeneration Programme [LA2]

Plans to put DHN at the centre of a 3 site regeneration plan. Connecting 5,000 new buildings to central heat provision, whilst exploring options to connect existing buildings.

- The Heat Network Programme is down to the determination of the Council Leader and the Chief Executive: without their efforts we would have lost faith very early on.
- It's a shame we don't have more, large, old and leaky municipal buildings which would make absolute economic sense as base loads. Even so we believe integrated heat is right for us.
- A good proportion of finance is secured at 4.5% from the Public Works Loan Board (PWLB).
- The lack of regulation of heat supply is a prime focus in negotiating the ESCo contracts.
- Heat load from new residential and commercial buildings is a big uncertainty in the model.
- If we weren't a rock solid [Party] seat, the CEO wouldn't have got the political backing for DHN
- By the time we get started it will have taken 3-5 years of planning: Heat is part of the delay.
- One thing that would make our job easier is to get clarity on the DCLG definition of Zero Carbon Buildings

Municipal Local Authority to integrating DHN thinking as part of its strategic plan [LA3]

- To minimise the number of OJEU procurement exercises we have decided to tender for a full joint venture for energy (including DHN), climate change, transport and other infrastructure.
- Our intention is to spin-out an energy focused SPV with the ambition to spread the use of DH.
- Heat network technology and procurement is complex; we are at the start of a long journey.

Investors

Large Insurer / Pension Fund. [Pension]

- For a robust business case in residential property we'd be happy to invest with a return of 3.9%.Our frustration with construction projects is the lack of certainty of programme and outturn cost.
- Our preference is for larger deals (say £100M) which defray the commercial and legal effort.
- In principle a DH scheme would fit with our portfolio, but it would need to be linked with the property ownership and long term rental.
- We'd need to find an alternative way through any commercial and legal complexity – it is not in our interest to get involved in protracted discussions.

Commercial Property Developer [CD1]

- There is major potential from pursuing a standardisation agenda for Heat Meter designs, pipes, equipment and communications. This will improve speed and cost; design and delivery.
- Developers are still concerned that heat is an un-regulated sector (unlike other utilities) and has a history of underperformance against design. Improving confidence in outcomes is vital.
- Currently there may be a need to cross-subsidise the cost of the residential heat network from the broader development fund to avoid an excessive burden on the future ESCO or residents. This makes like for like cost comparison difficult.
- There are solutions for most projects, but identifying them requires very technical resource.
- The pipe cost of including a connection point to another network is not high: The complexity comes in the pricing of heat and commercial arrangements between two networks.
- District Heat is becoming more attractive to new-build developers for multiple reasons:
- Development Carbon credits.
- Gas safety becoming costly and difficult to design into new commercial buildings
- Improved Corporate image
- Selling power from CHP units should be straightforward to manage, but both technical and pricing issues seem to be what makes the process difficult.
- Pre-site design and development takes too long: 6 months to agree solutions and 6 months to get to contract. The industry is not yet stable enough to consider partnering with one supplier.
- The idea of shared civil works costs is well worth pursuing; There is significant duplication on new-build sites; sometimes using the same civil specialists.
- ESCOs are looking for Rates of Return of 11%-12%
- Managing Risk is important; Heat Network Operation is best managed by a specialist ESCO. Construction programme by the developer or contractor.

Commercial Property Developer [CD2]

- Lengthy DHN contract negotiations get close to being on the masterplan critical path.
- Contractual complexity is frustrating and there must be a better way to commission DHN
- Assessing future heat load seems very speculative – it is certainly not an exact science
- Without being a technical expert; I do see that systems risk being over-specified.
- Based on experience from other residential developers there are cynical approaches to the London requirement for Decentralised Energy:
- Many see DHN requirement as a tax on development and purely a burden
- Developers may aim for minimum compliance without an interest in DHN benefits

- Network performance is not a consideration as they plan to sell the entire system

Heat Network Developer / Operator Commercial Lead [HND]

- Aspects of heat network delivery seem to attract excessive cost: The consumer interface (HIU) and associated metering is a case in point: Why is a simple appliance so costly?
- The contractual, legal and planning burden takes considerable resource and causes significant delay as a result of understaffing in public bodies and regulated industries which have little incentive to proceed rapidly.

Industry Experts

Co-Convenor of District Energy Vanguards' Network.

- UK heat networks are impacted by significantly inflated material costs (multiples times Scandinavian prices).
- The off-loading of risk from consultants, through main contractors to sub-contractors, inflates risk provision and margin.
- A buying group in Scandinavia has both demonstrated an opportunity to save significant cost and drive standardisation and innovation in the supply chain (HIU Prices reduced by 30%).
- There is a concern that turnkey developers do not demonstrate the ambition to improve cost of delivery and the lack of visibility of costs means that improvement is at best slow.

DECC [DECC]

- My main take away point is the opportunity to improve by shifting from bespoke schemes to standardised components.
- I looked at all the comments on the boards and it's no wonder local authorities often choose to opt for individual boilers – the complexity and expectations on the client are (too) high.

CAG Consulting [CAG]

- Heat networks are hard, in short some local authorities in particular may decide that they would rather spend their limited time and money on pursuing less complex opportunities either instead of or as an alternative to heat networks. This may also occur as a result of the diminishing capacity and capability that many LAs are experiencing.
- There is a need to address poor perceptions of heat networks – we identified what consumers might like, but it may also be worth thinking about what they may perceive as the dis-benefits (sacrifices) and address these in any future 'offer' as well (domestic users). I have come across a number of LA officers and some 'experts' who have doubts about heat networks.

Energy Systems Catapult

- What puts consumers off switching to Heat networks? Apart from the obvious point of gas boilers being cheap, reliable and trusted: There are other factors around concerns with monopoly supply, lack of knowledge, new boilers being panic buys (precluding a planned switch) etc. which might throw up other areas for further consideration in the project.

External Insight

In contrast to those experienced in DHN, perspectives from two contrasting pipeline related businesses were sought. Organisations operating in long established sectors (gas, water, telecoms)

Pipeline Civil Engineering Specialist. [Civils]

- Typically 80% of a new pipeline cost is in the excavation and reinstatement.
- There is significant opportunity for reducing cost (perhaps 20%) and disruption by using collaborative working arrangements and revised specification. In some instances new technology (tunnelling / boring) and with integration between utilities, the same teams could deliver multi-service pipeline delivery with a step-change in time per meter laid.
- However, the complexity of aligning specifications and contract requirements for multi-utility work should not be underestimated.

National Grid Infrastructure Upgrade Manager (retired) [NGrid]

- The opportunity for reduced costs for laying / renewing pipelines is considerable (30% or more), but the contracting structure used by utilities factors in multiple layers of risk and margin. Technical standards of existing utilities are a major burden to innovation: specifications tend to be over-cautious, but there is little appetite or incentive to change and reduce costs. Joint-utility street-works (particularly in cities) can have a major cost and disruption benefit, but the complexity of agreeing timing, cost and legal terms has meant that case-study successes have not become common practice.

28 Appendix C: Highlights from Key Documents

Prior research and reports on Heat Network Stakeholders and their requirements provide additional insight to Heat Network challenges and priorities. Important factors are included below as bullet-points for brevity.

28.1 Research into Barriers to Deployment of DHN (DECC, 2013)79 [DHNB]

The study is to enable understanding of the full range of barriers to DHN deployment. Research interviewed Local Authority and Property Developer led schemes which are operational, in development or which failed to proceed.

- Capital cost is more of a barrier to schemes in existing buildings than for new.
- Uncertainty of customer heat demand and its longevity.
- Initial funding for feasibility costs is a significant barrier [*HNDU has aimed to address this*]
- The required rate of return from investors varies widely from 3% (LA) - 18% (Commercial).
- The variability of costs for laying pipes is 'ridiculous' and unjustifiable.
- Skills gaps in design and delivery – both internally to project manage from a technical perspective and also sourcing reliable and affordable external advisors.
- Lack of widely accepted contract mechanisms.
- Lack of regulation and inconsistent pricing of heat (and power from CHP)

Potential enablers:

- Identifying mechanisms to underwrite risk to allow LAs to access lower cost finance
- A centralised advice resource would enable LAs to get schemes assessed rapidly
- Examine ways of encouraging waste to energy businesses to commit to local DHN
- Generic technical, commercial and legal models to reduce the burden on developers

28.2 Which Report – Getting a fair deal for district heating users (Which, 2015)80 [Which?]

This study was intended to complement the DECC 2013 study on owner-occupiers which lacked information on the experience of users already on a heat network. This study comprised a series of focus groups and telephone interviews with consumers on their experience of district heat networks.

- All-in maintenance & repairs is attractive to current DHN users.
- Some current schemes over-specified leading to higher costs and lower efficiencies.
- A current lack of regulation – not linked to Ofgem.
- Pricing and performance for similar systems & usage can vary by 100%.
- Building consumer confidence in DHN is crucial to overcoming resistance.
- Fixed fee and unmetered heat is appealing, particularly to those of limited means.
- Metered customers universally consider standing charges too high (£25-£40/mth).

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[79] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191542/Barriers_to_deployment_of_district_heating_networks_2204.pdf

[80] http://www.staticwhich.co.uk/documents/pdf/turning-up-the-heat-getting-a-fair-deal-for-district-heating-users---which-report-399546.pdf?utm_campaign=whichnews&utm_medium=social&utm_source=twitter&utm_content=Energyefficiencyreport143501042015&utm_term=twnews

- Fairness of pricing is a key concern: Either through poor performing networks or operators taking advantage of locked-in customers. Benchmarked prices would reassure.
- Developer led schemes have been improperly specified for efficient network operation.
- Poor system performance is more often too high a temperature rather than lack of heat.
- Private housing is likely to be put off DHN connection by disruption, inability to switch supply in future and current flexibility / popularity of individual gas heating.
- A lack of understanding of system operation, billing and cost transparency is widespread.
- ‘Constant hot water and heating, I love it.’
  ‘Boiling hot water and heating 24hrs a day.. communal heating works for me – I don’t do cold.’
- Heat suppliers should be required to assess the efficiency of networks annually and report.

28.3 Community Energy- Urban Planning For A Low Carbon Future81 [LowCO2]

- Future-proofing networks for expansion needs Local Authority leadership.
- Planning authorities can set specific requirements to facilitate connection
- Apartment blocks (5-15 storey) have the lowest network connection costs at a density of 120+ units per hectare.
  Low-rise apartments and townhouses add 50% to the connection cost (density 80/ha).
  Terraced housing is approximately double the apartment cost (density 80/ha).
- Semi-detached & detached properties 3-4 times the cost of apartments (density 40/ha).
- Mixed demand balances heat load – domestic has morning & evening peaks.

28.4 NHBC Foundation - Sustainable technologies: The experience of housing associations (2015)[82] [NHBC]

This primary research was commissioned by the NHBC Foundation to investigate the sector’s experiences of sustainable technologies. It identifies technologies that have worked well, those that have given rise to concerns and the nature of those concerns. 27 Housing Associations contributed.

The research focused on experiences in communal heating. The study separated reported feedback of participants who had experience in biomass boilers in communal heating and those who had communal heating (without biomass). The summary here focuses on the latter category.

Key findings (general)

- Two-thirds stated that the main reason for choosing which specific technology to install into homes is the **upfront capital cost**. Maintenance costs were also high up

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[81] http://www.theade.co.uk/community-energy---urban-planning-for-a-low-carbon-future_618.html

[82] http://www.nhbcfoundation.org/Publications/Primary-Research/Sustainable-technologies-NF63

the priority list with 38% citing this as a consideration. Over half considered resident 'ease of use' to be important in choosing a specific technology, and, although costs appear to be front of mind, only 19% considered the technology's payback term to be an influencing factor.

- The main suggestions made by respondents for successful incorporation of sustainable technologies in new-build projects include: (i) installing products that are easy to use and maintain, preferably with minimal user involvement, (ii) using contractors with experience of the products and their installation, (iii) ensuring there is clear communication between all parties including those involved in instructing users and in maintaining the equipment and (iv) developing a clear understanding of the products.

Key findings (communal heating)

- Some form of communal heating was installed by 43% of new homes since 2006 (36% gas, 11% biomass, 7% other energy source – with some using more than one type). This was based on the feedback from 185 housing associations.
- General satisfaction with communal heating (without biomass): 12% poor, 32% fair, 48% good and 8% excellent
- Feedback on communal heating systems not using biomass boilers was mixed. Some respondents found it cheaper for residents, improving efficiency and reducing maintenance costs. Eliminating the need to visit individual properties for annual gas servicing and certification was seen as a major cost and logistics benefit. However, some respondents spoke of problems with unevenly distributed heat and heat loss through lengthy distribution networks coupled with complex maintenance regimes. Resident satisfaction has suffered in some instances because the ability to choose their own energy supplier was being constrained. Challenges in ensuring accurate metering of individual usage has led to billing difficulties, which has resulted in some housing associations relying on estimates of consumption, or failing to recover costs at all.
- Communal heating (without biomass) was rated relatively highly (in comparison with alternative sustainable technologies) in terms of all categories evaluated including installation, maintenance and resident feedback and engagement.

28.5 DECC Study - Homeowners' willingness to take up more efficient heating systems (2013)[83] [DHome]

Introduction

This study explores the preferences and willingness to pay for more efficient heating options among homeowners (owner-occupiers) in Great Britain. It explored seven more efficient heating systems: Gas condensing boilers; Micro-combined heat and power (micro-CHP); Air source heat pumps (ASHPs); Ground source heat pumps (GSHPs); Biomass boilers; Heat networks; and Solar thermal.

Methodology

The study consisted of three phases:

- Phase 1: Qualitative Workshops
- Phase 2: Quantitative Survey and Choice Experiment:
  To explore homeowners' preferences between a range of more efficient heating technologies.
- Phase 3: Qualitative Interviews: To explore in depth the decision-making process dictating choices in the experiment.

Attitudes towards current heating systems

What do homeowners like or dislike about their current heating system?

The most common heating system used by homeowners was a gas boiler (80%). Many were using any form of combination boiler (67%) and the initial workshops suggested that such devices were the best regarded for heating homes – being effective at reaching the required temperature, supplying instant hot water on demand, being easy to control and compact in size and shape. They were also the preferred future means of heating, with 63% spontaneously saying they would next install a combination gas boiler.

Off gas grid workshop participants were less satisfied with their current heating system – which was most likely an oil boiler or electric storage system. Many viewed these as very expensive, and in urban off gas grid areas such systems (most likely electric) were often criticised as difficult to use and poor at reaching and maintaining the desired temperature. Many off gas grid homeowners would connect to the gas grid if possible.

What are the 'must-haves' for new heating systems?

Purchase and running costs were the most important criteria, more so than effectiveness, reliability or aesthetics. Specifically, 24% said low energy bills were most important and 23% cited the system being cheap to run as most important. These were followed by low capital costs (a further 10% said the system being cheap to buy and 5% said being cheap to install was the most important). **Reliability was also a common 'must-have'** and was the most likely criterion to appear in the top three important factors after low energy bills and a cheap to run system. One in ten (9%) said the most important factor for them was the system lasting a long time before breaking down.

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83 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191541/More_efficient_heating_report_2204.pdf

However, analysis of the trade-offs made between heating systems in the choice experiment showed a different pattern. Here, running costs generally did not have a decisive influence over the choice of system. The key determinant was the technology itself (dictating 54% of choices) followed by **the upfront grant (driving 13% of choices).**

Triggers to replace heating system

How often do homeowners consider replacing / replace their heating system?

Just under two-thirds (64%) had replaced the heating system in their current home; nearly half (47%) within the last ten years and 17% within the last three years. **Just over half (58%) expected to replace a heating system at least every fifteen years**, although 19% anticipated waiting more than 20 years. By contrast, 27% expected to replace their system at least every five years.

What are the triggers for homeowners considering replacing their current system?

A system breakdown was the most common reason respondents had replaced their heating system in the past (30% gave this as the main reason). ‘Non-emergency’ situations where their system was still working but was coming towards the end of its life were also commonly cited as the main reason, either because they were told it would not last much longer (14%), it needed repairs too often (14%) or they were told the parts would no longer be available in the future (3%). The most common reason other than actual or anticipated breakdown was as part of a wider property renovation (13% gave this as the main reason).

What would encourage homeowners to replace their heating system earlier (before it breaks down)?

Most (70%) would only consider a pre-emptive system replacement if their heating system started to need considerable repair. Running costs play some part in the decision: a third (37%) said they would be likely to replace if energy prices rose dramatically, and 34% if cheaper-to-run systems became available. Fewer (25%) would be encouraged by ‘more environmentally friendly’ systems. However, the choice experiment showed that in a gas price rise scenario, or when preferential tariffs were available for renewable heating systems, **the majority of homeowners would still opt to do nothing in a non-emergency situation.**

Decision making process

What processes do homeowners go through when deciding whether to replace their heating system?

First of all, there generally needed to be some trigger to start considering it. This was usually either a complete breakdown, or signs that the system was coming to the end of its life. For a smaller proportion, the trigger was making wider property renovations.

In non-emergency breakdown situations (i.e. not complete breakdown), the next key consideration for most was the age of the heating system. If it was less than ten years old, and not displaying any signs of breaking down, it was very unlikely that the homeowner would replace it. **Availability of finance for the new system was also critical, and was often balanced against the urgency of replacement.**

Among homeowners who had replaced the heating system in their current property, some (42%) had consulted their boiler serviceman for advice on what type of heating system to install, while 24% had consulted a friend (especially if that person had technical knowledge of heating or plumbing). Others consulted their energy supplier or a builder (14% each). Once homeowners had decided to replace their heating system, most (68%) did so within a year, with two in five (39%) doing so within three months. By contrast, one in five (18%) waited longer than one year. There were various reasons for postponement, ranging from specific family circumstances such as serious illness, to temporary moves away from the property for work. **However, a common theme was saving up to pay the upfront costs.**

What heating options would homeowners consider installing (unprompted)?

Gas boilers were the clear favourite for future installation. When asked spontaneously which heating system they would consider in the future, **90% of on gas grid respondents said a gas boiler (71% specifically a combination gas boiler)**. An oil boiler was most commonly mentioned by off gas grid homeowners (40%, with 25% specifically mentioning a combination oil boiler).

Preferences for more efficient heating systems

Which more efficient heating systems do homeowners find most attractive?

Homeowners in all phases of the research were shown one page factsheets providing basic information on each of the more efficient heating systems which were feasible for their home. (At this stage, no cost information had been given about the options).

For those connected to mains gas, the most appealing technology at this stage was a gas condensing boiler (80% were positive and only 5% negative about this technology). This was considered a familiar, proven and trusted technology needing minimal maintenance and space. The second most appealing was micro-CHP (46% positive), which was liked for similar reasons to the gas condensing boiler, although relative lack of familiarity counted slightly against it. The other systems had significantly less appeal. Two in five (38%) of those with private outside space were positive about GSHPs, with off gas grid homeowners the most positive (53%). The concept of using a readily available source of free energy from the ground appealed to many, but particularly to this group who often felt they had the space to make it viable. **A third (34%) of all homeowners were positive about heat networks, and more so still among those living in very high density areas (43%). They found the concept of a community network appealing both at an emotional and practical level, as they felt it increased the efficiency of generation and would therefore reduce household bills.** However, more homeowners felt negatively than positively towards ASHPs and biomass boilers. Both were felt to be visually unattractive, which reduced their appeal for many. The biomass boiler was considered as too much ‘hassle’ by many due to the regular fuel deliveries and maintenance.

What information would homeowners want about potential suppliers of more efficient heating systems and financial mechanisms to help pay for them?

Workshop and follow-up interview participants felt that the information provided on the one page factsheets was important and useful in helping them assess the appeal of each technology. In particular, **homeowners wanted to see information about the space required inside and outside the property,** including for the system itself and any fuel storage, and whether a hot water tank was required. Information on the responsibility to maintain, clean and fuel the system was critical for many. Some focused on the expected lifetime of the system, but **few wanted to know the installation time.**

In addition to the information provided, **a few homeowners would seek information about the proven reliability of the technology,** by which they meant the expected time before needing repairs, length of warranty, any weather conditions which would prevent effective operation, and how widely used the systems were in domestic British properties.

Many homeowners with lower incomes, or limited savings, would need information on the **financial assistance available to pay installation costs.** For those with capital, who tended to be aged 55 and over, the key information was about ongoing **financial assistance to reduce annual running costs.** Such homeowners were particularly keen to know the new systems' expected annual fuel bill.

How likely are homeowners to take up more efficient heating systems, in emergency and non-emergency situations? (results of the choice experiment)

Homeowners were asked to make a series of trade-offs between different efficient heating systems – being given financial information to help them make a decision. For each trade-off they were asked to indicate the option they preferred, and then to rate how likely they would be to actually install their selected technology in a non-emergency scenario.

In a non-emergency scenario, the majority of homeowners involved in this research would not make a replacement (**81% would do nothing … where heating systems were priced at their current value and no financial incentives were available**). The choice experiment found considerable barrier costs to these homeowners replacing their current heating system with a more efficient system in this situation (whether due to perceptions of it being disruptive to install, a hassle to maintain etc).

Even if gas prices increased by 40% and other fuel prices stayed at 2012 levels, the gas condensing boiler would be installed by the majority of homeowners.

Among **off gas grid homeowners who would make a non-emergency replacement, the most popular option was a heat network** (although 5% opted for a heat network this is unlikely to be a feasible option currently for most off gas grid homeowners). The proportion of homeowners likely to install one of the renewable options was similar for a biomass boiler, GSHP and ASHP (between 1% and 2%), and 91% would not make a replacement.

Homeowners would be more likely to make a replacement in an emergency situation. However, in this situation the majority of on gas grid homeowners would only consider installing a gas condensing boiler with a small minority likely to install any of the other more efficient heating systems. **Off gas grid homeowners were equally likely to be willing to install a heat network or a GSHP (34% likely)** with slightly fewer likely to install an ASHP or biomass boiler (31% and 2r9%).

How is the likely take-up of more efficient heating systems affected by the balance of upfront, running and maintenance costs?

The key determinant of choice between more efficient heating systems is the technology itself, rather than how much it cost to install or the financial incentive available. Homeowners assessed the suitability of technologies... in two key ways in (i) to assess how appropriately sized the system was for their particular property, and, (ii) at an intuitive level, how credible it sounded as a heating system which would be effective in a colder climate such as Great Britain.

The **upfront grant proved more influential in affecting homeowners' choice than did the upfront installation cost**, annual fuel bill or annual tariff payments. The grant drove

13% of the choices made, while the tariff amount and length each explained 9%, and the installation cost 8%. Finally, the estimated annual fuel bill explained 7% of the choices made.

Heat networks

The preceding text was taken from the Executive Summary. In addition, the following additional information on heat networks was taken from the main body of the report.

As part of the Phase 2 survey, homeowners were asked their awareness of various home heating systems. In reference to heat networks (including district and communal heating), **16% reported that they have heard of it and knew what it is**, 15% reported that they have heard of it but not sure what it is and **69% have never heard of it.**

People were presented with a fact sheet on **heat networks with 34% positive and 32% negative**. The survey showed that those in very high density areas were the most likely to be positive (43%).

Positives

- The concept of a communal heat supply was appealing to many workshop and interview participants. It was perceived as being **more cost and energy-efficient** – and **many liked to think about a community being linked together.**
- "*I like the sort of thought of being part of a network of consumers who are all likeminded*." Follow-up interview participant, on-grid homeowner, urban, small property, female, resp. 17
- **The lack of responsibility on the homeowner for maintenance** was also a plus for many of the workshop and interview participants. This was particularly true for off gas grid households who were very keen to be linked into a system with a readily available supply of energy.
- This was viewed as a **very reliable and constant source of heat** by many workshop participants, and they presumed it would be well maintained and run by professionals.
- A few of the workshop participants had positive previous experiences of living in properties connected to district heating – prompting favourable views here.
- "If I could go back to the place with a heat network I'd do it tomorrow; no maintenance, the service charge, constant hot water, regardless of how much hot water I use – just peace of mind, know boiler's not going to blow up in winter." Workshop participant, on-grid homeowner, urban, male

Negatives

- Views were tempered by fears that the building and installation of a heat network would be disruptive and difficult to install into an existing property and community.
- "Could it be installed in an existing build? I can see disruptions for properties that already exist." Workshop participants, on-grid homeowner, urban, male
- Some workshop participants were less attracted to heat networks as it conjured images of a large power station being built in their neighbourhood. These homeowners disliked both the aesthetic and safety implications of such a system.
- "These big stations…how many of them do you need and who wants to live next to these big buildings? How close would they be to neighbourhoods." Workshop participant, on-grid homeowner, suburban, large property, male
- Although the lack of maintenance responsibility was generally a plus point, it raised concerns for **a few who foresaw a loss of control**. They worried that this might mean problems were not promptly fixed, for instance.

Areas of uncertainty

- Most homeowners asked about **the basis for billing** a property on a heat network.

- A second key concern was whether a network would be run by a **private company or local authority**.
- A few workshop participants queried whether they would have **control of the timing and temperature of the heating**. When communicating heat networks it will be essential to reinforce this fact as it is a critical factor for any heating system according to the workshop participants.
- "I don't think you would accept any heating system that you couldn't control your heating." Workshop participant, on-grid homeowner, suburban, large property, male
- Some workshop and interview participants queried how realistic a heat network system was for their own area - either because other households would not adopt it, or because their (rural) area had insufficient homes to make it viable.

The table below shows attitudes to specific questions around heat networks.

	Strongly agree	Tend to agree	Tend to disagree	Strongly disagree
I like the idea that I would not be responsible for the maintenance of the heating system if I joined a heat network	30%	33%	7%	11%
I would be more interested in joining a heat network that charged me for amount of heat used rather than one which charged set amount each month	23%	32%	10%	13%
I would be more interested in connecting to a heat network if it was managed by my local council than if it was managed by an energy or other private company	8%	24%	15%	19%
I would be interested in connecting to a heat network in my current property	5%	20%	20%	28%
I would be put off buying a new property if it was connected to a heat network	9%	13%	28%	19%

29 Appendix D: IRR Calculations

Example Scheme: 40yr design life.

- 350 users paying £1,000/year. = £350k income
- Heat energy costs £100k/year = £250k net income
- Target IRR @ 18% → Available CAPEX = £1.39M = £4k/ home connection cost (challenging)
- Target IRR @ 3% → Available CAPEX = £5.7M = £16k/ home connection cost (comfortable)
- 4x the capital value available @ 3% vs.18% making a massive difference in scheme viability.
- Reducing the capital cost by 40% (£5.7M→£3.42M) improves the IRR from 3% → 6.7%

Years	IRR	3.0%	18.0%	IRR	6.7%
	CAPEX	-£ 5.70 M	-£ 1.39 M	CAPEX -40%	-£ 3.42 M
1	Net Income	£ 0.25 M	£ 0.25 M		£ 0.25 M
2		£ 0.25 M	£ 0.25 M		£ 0.25 M
3		£ 0.25 M	£ 0.25 M		£ 0.25 M
4		£ 0.25 M	£ 0.25 M		£ 0.25 M
5		£ 0.25 M	£ 0.25 M		£ 0.25 M
6		£ 0.25 M	£ 0.25 M		£ 0.25 M
7		£ 0.25 M	£ 0.25 M		£ 0.25 M
8		£ 0.25 M	£ 0.25 M		£ 0.25 M
9		£ 0.25 M	£ 0.25 M		£ 0.25 M
10		£ 0.25 M	£ 0.25 M		£ 0.25 M
11		£ 0.25 M	£ 0.25 M		£ 0.25 M
12		£ 0.25 M	£ 0.25 M		£ 0.25 M
13		£ 0.25 M	£ 0.25 M		£ 0.25 M
14		£ 0.25 M	£ 0.25 M		£ 0.25 M
15		£ 0.25 M	£ 0.25 M		£ 0.25 M
16		£ 0.25 M	£ 0.25 M		£ 0.25 M
17		£ 0.25 M	£ 0.25 M		£ 0.25 M
18		£ 0.25 M	£ 0.25 M		£ 0.25 M
19		£ 0.25 M	£ 0.25 M		£ 0.25 M
20		£ 0.25 M	£ 0.25 M		£ 0.25 M
21		£ 0.25 M	£ 0.25 M		£ 0.25 M
22		£ 0.25 M	£ 0.25 M		£ 0.25 M
23		£ 0.25 M	£ 0.25 M		£ 0.25 M
24		£ 0.25 M	£ 0.25 M		£ 0.25 M
25		£ 0.25 M	£ 0.25 M		£ 0.25 M
26		£ 0.25 M	£ 0.25 M		£ 0.25 M
27		£ 0.25 M	£ 0.25 M		£ 0.25 M
28		£ 0.25 M	£ 0.25 M		£ 0.25 M
29		£ 0.25 M	£ 0.25 M		£ 0.25 M
30		£ 0.25 M	£ 0.25 M		£ 0.25 M
31		£ 0.25 M	£ 0.25 M		£ 0.25 M
32		£ 0.25 M	£ 0.25 M		£ 0.25 M
33		£ 0.25 M	£ 0.25 M		£ 0.25 M
34		£ 0.25 M	£ 0.25 M		£ 0.25 M
35		£ 0.25 M	£ 0.25 M		£ 0.25 M
36		£ 0.25 M	£ 0.25 M		£ 0.25 M
37		£ 0.25 M	£ 0.25 M		£ 0.25 M
38		£ 0.25 M	£ 0.25 M		£ 0.25 M
39		£ 0.25 M	£ 0.25 M		£ 0.25 M
40		£ 0.25 M	£ 0.25 M		£ 0.25 M

30 Appendix E: Provisional Solution Evaluation Criteria from Contract

[Extract from the ETI's project contract, specification of deliverable D03]

For each solution the report should include (i) a clear, detailed definition of the innovative solution, (ii) a statement of how the solution was identified, and (iii) a detailed, evidence-based assessment of the solution and its impact (both qualitative and quantitative) for DHNs across a range of potential market groups. This assessment will be based on the evaluation criteria determined during WP1 and, subject to any changes which may be agreed when finalising those evaluation criteria during WP1, shall comprise:

- potential impact on capital and through-life costs (relative to baseline costs of both the DH network and the whole DH system), including costs of installation, costs of above-ground disruption and costs of any other relevant factors;
- potential impact on the operation, performance or other aspects of the DHN, including (i) efficiency, (ii) responsiveness to demand, (iii) system reliability and (iv) system flexibility to accommodate future supply and customer connections or interconnection between DHNs;
- potential impact on the general benefits of heat networks as a method of heat supply (for example: the effective delivery of large quantities of heat; the ability to transfer water at different temperatures, dependent on the application; long asset life; and the ability to utilise hot water from different heat sources, without undue impact on householders);
- constraints on deployment, such as particular types of DHN, location, environment, geology, application, housing type, etc; and any of these or other factors for which the solution is particularly well suited;
- technical feasibility and any implications for commonality of technical standards across the industry;
- health, safety or environmental impacts specific to the proposed solution (comprising significant increase or reduction in risks in comparison with current practice, for which an initial, high-level assessment will be carried out in order to inform selection of solutions and route mapping in WP6 & WP7);
- synergies with other sub-surface infrastructure (particularly gas, hydrogen and electricity networks) and recommendations as to how these synergies could be exploited
- information regarding the relative difficulty of installing DHNs (compared to other network infrastructure) arising from technical issues, planning/consenting issues or social acceptance issues, and the impact of the proposed solution on these issues;
- suitability for deployment in the UK (noting any relevant differences between the UK and other countries which affect its suitability for deployment in the UK);

31 Appendix F: Evaluation Template

Capital cost and other costs will be assessed quantitatively using the cost model. Other measures will be assessed on a five point scale on the basis of the **impact** they have on the value of DHN deployment:

- Major positive impact : Score 2
- Limited positive impact : Score 1
- Minimal impact Score 0
- Limited negative impact : Score -1
- Major negative impact. Score -2

The project team will strive to ensure consistent use of the scale by contrasting solution scores and using common descriptors in the assessment.

An example of a standardised, quick to fit, HIU is given as a worked example in the table below. The key benefit here is an assumed reduction in capital cost. A key potential barrier is to agree a standardised set of HIUs across the UK and, ideally, internationally to drive down price.

	Evaluation Criterion	**Description / examples**	**e.g. Quick Fit Standard HIU**	
1	Capital Cost	CAPEX Cost saving	£?	Model
2	Outcome Certainty	Programme, cost, revenue income and take-up.	0	Checklist
3	Other costs	OPEX Labour, fuel, maintenance and replacement	£?	Model
4	System Performance	Technical & thermal performance, reliability, flexibility	0	Checklist
5	Future Flexibility	Alternative heat & temperatures, extend & connect.	0	Checklist
6	Attractive to Customers	Improved value proposition for Users or Investors	0	Checklist
7	Reduced Complexity		+2	Checklist
8	S.H.E. Impact	Safety, Health & Environmental impact	0	Impact
9	Ability to scale	Constraints on deployment due to location etc.	+2	Checklist
10	Revenue and synergies	Value from links with other sub-surface utilities	0	Checklist
11	UK plc Value	CO2, economic & policy impact	0	Checklist
12	Technical Feasibility	How near market is the solution?	0	Checklist
13	Effort	Investment in capital and time needed, likelihood of success	0	Checklist

Table 34: Evaluation Example – Standardised HIU

A ‘checklist’ has been prepared to support solution development. It is to help clarify what is meant by each criterion and aid consistency of evaluation. This checklist is for the qualitative measures only and the current version is shown in Table 35.

Detailed Checklist		**Rating (-2-1/0/+1+2)**

Certainty			
2.1	Capital	Improved confidence in capital cost	
2.2	Programme	More certain and/or shorter programme	
2.3	Take-Up	Increased confidence in user take-up	
2.4	Revenue	Greater certainty of revenue	
System Performance			
4.1	Thermal performance	Change in thermal efficiency (Measure or impact?)	
4.2	Reliability	Mean Time Between Failures & Mean Time to Repair	
4.3	Lower temperatures	Potential to be effective at lower system temperature	
4.4	Capacity buffering	Ability to assure supply at times peak demand	
Future Flexibility			
5.1	Alternative heat sources	Adaptable to a range of input heat sources	
5.2	Variable temperatures	Capacity for reduced or variable temperatures	
5.3	Extend and connect	Options to extend and interconnect	
Attractive to Users & Investors			
6.1	Consumer Costs	Heat / hot water cost & maintenance vs. current.	
6.2	Consumer Proposition	Confidence to switch: Attractive Simple, low risk, reduced time on site and disruption	
6.3	Commercial complexity	Installation / changeover disruption	
6.4	System performance	Heat / hot water capacity and responsiveness vs. current.	
Reduced Complexity			
7.1	Product	Shift from bespoke design towards product	
7.2	Procurement	Simple transactions - Enablers, User & Investors	
Opportunity to Scale			
9.1	Typology A	Impact on City Centre Typology	
9.2	Typology B	Impact on High Density Flats Typology	
9.3	Typology C	Impact on High Density Terraced Typology	
9.4	Typology D	Impact on Medium Density Residential Typology	
9.5	Typology E	Impact on Low Density Residential Typology	
Increased Revenue			
10.1	Shared Civils	Offset Capex with shared civils / trenching	
10.2	Trench Revenue	Revenue from installed pipes, ducts, wires or fibres	
10.3	Electricity sales	External electricity sales and DSR.	
10.4	New service offering	Additional revenue opportunities	
UK plc External Stakeholder Value			
11.1	CO2 Budget Impact	How much CO2 can be saved?	
11.2	Policy Impact	Solutions require minimal policy change	
11.3	UK benefit for jobs	Significant increase in jobs or job security?	
11.4	Potential for export	Might this solution enable increased UK Export?	
Technical feasibility			
12.1	Technical feasibility	How near market is the solution?	
12.2	Standards	Any implications for commonality of technical standards?	
Effort			
13.1	Investment Required	Log scale: <=£500k, £500k- £2M, £2-5M, £5-10M, £10M+	
13.2	Technical Innovation	Innovation Level: TRL 10-9, 8-7, 6-5, 4-3, 2-1	
13.3	Anticipated Timescale	Time to deliver value: <=18mths, 18mths-3yrs, 3-5yrs, 5-10yrs, 10yrs+	
13.4	Likelihood of success	Certain, Probable, Likely, Possible, Unlikely	

Table 35: Checklist of Factors Associated with Each Evaluation Criterion

32 Appendix G: Summary of interactions with European Experts

32.1 Introduction to survey

As an extension of the original scope of works, it was considered valuable to undertake an initial international survey to identify significant differences between international and UK practice. The objective was to provide useful information about international practices.

As a first step, the project team identified leading countries in the field of district heating where it was thought that some useful knowledge could be gained. The countries selected were Denmark, Sweden, Finland and Germany. The project team then circulated a questionnaire to at least one expert from each country with whom Robin Wiltshire had an existing working relationship.

In total, feedback was received from seven individuals who come from both academia and the district heating industry. All of these individuals are content for their information to be included in this report and used by the ETI. However, the respondents preferred their contributions to be anonymised given that ETI wished the ability to use this information however they wished.

The survey comprised both general questions as well as more specific questions to focus on different elements of the process including focussing on areas where limitations in UK practice are already known.

32.2 Questionnaire

The following questions were asked of all individuals.

General

1. Do you have an opinion about why district heating costs may be substantially less in your country than in the UK?

For example, there may be issues of market size or the level of expertise? Does DH pipe installation cause more problems than that of other services?

Design

2. Do you encounter the following issues in your country?
    a. In the UK, it is typical for several different firms to carry out the work for different stages within the design, procurement and construction process, and we believe this leads to solutions which are not well integrated.
    b. The district heating system design extends to the boundary of a plot, but the performance of the *whole* system is often weak because of poor design of the *local* system, i.e. within the building. We believe this leads to people designing defensively leading to over-sized equipment.
    c. The system has too many heat exchangers which makes the system less efficient.

Data for building energy use

3. There is very little data on DH systems in the UK, mostly because there are relatively few systems. However, currently in the UK, data is being collected on both space heating

and domestic hot water demands. Is there comprehensive basic data collection in your country for both building energy use and DH system performance?

Sizing of district heating systems

4. Do engineers oversize systems in your country? Is taking account of diversity the full solution to this problem?

Engineers in the UK typically oversize systems to avoid the risks associated with undersizing heating systems. In the UK, district heating systems invariably involve CHP. If the CHP is oversized then it either will not be functioning for the number of hours assumed in the business case or there will be overheating in the buildings causing discomfort, wasted energy and high customer bills. It also means extra cost incurred on the plant itself. Is taking account of diversity the full solution to this problem?

5. Do you apply a diversity factor only to hot water use, or to space heating as well? Is there a space heating diversity curve?

We understand that hot water use is much more dependent on personal choices ("a social heat demand" – Werner and Fredriksen), while space heating is much more dependent on weather conditions and building fabric standard ("a physical factor" – Werner and Fredriksen). However, limited aspects of space heating demand are also social such as night setback, effect of poverty etc.

Components of district heat networks

6. How widely are plastic pipes used in your other country? What is your view on the longevity of plastic pipes?

We understand that steel pipes last a very long time provided the water quality is good. What is your view about plastic pipes? We understand that there is less knowledge around their performance over the longer term. Is water quality equally important for plastic pipes?

7. If we move to lower temperature systems would you replace steel pipes with plastic pipes (e.g. when the existing steel pipes need to be replaced).

Feedback from one pipe supplier is that plastic pipes can only operate at 90°C for one year of the 30 year life – the rest of the time the temperature should not exceed 80°C.

8. Do you have any opinions about the effectiveness and reliability of HIUs?

There seems to be greater choice now (e.g. Eastern European firms coming into the market). If built to EN standards they should be equivalent, but they may not all be as good at handling temperature stresses?

Installation

9. Do you favour open trenches for installation or one of the trenchless digging approaches (e.g. pushing pipe between pits)?

10. How widely is directional drilling used in your country?

We believe that directional drilling is more widely practised in mature DH countries – is this the case? Is it expensive in your country? It currently has limited use in the UK and when it is used, it is at greater cost than trench digging.

11. What is your approach to mapping underground services?

This question is about knowing exactly where underground services are. In the UK we usually start with a desktop survey, and then potentially do a proper scan (e.g. ground penetration radar) to track underground services or other obstacles in detail. However, ground penetration radar is not very good at getting the depth of utilities accurately. This leads to problems and extra expense with installation. Are there better ways used in your country?

12. What is the state of the art for pipe installation?

Is it cold laying? What is the best technique to ensure quality but minimise cost?

13. Do you have the right to dig up roads for installation of district heating?

We understand that in Denmark, operators have the right to dig up road for installation of district heating. Is this also the case in other countries?

Operation

14. What parameters of a district heating system do you measure and control?

15. Should we apply night setback?

Should we turn off heating during times of the day to save pumping cost? In most countries, night setback is not used. But might there a case to do this in a relatively benign climate like the UK's?

32.3 General

The interviewees were initially asked about why district heating costs may be substantially less in their country than the UK.

- Sweden: The key difference identified was around standardisation. Given their significant experience, Sweden have standardised manufacturing and processes. Several examples were provided. Many substations are no longer designed locally, but assembled in factories and installed as prefabricated units. A similar approach is taken for district heating pipes. They also have established urban routines for putting pipes into the ground.

- Denmark: Several key differences were highlighted.
    - Traditionally politicians allocate district heating to larger areas, where everybody is required to connect. This achieves greater economies of scale for the specific schemes.
    - There was a view that a key difference was the cost of capital. In Denmark there is municipal financing and guarantees, resulting in low capital financing costs.
    - Based on anecdotal evidence, the view was that due to various reasons, including inexperience, in UK the DH network investment cost could be up to 100% higher than is experienced in Scandinavian countries.
    - The greater availability of local knowledge and skills was seen as being of significant benefit in Denmark. Knowledge includes many guidelines for local

tradesmen and technicians in Denmark to assist them during the installation of district heating pipes. It was thought that in the UK, there is greater reliance on specific experts and such an expert is much more expensive than a standardised guidebook. In terms of skills, this mainly relates to technical abilities and labour-related tasks. It is more common to have tradesmen with specific skills related to district heating in well-established district heating countries like Denmark (e.g. a district heating welder) than in the UK.
    - A key reason for lower operating costs was identified as being that all of the DH utility firms are non-profit making companies. The utilities are either owned by the consumers or by the community.

- Finland: One respondent highlighted that the country benefits from lower operating costs as the basic infrastructure was built many decades ago and investment costs have depreciated. Almost all of the major cities have approximately 80 % of the buildings connected to district heating. Hence, given its prevalence, it is often cost-effective to connect new buildings to existing district heat infrastructure. The level of expertise (including network design and system operation) was deemed to be high but was seen as a small factor for overall cost efficiency.

The other respondent noted in general the greater market size and market competition resulted in operators needing to be cost effective, and they tended to be leaner organisations. Furthermore, Finnish companies have greater expertise, experience and deliver a more uniform service (e.g. codes of practice of Finnish Energy are followed by member companies).

The respondent continued by focussing on networks - design mostly by DH companies themselves, normally simplified design based on manufacturers' manuals/tables/experiences, no oversized design/calculation/safety measures, competition on product/service market (e.g. 4 domestic DH pipe manufacturers, many small contractors on the market), high level of standardisation (e.g. pipe insulation thicknesses), quality assurance and certification (components, contractors, fitters), extensive use of twin pipes, extensive use of cost effective but reliable "steel sheet +shrink sleeve" joint method, always preheated installation (significant experience)

32.4 Design

32.4.1 Integrated delivery

In the UK, it is typical for several different organisations to carry out the work for the different stages. It is considered that this leads to solutions which are not well integrated. The approach taken in the other countries was explored. In Denmark, it appears that there is typically a main consultant who has overall responsibility of the system performance and will manage the subcontractors. In both Finland and Sweden, there are standardised ways of working and those in the different disciplines know their roles. Furthermore, it was noted that in Finland, the DH system design is undertaken mostly by DH companies, extending to customer heat meters. The customer substations are owned by customers but design and installation instructed and controlled by the DH company. However, it was noted that integration can still be a problem in Sweden, especially between electricians and plumbers.

32.4.2 Number of heat exchangers

Respondents were asked about whether they experience issues of having too many heat exchangers which can make the system less efficient.

- Sweden: In Sweden, there is only one heat exchanger in the whole supply chain from the heat supply plant heat exchanger to the customer heating system and it is located in the customer substation. The Swedish respondent noted that systems in Copenhagen and Vienna have often two heat exchangers in their supply chains.

- Germany: Too many heat exchangers leads to unnecessary losses and the respondent highlighted that Nordic countries often use direct systems.

- Finland: The key is whether the connection is set up in series or in parallel - having many heat exchangers (heat-substations) connected in series makes the system inefficient (except individual customers heating exchanger and hot water exchanger partially in series) but having many heat exchangers connected in parallel makes the system efficient.

- Denmark: In Denmark, heat exchangers are generally not serially connected in the DH system. It is one heat exchanger at the heat plant to protect the heat plant from dirt in the DH system and one heat exchanger at the consumer to protect the DH system from dirt in the building installation. The DHW heat exchanger is parallel connected so it has no influence on the DH system efficiency. It was noted that insulated heat exchangers are typically around 99% efficient and the main issue with the heat exchanger in DH systems is slightly higher supply temperature and the increased return temperature (few degrees), which leads to higher network heat losses. However as most of the time the DH system is running under a part load the effect of each heat exchanger is not so big.

It was noted that heat exchangers are generally preferred due to the investment protection and the hydraulic separation, which increase investment protection and the operational safety of both the DH system and the building installation. Additional heat exchangers are typically applied in case of very big networks like the Copenhagen network to both protect the enormous investment and simplify the control of the whole system, which can become quite hard in very large networks.

For the building radiators the maximum pressure level can be lower than the pressure of the DH media, meaning an indirect unit is needed (seen as being far more economical than changing the radiators).

A further respondent said that in Denmark, heat exchangers are often used between high pressure (25bar) transmission network and the local district heating network (10bar or 6bar). In Jutland it is usual to have a direct system without heat exchangers between district heating system and the space heating system. In Zealand and Copenhagen, an indirect system is used with heat exchangers between district heating system and the space heating system. It is a question of saving cost and temperature differences versus safety. The respondent suggested that the best solution is to have indirect systems with heat exchangers with very high heat transfer capacity.

32.4.3 Availability of data on the performance of district heating systems

Respondents were asked about the availability of data regarding the performance of district heating systems in other countries in order to inform design. There is limited data in the UK, mainly because of there being relatively few systems and a tendency to secrecy. Mixed response was received from Finland. One respondent noted that most data is collected (e.g. supply and return temperatures and the water flow) from the customer-side as 15 minute-averages and sent to companies databases every day through mobile data or radio network. On the primary side, information is supplied through SCADA systems which can be real time. The other respondent noted that to his knowledge, there is no comprehensive data collection, neither on space heating/domestic hot water (DHW) nor customer flow and return temperatures. He continued by explaining that average specific heat consumption in DH heated houses in Finland is now about 35 kWh/m^3/year of which DHW accounts for 20-40 % in residential buildings and the share is growing with improving energy efficiency. Other countries noted that there is good data on energy consumption of buildings and consumer heat meter readings from district heating systems, including some dedicated DHW data.

A Danish respondent stated that the radiator flow and return temperatures are typically based on the temperature difference between supply and return of both radiators and district heating of 30°C as a minimum. This is because the design of radiators typically has been on the safe side and the heat loss of existing buildings has been reduced due to new windows etc. There is a large potential to heat rooms by the use of lower temperatures, applying using the radiator formula based on the logarithmic mean temperature difference between the radiator supply/return and the room temperature. If the radiators are conventional high plate radiators with a thermostatic radiator valve coupled to a two pipe system, the return temperature can be reduced to about 25°C except for very cold periods. This low return temperature is valuable in the flue gas condenser of the boilers and in Denmark, many district heating companies offering customers a rebate of about 1% on price of heat per degree the return temperature is lower than a typical reference of 45°C. So by using a thermostatic radiator valves that are set to the desired comfort temperature and are allowed to keep the dwellings heated all the time (i.e. no night setback), it is possible to reduce the return temperature from 45°C to about 25°C and thereby save about 20%. The critical factor is that just one radiator with a fully open thermostatic control valve (equivalent to a set point of 28°C) may result in sufficient water flow that the return temperature of the whole building is increased. But there are a number of solutions to avoid this.

The respondent proposed that it may be useful to implement low temperature district heating in two steps:

- In the first step, the heat production is based on boilers that can easily supply high temperatures but has a big benefit of low return temperatures. In this step a sufficiently high temperature of 60-80°C is provided but the return temperature is reduced to 25°C most of the year.

- In the second step, the heat is taken from low temperature industrial waste heat and solar heating plants and deep geothermal heat and heat pumps where supply temperature of 55°C is a large benefit. In this step the supply temperature can be adjusted to minimise the supply temperature or the average of supply and return temperatures.

The first step is also good to ensure the heating system can be controlled to work with very low return temperatures. This makes it easy to realise the second step.

32.4.4 Sizing of district heat networks

Engineers in the UK typically oversize systems to avoid the risks associated with undersizing. This can result in either the system not functioning for the number of hours assumed in the business case or the buildings being overheated causing discomfort, wasted energy and high customer bills. It also means extra cost incurred on the plant itself. Respondents were asked whether oversizing is also a problem for them and whether taking account of diversity solves this problem.

Sweden: Some over-sizing is inherently provided, since the component selected will be the next largest component available. It is generally a cost issue as larger components are more expensive. In addition, over-sized control valves do not operate properly. However, over-sized heat exchangers and pipes can be beneficial with respect to operation costs and expansion possibilities. Over-sized CHP units can be addressed by connection of more customers to the existing CHP plant. Any overheating is associated with a lack of proper heat demand control.

Germany: Oversizing was noted to also be an issue in Germany. There is a lack of building heat demand monitoring and optimisation and simulation of complex non-residential buildings to be able to consistently make optimal sizing decisions. It was suggested that it is very important that the DH design extends to include the substation design otherwise an optimisation of return temperatures is difficult.

Denmark: In Denmark, the CHP is dimensioned for base load purposes which should in theory avoid this issue. Peak load demand is then met with inexpensive boilers running on high cost fuels and distributed within the network – this reduces the dimensions of the main pipe network. This does not help with oversizing of the pipework leading to the last consumers in each branch – to aid this, diversity factors are applied for both the space heating and DHW. It was noted that an approach to minimise oversizing could be to design the system for 70-80% of maximum load and to raise the network supply temperature when higher heating demand.

Traditionally some DH networks have been oversized, based on the expected future expansion plans. This has led to oversized DH networks in some areas (typically smaller cities in countryside where the expected expansion did not come true). The method today is to design towards what is known to be built in the future. There is not an issue of excessive heat source overheating the buildings - the control equipment would react if the building is being heated too much and automatically adjust the flow to fulfil the actual demand.

Finland: It was noted that oversizing in general is typically not a problem. Oversizing (heat production, network and customer substations) is generally not a good idea. Small oversizing of the heat exchanger is acceptable as it leads to better cooling. Taking account of diversity is one but not the full solution. However, over-sizing should be included for when it is judged that the network or consumption will grow. In Finland, there is usually a general plan of the city for the next 30 years and the system is designed accordingly based on this. A good rule of thumb is that CHP power plant should have at least 4500-5000 hours of peak load usage.

32.4.5 Diversity factors

The respondents were asked whether they apply a diversity factor only to hot water use (which is more dependent on personal choice and thus varies between homes) or to space heating as well (which is more dependent on weather conditions and building fabric performance but there are some aspects that are social such as night setback, effect of poverty etc). Furthermore, the respondents were asked whether there is a space heating diversity curve available.

Sweden: In general, diversity is not normally applied to space heating but only to hot water preparation. Night setback control is only effective in buildings with high heat demands (i.e. with little insulation) and not effective in well-insulated buildings, resulting in no demand for diversity factor for space heating in Sweden. However, the respondent suggested that it is not appreciated that district heating systems can benefit from diversity in demands and harmonised behaviour (such as night setback control).

Germany: The respondent was aware of factors used to limit oversizing the units for multi-family dwellings. However, as he did not design DH systems, he was not aware if diversity factors are generally being used.

Denmark: One respondent noted that traditionally, diversity factors have been used for space heating - approximately 60% simultaneity for a group of several hundred houses. The same approach applies for low-energy houses, but care should be taken due to the fact that they consume typically more energy than estimated.

Finland: In Finland, they do now apply diversity factors for space heating (in addition to DHW). The space heating curve is coded to the substations controller. Customers (in this case, the metered entity which would be a local community entity at block or small district level) can adjust their temperature curves for the secondary side for instance. The respondent agreed that hot water usage generally depends on the time of day (social behaviour) whilst space heating is dependent on the outside temperature. However, this can be complicated where there is air conditioning as it is dependent on both outside temperature and social behaviour.

The other Finnish respondent noted that normally only variation in DHW demand is taken into account, but can be applied to both case by case. No general diversity curve exists, a curve often used for DHW: Φ = 57+15,3[ln(n3-n2+1)]1,17, where n=number of flats. When dimensioning DH network the diversity factor is usually between 0.7 and 0.9.

32.5 Components

32.5.1 HIUs

Respondents were asked about their views on the effectiveness and reliability of HIUs. One respondent highlighted that there is currently no EU standard to ensure the minimum efficiency of the HIU. Furthermore, there is always a question about equipment quality and control accuracy. The respondent noted that temperature control is a big issue, especially when it comes to DHW generation, as is experience when taking a shower. Furthermore, the efficiency of the heat exchanger to cool the supply is also of concern and can vary greatly between applied heat exchangers. The selected control valve has an impact on the return temperature. Finally, the respondent noted that they have experienced that low quality equipment is also not as good at handling unavoidable pressure variations in the DH system. A further respondent noted that indirect HIU is the norm in Nordic countries and also in Eastern Europe. Direct HIUs are not recommended as they give too much restriction on the primary side design, resulting in high capital cost. Finally, one of the Finnish respondents simply stated that HIUs (substations in flats) are not used.

32.5.2 Plastic pipework

A question was asked about how widely plastic pipework is used in their country and their long term performance.

Sweden: Plastic pipes are not generally used in city-wide networks in Sweden as network temperatures are still too high. However they are used in separate systems with low temperatures and in customer's heating systems (e.g. plastic pipework in radiator systems). The respondent tested ten years ago some separate plastic DH systems which had been running for 10-15 years and they were in good condition.

Germany: Plastic pipes are mainly used in smaller DH systems. Cities tend to have at least peak forward temperatures above 110 °C which does not allow the use of plastic pipes. Plastic pipes can make the DH network significantly cheaper and are especially suited for engine based CHP plants or other sources of heat below 80°C. In Germany, they can also use Polybutylene instead of PEX pipes. Plastic pipes tend to allow more oxygen diffusion into the DH water, thus making the water more corrosive so an oxygen diffusion barrier is used. Care is needed in their design as plastic networks are sensitive to thermal degradation.

Denmark: Plastic pipes are generally used in Denmark when the temperature levels and pressure conditions allow. They are typically available up to DN100 single pipe and DN63 for twin pipes. The lifetime of the plastic pipes is heavily related to the temperature levels and therefore they are more important in low temperature district heating schemes. A significant benefit of the plastic pipes is the ease of installation. Their flexibility can significantly reduce the installation time and cost. When applying plastic pipes it is very important to install pipe with diffusion barriers to prevent oxygen penetration, which would lead to corrosion in installed equipment and steel pipes in other locations of the network.

Finland: One Finnish respondent noted that there used to be problems with plastic pipes due to oxygen diffusion through plastic to the water. This would lead to corrosion in customers' heat exchangers and metal parts. Now pipe suppliers say that they can install barriers against oxygen diffusion. In practice, plastic pipes are not used in district heating so much as the pressure and temperature are not appropriate (PN16 & 120 °C in Finland and Sweden). Utilising plastic pipes would require heat exchanger station which would make the system less efficient. The cost of the plastic pipes are less than in steel pipes in sizes <DN400. Problems would come when making new connections to the network etc. The use of plastic pipes is being investigated for district cooling networks.

The other Finnish respondent agreed that plastic pipes are practically not used at all in DH systems. Despite specific advantages, they are not competitive with steel pipes (cost efficiency, length of experience, reliability, uncertainty of lifetime, heat losses, oxygen diffusion, temp/pressure limits). The lifetime of pre-insulated rigid steel pipes has proved to be long (at least 50 years and potentially 100 years or more). Twin pipes have already been extensively used with very good experience and low damage rate for more than 30 years. For in-house connections, flexible steel may be used, but not plastic nor copper even in low temperature systems.

An additional question was asked about whether, if they moved to lower temperature systems (and thus addressed concerns of thermal degradation of the plastic pipes), they would replace steel pipes with plastic pipes (when the existing steel pipes need to be replaced). Respondents from Sweden, Germany and Denmark said that they would, in particular the German respondent highlighting that a plastic network can be significantly cheaper than a steel network.

32.6 Installation

32.6.1 Trench vs trenchless digging

Respondents were asked whether they favoured open trenches for installation or digging pits and pushing pipe between them. The respondent from Sweden highlighted that open trenches typically provide the lowest cost. However, trenchless digging is used in very severe situations such as crossing heavy traffic roads, railroads and rivers. Both Finnish respondents also noted that trenches are preferred, with one again noting that road/railway/river crossings may often use directional drilling or pipe pushing.

32.6.2 Underground services

Respondents were asked about the information available about exactly where underground services are located. For comparison, it was explained that in the UK, there is initially a desktop survey prior to a radar scan to track services in detail. However, a radar scan is not very good at accurately determining the depth of utilities and can lead to problems and extra expense associated with installation.

One of the Finnish respondents noted that they use the same methods as the UK. They receive all of the utilities infrastructures on map. This data has been GPS measured from early 2000s. For older installations, the location can significantly differ from the map. Radar is used to mark exact locations of electricity lines – however, sometimes it is trial and error. There can be surprises but the respondent was not aware that the cost of the installations of DH network are higher due to this. The other Finnish respondent provided similar feedback noting that normally a desktop survey/information available from the location is used. For older pipelines/cables the information, especially the depth, is roughly estimated, but usually no radar scan or similar method is used to provide more detailed information.

It was noted that in Sweden, all pipes and cables from various urban infrastructures are collected in common urban databases. If in doubt, it is possible to ask an infrastructure provider to mark their pipes or cables in the vicinity of your pipe project. This service is normally provided for free, since these providers wish their infrastructure not to be damaged.

32.6.3 Pipe installation

A question was asked around what is state of the art for pipe installation e.g. cold laying? What is the best technique to ensure quality but minimise cost? Responses were received from the two Finnish representatives.

The first respondent suggested that cold laying should be avoided wherever possible and then where used the locations should be marked in the accompanying documentation. Cold laying has the problem of getting the outside water into the joints. This is due the expansion of the steel pipe which then will rip apart joints seal and insulation. Within 5 to10 years, it is expected that outside water will corrode through the joints in cold laying installations.

The state of the art approach is to use pre-insulated fixed flow pipes. The proper way of installing these is to use friction to compensate for the expansion and contraction of a steel pipe – typically explained in detail in pipe suppliers' manuals. The network is brought into use in, say, 200 to 500 metre sections to expand the steel pipe prior to welding the joints. (In effect this means sending water through the pipework before making the joints. This would involve putting valves at the end of the line or seal the ends temporarily – valves being the preferred choice. Then a small circulation pipe is put between supply and return – to short-circuit the network – and let the steel pipe expand). After that, the trench should be filled and let the friction fix the pipe to the ground.

The second respondent similarly confirmed that the state of the art approach is pre-heated installation. Cold laying is only used in special cases. Cold laying could be an option with lower temperatures, but not with the Finnish maximum of 120°C.

32.6.4 Directional drilling

Respondents were asked about the prevalence of directional drilling and whether it is expensive. As comparison, it was noted that in the UK it is very difficult to get permission to go under railway lines and, even when it is used in the UK, it is expensive.

Both Finnish respondents noted that directional drilling is generally used in specific cases e.g. road, railway or river crossings, and the drilling companies are aware of this. One of the respondents noted that there is competition in the market which helps keep the prices down. and did not view it as being overly expensive – it is never a showstopper. It was noted that in general it is more expensive than the use of trenches. It was also noted that in Finland it can also be difficult to get permissions to drill under freeways or railroads.

The Swedish respondent referred to his earlier response that trenchless digging is used only in very severe situations such as crossing heavy traffic roads, railroads and rivers.

32.6.5 Digging roads

A question was asked about the rights operators have to dig up roads for the installation of district heating in different countries. Most Swedish district heating companies are municipal, so an internal agreement gives the local energy company the right to use roads for their purposes. Private district heat companies also have similar arrangements. In Finland, one of the respondent stated that operators typically are provided with permission to dig up roads but it needs co-operation with cities authorities or with the owners of the road. In some cases it is necessary to drill under the road but a way is always found. The other Finnish respondent stated that there is no general right in Finland to cross the road by digging but it can be possible depending on the road (e.g. significance, traffic, location).

32.7 Operation

32.7.1 Monitoring

A question was asked about what parameters are measured and controlled in each country.

Sweden: The following parameters are measured: flow, supply temperature and return temperature at heat supply plants. Differential pressures at several critical points in the network.

Denmark: One respondent stated that the general parameters of interest are: flow, temperature, pressure, water leakage, water quality and energy. Another Danish respondent stated that the following are of interest: energy and supply and return temperatures (and referenced Kamstrup: https://www.kamstrup.com/en-uk). The flow is controlled to provide the needed energy and temperatures.

Finland: One of the respondents highlighted that it is important to measure differential pressure (supply pressure minus return pressure) from the critical customers (usually at the outskirts of the network) and suction sides of the pump stations. This will tell if there is enough heat provided to the network (flow for every customer). Supply temperature is measured at the heat production plant and it is adjusted based on the outside temperature. As customers control the amount of the water flow in the network, the supply temperature controls the heat fed in the network. The other respondent simply noted that the following are measured and controlled: energy, load, flow, temperatures, pressures and pressure differences.

32.7.2 Night setback

Respondents were asked whether heating should be turned off during times of the day to save pumping cost. For example, whilst in most countries there is no night setback, there may be a case to do this in a relatively benign climate like the UK’s.

Sweden: Some setback control can be used in order to reduce demands at peak hours. Göteborg Energy commenced applying this method some years ago and the respondent presented the approach at the Reykjavik symposium in 2008.

It was noted that the efficiency of night setback control is associated to the heat insulation quality for a building. The respondent could not see the connection between a benign climate and night setback control.

Denmark: One respondent noted that, in general, night setback only makes sense for buildings with low (short) time constant (lightweight building construction with poor insulation or high ventilation losses), and is only possible where the owners agree so typically used in single family houses. The building needs to be able to cool down to the setback temperature and stay there for some period of time if any savings are to be achieved. Load shifting / flexibility is more relevant for the longer-term perspective. This to avoid peak loads and the operation of peak load boilers.

The respondent continued by highlighted that a commonly discussed problem with night setback is the high peak load once the heating starts again. This high peak load can cause problems with the DH system operation and may require expensive peak load boilers. The peak can be avoided by a “slow” ramp up of the load (e.g. an electronic TRV can provide this feature).

The pumping cost savings might be smaller than expected as the pumping power relates to the flow to the third power. So with any excess flow, the inevitable peak load once heating is started again after the setback will have significant impact on the savings.

Another Danish respondent had a similar viewpoint. Night set back should be avoided for dwellings and the better insulated non-domestic buildings. For modern buildings with a good insulation level, the temperature drop during night is small and the potential heat loss savings from night set back is small. Overnight, the heat demand is accumulated and this creates a large peak load in the morning and a high return temperature. This is bad for the efficiency of the district heating and constant heating with a lower return temperature is a bigger benefit. It is a myth that a lot of heat is saved because the house is cold in the morning – it just results in accumulating heat demand and lower comfort. Poorly insulated houses with high heat loss may save energy but then improvements to the insulation and air tightness would be a better solution. Better thermally performing buildings would also make it possible to avoid oversizing thermal networks and heat production.

Finland: The first respondent stated that it is most important to keep the network temperature at the right level according to the supply temperature curve based on the outside temperature. Customers control the flow in the network via a control valve in the substation, which means that at night-time the flow will decrease and thus the heat production at the plant will go down and so does the pumping as pressure losses will decrease. With correct automation and controls pumping energy is optimised automatically. At least in Nordic countries pumping should always be maximised in order to get the heat losses down. In typical Nordic DH system annual heat energy losses are ten times greater than energy from pumping. It was also noted that electricity is usually cheap in Finland. [In a subsequent exchange of emails, the Finnish correspondent stated that his above comments on pumping energy related to the primary circuit. He noted that the use of setback could

save heating energy but its effect on secondary pumping energy would be low - pumping energy in the secondary circuit is a small component of the total energy usage.]
Many of these issues are easier to manage when the system is larger – a better mix of loads leading to better overall performance. It is difficult to make the initial phases viable and perform well. We need (perhaps) a 15 or 20 year plan to lead to large scale schemes that will save a lot of carbon. The Stratego project demonstrated that on that timescale the cost of the pipework is seen as less of an issue. The second Finnish respondent agreed with this and stated that from experience by experience the technical lifetime of pre-insulated pipes is much higher than 20 years.

The second respondent also stated that pumping cost is not a big issue (in Finland pumping energy is about 0.5 % of the delivered heat in an average). He did not think that turning off heating was a good idea (e.g. service quality, strain to the system).

33 Appendix H: Summary of Discussion with Cowi

Meeting with COWI, Arhus, Denmark, 16th February 2016

Gillian Dyer and Michael Lassen Schmidt of COWI, Andrew Cripps of AECOM

Executive Summary

Key observations from the session with COWI are:

- Cowi have access to a national Danish database of energy use of *all* buildings. This makes feasibility studies quicker and more accurate.
- There is a prescribed system for doing feasibility studies in Denmark with standard tools and consistent data provided. This again provides consistency and saves cost.
- All District Heating companies in Denmark operate on a not for profit basis, with loans underwritten by the municipality. This greatly reduces finance costs and removes profit element.
- The performance and pricing of all companies is made public, allowing public scrutiny. A DH company will adjust its prices to remain financially viable so some DH companies have higher than average heat prices.
- Because of the tradition of delivering DH in Denmark, all engineers / builders understand the systems, reducing the problem of incompatible building solutions that is seen in the UK.
- The physical solution is essentially the same as has been used in the UK. Most clients are conservative in approach and so steel is still the dominant pipework material, and the move to lower supply and return temperatures has been slow.
- Overall the delivered cost of heat is not cheap, but they do have a diverse heat supply system and the capacity to achieve even lower carbon emissions.

History of DH in Denmark

Denmark has had DH since the 1920s. Early schemes were purely commercial but also inspired by their cooperative culture. The first scheme included a waste incinerator with steam pipes. There was no policy support at that time.

For a long time, the normal solution in Denmark has been block heating. This helped the switch to DH.

The 1970s energy crisis had big impact, as they needed to reduce reliance on oil imports. This led to the 1979 Danish Heat Law which was a key part of the process of change. It sets out:

- requirement for heat planning at each level of government, municipality takes the lead, and
- areas split into gas and DH areas.

Implementation

When expanding district heating into new areas, there is normally an offer to the street – “sign up now and you get reduced connection cost”. People normally do sign up - 60-80% is typical in the short term.

In some areas, consumers are forced to connect but then the connection cost is free. If you sign up you have to pay annually for the heat connection, and then for each unit of heat provided. You do not have to take heat – although it would be unusual not to do so.

There are now around 450 networks across Denmark which comprises 64% of total heat demand, and rises to 98% in urban areas. Some DH companies own major power plants which feed into the DH system.

<u>Regulation issues</u>

Each district heating area is a natural monopoly. All district heating companies are not for profit and owned by the users (either via a co-op, or via the Local Authority). Prices are regulated by the Danish DHA.

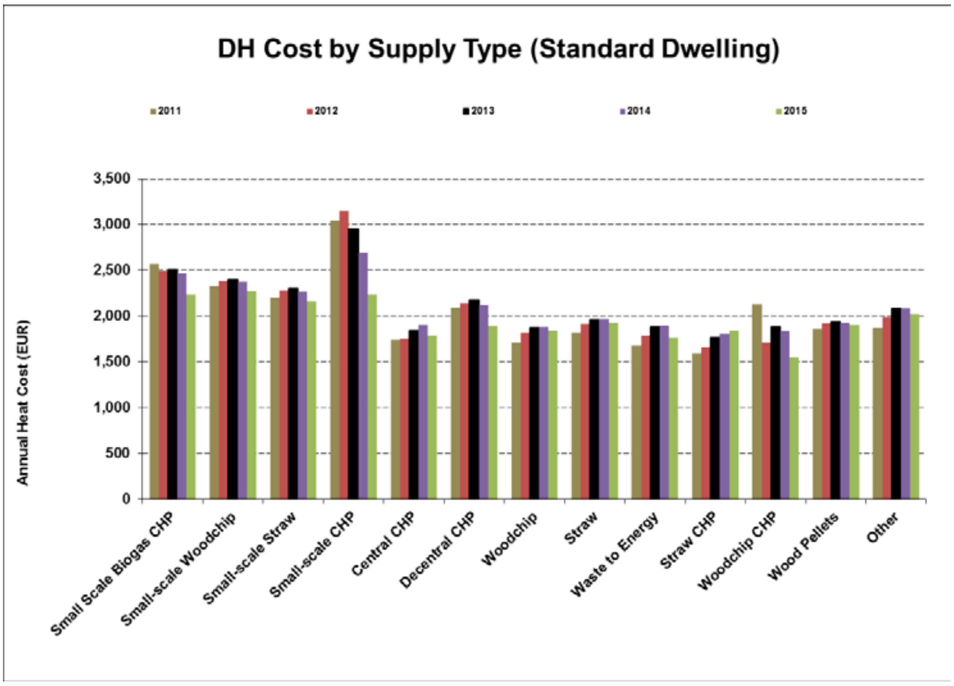
There is a 2015 benchmark document (in Danish) which contains all of the schemes and data, users, network, energy, costs[84]. Hence such information is transparent.

Some small DH companies have made losses and the users then have to pay a higher heat price as a result. This has led to problems with house sales as the heat prices are high and people do not want to buy in to them. One company is in the process of closing down – it was a small company, and the investment levels were too high. COWI believe there are no more than 20 companies with comparably high heat prices.

There is an element of protection for gas companies, DH schemes are not normally allowed to use biomass as this would damage *gas* usage. This is an example of the non-free market that they are operating in, with controls on different aspects to protect other companies.

<u>Open data</u>

As noted above, benchmark data is available which contains extensive data on costs within different DH companies. An example of the information made available is shown below.



Prices are shown for different fuels, based on standard information. Information is published on all companies in the country, leading to a media discussion each year. DH companies

84 http://www.danskfjernvarme.dk/viden-om/aarsstatistik/benchmarking-statistik-2014-2015

compete to be the best, but given that the organisations are local monopolies there is not financial competition in the way that might apply in other sectors.

Although the businesses do not make profit, they can collect money for investment over a period of 5 years before and after the work is done. For example, to fund the installation of biomass or heat pumps.

The price for heat is around 15,000 DKr for a normal home (floor area of 130 m^2). It is worth noting that this is quite high in UK terms (i.e. it amounts to £1,500 per year). However, it is important to note that Denmark is colder than the UK (example heating degree days are ~2700 for near Arhus compared to 1800 near St Albans). Hence the same home would require less heat in the UK. However this colder climate means homes are typically better insulated in Denmark and generally heated steadily all the time.

Energy use data

Denmark has a national database for every building, providing both energy use and fuel type [85,86,87]. This saves an enormous amount of time as compared to the UK, but of course there is a cost to maintaining this database. Some building information is based on benchmarks, but nearly all is based on actual usage data. Smart meters are further improving this information.

Feasibility process

In Denmark, the feasibility process is very tightly defined by a law to cover the process – ‘making a proposal’. It applies whether a company wants to expand its network or start a new one.

The method requires the use of one of the approved models. These contain standard costs and catalogues of equipment performance, inflation assumptions etc.

These standard data are used as inputs to the modelling, meaning that answers are comparable from different consultants. There can still be disagreements over costs - there are long legal cases between gas companies and DH - but in general it reduces the variation between different sets of calculations.

Although, DH is widespread in Denmark, there is still quite a lot of room for growth – there are remaining gas supply areas where DH can expand into.

System designs – focus on Arhus

Some systems have local boilers as well as larger central plant, whereas others are heated entirely from sub-stations off of the main distribution lines.

District Heating systems generally are split into:

- Transmission systems: These run at high temperature and pressure (120 °C and 25 bar) and are used for transporting heat over large distances. No users are directly connected to the transmission systems.

[85] www.ens.dk/en
[86] http://www.ens.dk/en/supply/heat-supply-denmark
[87] https://www.ois.dk/

- Distribution Systems: There comprise lower temperature and pressures and are used to connect to users and take their heat either from the transmission system (via heat exchange stations) and/or from local heat generation plant.

The transmission and distribution systems may be owned and run by separate companies, e.g. the transmission company will sell to a number of distribution systems (as in Copenhagen) or may all be owned and run by the same entity (as in Arhus).

Heat input to systems may come from assets owned by the district heating company, or may be bought from third parties. For example, in Arhus heat is supplied by Dong Energy from the 700MW power station and sold to Arhus district heating company. Arhus district heating company also generate their own heat from several other generating assets owned directly by themselves.

The local scheme has a 700MW coal station, 15 km from Arhus, supplying heat at up to 120ºC, 25 bar. They are shifting to straw and wood chip. They are also adding an electric boiler to use spare electricity when wind power is too high, and a 30 MW straw plant is being added and large scale heat pumps in Arhus as part of new building projects.

One local waste to energy site has no thermal store, so it has to supply all the time. They are planning to add a thermal store at the same time as they are adding a biomass boiler. The Arhus network covers nearly every home. One biomass plant is shared with the neighbouring town.

Tvis is a large scale – multi-town network to the South of Arhus. It uses a lot of heat from the Shell refinery.

Trends in Denmark

The trend is towards lower temperatures, with supply temperatures at 60°C or lower, as it helps with integration of heat pumps and solar technologies, and reduces heat losses. It will be necessary to modify existing buildings to achieve this, which can be expensive, but should still result in overall savings.

Cowi are currently working on a low temperature scheme with a supply temperature of 50°C, and providing hot water directly at 45°C, with legionella being managed by reducing the amount of water stored. This is based on a German regulation and results in less than 3 litres in the heat exchanger, 5 litres in pipes to tap. It is more difficult to apply with storage tanks, but direct electric can be used to boost the temperature when needed. Homes in Denmark tend to have smaller tanks than in the UK, and most Danish homes do not have local storage so this is less of an issue than for the UK. Careful housing design is needed to implement all of this.

This system includes a Special Danfoss heat exchanger to work at these temperatures. The solution used still has steel pipe in the street, with plastic pipes to homes in ducts to allow easier replacement.

There would be resistance to use of plastic for major pipes because of the trusted tradition of using steel for the main pipes. The boards of the DH companies make these decisions and they would be likely to stick with steel. This is an aspect where Denmark is more conservative. Danish Technical University (DTU) is doing lots of work on innovation, but the pipes in the road are still steel.

Metering

Original systems were metered on the flow of water and not heat - the user paying based on the volume of water flowing through the system on the assumption of a low return temperature. In the early systems the return temperature was not specified. Therefore, it was advantageous for operators/owners of the buildings to slow the flow of water down as much as possible and extract as much heat as they could from the flow. As a result they get better at returning a lower temperature. In winter they would be working at 90°C flow and 40-50°C return temperatures.

Nowadays, meters measure both flow and temperature and you can measure and charge for heat delivered.

Site work and access to roads

DH companies are a municipal supply and have access to the ground, so there are no legal costs associated with most areas for way leaves. Some issues remain with private land, but this is not generally a major problem. It was not known if DH companies pay costs for road closure.

In one scheme, Cowi had to add a by-pass pipe to supply heat through the summer whilst major repairs were done. This was a smaller pipe than the one being replaced, as demands were lower in summer. It is usual to carry out any repairs and additions during summer when the load is low, and a bypass can be used in many instances to limit interruptions to heat supply during longer improvement projects. Work can happen during winter but it has to be really quick. There was a break down in Arhus around Xmas 2015 – they lost heat for one day.

In Denmark, they backfill with materials to a standard specification, which is essentially as occurs in the UK. There is a standard solution with sand packing around the pipes, and aggregates.

In Denmark, they drill underneath major roads or railways. But this is generally expensive compared to trenching so not done otherwise.

Overall, it was thought that trench digging was similar to the UK. It is the same as for cold water pipes and the processes are well established. The welding and other specific installation skills are likely to be areas where costs may be higher in the UK.

Twin or single pipe

Twin pipe is slightly better for heat losses, but the pipe costs more. But with twin pipe, it should be possible to have a narrower trench which should save cost. It is difficult to identify differences for installation costs, however operational costs are reduced when using double pipes.

Network operation

There is a Schneider software tool that COWI use to try to reduce operational energy losses – optimising of systems. They have around 50 people who help look after networks for the DH companies. This includes working on integration of smart meters with SCADA data, integrating with TERMIS software analysis. Where people return water at too high a temperature, the district heating company can go and help fix problems.

With this software, Cowi can optimise new designs to reduce sizes of pipes, but this has to take account of future potential connections. Within future proofing, there is an option to reduce return temperatures in buildings which provides extra capacity to allow more clients to be added.

Cowi offer thermal imaging of cities to see where losses are occurring. Cowi have their own planes for thermographic work and mapping.

Innovation and fuel changes

Cowi are seeing a switch from waste to biomass. They do not have enough waste in Denmark anymore because of recycling – some is imported from the UK, including unsorted waste.

Having the large base load within existing networks means that adding a new supply system is not much of a risk. This could be an issue in the UK where a system based on a heat pump say could be risky if it hits trouble and there are only back-up boilers left. So Denmark's scale is an advantage here.

The municipality also often has control of the buildings, which aids testing innovative solutions, such as the low temperature case study reported above. Here the homes were council-owned social housing. This makes it easier also to gain access to make sure that the buildings are operating properly at the lower temperature.

It is important to get the network temperature down to aid renewables including heat pumps, solar and waste heat. Also easier for CHP take off and waste heat sources.

The heat law banned electric heating as part of the drive for energy saving. This has been changed to allow the use of spare wind electricity to generate heat which is beginning to be seen now.

Contracts

Less risk is transferred to contractors as the DH companies have a better understanding of what is going on. This is likely to reduce typical costs as the contractor does not need to price for all risks.

More design work is done in advance – production of detailed drawings with information from the designer on gas network for example. Firms like COWI design for tender with Regulations that cover what has to be included in the tender package. The installer does the final details of the design so they can provide warranty on e.g. junctions and expansion systems.

It was noted that things change slowly in Denmark. There have been many years of discussions about using lower temperatures, and it is only now starting to change. But this may change as old hands retire to be replaced by a new generation of energy managers.

Other points

It is normal for heating to stay on all the time controlled by thermostats in each room (often no central thermostatic control or timer).

Rural areas are usually off grid. But a new house 15km from Arhus was built connection ready, and was connected some years later when the heat network reached it.

At present the UK market is small – information is not transferred as well. As an example, Cowi heard of a sales representative in the UK who did not know of all the products their company sold in other countries e.g. Denmark. So, in the UK, we may not be getting the best options made available to us.

In the UK, we will need to see secure return to allow funders like pension funds to invest – this might need guarantees. Offering these guarantees could be a much cheaper solution for central Government than capital funding systems directly.

A problem Cowi foresee in the UK is that plumbers / DIY people do not understand heat exchangers and may tinker with them in an unhelpful way to try to get more heat out.

34 Appendix I: Summary of IEA Annex Work

International Energy Agency District Heating and Cooling research programme

The International Energy Agency District Heating and Cooling research programme was established in 1983. Its aims are to improve the design, performance and operation of district heating systems. It carries out research projects in three-year annexes which comprise 4 to 6 projects. The current members of the programme are Canada, Denmark, Finland, Germany, Korea, Norway, Sweden, UK and USA. Reports are produced for all projects and are available at the web-site: www.iea-dhc.org. Relevant projects are outlined below.

IEA Annex VI (completed (2002)

Pipeline laying in combination with horizontal drilling methods – This provides a useful analysis of trenchless pipe laying methods. It reports that the most suitable drilling methods for trenchless construction are horizontal hydraulic drilling for longitudinal laying of supply pipelines and the drilling with an earth displacement hammer (earth rocket) for the laying of house service connection pipelines. In the case of horizontal hydraulic drilling the ground is hydraulically worked with a bentonite suspension. With the earth rocket, a drill head attached to the pipeline is driven through the ground by a pneumatic hammer. In the report different drilling methods are described and their properties and limits of application compared one with another. Compared with conventional construction, the trenchless pipeline construction method involves a higher risk, which can however be kept small if there is careful planning and conscientious operation. It offers advantages in that potentially building times can be considerably shortened and roads need only be opened up at the launching and target trenches. However, a key obstacle at the time of reporting is that the building costs are still not cheaper than for conventional techniques. We note that trenchless pipe laying is not favoured by an experienced respondent to AECOM's separate survey but may be of interest in appropriate and difficult circumstances in our towns and cities.

District heating network operation – Whilst not directly applicable to the current study, it compiles experience from the operation of district heating pipelines over many years. Its intention is to make experiences of other supply companies available to those operators to reduce their running costs.

District heating and cooling connection handbook – This report is intended to assist engineers and consultants in designing and implementing conversions of building HVAC systems to accept hot and chilled water from district energy systems. Chapter 11 focuses on key elements that should be considered when designing the interface between the existing building heating system and the district heating system. This may prove useful later in the project.

IEA Annex VII (completed (2005)

Strategies to manage heat losses – technique and economy – This is principally of interest to older DH systems and whether and when to replace the existing pipelines with modern pre-insulated pipes. However, Section 3.3 entitled Special Laying Methods may be of interest, including Section 3.3.1 'Laying Pipes on Top of One Another', although this method may now be largely superseded by twin pipe systems.

A comparison of distributed CHP/DH with large scale CHP/DH – This presents an economic and environmental comparison between CHP/DH at different scales. It shows generically the benefit of scale of the network and demonstrates that it is important that a strategic view of final system extent should be kept in mind right from the start to reduce overall costs.

Improvement in operational temperature differences in district heating systems – This covers the issue of how to achieve efficient sub-stations in operation and minimise high return temperatures. This could reduce necessary plant capacity and operation, as well as reduced heat losses and pumping costs.

Biofouling and microbiologically influenced corrosion in district heating networks – It covers an important issue for ensuring systems, and in particular the district heating pipes, achieve the lifetime claimed. Systems not addressing these and wider importance of water quality do so at their peril – the results can be quick and catastrophic. These are important considerations if developing an innovative system for the future.

IEA Annex VIII (completed (2008)

Cost benefits and long-term behaviour of a new all plastic piping system – This report concerns a particular product; given the work is around 10 years old, it may be of limited value. However, useful generic information on plastic piping is included. Opinions differ on the use of plastic pipes but where these can be used they offer significant benefits. Plastic piping is flexible and is laid directly from a roll. Pipe joints can be installed above ground and then lowered. Part of the trench size for steel pipes is to allow space for welding and consequently trench size is less for plastic pipes. Reduced friction means plastic pipes can be smaller. Longevity of plastic pipes is not fully known yet, but there are fewer joints than for steel pipes, joints being the most vulnerable part of a network. Attention must be paid to temperature of the carrier (plastic pipes deteriorate quickly if the temperature is too high), but there are other reasons for seeking to reduce temperatures in systems where possible.

IEA Annex IX (completed (2011)

District heating for energy-efficient building areas – This is the first study that looked at the issue of whether and when DH is an appropriate energy solution for highly energy efficient buildings. This project is of significance in the future UK context: to what extent should an expensive infrastructure solution be appropriate for buildings that don't need very much heat? In particular, where the buildings are widely separated caution is advised. New techniques are seen as 'moving the goalposts': for example twin pipe plastic pipe systems reduce heat loss and are cheaper to install. Therefore the threshold for economic viability is seen to move to a lower heat demand density than before. This project also helped to bring forward the concept of lower temperature systems which was developed in future follow-on projects (see later Annexes).

Interaction between district energy and future buildings that have storage and intermittent surplus energy & Distributed solar systems interfaced to a district heating system that has seasonal storage – These two linked projects look in depth at the dynamics between supply and storage for a particular solar district heating system, featuring borehole based seasonal storage. Whilst not directly relevant for the current study, it might be a useful reference where storage is being considered.

The potential for increased primary energy efficiency and reduced CO2 emissions by DHC – This project concerns development of a method to calculate primary energy and greenhouse gas emissions for the whole district heating supply chain. Although not directly relevant to this project, the use of life cycle assessment (LCA) methods and identification of actual and potential data sources may lead to data that is also helpful in a consideration of time and motion e.g. Section 5.5 in respect of excavation of trenches.

Policies and barriers for district heating and cooling outside EU countries – This study was carried out for non-EU countries, while a companion project was developed for EU countries under the auspices of the Intelligent Energy Europe project EcoHeat4EU. These reports are not of direct relevance to the current project but are worth bearing in mind as a comprehensive reference resource.

IEA Annex X (completed 2014)

Economic and design optimisation in integrating renewable energy and waste heat with district energy systems – Future strategy is for greater integration of DH with renewable heat and secondary heat sources. This guide covers the basic principles for integrating each renewable and waste heat source with a DH system. This integration is predicated on sympathetic network design characteristics. As such, this is a useful reference resource for the current project in considering and evaluating alternative innovative designs.

Towards 4th generation DH: experiences with and potential of low temperature DH – The goal of increasing energy efficiency and achieving a wide application of renewable energy presents a challenge to district heating. Without technical innovation, DH development will be hindered due to the significant building energy reduction and will not be able to compete with on-site heat generation technologies. This project focuses on low temperature district heating (LTDH) for new-build systems. Overall, the report argues that LTDH makes DH economically competitive comparing with local heat generation units in the areas with low heat density or with low-energy buildings. The report describes the concept of LTDH, collects and discusses successful examples of the implementation of LTDH in the building heating sector.

Specific benefits of LTDH include the following:

- Heat distribution: reduced heat losses, improved harmonization between heat supply temperatures and heat demand temperatures, reduced thermal stress in steel pipes, the possibility of using other pipe materials (e.g. plastic pipework), reduced boiling risk, and reduced risks for scalding.
- Heat supply: improved power-to-heat ratios in steam CHP plants, greater heat utilisation from flue gas condensation when using fuels with moisture, higher coefficients of performance in heat pumps, greater utilization of low-temperature industrial excess heat, increased utilization of geothermal heat, higher conversion efficiencies in central solar collector fields, reduced heat losses, and greater utilization of thermal storage.

The current barriers for LTDH are high-temperature heat demands, legionella growth at low hot-water temperatures, substation faults at lower temperatures, and shortcut flows in distribution networks. These barriers and ways of overcoming them are discussed.

The relevance of very low temperature DH systems is viewed as being most applicable to new-build systems. Whilst not raised in this paper, exemplars show that customers can be effectively supplied at this delivery temperature, and if thermal networks are evolving in this direction, there is a question whether the UK should go straight for the state-of-the-art leapfrogging earlier system regimes? Current examples of LTDH have mainly been small scale pilot projects. This includes Greenwatt Way (Slough) where customers have been effectively supplied with a 50°C – 55°C supply.

The report summarises that the distribution capital cost and distribution heat loss are proportional to the inverse of the heat density. Hence, these two parameters depend on a combination of specific heat demands and the concentration of buildings, expressed by the plot ratio. The report states that the case studies show that both acceptable distribution capital costs and acceptable distribution heat losses can be achieved for low-energy buildings with low specific heat demands, if these buildings are concentrated. High distribution costs will, however, mean that district heating is not viable for low-energy buildings located in areas with low plot ratios.

IEA Annex XI (ongoing)

This work is currently not published and an outline of the work is simply provided here.

Transformation roadmap from high to low temperatures district heating systems – This project follows on from the Annex X 4GDH project. Having seen that small new-build energy efficient developments can be served even by very low temperature supply, this project is investigating whether the same principle can be applied to existing DH systems. Case studies are being collected to demonstrate outcomes. One challenge is the difficulty of obtaining actual data. Specifically, the project team wished to obtain data regarding the actual temperature demand *at the radiator* but most systems either do not collect this information, or they do not wish to share it. However, it is only by close examination and analysis of systems that the key area of better substations, better control and better overall system balancing can be achieved.

Plan4DE: reducing greenhouse gas emissions and energy consumption by optimising urban form for district energy – This project is examining early planning aspects including taking into account how layout of developments can influence and assist DH. This project will produce a planning tool and is producing a series of webinars.

Smart use as the missing link in district energy development: a user-centred approach to system operation and management – This project will help users to understand their systems better and help to understand and partake in energy efficient operation.

IEA Annex TS1 (on-going)

This is the first Task-shared Annex in IEA DHC history. It allows member countries and sponsors to link national research to benefit from international developments. The objective of IEA DHC Annex TS1 is to demonstrate and validate the potential of low temperature district heating as one of the most cost efficient technology solution to achieve 100% renewable and GHG emission-free energy systems on a community level.

The Annex comprises five sub-tasks:

- Sub-task A: Methods & Planning tools for low temperature district heating networks.
- Sub-task B: Technologies for low temperature district heating networks.
- Sub-task C: Communities / Interfaces.
- Sub-task D: Case studies and use cases.
- Sub-task E: Dissemination.

A draft output from sub-task D has been received. Most detail is currently provided on a UK pilot project.

Greenwatt Way scheme (UK): This research project comprises ten homes meeting Level 6 of the Code for Sustainable Homes (CSH) provided with heat from a range of renewable heat technologies via a mini district heating scheme, plus photovoltaics (PV) to provide renewable electricity. Each home is fitted with one substation with direct connection for space heating and an instantaneous heat exchanger for DHW. The scheme is designed to operate at a constant flow temperature of 55°C; domestic hot water is supplied at 43°C.

Radiators are sized to achieve 55/35°C. The Mechanical Ventilation and Heat Recovery (MVHR) system is fed water from the radiator circuit which allows further cooling of the return temperature of the district heating system and was deemed effective in operation. The energy centre comprises a mix of solar thermal panels, ground source heat pumps, air source heat pumps, biomass boiler and thermal store.

The mini DH network was built from a mixture of Logstor steel pipes and Aluflex pre-insulated twin pipes. The main pipeline is 98 m long with a diameter ranging from 50 mm to 32 mm. Connection to the homes was carried out via approximately 67 m of trench length with a diameter of 25 mm (twin steel pipes for flats and information centre) and 26 mm (twin Aluflex pipes for houses).

35 Appendix J: Summary of 4DH Centre Work

The 4DH Research Centre is based in Denmark and led by Professor Henrik Lund. The Centre was set-up in 2012 and is a collaboration between industry, universities and the public sector to investigate the potential for and develop 4th Generation District Heating (4GDH).

There are three principal areas of work (Work Packages):

- **Work package 1: District Heating Grids and Components -** This WP will focus on the research, development and evaluation of low-temperature district heating systems based on renewable energy. The research will provide new knowledge on the hardware and software technologies of the new generation of district heating systems supplying heat to existing buildings and new low-energy buildings. The hypothesis is that low-temperature district heating, with a general supply and return temperature of 50°C and 20°C, can be used in existing district heating systems, if minor modifications are implemented in the systems for room heating and domestic hot water supply of the existing buildings. The results of WP1 are used in the other WPs to identify the overall optimal way of realising the energy system without the use of fossil fuels.
- **Work package 2: District Heating Production and System Integration -** This WP will develop energy systems analysis tools, methodologies and theories for the study and scenario-building of future sustainable energy systems with the aim of identifying the role of district heating systems and technologies in various countries. This includes an investigation of the balance between heat savings and heat supply as well as the balance between the supply of individual houses through collective or individual systems, respectively. Moreover, the WP focuses on the development of strategies and software tools for decision-making support to local DH companies and energy planners. This involves a change in the operation as well as the step-by-step investment, from fossil fuel-based CHP plants mainly on the spot market to plants based on renewable energy resources at all levels of the electricity markets.
- **Work package 3: District Heating Planning and Implementation -** This WP focuses on the further development of the planning and management systems based on spatial analysis and geographical information systems (GIS) as a tool for planners and decision-makers. This includes the further advancement of theories and methodologies as well as the design of specific public regulation measures. The latter will focus on how to manage the conflict between implementing energy conservation in buildings and, at the same time, utilising available low-temperature heat sources in district heating, seen from planning, organisational and legal perspectives.

For the ETI project, the most relevant 4DH Centre projects are part of Work Package 1 and include the following.

- **WP1.1: Heating of existing buildings by low-temperature DH** - This project is assessing whether it is possible to heat all types of existing buildings by use of low-temperature district heating with a supply temperature of 50°C, except for short periods with very cold weather when a higher temperature is necessary. Detailed simulation calculations of the typical buildings are being undertaken to compare dynamic heating load and compare to the heating power of the existing heating components with a low supply temperature.
- **WP1.2: Supply of domestic hot water at comfort temperatures without legionella** - The aim of this project is to provide optimal solutions for handling legionella problems in different low temperature domestic hot water systems. The problem of legionella in hot water systems arises, when constructing low temperature district heating systems. To achieve low teperature district heating, the supply temperature of the district heating

water will be lowered from around 75°C to around 55°C. However, this boosts the risk of legionella in domestic hot water. In this project, multiple factors will be taken into consideration, such as the building type, the system volume, whether renovation will be involved and the structure of heating system. Cutting edge techniques for district heating and water treatment will be considered. Analysis of economic performance will also be included.

- **WP1.4: Minimising losses in the DH distribution grid -** Low-temperature DH affords a significant reduction in the distribution heat losses. This project is focussing on developing and utilising additional technical solutions (e.g. drag reducing additives, pulse operation, local temperature boosting by heat pump, new materials of pipes and insulation) by which the thermal, temperature and electrical losses in DH distribution systems can be further reduced. Modelling and simulation of the total distribution grid, including modelling of the individual components, is being carried out. The intention is that the model will be able to identify and eliminate potential component sub-optimisation and point out other potential critical focus areas in the DH grid. The project includes a review of innovative designs and concepts of distribution pipes and other components.

A specific output from this work gives a useful overview of the project:

4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems; Lund H, Werner S, Wiltshire R et al; Energy 68 (2014), 1-11

This paper defines the concept of 4th Generation District Heating (4GDH). It does this through setting out the challenges that district heating will need to meet in order to be commercially viable and relevant in a future sustainable energy system. This paper is of particular interest to the ETI project as it: (i) identifies some key needs for future heating systems and (ii) proposes a vision for how district heating systems as a whole may change over coming decades, which is important context as this ETI project looks to identify innovation to substantially reduce the capital costs of heat networks and deliver an attractive value proposition.

The five challenges detailed in this paper can be summarised as follows.

1. Ability to supply low-temperature district heating for space heating and domestic hot water (DHW) to existing buildings, energy renovated existing buildings and new low-energy buildings. This is in the context that for new buildings and renovated existing buildings comfort can be achieved by lower supply temperatures. Some of the sub-challenges here may be relevant to the ETI project in terms of the integration between the building and network (e.g. in terms of specifications for future HIUs) including delivering low temperature space heating and DHW systems and intelligent control of the heating of buildings.
2. Ability to distribute heat in networks with low grid losses. This is in the context that the heat density will reduce as the building stock becomes more thermally efficient and grid losses need to reduce such that the system remains commercially viable. Some of the sub-challenges here around the network may be particularly relevant to the ETI project including the needs for low temperature networks, smaller pipe dimensions, pipes with improved insulation, supply and return pipes in a loop layout to establish circulation of supply pipe during the summer and intelligent control and metering of network performance.
3. Ability to recycle heat from low-temperature sources and integrate renewable heat sources such as solar and geothermal heat. This is in the context of both a decarbonised future and the need to be resource efficient. This is peripheral but potentially relevant to the ETI project in terms of the integration needs between the heat network and future heat sources. It is noted that such sources may be both centralised and decentralised.

4. Ability to be an integrated part of smart energy systems. The context here is that in a future energy system, the different sub-systems (electricity, thermal, gas) need to be combined and co-ordinated to identify synergies to achieve an optimum solution. For example, it may be appropriate to thermally store intermittent renewable electricity production in a district heating system.
5. Ability to ensure suitable planning, cost and motivation structures. This is in the context that a 4th Generation Heating system is reliant on many more actors to deliver it than for previous generations of district heating. For example, unlike fossil fuel technologies which are based on large power stations, renewable energy system technologies may benefit from a wider distribution of both centralised and decentralised sources.

There is some further discussion about the competitiveness of district heat networks. To date the trend has been towards lower distribution temperatures, material lean components and prefabrication leading to reduced man-power requirements at construction sites. To continue this trend, it is proposed that a future 4th generation of district heating technology should comprise lower distribution temperatures, assembly orientated components, and more flexible pipe materials. Furthermore, as an important driver in the further development of district heating infrastructure and technologies, there needs to be an institutional framework in which infrastructural planning is used to identify and implement where to have district heating and cost incentives put in place to achieve an optimum balance between investment in savings vs production and an optimum integration of renewable energy.

The lead author of this paper is Henrik Lund who is also the head of the 4DH Centre (see separate write-up). As such, the challenges described in this paper align with the research activities being carried out at the Centre.

36 Appendix K: Summary of Advanced District Heating and Cooling Book

Advanced District Heating and Cooling (DHC) Systems, Woodhead Publishing, 2016

This book is a detailed reference source for advanced district heating and cooling systems. Each chapter is written by one or more experts in the field and the book edited by Robin Wiltshire of our project team. Of particular relevance, several chapters cover international state-of-the-art and potential future trends in the heat networks.

Section 9 – New developments in pipes and related network component components for district heating

Introduction

The chapter commences by stating that since the introduction in the late 1960s of third generation heat distribution – pre-insulated bonded pipes with plastic casing – technology development has been largely incremental. No significant change in design has been introduced, with the exception of the diffusion barrier on the inside of the casing pipe. Advancement has been made in installation, leading to more cost-efficient methods, and steps have been taking towards the introduction of flexible pipes.

It also notes that the main driver for development in pipes and components is cost reduction. This applies to both investment costs and lifecycle costs, which in turn leads to a need for improved thermal insulation performance and reduced heat losses.

Pipes

- Rigid pipes:
    - Casing: The high density polyethylene (HDPE) casing pipe has not developed in any significant fashion over recent years with the exception of the introduction of a diffusion layer barrier and a reduction in wall thickness. Incremental progress is being made to improve its mechanical properties.
    - Thermal insulation: Incremental progress is being made in that polyurethane (PUR) foam insulation is being continually improved with regard to thermal properties. Potential improvements investigated over the last decades comprise for example Polyethylene Terephthalate (PET) foam insulation, casing free pipe configuration and various types of new blowing agents for optimising PUR foam properties. It notes that one interesting recent development is a promising new hybrid, PUR/vacuum insulation, where recent laboratory tests demonstrate a 30% reduction in thermal conductivity.

- Flexible pipes:
    - General: Service pipes are usually made from copper, thin-walled steel, cross-linked polyethylene (PEX) or polybutylene (PB). They have the advantage in that they can potentially reduce installation costs: they can be coiled and hence delivered in long lengths which reduces or eliminates the need for buried joints, and do not require straight trenches and can more easily go around obstacles. However, they cannot usually carry as high pressure as regular steel pipes and, in particular for plastic pipes, the supply temperature must be limited.
    - Plastic service pipes: PEX is the standard plastic material of choice for high temperature applications. When originally introduced no diffusion protection was used which resulted in some corrosion problems and consequent bad

reputation. At present, plastic pipes are protected against oxygen diffusion by a vapour barrier, e.g. EVOH (ethyl vinyl alcohol copolymer), or an aluminium layer. One drawback of PEX is that it cannot be welded due to its thermoset properties and therefore couplings are required. PB is weldable and various such systems have been investigated.
    - Thermal insulation: Often PE foams or mineral wool are used, but there is also a semi-flexible PUR foam variant.
    - Network designs: The book reports on other pipe designs trialled e.g. EPX PEX has low price and easy installation but is limited by being permeable to water.

- Pipe configurations:
    - The book reports that twin pipe configuration is becoming increasingly popular – the thermal properties are improved and require less raw materials and space (AECOM note: there was opposition to using twin pipe in the UK at the WP1 stakeholder workshop). They are feasible only for fairly small dimensions. Multi-pipe configurations – more than two service pipes - have also been analysed with one paper concluding that there is the potential for savings in investment and energy with more refined pipe assembly design e.g. two supply pipes, where a smaller one is used normally and extra energy supplied through the second pipe when needed (AECOM note: given the opposition to twin pipe, this solution may lie well into the future).

Joints

The book states that joints are fairly sophisticated and place high demands on workmanship, good conditions on-site at installation and sensitive to backfill. Recommendations are provided for improving joint design in different situations.

Installation methods and excavation work

- General: It is suggested that installation costs are significant and that there are significant potential savings from minimising earthworks, both in terms of labour and machine time.
- Existing soil: Current practice is to use backfill material. Significant cost savings can potentially be achieved from reusing excavated existing soil as backfill by not needing to buy and transport large quantities of gravel material. Reductions in capital costs for construction works have been estimated as being between 10 and 20%. Risks from the re-use of excavated backfill include subjecting the pipe wall to point loads from large rocks.
- Shallow trenches: Another way to reduce costs would be to reduce the depth and therefore volume of excavation. The book highlights potential barriers and trials to overcome such limitations. Trial suggests that this technique is better for preserving the road surface as less soil is disturbed and requires settling.
- Trenchless techniques: Such techniques (e.g. horizontal drilling) are being used more frequently where open trenches are undesirable or impossible e.g. road or river crossings.
- Other techniques: The book suggests alternative techniques being investigated including making the trench narrow which have advantages including faster installation.

Future trends

The chapter finishes by summarising future trends.

- A key trend is around fourth generation district heating (4GDH) with lower distribution temperatures. Relevant research priorities for delivery of 4GDH including reduced heat losses, less invasive works and integrated and standardised solutions.
- It is expected that trenchless laying techniques will become more common in urban areas. Whilst this approach causes some damage to pipes, with care it is seen as being reasonable and not exceeding the level of initial damage during loading and unloading to transport to site. Furthermore, twin pipes will be used to a greater extent and for larger pipe sizes, as it requires less excavation work – which in turn makes trenchless laying less daunting. Furthermore, the concept of backfilling with existing soil has great potential.
- Installation requires several different labour skills (e.g. welders and joint-installers). There has been limited success with coupling-like connectors for steel pipes but there are existing coupling solutions for flexible pipes which are likely to increase in use as distribution temperatures reduce. (It is noted that given both the limited success with coupling-like connectors for steel pipes and that the WP2 Cost Model Methodology and Analysis showed that the cost of steel pipe joints is a relatively small component of the overall network costs, identifying solutions around coupling-like connectors for steel pipes is not planned to be a key focus for Stage 2).

Chapter 10 – New developments in substations for district heating

There appears to be little development in the composition of sub-stations since the introduction of district heating. However, the heat exchangers have been miniaturised and the controllers are now digitally operated, and the reduction is size allows substations now to be pre-fabricated off-site.

There are still significant opportunities for standardisation across the European market. There are a significant number of configurations (e.g. rating of heat exchangers) and significant variation in terms of thermometers, manometers, strainers etc. There will probably need to be a different control strategy for different network conditions and connected buildings.

It is likely that in the future the sub-station will become smarter e.g. integrating with data from the consumer or energy supplier to improve overall performance. This includes greater diagnostics which are currently seen as primitive compared to the automotive industry. It will also need to meet the demands of a 4GDH system including the ability to increase the differential pressure in order to distribute the heat to the consumer. Hence with different and lower temperature regimes, older substation designs may well be sub-optimal for future DH systems.

Chapter 11 – Temperature optimisation in heating systems

This chapter discusses the temperatures in DH systems which impact on system efficiency and thus lifecycle costs. It emphasises that there is no single perfect system design but is dependent on a number of different factors e.g. the temperature demands in the buildings internal systems.

It discusses issues around the sizing and oversizing of systems. It also discusses system balancing and its impact particularly on the return temperature – important considerations being radiator sizing and integration of thermal storage. In particular, there is a substantial oversizing of the radiator system in general and of the radiator surfaces in particular due to an overestimation of a building's heat losses (which may reduce over time with energy efficiency measures introduced) and providing a safety margin in design. Some pitfalls noted are: (i) the approach of reducing the flow to radiators to reduce internal temperatures is rarely economic, (ii) a reduction in DH supply temperature can lead to an increase in return temperature if not carefully addressed and (iii) high return temperatures may be due to customer behaviour but the main cause is malfunction of the sub-station.

Practice varies among, and within, countries as to whether to use indirect or direct DH connection and where each is more appropriate. It notes that the use of heat exchangers in an indirect system involves higher costs but it is not evident that the total cost of the installation is higher than a direct system when all differences in the two approaches are accounted for. The approach of cascading is discussed, i.e. have multiple heat exchangers in series, which can lead to lower return temperatures albeit care is needed in having too many heat exchangers. It is also possible to use system return as supply to a development that is highly energy efficient – albeit this will depend on a new development being located to an older established system.

The economic value for optimised temperature is discussed. An evaluation in Sweden of 27 DH schemes revealed a value for reduced return temperature of 0.15€/MWh/°C. It is also noted that whilst traditionally the focus has been more on the return than supply temperatures (e.g. to increase the heat output of flue gas condensers), this is likely to change due to the motivation to use lower temperature networks and renewable heat sources.

This chapter reviews existing and future ways to implement optimisation of system temperatures. Radiator systems (as opposed to underfloor and warm air systems) are likely to be here to stay for the foreseeable future, and hence the consequent focus for better performing DH falls on substations. It posits that one way forward may be that DH flow being calculated and governed, by measuring the temperature and flows in the substation and the required flow continuously computed, rather than regulated by feedback control. Special substations were developed for 4GDH systems yielding regimes as favourable as 50°C/20°C. Another area of focus is the use of local thermal storage. Underfloor systems are likely to be most relevant for lower energy new-build and reference studies as to the pros and cons of such heating systems. There is a reference to a new radiator control method based on the control of both the supply temperature and flow rate in the radiator system which aims to continually adapt to provide the lowest possible return temperature. There is also the suggestion that existing radiators could function effectively at lower supply temperatures through the use of increased means of convection (e.g. radiator fans).

Chapter 12 – District heating monitoring and control

This section presents discussion on the control and monitoring of DH systems to deliver higher efficiency and financial benefits. It discusses how DH control systems of substations are designed in general, and introduces results of some research as to how the performance can be improved. It also presents how fault detection methods can be applied to hourly DH data to automatically detect faulty substations.

37 Appendix L: Literature Review and Horizon Scanning

37.1 Use of lower operating temperatures/regimes that can reduce costs

Summary

Using low temperature operating temperatures is one key area where most research is taking place in regards to district heating. In general, it can be concluded that both low-energy and existing buildings can be supplied Low-Temperature District Heating (LTDH) with a supply temperature of 50°C and still meet the requirements for DHW and thermal comfort if the DH substation, the DHW system and the space heating system are designed for low-temperature operation [1].

By doing both an energy and exergy analysis of low temperature district heating some important conclusions have been drawn: [2]

- LTDH supplies hot water with reduced temperature which leads to significant network heat loss reduction.
- Compared with the district heating storage tank (DHST), the instantaneous heat exchanger (ITHE) has both a larger network heat loss and a larger network exergy loss due to heat loss.
- The heat loss reduction due to improved network design is greater for medium operating temperatures than low operating temperatures, and is higher in the ITHE than that in the DHST.
- The system performance is degraded by using thermal by-pass at the consumer end.
- There is a large performance improvement margin through further reducing the exergy destruction for domestic hot water and space heating preparation.

The different components of a low temperature district heating system are also being investigated such as: the study of substations for instantaneous DHW [3] and achieving low return temperatures [4], the use of industrial waste heat to increase efficiency of the DH [5] and integration of heat pumps (HP) into LTDH with proposals to use chemical HPs instead of mechanical HPs [6]. Another study investigates the flexibility in reducing the supply temperature of DH with the help of refurbishment. It was found that for a typical single-family house from the 1970s, even a small refurbishment measure such as replacing the windows allows the reduction of the maximum DH supply temperature from 78°C to 67°C and, for 98% of the year, to below 60°C [7].

The overall piping network is a significant contribution to the total capital and operational cost, and optimisation of the piping network is important for cost implications. In one study [8], the piping network for a university campus and common piping network design parameters which are heat centre location, TPL, pipe materials and installation types, are studied to minimise the total investment and operational cost. They conclude that to minimise the total investment and operational cost of piping network, the heat centre should be located close to the buildings where the building density, and consequently thermal load density, is high.

Finite Element Modelling (FEM) was used to investigate the potential for energy savings in the case of twin pipes, asymmetrical insulation of twin pipes, double pipes and triple pipes [9]. It was reported that with regards to twin pipes, the vertical placement of twin media pipes inside the insulation barely affects the heat transfer, in comparison to the horizontal placement; the difference between the two configurations is less than 2% for the cases considered. Moreover, it was demonstrated that the asymmetrical insulation of twin pipes leads to lower heat loss from the supply pipe (from -4% to -8%). Consequently the temperature drop of the supply water decreases and that is relevant for low-temperature applications. At the same time, the heat loss from the return pipe can be close to zero. With regards to the double pipe system, it is possible to cut heat losses by 6-12% if an optimal design of double pipes is used instead of traditional twin pipes, without increasing the investment costs.

Research [10] was conducted to investigate a method for the design of a low-energy district heating (DH) system, concerning different pipe dimensioning methods, substation types and network layouts. Computations were carried out separately on each of the pipe segments which comprised the DH network. The applicability of the developed optimisation method was shown to be highly useful in pipe dimensioning and being superior to traditional dimensioning methods. It was shown that a significant reduction in heat loss from the DH network could be achieved.

Various technical aspects of low-energy DH systems have also been studied in detail including, in particular, different substation types and network layouts [11]. It is suggested that employing a diversity factor at each level of a pipe segment is useful, in particular to avoid over-dimensioning since the consumers in a district do not all consume heat at the same time. Use of booster pumps and their relevance to avoid over-dimensioning in cases in which the maximum static pressure allowable is very limited is also investigated, as are important characteristics of different network layouts, the particular usefulness of looped network layouts in areas of dense population and the superiority of branched DH networks with bypasses at leaf-nodes in matters relating to heat loss and the satisfaction of consumer needs.

Apart from optimising the district heating pipe network there is an interest in integrating renewable technologies such as heat pumps into DH for savings and efficiency of the system. Feasibility of a DH consumer unit with micro heat pump for domestic hot water (DHW) preparation in a low temperature (40°C) DH network has been investigated [12]. The results show that the proposed system has the highest efficiency. Another study evaluates the power consumption and efficiency of booster heat pumps for hot water production in a low temperature district heating network [13]. Of the three heat pump configurations examined, two are implemented on the primary side to boost the network stream, and one is intended to increase the temperature of the tap water directly. Results show that the best configuration shows exergetic efficiencies higher than 0.5 when the operating temperature is around 45°C.

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Journal/Conference Papers:

Paper 2:

Title: Energy and exergy analysis of low temperature district heating network

Journal: Energy

Authors: Hongwei Li and Svend Svendsen

Year: 2012

Description: In this paper, a hypothetical low temperature district heating network is designed to supply heating for 30 low energy detached residential houses. Through simulation, the overall system energy and exergy efficiencies are calculated and the exergy losses for the major district heating system components are identified. Based on the results, suggestions are given to further reduce the system energy/exergy losses and increase the quality match between the consumer heating demand and the district heating supply.

Paper 3:

Title: Numerical modelling and experimental measurements for a low-temperature district heating substation for instantaneous preparation of DHW with respect to service pipes

Journal: Energy

Authors: Marek Brand, Jan Eric Thorsen and Svend Svendsen

Year: 2012

Description: This paper describes some practical approaches to the implementation of low temperature district heating (LTDH) with an entry-to-substation temperature around 50°C. Results show that the way that the service pipe is operated has a significant effect on waiting time for DHW, heat loss, and overall cost. Furthermore, the service pipe should be kept warm by using a bypass in order to fulfil the comfort requirements for DHW instantaneously prepared.

Paper 4:

Title: Achieving low return temperatures from district heating substations

Journal: Applied Energy
Authors: Henrik Gadd and Sven Werner
Year: 2010
Description: This paper presents a novel method using the temperature difference signature for temperature difference fault detection and quality assurance of eliminated faults. Annual hourly datasets from 140 substations have been analysed for temperature difference faults. From these 140 substations, 14 were identified with temperature difference appearing or eliminated during the analysed year. Nine appeared during the year, indicating an annual temperature difference fault frequency of more than 6%.

Paper 5:
Title: Industrial waste heat utilization for low temperature district heating
Journal: Energy Policy
Authors: Hao Fang, Jianjun Xia, Kan Zhu, Yingbo Su, Yi Jiang
Year: 2013
Description: The purpose of this paper is to propose a holistic approach to the integrated and efficient utilisation of low-grade industrial waste heat. Furthermore, low temperature DH network greatly benefits the recovery rate of industrial waste heat. This study finds three advantages to this approach: (1) improvement of the thermal energy efficiency of industrial factories; (2) more cost-efficient than the traditional heating mode; and (3) CO2 and pollutant emission reduction as well as water conservation.

Paper 6:
Title: On the robustness, effectiveness and reliability of chemical and mechanical heat pumps for low-temperature heat source district heating: A comparative simulation-based analysis and evaluation
Journal: Energy
Authors: A.N. Ajaha, A. Mesbah, J. Grievink, P.M. Herder, P.W. Falcao and S. Wennekes
Year: 2008
Description: This paper provides a comparative study through simulations, of the effectiveness, robustness and reliability of the often two most promising heat upgrading technologies (the chemical and mechanical heat pumps) systems for the sustainable heat upgrading of low-temperature heat sources for district heating. The simulation results reveal that for a low to medium energy demand, low-temperature heat source upgrading using the chemical heat pumps seems more promising than the mechanical heat pumps, while the mechanical heat pump is best suited for high energy demand space heating.

Paper 7:
Title: Renewable-based low-temperature district heating for existing buildings in various stages of refurbishment
Journal: Energy
Authors: Marek Brand and Svend Svendsen
Year: 2013
Description: This paper investigates how low the DH supply temperature can be without reducing the current high level of thermal comfort for occupants or the good efficiency of the DH network. This research shows that renewable sources of heat can be integrated into the DH system without problems and contributes to the fossil-free heating sector already today.

Paper 8:
Title: Piping network design of geothermal district heating systems: Case study for a university campus
Journal: Energy
Authors: Nurdan Yildirim, Macit Toksoy, Gulden Gokcen
Year: 2010

Description: Geothermal district heating system design consists of two parts: heating system and piping network design. In this study, piping network design optimisation is evaluated based on heat centre location depending upon the cost and common design parameters of piping networks which are pipe materials, target pressure loss (TPL) per unit length of pipes and installation type. Then a case study for a university campus is presented.

Paper 9:
Title: Method for optimal design of pipes for low-energy district heating, with focus on heat losses
Journal: Energy
Authors: A. Dalla Rosa and H. Li, S. Svendsen
Year: 2011
Description: The synergy between highly energy-efficient buildings and low-energy district heating (DH) systems is a promising concept for the optimal integration of energy-saving policies and energy supply systems based on renewable energy (RE). Network transmission and distribution heat loss is one of the key factors in the optimal design of low-energy DH systems. Various pipe configurations are considered in this paper: flexible pre-insulated twin pipes with symmetrical or asymmetrical insulation, double pipes, and triple pipes. These technologies represent potential energy-efficient and cost-effective solutions for DH networks in low-heat density areas. Finally, the article describes proposals for the optimal design of pipes for low-energy applications and presents methods for decreasing heat losses.

Paper 10:
Title: Improving the dimensioning of piping networks and network layouts in low-energy district heating systems connected to low-energy buildings: A case study in Roskilde, Denmark
Journal: Energy
Authors: H.I. Tol and S. Svendsen
Year: 2012
Description: A number of general conclusions not yet taken up can be drawn. One is that a district heating system should always be designed in accordance with what works best within the district itself. Another conclusion is that it is highly important to take into consideration, for each pipe segment separately, the degree of simultaneity of the heat consumers involved. In addition, it appears that significant savings can be achieved by use of the proposed optimisation method, which makes use of the pumping head lift in all closed loops of a DH network. Buffer tanks for DHW production, installed in each substation, were found to reduce the pipe dimension of the DH network appreciably and the heat loss from it to be reduced as well. One can note too that the mixing of supply and return heat carrier waters that can occur through bypasses being located in leaf nodes does not cause any excessive increase in temperature, except under conditions of extremely low heat demand, the return temperature there also tending to be rather moderate. One should note too that looped DH networks without a bypass tend to contain a considerable amount of supply heat carrier medium, which can lead under certain conditions to considerable drops in temperature and to greater loss of heat from the DH network than from a branched DH network having bypass units in the leaf nodes.

Paper 11:
Title: A comparative study on substation types and network layouts in connection with low-energy district heating systems
Journal: Energy Conversion and Management
Authors: Hakan Ibrahim Tol and Svend Svendsen
Year: 2012
Description: The study deals with low-energy District Heating (DH) networks operating in low temperatures such as 55 C in terms of supply and 25 C in terms of return. The network

layout, additional booster pumps, and different substation types such as storage tanks either equipped or not equipped in domestic hot water production site were examined. Effects of booster pumps on pipe dimensions in the latter case were investigated. Temperature drops during the summer months due to low heat demands of consumers were explored.

Paper 12:
Title: Low temperature district heating consumer unit with micro heat pump for domestic hot water preparation
Conference: The 13th International Symposium on District Heating and Cooling
Authors: E.Zvingilaite, T.Ommen, B. Elmegaard and M.L.Franck
Year: 2012
Description: Different concepts for domestic hot water preparation when district heating supply temperature is reduced to 40°C have been presented and compared in the article. The reduction of DH temperature implies the use of an additional energy source (electricity) for DHW preparation. Two main concepts of utilising the additional energy have been compared – based on heat pump and electric heater technologies. According to the recent Danish Building Regulations the DHW system with the micro heat pump is the best alternative, due to the lowest electricity consumption.

Paper 13:
Title: Exergetic evaluation of heat pump booster configurations in a low temperature district heating network
Conference: Proceedings of ECOS 2012 – The 25th international conference on Efficiency, cost, optimization, simulation and environmental impact of energy systems
Authors: Torben Ommen and Brian Elmegaard
Year: 2012
Description: Three heat pump schemes were singled out for evaluation in a low temperature district heating network in order to increase tap water temperature to meet the Danish standard. Out of the three heat pumps, two are used to boost the network temperature prior to heat exchange with the tap water, while the third is used to boost the temperature of the heated tap water.

37.2 Ground Radar and other Asset Location Technologies

Summary

From a review of available literature ground penetrating radar (GPR) is found to be a relatively well established and developed technology with early papers dating back to the early 90's [1][2]. Many of the more recent papers concerning locating utility and service assets refer to the use of GPR as the primary method of location [3][4][5]. This is largely due to GPR being able to detect a wide range of different types of asset materials (although it cannot distinguish between them) and is able to provide a determination of the depth of buried assets [3].

However, there are a variety of different asset locating technologies available that in certain circumstances are better suited and/or can provide more information on the buried asset. These technologies include:

- Electromagnetic line locators (appropriate for sensing metal utility pipes are cables),
- infrared thermography. and
- acoustic techniques [6][3].

Each sensing technology has their own advantages/disadvantages and can behave differently in different types of earth/soil [3], [7]. Several of the papers propose the integration of these sensing technologies with GPR to provide a more accurate and informative sensing strategy [4][8][9][5][10]. Such a 'multi-sensor' approach could possibly also be used for a determination on the current condition of the buried assets.

Typically proper interpretation of GPR data requires a trained and experienced user to effectively operate such devices [3]. A number of papers suggest that an easier more automated way of interpreting GPR data would allow for fast and accurate surveying of asset sites to be conducted [8][11]. Furthermore, with a simplification of GPR data being possible, GPR data could be easily overlaid and integrated via software with data from other sensors to provide the surveyors with a more descriptive visualisation of the buried asset [9]. Current GPR products are also found to be integrated with global positioning system (GPS) receivers such that users can also provide a universal reference for the measurements they make [12]. This would facilitate the easy integration of data, forming a universal database, from multiple surveys conducted at various times for a variety of assets in the same proximity. This has been suggested by a number of papers in this review [7][4].

Creation of a universal database of asset locations for a city or town could inform on what assets can be found at a certain location, who owns the asset and what condition it might be found in. Furthermore, such a database could inform on the type of earth/soil in the vicinity of the asset; this information would be useful to surveyors when deciding the best 'multi-sensor' approach for asset location[7]. Some researchers have even proposed the use of a decision tool for the quick selection of location technologies based on a variety of criteria including earth/soil type[13]. A doctoral thesis by Shuai Li of Purdue University, published in 2014 discusses the integration of GPR, GPS and geographical information system (GIS)[14]. Since this work was published relatively recently the integration and adoption of all these technologies in industry may not have been fully realised as yet.

GPR and other locating technologies appear to be well developed with a number of different products available on the market (see datasheets [12][15][16]). These types of product seem to be used by many surveying companies allowing them to provide a wide variety of services (see reports [17][18] and websites[19][20][21][22]).

However, there may be room for improvement of such services in terms of their accuracy, depth of information and speed via implementation of some of the suggestions discussed above.

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Journal/Conference Papers:
Paper 1:
Title: Underground asset location and condition assessment technologies
Journal: Tunnelling and Underground Space Technology
Authors: Costello, Chapman, Rogers, Metje
Year: 2007
Description: Review of current locating technologies for pipes and services with emphasis on describing their application and limitations. Also includes review of condition assessment technologies for proactive approach to pipeline maintenance. Paper concludes that a multi technology sensing approach is needed for location and condition assessment of assets.
Notable:
Listed locating technologies: Magnetometers; Electromagnetic line locators; Ground Penetrating Radar (GPR); Infrared thermography and Acoustic techniques.
Listed condition assessment technologies: CCTV; Sewer scanner evaluation technology; Sonar and laser surveys; Pipe inspection real-time assessment technique; Magnetic flux leakage; Eddy current; Wave analysis technique; Impact echo; Leak detection techniques; Leak noise correlator (WRc); Project sahara; GPR and Infrared thermography.

Paper 2:
Title: Condition assessment of the buried utility service infrastructure
Journal: Tunnelling and Underground Space Technology
Authors: Hao, Rogers ….
Year: 2012
Description: Review of current state-of-the-art technologies for condition assessment of underground utilities. Advantages and technical challenges discussed. Recommendations on how to deal with these challenges are made. Paper concludes that in assessing asset condition the condition of the ground in which the asset is buried should also be taken in to account when selecting technologies and planning for other buildings or new asset construction in the area.
Notable: Proposal for an integrated database containing ground properties, utility infrastructure and surface infrastructure properties and current condition.

Paper 3:
Title: Ground Penetrating Radar as a Subsurface Environmental Sensing Tool
Conf Proc: IEEE
Authors: Peters, Daniels and Young
Year: 1994
Description: Early paper on GPR. Includes basic concept of GPR and discussion of possible applications, utility services detection is mentioned.
Notable:

Paper 4:
Title: Maximizing the information return from ground penetrating radar
Journal: Journal of Applied Geophysics
Authors: Olhoeft
Year: 2000
Description: Early GPR paper, discusses access/situational, technological and geographical limitations to the use of GPR and suggestions to overcome therm.
Notable:

Paper 5:

Title: Use of approximate reasoning techniques for locating underground utilities
Journal: Tunnelling and Underground Space Technology
Authors: Lanka, Butler and Sterling
Year: 2001
Description: Paper discusses a means to combine three sources of asset location information, including GPR, to obtain more accurate location of underground utilities. Paper suggests that a means of simply interpreting GPR data would aid in its integration with other information sources.
Notable:

Paper 6:
Title: Mapping the Underworld – State-of-the-art review
Journal: Tunnelling and Underground Space Technology
Authors: Metje, Atkins…..
Year: 2007
Description: Paper describes the MTU project with one of the four aims of the project being the development of a multi-sensor device for accurate remote buried utility detection. Each type of sensor behaves differently depending on ground conditions; accurate knowledge of this will aid optimisation of each technology.
Notable: Three technologies selected for multi-sensor: GPR, low-frequency quasi-static electromagnetic field detection and acoustic detection. Describes the latest developments in GPR: impulse GPR, frequency modulated continuous waveform (FMCW) GPR, stepped frequency continuous waveform (SFCW) GPR and attempts to combine GPR with other sensing technologies.

Paper 7:
Title: Innovative process to characterize buried utilities using Ground Penetrating Radar
Journal: Automation in Construction
Authors: Lester and Bernold
Year: 2007
Description: Paper discusses a means of processing GPR data. Method is more accurate, in comparison to raw data, at pin-pointing the location of ferrous and non-ferrous utilities.
Notable:

Paper 8:
Title: A decision tool for the selection of imaging technologies to detect underground infrastructure
Journal: Tunnelling and Underground Space Technology
Authors: Jeong and Abraham
Year: 2004
Description: Paper describes a decision tool for the selection of appropriate imaging technologies for the successful identification of underground utilities. Ten critical criteria are identified for selection of appropriate imaging technologies. Software called IMAGTECH.
Notable: Notes on research underway at the Trenchless Technology Center (TTC) at Louisiana Tech University.

Paper 9
Title: Detection of landmines and underground utilities from acoustic and GPR images with a cepstral approach.
Journal: Journal of Visual Communication and Image Representation.
Authors: Umar…..
Year: 2010
Description: Describes a means of interpreting GPR image data in terms of pattern recognition. Approach utilises artificial intelligence for the determination of asset existence and location. Method could potentially reduce operator training.

Notable:

Paper 10
Title: Ten years of experience with leak detection by acoustic signal analysis
Journal: Journal of applied acoustics
Authors: Fuchs and Richle
Year: 1991
Description: Early paper on acoustic signal correlation techniques for detection of leaks in buried water pipes.
Notable:

Paper 11
Title: Mapping underground utilities within conductive soil using multi-frequency electromagnetic induction and ground penetrating radar
Journal: Arab Journal of Geoscience
Authors: Rashed and Atef
Year: 2015
Description: Recent paper on combination of asset sensing within conductive soil
Notable:

Paper 12
Title: A Multi-Sensory Approach to 3-D Mapping of Underground Utilities
Report: NIST Special Publication
Authors: Bernold, Venkatesan and Suvarna
Year: 2003
Description: Describes a multi-sensing technology that attaches to digging equipment. Sensor uses combination of electromagnetic induction and GPR.
Notable:

Topic 1, Ground Radar and other asset location technologies, Technical/Industrial Reports, Websites and Datasheets:
Website 1:
Title: RPS Group Surveying Services
Year:
URL: http://www.rpsgroup.com/UK/Services/S/Surveying.aspx
Description: A surveying company describing current technologies used for utility sensing. Several case studies are described.
Notable:

Website 2:
Title: Sandberg GPR
Year:
URL: http://www.groundpenetratingradar.co.uk/ground-penetrating-radar-surveys/utility-surveys/site-utility-surveys.html
Description: A GPR surveying company describing current technologies and procedures used for utility sensing. Several case studies are described.
Notable: Technologies used include GPR and Electromagnetic surveys

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Report 1
Title: Supply/Demand Appraisal
Report: United Utilities Business Plan 2010-2015
Authors:
Year:
Description: A chapter of the united utilities business plan. Mentions several sensing technologies that the company is either using or planning to develop and use.

Notable: Technologies include: Acoustic loggers; Network modelling; Insertion probes (Sahara); Project Neptune; Infrared thermal and radar imaging; Insertion noise microphones; Insertion differential pressure sensors and GPR.

Report 2
Title: Avoiding danger from underground services
Report: Health and Safety Executive
Authors:
Year: 2014
Description: Report provides guidance and description of current locating technologies for use in commissioning, planning, managing and carrying out work on or near underground services.
Notable: Describes several sensing technologies currently in use.

Website 3:
Title: CenTara Utility Mapping
Year:
URL: http://www.centara-ltd.com/solutions/utility-mapping.htm
Description: A utility mapping company providing a variety of services in locating underground assets.
Notable: GSSI Ground penetrating radar, electromagnetic underground utility location mapping surveys.

Website 4:
Title: LincEnergy – Natural Gas Measurement, Underground Utilities and More Blog
Year: 2013
URL: http://www.lincenergysystems.com/linc-energy-blog/entry/what-are-the-common-underground-utility-location-methods#.VpkN2ssny5s
Description: Blog asks the question: what are the common underground utility location methods? Several technologies are described.
Notable: Electromagnetic utility locating, acoustic pipe locator, GPR, Hydro or Vacuum excavation (potholing)

Datasheet 1:
Title: SENSIT Technologies, Ultra-TRAC Acoustic Pipe Locator
Year:
URL: http://www.gasleaksensors.com/brochures/sensit_ultra_trac_apl_brochure.pdf
Description: Datasheet/brochure for acoustic pipe locator product. Is able to locate plastic pipes.
Notable:

Datasheet 2:
Title: GSSI UtilityScan
Year:
Reference:
URL: http://www.geophysical.com/utilityscan.htm
Description: Datasheet/brochure for GPR product. Product is described as the industry standard GPR for the location of subsurface utilities.
Notable: System receives GPS location signals

Datasheet 3:
Title: 3M Locating Dynatel Advanced Pipe/Cable Locator 2220M
Year:
URL: http://multimedia.3m.com/mws/media/487162O/3mtm-dynateltm-advanced-pipe-cable-locator-2220m-data-sheet.pdf

Description: Datasheet/brochure for electromagnetic induction pipe/cable product.
Notable: For locating metal pipes and cables.

37.3 Trenchless technologies

Summary:

On reviewing the available literature trenchless technologies (TT) appear to be a fairly well developed set of drilling and in-situ repair techniques with papers and literature dating back in to the 90's [1]. There are a variety of techniques for creating boreholes of different sizes appropriate for different earth/soil types at different depths [2]. These include

- thrust boring,
- impact ramming,
- fluid jet tunnelling and
- pipe jacking.

Micro-tunnelling is a form of pipe jacking restricted to bore sizes less than 900mm at depths of up to 4m and is likely an appropriate approach for pipe installation for a large part of a district heating network [2]. With this type of method a steerable, remote controlled boring tool proceeds along a planned route between two points that avoids any obstacles that might be in the way. As the boring tool proceeds, pipe sections or temporary pipe casings are pushed in behind the tool. In the case of flexible pipes, these can follow the boring tool without a break in the pipe as appears to be done by some district heating pipe manufacture and installation companies.

One area for improvement might be the integration of boring tool location data taken from surface ground penetrating radar (GPR) measurements and horizontal acoustic technique measurements (or other horizontal location system) with electromagnetic induction proximity data provided by a sensor mounted on the boring tool as suggested by one paper [3]. This could provide accurate, near real-time, 3D location of the boring tool and its position with respect to installed assets/obstacles. A combination of these sensing technologies, excluding GPR, may also be effective in potentially inaccessible locations (such as underneath a road) as suggested by another paper [4] [5]. This would allow for better versatility and risk management of a planned project. A high level of expertise is required from TT operators, therefore methods to simplify or improve accuracy and reliability of the TT equipment can lessen the burden on the operators.

Trenchless technologies also incorporate methods to repair or replace existing installed pipe lines [2][6]. One such method is pipe bursting in which a damaged pipe section is purposefully burst and pushed into the surrounding soil to make room for a replacement section [7]. Another more interesting method for replacement/repair (and perhaps also for new installation) is soft lining systems with a cured-in-place pipe [2]. In this case a fabric liner is impregnated with a polyester or epoxy resin mixed with a catalyst and then forced into the existing pipeline (or new borehole). Once set the repaired (or perhaps new) pipe is made of resins that can be cheap with good resistance to heat and chemicals.

Many of the papers in this review highlight the economic and environmental benefits of TT. One paper compares the life-cycle cost of TT and open-cut pipeline construction projects [8]; TT is concluded as being more cost effective and is also found in another paper to be environmentally less damaging [9]. Another paper describes a method for quantitatively assessing and comparing the direct social and economic costs of a variety of TT [10]; paper concluded that TT results in some economic benefits, better productivity, safer work environment and better structural conditions.

Site appropriate TT decision tools [11], social cost savings calculators [12] and risk assessment methods [5] are discussed in other papers. There are a number of companies that offer a variety of TT services (see [13][14][15]) and other companies or government

agencies have investigated the benefits of TT (see [16][17]). Finally the UKSTT (United Kingdom Society for Trenchless Technology) is a registered charity involved in the development and promotion of TT [18].

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Book 1:
Title: An introduction to trenchless technology
Authors: Kramer, McDonald and Thomson
Year: 2012
Description: Book provides an in-depth summary of the available technologies and techniques.

Notable:

Paper 1:
Title: Trenchless Technologies Decision Support System Using Integrated Hierarchical Artificial Neural Networks and Genetic Algorithms
Journal: ASCE Pipelines
Authors: Amr Fathy; Soliman Abu-Samra; Mohamed Elsheikha; and Ossama Hosny
Year: 2015
Description: Description and review of current trenchless technologies (TT). Paper focusses on introducing a frame work for developing a TT decision support system (TTDSS). Tool shown to be useful in deciding the best method for a given project.
Notable:

Paper 2:
Title: HORIZONTAL DIRECTIONAL DRILLING: PROFILE OF AN EMERGING INDUSTRY
Journal: ASCE Journal of Construction Engineering and Management
Authors: Erez N. Allouche, Samuel T. Ariaratnam, and Jason S. Lueke
Year: 2000
Description: Early paper reviewing the results obtained from 49 horizontal, directional drilling (HDD) contractors in the US and Canada. Describes potential for growth of the HDD industry.
Notable:

Paper 3:
Title: Utilization of Trenchless Construction Methods in Mainland China to Sustain Urban Infrastructure
Journal: ASCE Practice Periodical on Structural Design and Construction
Authors: Samuel T. Ariaratnam, M.; Wing Chan; and Derek Choi
Year: 2006
Description: Paper describes a variety of trenchless technologies, directional drilling, pipe ramming and pipe bursting. Paper refers to various case studies in which each of these technologies is used.
Notable:

Paper 4:
Title: Life-Cycle-Cost Comparison of Trenchless and Conventional Open-Cut Pipeline Construction Projects
Journal: ASCE Proceedings
Authors: Mohammad Najafi and Kyoung Ok Kim
Year: 2004
Description: Paper presents an investigation of the cost-effectiveness of constructing underground pipelines with trenchless methods in urban environments in comparison to conventional methods. Trenchless methods argued to be more cost-effective.
Notable:

Paper 5:
Title: Applications of Horizontal Characterization Techniques in Trenchless Construction
Journal: ASCE Journal of Construction Engineering and Management
Authors: Erez N. Allouche, Samuel T. Ariaratnam, and Simon M. AbouRizk
Year: 2001
Description: Paper reviews a variety of horizontal site characterisation technologies to be used in coordination with TT. Paper concludes that site investigation can be enhanced via

horizontal site characterisation and existing databases should be expanded to better account for data provided by these methods.
Notable:

Paper 6:
Title: TTWORLD: A WEB-PORTAL FOR ASSESSING THE SUITABILITY OF TRENCHLESS CONSTRUCTION METHODS FOR UTILITY PROJECTS AND ASSOCIATED SOCIAL COST SAVINGS
Journal: ASCE Proceedings Pipelines, Infrastructure's Hidden Assets
Authors: J. Matthews and E. Allouche
Year: 2009
Description: Paper describes a comprehensive and easy to use software tool for the evaluation of alternative construction methods that can be employed in the installation and rehabilitation of buried pipes and manhole structures. A social cost savings calculator is included in the web-based tool to help users evaluate trenchless technologies in comparison to conventional methods.
Notable: Tool not available at specified location.

Paper 7:
Title: Evaluation of Trenchless Technology Methods for Municipal Infrastructure System
Journal: ASCE Journal of Infrastructure Systems
Authors: Yeun J. Jung and Sunil K. Sinha
Year: 2007
Description: Paper describes a method for quantitatively assessing and comparing direct social and costs associated with municipal underground pipeline construction of a variety of TT. Paper concludes that the application of trenchless technology in underground pipeline construction results in economic benefits, better productivity, a safer work environment, and better structural conditions.
Notable:

Paper 8:
Title: Lead pipe rehabilitation and replacement techniques for drinking water service: review of available and emerging technologies
Journal: Tunnelling and Underground Space Technology
Authors: Glen R. Boyd, Neil K. Tarbertb, Roger J. Oliphantb, Gregory J. Kirmeyerc, Brian M. Murphyc, Robert F. Serpented
Year: 2000
Description: Early paper describes several 'emerging' technologies for rehabilitation and replacement of small diameter lead pipes (<25 mm) for water service. Each technique is described with its own advantages and disadvantages.
Notable:

Paper 9:
Title: Risk Evaluation for Maxi Horizontal Directional Drilling Crossing Projects
Journal: Journal of Pipeline Systems Engineering and Practice
Authors: Baosong Ma; Mohammad Najafi; Hua Shen; and Langhui Wu
Year: 2010
Description: This paper addresses the risk assessment for Maxi HDD projects. The combination of the fuzzy comprehensive evaluation method and analytical hierarchy process was adopted as the basic model. This combination is shown to means of establishing risk control measures in these types of project.
Notable:

Paper 10:

Title: Sustainable development through innovative underground infrastructure construction practices
Proceedings:
Authors: Ariaratnam, S.T.
Year: 2013
Description: An assessment of the environmental impact of TT in comparison to conventional open cut excavation methods. TT methods are found to emit 80% less emissions in comparison to conventional methods.
Notable:
Technical/Industrial Reports, Websites and Datasheets:
Report 1:
Title: State of Technology for Rehabilitation of Wastewater Collection Systems
U.S. Environmental Protection Agency
Authors: Sterling….
Year: 2010
Description: Large report, the emphasis of which is trenchless technologies and highlights potential room for improvement in existing TT.
Notable:

Report 2:
Title: Trenchless Technologies in pipeline construction
3R International Special Edition
Authors: Nico Hulsdau
Year: 2004
Description: Report describing a wide variety of trenchless technology aspects.
Notable:

Report 3:
Title: Synthesis of Trenchless Technologies
Virginia Centre for Transportation Innovation and Research
Authors: Lindsay Burden and Edward Hoppe
Year: 2015
Description: Report examining the current state of practice of state highway agencies regarding methods and specifications for using TT. Report concludes that TT is widely adopted but design guidelines and construction specifications vary significantly. Accurate subsurface characterisation is critical to the selection of appropriate TT methods. Current monitoring of trenchless construction is usually limited to observations of installation procedures and surface monitoring. A high level of expertise is required from TT operators.
Notable:

Website 1:
Title: Perco – Specialists in Trenchless Technology
Year: 2013
URL: https://perco.co.uk/
Description: A TT construction company specialising in new pipe installation and existing sewer rehabilitation.
Notable:

Website 2:
Title: Terra Solutions Ltd
Year: 2016
URL: http://www.terrasolutions.co.uk/services/
Description: A TT construction company providing a full range of services including TT.
Notable:

Website 3:
Title: UKSTT
Year: 2016
Reference:
URL: http://www.ukstt.org.uk/trenchless-technology/introduction
Description: The UKSTT (United Kingdom Society for Trenchless Technology) is a registered charity involved in the development and promotion of Trenchless techniques, sometimes termed No-Dig techniques.
Notable:

37.4 Emerging plastic pipe technologies for higher temperature operation

Summary

In reviewing the literature for emerging plastic pipe technologies for higher temperature operation it was considered prudent to firstly identify the types of plastic pipes currently used for various applications. The European Plastic Pipes and Fittings Association provide a guide to materials commonly used for plastic pipe systems [1]. On review of this guide the following plastics are identified:

- Polyvinyl chloride (PVC) most common.
- Polyethylene (PE) is sometimes used in pipe lining and trench-less technologies.
- Polypropylene (PP) thermoplastic can operate continuously up to 60°C and can operate for short periods at 90°C.
- Cross-linked polyethylene (PEX) can be used at temperatures from below freezing up to almost boiling. Very flexible and is used currently in district heating piping systems.
- Polybutylene (PB) sometimes referred to as Polybutene has good strength and flexibility at elevated temperatures.
- Polyethylene of raised temperature resistance (PE-RT) [2].

From this list of materials, plastics incorporating polyethylene or polybutylene were considered to have the greatest potential for heat resistance. On querying available databases for recent literature on studies concerning these types of plastic a number of papers were found. Some of these papers concerned degradation studies of PE type pipes subject to a variety of conditions and exposure to different chemicals [3][4][5]. While a number of other papers describe some new research in altering the properties of PE and PB type plastics for greater impact strength, heat distortion temperatures and resistance to rapid crack formation [6][7][8]. Another paper suggests a change in the extrusion method of PB pipes can improve pipe hoop strength[9].

A couple of papers refer to the use of plastic pipes in heat transfer applications, with plastic being selected with improved thermal conductivity; as an example one such paper describes the replacement of metal components with plastic ones for dehumidifier systems [10]. A more interesting and pertinent paper describes the use of cross-linked polyethylene pipes, reinforced with carbon nanotubes, for geothermal applications [11]. Such pipes were found to be more resistant to thermal decomposition in comparison to ordinary PEX pipes. Another potentially useful paper describes a novel series of ring-chain polymers that show good thermal stability; paper reports that these polymers exhibit decomposition temperatures for 5% mass loss ranging between 493-540°C [12].

On reviewing the types of plastic (and non-plastic) pipe systems currently in use by companies specialising in pipe systems for district heating networks, two companies were found to use PEX and PB pipes for such applications [13][14][15].

One advantage of plastic pipe systems incorporating PB pipes as claimed by the manufacturer is that the inherent elasticity of material allows the pipe system to self-compensate such that no expensive expansion loops or bellows are required as in steel pipe systems. An example is FLEXENERGY insulated pipe solutions who offer the Flexalen 600 pre-Insulated pipe system. This system offers a range of coiled or straight insulated pipes with single or multiple carrier pipes. Sizes range from 25mm to 225mm OD on the carrier pipe indicating that this system could be used for many different stages of a district heating network. This PB pipe system has a maximum short-term operating temperature of 95°C at 5 to 8 bar.

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Journal/Conference Papers:
Paper 1:
Title: Ageing study of different types of long-term pressure tested PE pipes by IR-microscopy
Journal: Polymer
Authors: Raquel Maria, Karsten Rode, Tobias Schuster, Guru Geertz, Frank Malz, Abhishek Sanoria, Harald Oehler, Robert Brüll, Mirko Wenzel, Kurt Engelsing, Martin Bastian, Emmanuelle Brendl
Year: 2015
Description: An investigation of the thermo-oxidative long term degradation of common types of PE pipe. A method is developed to quantitatively determine the content of the phosphite additives in PE pipes.
Notable:

Paper 2:
Title: The structural performance of thin-walled polyethylene pipe linings for the renovation of water mains
Journal: Tunnelling and Underground Space Technology
Authors: J.C. Boot, Z.W. Guan, I. Toropova
Year: 1996
Description: Early paper describes instances in which a plastic thin walled lining can be used to yield both cost savings and a larger renovated pipe bore.
Notable: Medium density polyethylene

Paper 3:
Title: Experimental analysis of an internally-cooled/heated liquid desiccant dehumidifier/regenerator made of thermally conductive plastic
Journal: Energy and Buildings
Authors: Jun Liua, Tao Zhanga, Xiaohua Liua, Jingjing Jianga
Year: 2015
Description: Paper describes the replacement of conventional metal materials with plastics for use in internally cooled/heated dehumidifiers/regenerators using liquid desiccant.
Notable: Plastics were shown to have comparable heat transfer characteristics in comparison to metal components.

Paper 4:
Title: Super Toughened and High Heat-Resistant Poly(Lactic Acid) (PLA)-Based Blends by Enhancing Interfacial Bonding and PLA Phase Crystallization
Journal: American Chemical Society
Authors: Ling Lin, Cong Deng, Gong-Peng Lin and Yu-Zhong Wang
Year: 2015
Description: Paper describes a method to incorporate polycarbonate(PC) into ploy(lactic acid)(PLA) to prepare the high-PLA-content PLA/PC blends with high impact strength and heat distortion temperatures. This type of polymer is considered a promising substitute to some petrochemical-based polymers.
Notable:

Paper 5:
Title: Effect of molecular weight distribution on rheological, crystallization and mechanical properties of polyethylene-100
pipe resins
Journal: Journal of Polymer Resins
Authors: Tong Wu & Lei Yu & Ya Cao & Feng Yang & Ming Xiang
Year: 2013
Description: Paper describes how the introduction of homopolymerized low molecular fraction in polyethylene-100 (PE100) resins could enhance the crystallization capacity for the improvement of rapid crack formation resistance.
Notable:

Paper 6:
Title: Ageing of polyethylene at raised temperature in contact with chlorinated sanitary hot water. Part I – Chemical aspects
Journal: Polymer Degradation and Stability
Authors: J. Castillo Montesa, D. Cadouxa, J. Creusb, S. Touzainb, E. Gaudichet-Maurinc, O. Correca
Year: 2012
Description: Paper describes ageing of polyethylene pipes used for hot water inside buildings when subjected to disinfection chemicals such as sodium hypochlorite. Study

showed that degradation for certain concentrations was confined to the immediate inner surface of the pipe; suggesting a minimum thickness is required such that the pipe is not weakened.
Notable:

Paper 7:
Title: Ketene Functionalized Polyethylene: Control of Cross-Link Density and Material Properties
Journal: Journal of the American Chemical Society
Authors: Frank A. Leibfarth, Yanika Schneider, Nathaniel A. Lynd, Alison Schultz, Bongjin Moon, Edward J. Kramer, Guillermo C. Bazan and Craig J. Hawker
Year: 2010
Description: Paper describes a means of tuning cross-linked polyethylene properties by comonomer incorporation and elucidate valuable structure/property relationships in these materials.
Notable:

Paper 8:
Title: Structure and performance of polybutene-1 pipes produced via mandrel rotation extrusion
Journal: Journal of polymer materials engineering
Authors: Wei Liu, Qi Wang and Min Nie
Year: 2014
Description: Paper describes a new rotational extrusion process for the manufacture of polybutene-1 pipes. New method provides an improvement in mechanical hoop strength of such pipes suggesting these pipes could operate at a higher pressure in comparison to conventionally manufactured pipes.
Notable:

Paper 9:
Title: Mechanical, Thermal and Morphological Behaviours of Polybutylene Terephthalate/Polycarbonate blend nanocomposites
Journal: International Letters of Chemistry, Physics and Astronomy
Authors: P. R. Rajakumar, R. Nanthini
Year: 2013
Description: Paper describes fabrication of a polybutylene Terephthalate (PBT) / Polycarbonate (PC) nanocomposite blend. The PBT/PC material is shown to have improved impact strength and thermal stability in comparison to pure PBT in some cases. Paper suggests that the blending of multiple polymers is becoming the established method for designing tailor made polymer materials.
Notable:

Topic 2, Emerging plastic pipe technologies for higher temperature operation, Technical/Industrial Reports, Websites and Datasheets:
Website 1:
Title: The European Plastic Pipes and Fittings Association
Year:
Reference:
URL: http://www.teppfa.eu/fast-guide-to-materials/
Description: A guide to various materials commonly used for plastic piping systems.
Notable: Four main types of plastics used in plastic pipe systems. PVC, PE, PEX and PP. PVC (polyvinyl chloride) most commonly used. PE (Polyethylene) is used in lining and trench-less technologies. PP (thermoplastic made from Polypropylene), good performance at operating temperatures up to 60°C (continuous), can be used for short periods at 90°C. PEX (Cross-linked polyethylene) can be used at temperatures from below freezing up to almost

boiling, very flexible. PB (Polybutylene), PE-RT (Polyethylene of Raised Temperature Resistance) and ABS (Acrylonitrile-Butadiene-Styrene) are other high temperature plastics.

Report 1
Title: PE-RT, A NEW CLASS OF POLYETHYLENE FOR INDUSTRIAL PIPES
Report: Plastics R&D, The Dow Chemical Company
Authors: Schramm and Jeruzal
Year: 2003
Reference:
Description: Describes characteristics and applications of PE-RT.
Notable: Satisfy ISO 10508. Requirements: Pressure 2-10 bar. Temperature 20-110°C. Lifetime minimum 50 years.

Datasheet 1:
Title: Calpex district heating pipe
Year:
Reference:
URL:
Description: Datasheet/brochure for cross-linked polyethylene district heating pipe
Notable:

Datasheet 2:
Title: Flexwell district heating pipe
Year:
Reference:
URL:
Description: Datasheet/brochure for steel district heating pipe
Notable:

Datasheet 3:
Title: Flexenergy Insulated Pipe Solutions
Year:
Reference:
URL:
Description: Datasheet/brochure for all plastic district heating distributions systems
Notable:

37.5 In-situ jointing technologies

Summary

Using plastic pipes for district heating can reduce installation costs due to lower number of joints and time/cost of connections [1]. The weak spots in plastic piping systems generally occur at the joints, since these are often made in situ [2]. Jointing systems that comply with EN 489 [3] are designed to withstand ground forces and remain leak tight throughout a technical life of at least 30 years. A three-step quality control method was developed specifically for onsite installation in a study by examining three jointing techniques i.e. cross-linked polyethylene joint (PEX), polyethylene shrink joint and welded joints [4]. The study concludes that on-site supervision and installer's staff training can easily prevent errors in jointing.

From the literature review carried out it was observed that ‘in-situ jointing techniques for district heating’ is not a topic of great interest in academia. Instead, it is mostly the R&D departments of industrial companies that are competitively investigating and developing such technologies. Ample interest is shown in developing jointing products for cross-linked polyethylene (PEX) pipes which can be used with temperatures of up to +95° C [5] [6] [7] [8]. Pipes are typically adhesively bonded whilst the outer casings undergo electro-fusion for a tight seal which is considered to be both economic and reliable. Some of the advantages of elecrofusion fitting jointing technique combined with the properties of cross-linked polyethylene are: [5]

- Temperature resistant up to +95°C.
- Corrosion resistant.
- Cost-effective.
- Good chemical resistance.
- Modular construction principle for a cost-effective combination of necessary fittings depending on the requirements on the construction site.

VitalEnergi introduced a jointing method known as the Band Muff to the UK in 1988 made of high-density polyethylene (HDPE) (originally developed by IC Moller in Denmark and now sold through Logstor). According to the company the Band Muff is the most secure fusion welded jointing system currently available for pre-insulated pipes. The joint is given extra strength as the Band Muff and the outer casing are welded together using embedded copper wires, to form one unbreakable joint. Additionally, computer-controlled welding equipment has been developed to reduce the installation time to a minimum [11].

An even older (approx. 30 years) well-proven underground jointing technique for pre-insulated pipes is the steel fitting system. The material is usually Steel/Polyethylene coated. The unique technical and economical characteristics of the steel fitting system reduces the number of joints required, which means fewer potential failures, improving life-cycle costs. The steel fittings are delivered to site in two halves and when fitted over a sealing strip onto the pre-insulated pipe form a water tight seal. This high quality fixing is an excellent option for customers who are more concerned about short term capital costs than the system's overall life-cycle [11].

The University of Ulster, UK researched the options for retrofitting a new district energy piping system to deliver heat to its campus buildings. They suggest that using Polybutene-1 (PB-1) resulted in significant cost savings for the University. Fusion welding is by far the quickest and most effective way to joint district heating installations. PB-1 has also proved to be cost effective in terms of running costs given the fact that it is far more efficient against heat loss than steel, providing savings in excess of 40% [14].

Another jointing technique that is popular in the industry is to use press couplings (typically made of brass) for joining PE-X pipes albeit on a smaller scale compare to the former methods [9] [10].

For metal pipes in-situ anticorrosive protection of welded joints and/or of damaged coating areas can also be carried out. One technique utilises ready-to use sheathing/band made of thermoplastic material which is applied on the joint by a suitable device placed on the pipe in the area to be coated, turning around the pipe wrapping and pressing with the desired pressure the sheathing/band/tape onto the pipe itself and ensuring a strong adherence to the support/pipe and the absence of air bubbles entrapped between the sheathing/tape and the pipe [12]. Another reliable and cheaper jointing technique which can be carried out in the presence of liquids (e.g. oil and water) is the LOKRING jointing technology [13].

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[11] https://www.vitalenergi.co.uk/technologies/joint-systems/
[12] Culzoni, F. and Berti, E. (2002). Method for anticorrosive protection in situ of welding joints and/or of damaged coating areas of metal pipes, Google Patents.
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37.6 New controls/ measurement systems that can contribute to savings

Summary

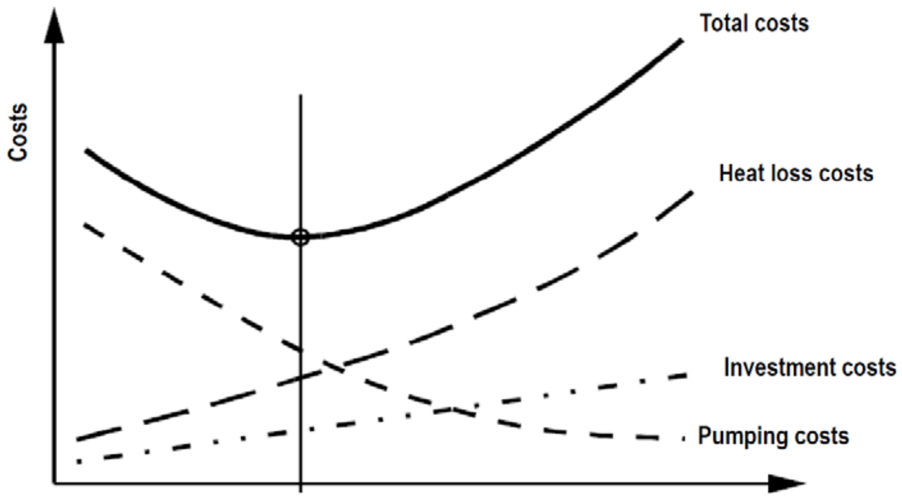
According to REHAU [1] district heating network designs need to be optimised in order to achieve savings by considering:

1) Reducing installation costs
   - Plastic pipes reduce the installation cost due to number of joints and time/cost of connections.
     - With an operating pressure of 6 bar, the service life of PE-X pipes is min. 30 years under the following conditions:
       - Continuous operating temperature of 85°C.
       - Continuous operating temperature of 80°C, with 90°C for one month per year and 95°C for 100 hours per year.
   - Backfilling costs can be reduced by installing in ‘soft-dig’ areas rather than roads.
   - Can twin pipe be used?

2) Using a smaller pipe diameter
   - New systems often use flow temperatures of ca. 80°C:
     - Extends pipe lifespan.
     - Makes a safer network (no steam).
   - Ensure return temperature is as low as possible (high ΔT):
     - Reduces pipe size > reduce capital costs for pipe & installation.
     - Ensures low-grade heat can be used (e.g. waste heat from CHP).

3) Increasing the heat density/optimising diversity
   - 100% peak demand of the heating system needed for a small part of year only – hence systems are likely to be oversized.
   - Different groups of buildings require varying diversity factors (example CIBSE figures on right).
   - The diversity factor is the measure of probability of a peak demand.
   - Consider regulating peak and non-peak load by installing multiple boilers for 1 heat load (1000kW as 400+600kW).

There is balance of investment vs operational costs that needs to be kept in mind when designing district heating networks:



Steel & polymer network pipes can be combined for large DH schemes, called hybrid systems [2]. Some of the benefits are:

- High temperature / volume steel mains (e.g. 150-300mm).
- Cost-effective to install flexible polymer house connections.
- Can use polymer for smaller 'spines' off the mains.

Typically a branch network (with a main distribution pipe) is used for district heating. However, a ring main offers some benefits for certain projects:

- Allows multiple heat sources (future connections).
- Flexibility of design.
- Reliability.
- Redundancy.

New DH systems using mass flow control meant for the concept of a ring network technology where mass flow rates in consumer substations are controlled by pumps with inverters to improve heat transfer are expected to be more readily employed. It will replace the traditional DH network and control in which water flow is throttled by control valves. For an example application the new flow rate was reported to be 46%, the pressure loss 25%, and the pumping power 12% of their former values in the pipes. The heat losses increase slightly with higher outdoor temperatures. The return temperature is lowest with the new technology [3].

A good example of connecting many heat production units that were geographically separated over large distances is the city of Copenhagen. As the heat network was extended to new parts of the city, new distribution networks were connected through additional hydraulic interface stations. Local peaking plants were also constructed to meet peak demand events. These were embedded within the distribution networks as an alternative to placing them at the main heat production facilities. This approach allowed the transmission network to be designed and optimized around a higher operating pressure/high velocity concept which in turn enabled the use of low diameter pipework. At the same time, the distribution networks could be optimized for local conditions without having to meet the design requirements of the transmission network. The overall impact was a low construction cost relative to the alternative design options [4].

A study demonstrated significant carbon emissions savings achievable through the addition of thermal storage in a test case of a CHP-DH system which uses gas reciprocating engines typical of many CHP-DH systems in the UK. The study shows that the embedded carbon of the store, supply pipes and foundations are rapidly paid back by the additional carbon savings resulting from the more efficient operation of the CHP-DH system and consequent displacement of grid electricity [5].

There is an increasing interest by researchers in academia in terms of different approaches of control and monitoring of district heating systems and networks. One area of particular interest is sub-stations and increasing their performance. One study [6] aimed at improving the monitoring and control of district heating systems through the use of agent technology. In order to increase the knowledge about the current and future state in a district heating system at the producer side, each substation was equipped with an agent that makes predictions of future consumption and monitors current consumption. The contributions to the consumers, will be higher quality of service, e.g., better ways to deal with major shortages of hot water, which is facilitated by the introduction of redistribution agents, and lower costs since less energy is needed for the heat production.

Another piece of research [7] shows how increasing the temperature difference (DT) across the substations can result in less water need to be pumped through the district heating network, and a higher overall fuel efficiency can be obtained in the district heating power plants. When higher fuel efficiency is achieved, the usage of primary fuel sources can be reduced. A similar study [8] evaluated whether the primary supply temperature in district heating networks can be used to control radiator systems in buildings connected to district heating; with the purpose of increasing the DT. The results confirm that it is possible to control the radiator system based on the primary supply temperature while maintaining comfort; however, conclusions regarding improvements in DT were hard to distinguish. However, these changes to supply temperature set-point affect the overall operating cost and can be reduced by selecting appropriate control period selection. Eleven hypothetical scenarios spanning five different networks have been simulated under a variety of control policies in a study [9]. When compared to a constant supply temperature strategy, the best policy in each case achieved a loss reduction of 5–24%.

Dynamic models can be used to reduced long transport time delays in direct district heating systems lag times using a Smith predictor [10]. Optimal set point profiles of supply water temperature as a function of outdoor air temperature have been determined. The use of optimal set point control strategy resulted in energy savings of the order of 19–32% when the influence of internal load was considered. Dynamic modelling has also been utilised to elucidate two importance parameters; lag time and relative attenuation degree which can help technicians regulate the DH systems in the process of operation and management [11]. Another modelling technique that is of interest is the aggregated modelling which help simplify DH networks by gradually reducing the topological complexity of the original network [12] [13].

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Journal/Conference Papers:
Paper 3:
Title: Static study of traditional and ring networks and the use of mass flow control in district heating applications
Journal: Applied Thermal Engineering
Authors: Maunu Kuosa, Kaisa Kontu , Tapio Mäkilä , Markku Lampinen , Risto Lahdelma
Year: 2013
Description: Mass flow rates of DH water in consumer substations are controlled by pumps with inverters to improve heat transfer. The new control system will enable new temperature curves to be adopted for supply and return temperatures. Numerical results are compared to those achieved with the traditional technology. The new flow rate is 46%, the pressure loss 25%, and the pumping power 12% of their former values in the pipes.

Paper 6:
Title: An Agent-Based Approach to Monitoring and Control of District Heating Systems
Journal: 15th International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems
Authors: Fredrik Wernstedt and Paul Davidsson
Year: 2002
Description: The aim is to improve the monitoring and control of district heating systems through the use of agent technology. In order to increase the knowledge about the current and future state in a district heating system at the producer side, each substation is equipped with an agent that makes predictions of future consumption and monitors current consumption. However, a new type of "open" substation has been developed which makes the suggested agent-based approach possible.

Paper 7:
Title: Improved district heating substation efficiency with a new control strategy
Journal: Applied Thermal Engineering
Authors: Jonas Gustafsson , Jerker Delsing, Jan van Deventer
Year: 2010

Description: New alternative controls approach for indirectly connected district heating substations which results in an increased DT across the substation. An improved DT situation in a district heating network enables larger gains and savings at the district heating system level.

Paper 8:
Title: Experimental evaluation of radiator control based on primary supply temperature for district heating substations
Journal: Applied Energy
Authors: Jonas Gustafsson, Jerker Delsing, Jan van Deventer
Year: 2011
Description: Evaluates whether the primary supply temperature in district heating networks can be used to control radiator systems in buildings connected to district heating; with the purpose of increasing the DT. The results confirm that it is possible to control the radiator system based on the primary supply temperature while maintaining comfort; however, conclusions regarding improvements in DT were hard to distinguish.

Paper 9:
Title: Control period selection for improved operating performance in district heating networks
Journal: Energy and Buildings
Authors: K.C.B. Steer, A. Wirth, S.K. Halgamuge
Year: 2011
Description: The frequency of adjustments to the supply temperature set-point in district heating networks influences the overall operating cost in two ways: adaptability to changes in network conditions; and availability of time for determining an appropriate response. In this paper they investigate this trade-off and show that operating costs can be reduced through appropriate control period selection.

Paper 10:
Title: A control strategy for energy optimal operation of a direct district heating system
Journal: International Journal of Energy Research
Authors: Lianzhong Li and M. Zaheeruddin
Year: 2004
Description: A dynamic model of a direct district heating system (DDHS) is developed, and an energy optimal control strategy is designed. The use of a Smith predictor (SP) to deal with this type of time delay is explored. An SP is designed by using the reduced-order dynamic model and implemented on the full-order model. Also, optimal set point profiles of supply water temperature as a function of outdoor air temperature have been determined. The use of optimal set point control strategy resulted in energy savings of the order of 19–32% when the influence of internal load was considered.

Paper 11:
Title: Modelling the dynamic characteristics of a district heating network
Journal: Energy
Authors: Pengfei Jie , Zhe Tian, Shanshan Yuan , Neng Zhu
Year: 2012
Description: Through the study of the primary system and secondary system in DH systems, dynamic models of the DH network are built in this paper. Two important parameters, lag time and relative attenuation degree, mathematical expressions representing the dynamic characteristics of the DH network are described. The two parameters will help the technicians to regulate the DH systems in the process of operation and management.

Paper 12:

Title: A comparison of aggregated models for simulation and operational optimisation of district heating networks
Journal: Energy Conversion and Management
Authors: Helge V. Larsen, Benny Bøhm, Michael Wigbels
Year: 2004
Description: Through the study of the primary system and secondary system in DH systems, dynamic models of the DH network are built in this paper. Two important parameters, lag time and relative attenuation degree, mathematical expressions representing the dynamic characteristics of the DH network are described. The two parameters will help the technicians to regulate the DH systems in the process of operation and management.

Paper 13:
Title: Aggregated dynamic simulation model of district heating networks
Journal: Energy Conversion and Management
Authors: Helge V. Larsen, Halldor Palsson , Benny Bøhm , Hans F. Ravn
Year: 2002
Description: A method is presented in which a fully described model of a DH network is replaced by a simplified one, with the purpose of reducing simulation time. This simplified model is generated by gradually reducing the topological complexity of the original network.
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38 Appendix M: Components within Prelims Cost

Mobilisation (Prior to site commencement)

- Lead / Principle Designer during Mobilisation
- Mobilisation / Planning Manager
- SHEQ Mobilisation Manager
- Senior PM Costs
- Site Manager (SM) Costs
- Estimation / Procurement Support

Site works

- Office + 50/50 Office or Changing / Kitchen Unit with steps.
- Welfare - 2 in 1 toilet unit inc Maintenance
- Welfare - Additional Changing Room Facilities
- Storage / Container Unit
- Site Cabins Delivery and Collection (based on 1 no. units)
- Site Signage and Specific Stationary
- Generator, fuel and fuel bowser
- Temporary services to cabins including electrical supply, drainage, water supply, cleaning, IT Equipment Costs, broadband, cabin supports etc
- Site Compound Fencing (Based on XX no.panels)
- Site Compound Fencing Delivery and Collection (1 load)
- Waste Management (Skip hire etc)
- Other Equipment - Full time machinery, access, scaffolding, temporary protection, dust sheets, Time-lapse CCTV, cleaning etc
- Other Site Mobilisation - Additional cabins, special site logistics / route, showers, site lighting, fire equipment, spillages, security, PPE, first aid, environmental / pollution / noise control

DE Site Works

- Land Rental Costs for Site Equipment
- Oasis Unit (Toilet Unit)
- COSHH Store
- WAC Testing
- Event delay costs
- GPS Equipment

Traffic Management

- Road closure costs
- Traffic management equipment hire
- Sound baffle screens
- Road Sweeping

Site Management

- Lead / Principle Designer during site works
- Senior PM Costs
- PM Costs
- Site Manager (SM) Costs
- Quantity Surveyor (QS) Costs
- SHEQ Manager

- Planning Manager
- Commissioning Manager / Engineer
- Demobilisation and Handover Manager
- Other Manager's (Electrical, Mechanical, Controls etc)
- E&S Team Costs
- Refrigeration Team Costs
- Temporary Works Coordinator (TWC) for Civils
- Lead / Principle Designer Travel and Lodge
- Senior PM Costs Travel and Lodge
- PM Costs Travel and Lodge
- Site Manager (SM) Costs Travel and Lodge
- Quantity Surveyor (QS) Travel and Lodge
- SHEQ Manager Travel and Lodge
- Planning Manager Travel and Lodge
- Commissioning Manager / Engineer Travel and Lodge
- Demobilisation and Handover Manager Travel and Lodge
- Other Manager's Travel and Lodge
- Temporary Works Coordinator for Civils Travel and Lodge
- Weekend Working (Per Person / Weekend)

Documentation and Support

- O&M / Handover Manuals, Client Documentation Support, printing costs, Document Controller etc
- As built / record drawings, labelling, asset numbering / list etc
- Wall Hanging drawings, finishing signs etc
- Administration

Other Prelims / Premium Costs

- Insurances
- Other Cash flow charges / Interest
- Special site requirements / policies - access routes, dress code, downtime, client / stakeholder management / legal , premium car parking, ferry / plane costs etc %
- Additional fees / costs - RHI, CEF Fees, PB Stage, Pre-Contract, CSCS, Bonds, Guarantee, Main Plant Collateral Warranties, etc %
- London weighting charges - 10% of Site Management Prelims

Long term contract specifics

- Additional Office Equipment i.e. plotter
- Stakeholder Liaison Officer
- Stakeholder Liaison Officer Travel and Lodge

39 Appendix N: Contrasts between the Current DHN Proposition and Counterfactual Alternatives

The work of Work Package 1 includes contrasts between the current DHN proposition and counterfactual alternatives to deliver heat. Further work was undertaken for WP3 and key differences are captured here.

This Appendix starts with a general evaluation of key differences between DHN and alternative heating technologies in general, and then provides some more specific differences between DHN and individual alternative heating technologies.

General

- **Commercial viability and heat density:** The commercial viability of district heating depends on the heat density within the area served by the heat network – the ability to offset the substantial upfront capital cost with sufficient heat revenue. By contrast, the commercial viability of individual building solutions is generally less sensitive to the energy use of surrounding buildings. Gas infrastructure costs more per connected home in less dense areas but the costs have been shared equally between consumers and are in any case a smaller proportion of the total cost of heat provision. There are still areas where the heat density does not justify the cost of gas infrastructure e.g. some rural communities.

- **Additional infrastructure:** District heating requires the provision of additional infrastructure (significant cost, time and disruption) and the retrofitting of the existing heating systems in buildings (e.g. replacing the existing boiler with a HIU). By contrast, simply replacing an existing gas boiler with another is cheaper and more convenient (around £2000). Changing an existing heating system to a heat pump would incur similar cost to the district heating option. Air-source or ground source heat pumps will require more space than for gas boilers or DH. In addition, for ground source heat pumps, the groundworks required to install the ground loops can be expensive and disruptive (and planning permission may be required under certain circumstances).

- **Trigger point for replacement of heating system:** The trigger point for change is a crucial element. In a survey of householders[88], the most common reasons for changing their heating system were actual or anticipated breakdown: actual system breakdown (30%), the householder told that the system was coming towards the end of its life (14%), the system needed repairs too often (14%) or they were told the parts would no longer be available in the future (3%). The most common reason other than actual or anticipated breakdown was as part of a wider property renovation (13%).

Most of those surveyed (70%) would only consider a pre-emptive system replacement if their heating system started to need considerable repair/s. Running costs play some part in the decision: a third (37%) said they would be likely to replace if energy prices rose dramatically, and 34% if cheaper-to-run systems became available.

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88 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191541/More_efficient_heating_report_2204.pdf

Given that a boiler may last for 15 years or more, in a specific geographical area, a relatively small minority of building owners will choose to have their boiler replaced in any given year. In contrast, for DHN to currently be commercially viable given the high up-front capital investment, a significant proportion of the buildings along the path of the heat network need to be connected either initially or soon after. Hence, as a result, the main DH networks that are operational in the UK have been initiated by local authorities, with connection to residential and non-residential buildings that they are responsible for or have influence over. These buildings act as anchor customers who are required to initiate schemes and long-term heat supply contracts are negotiated to support the capital investment. However to fulfil the economic potential for DH in the UK it will be necessary to go beyond this initial customer base.

- **Competition:** DHN schemes are natural monopolies and the consumer normally enters into a long-term contract for the provision of heat. For alternative means of heating e.g. using gas or electricity, the consumer can change their energy supplier if they are not happy with, say, the energy price or the level of customer service. With DHN a switch away from DH supply back to gas say may be possible but likely to be expensive and disruptive. For a block of flats conversion to a gas system by one resident would be particularly difficult. In the future some elements of the heat supply could be subject to greater diversity and competition e.g. on large networks there can be multiple heat sources and customer services such as metering and billing and HIU maintenance can be provided competitively from a number of suppliers.

- **Regulation of energy supplies & consumer protection:** Both gas and electricity supplies are regulated, whereas DHN is not. Regulated industries offer certain levels of customer protection with standards set by the Regulator Ofgem. At present an industry led voluntary customer protection scheme has been set up (the Heat Trust) which will replicate some of the protections available to customers of gas and electricity. This includes an independent complaints process through the Ombudsman.

- **Regulation of energy supplies & laying of infrastructure:** Statutory utilities benefit from regulations which assist in the laying of infrastructure, e.g. rights to install infrastructure in the highway, compulsory purchase powers and national agreements with certain landowners e.g. the Canal and River Trust. In contrast DH companies need to obtain a licence for carrying out works in the highway from the Highways Authority for each project. In some cases these licences have been refused or specific constraints imposed. In addition, planning permission may be required for each part of the network; although some local authorities supportive of DH[89] have produced a Local Development Order which provides an authority-wide process for planning this is not commonplace.

- **Business rates:** DHNs are subject to business rates as any other business. In most cases the business rates calculated for DHNs result in a much higher cost than for the gas and electricity industries per unit of energy delivered. The gas and electricity industry rating arrangements were agreed nationally many years ago and were calculated on a different basis. When developing a new project there is often uncertainty in the future liability for business rates due to inconsistency in approach across different regions of the UK.

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[89] The District Heat Local Development Order, London Borough of Newham, March 2013

- **Access for maintenance:** For DHNs, there is the benefit of less need to access properties for maintenance as the heat generator is located outside of the properties. This reduces disruption to those in the building as well as others (such as social landlords) who would need to gain access to the building. Landlords have a statutory duty to carry out an annual safety inspection on all gas appliances and gaining access is a critical part of fulfilling this legal obligation. Although some maintenance and inspection is advisable for the HIU and heat meters this is not a legal obligation.

- **Maturity of utility & cost:** DHN is still in its infancy in the UK compared to many of the alternatives and there is the potential for cost savings and/or including other value-added items in a DHN offering.

- **Transition to low-carbon economy:** DHNs enable easier transition between fuel types and delivery of lower-carbon heating; changing one large heat source to a lower carbon alternative is easier than replacing the equivalent number of individual systems. Furthermore, the scale of heat provision centrally provides additional opportunities for low carbon sources that individual building solutions cannot harness e.g. utilising heat from rivers or sewers, heat extraction from thermal power stations or utilising excess wind energy via large-scale heat pumps. Furthermore, DHNs provide the flexibility of integrating multiple alternative and complementary low-carbon sources which can respond to demands and drivers on the electricity grid at a national level, something which would be expensive and complex to achieve at an individual building level.

A separate point raised by an investor outside of the WP1 workshop is that district heating receives no incentives in the UK. Given the relatively high capital costs, it can be difficult make a project commercially viable when compared to on-site low carbon solutions that do receive an incentive of some kind.

Contrast between DHN and Gas Boilers

- The majority of existing buildings are heated from gas-fired boilers. This technology is now well-established and understood and has a high degree of customer satisfaction. It is important to recognise that there is currently no compelling reason for users to change to DHN.

Contrast between DHN and Oil Fired Boilers

- Users of oil boilers suffer from issues of both fuel price volatility and the inconvenience of storage. Heat networks could offer reduced sacrifices. However oil boilers are normally found in low density rural areas off gas grid and so less suited to DHNs except in particular circumstances (such as a high density village off gas grid).

Contrast between DHN and Direct Electric Heating

- Direct electric heating has the highest running cost compared to alternative heating solutions although capital costs and maintenance costs are much lower. Hence DHNs will have a significant potential operating cost advantage. Off-peak electric heating is a lower cost but users find this system more difficult to control. DHNs may offer a smaller cost advantage but improved customer experience with greater controllability.

Contrast between DHN and Heat Pumps

- Relatively few homes currently have heat pumps and hence DHN will normally provide an alternative rather than a replacement. Similar to DHN, the Government views significant market potential for heat pumps in a low-carbon future.

- Heat pumps will require a hot water tank to produce the hot water which may be seen as a disadvantage in terms of losing space. DHNs can deliver hot water either instantaneously as for a gas combi boiler or with a hot water cylinder so DHNs offer more flexibility.

- Heat pumps take additional space – significantly more than for a gas boiler or a DHN HIU. For an air-source heat pump this will be outside the property and for a ground source heat pump this is normally inside but with significant ground area required as well.

- Air source heat pumps will have additional noise generated externally which may be an issue in denser housing where there is a high take-up of ASHPs in one locality. The DHN itself does not have any noise impact during operation within the property although noise and emissions to air do need to be carefully controlled at the Energy Centre which may also be close to housing.

- Heat pumps operate more efficiently at a lower supply temperature and changes are likely to be required to the existing heating system e.g. the need for low-temperature radiators to be installed, underfloor heating and / or improvements to the insulation of the property to allow lower temperature operation.

- Heat pump systems will typically result in longer heat up times than gas boilers because they are sized with limited additional capacity for intermittent operation. The decision to limit the size of the heat pump is driven by a few factors:
    - Heat pumps cost more than boilers – ground source heat pumps being especially expensive.
    - The output of heat pumps reduces as the heat source temperature drops. So in the case of an air source heat pump, if the outside air is, say, -5°C then the output available for the ASHP will be less than its rated output.
    - ASHPs also need to go through defrost cycles if the outside air is cold and humid (like the UK often is). When the system is running a defrost cycle it is not delivering any heat to the building, so the system is often designed to run all the time so that a short period of no heat is not noticed. If the heating was set to come on and heat a cold building up over say a 1 hour period then it might well need to go into defrost within that hour period and so the building would then take longer to get up to temperature.

All of these factors, coupled with the fact that heat pumps are currently often used in well insulated buildings, mean that heat pump systems are often designed to run more or less continuously. This allows the units to be undersized which saves money. Hence, whilst there is nothing inherent about a heat pump that makes it slow to respond, heat pump systems are often designed so that they do respond more slowly.

- Heat pumps can be more complex than traditional gas boilers – both to install and maintain. This is currently a challenge with relatively few specialists available and Users may use their local plumber and/or electrical engineer with a risk of lower than expected performance. The availability and reduced-cost of appropriate skills can be expected to improve over time with greater uptake of heat pumps. By contrast, with large-scale district heating schemes, Network Developers and Operators should be able to access and be willing to pay for specialists to install and maintain the system, although if there is rapid growth in DHNs shortage of skills will still be a risk.

40 Appendix O: Initial Set of Challenges

Reduce Capital Cost (3 challenges):

- Reduce capital cost of civil engineering cost by a set amount
- Reduce capital cost of material & equipment (e.g. HIU) by a set amount
- Reduce capital cost of installation & commissioning by a set amount

Reduce Operating Cost (3 challenges):

- From greater system efficiency e.g. reduced heat and pumping losses
- Reduced maintenance cost e.g. more robust equipment design for easy maintenance
- With lower staff & overhead e.g. the use of remote diagnostics to reduce staff cost

Improve Cost Certainty (3 challenges):

- Improve material & equipment cost certainty to within a confirmed tolerance
- Improve civil engineering cost certainty to within a confirmed tolerance
- Improve installation & commissioning cost certainty to within a confirmed tolerance

Reduced Time on Site (3 challenges):

- Accelerate pipe laying
- Reduced main – property connection
- Reduced HIU Installation

Increase Network Developer & Operator Revenues (3 challenges):

- Through increased take-up.
- Alternative revenue streams.
- Off-set capital cost with joint street works.

Improved Systems Architecture (1 challenge):

- Identify opportunities for improved network optimisation and innovation.

Improving the User Value Proposition (4 challenges):

- A compelling offer for Private and Social Landlords. Tested improvement.
- A compelling offer for Owner Occupiers. Tested improvement.
- A compelling offer for Tenants. Tested improvement.
- A compelling offer for Local Authorities. Tested improvement.

Improving Investor and Developer Value Propositions (5 challenges):

- Reduced complexity & risk to meet RSL investor requirements.
- Reduced complexity & risk to meet Local Authority requirements.
- Reduced complexity & risk to meet 3rd party investor needs.
- Improved IRR & reduced risk for Network Developers.
- A proposition which meets Green Investment Bank criteria.

Develop approaches to manage rather than off-load risk to reduce costs (1 challenge)

Reducing Cost & Delay Engaging Enabling Stakeholders (1 challenge):

- Opportunities to simplify and standardise interactions with enabling stakeholders.

41 Appendix P: Evaluation of the Initial Set of Challenges

Table 36: List and description of Challenges (prior to selection and refinement)

Key Priority Area	Challenge	Evaluation (Scope/Value/Effort)
Improving Cost Certainty	New Legal / Commercial / Risk Models This challenge recognises the potential of alternative commercial and delivery models reducing the cost of money by reducing risk. For example, municipalities provide a guarantee underwriting DHNs in Denmark.	Probable Selection • Scope: Marginal • Potential Value: High (major impact on IRR expectations) • Project Effort: Low (understanding commercial and legal drivers rather than changing them) • Expected Delivery Effort: High (changing legal and commercial framework across industry)
	Improved Material Cost Certainty Improving the cost certainty of the physical materials and components.	Rejected • Scope: Core • Potential Value: Low (cost variability is not currently viewed as a major problem for equipment and material) • Project Effort: Medium • Expected Delivery Effort: Medium
Reducing Capital Cost	Reduced Civil Engineering CAPEX This was demonstrated by WP2 as being a significant capital cost component. Two other originally separate challenges were incorporated here – improving the certainty of capital cost and time (to minimise disruption). These were grouped here as seen as crucial enablers of reduced	Firm Selection • Scope: Core • Potential Value: High (potential to reduce significantly DHN capital cost) • Project Effort: Low (significant potential for quick wins, albeit achieving full potential reduction in cost will

Key Priority Area	Challenge	Evaluation (Scope/Value/Effort)
	CAPEX as well as being additional stakeholder requirements in their own right.	require full process redesign) • Expected Delivery Effort: High (influencing multiple actors across national industry and sustaining improvement)
	Reduced Materials & Equipment CAPEX This was demonstrated by WP2 as being a significant capital cost component. It covers all physical materials and components from Energy Centre output to HIU. This also captured the originally separate challenge to improve the certainty of cost for materials and equipment.	Firm Selection • Scope: Core • Potential Value: High (potential to reduce significantly DHN capital cost) • Project Effort: Low (significant potential for quick wins, albeit achieving full potential reduction in cost will require deeper engagement) • Expected Delivery Effort: Medium (once opportunity highlighted, commercial ambition will drive change)
	Reduced Labour and Installation CAPEX This was demonstrated by WP2 as being a significant capital cost component. This challenge comprises all non-trench related labour e.g. pipe-laying, welding, pump M&E, connections. This also captured three originally separate challenges: to improve the certainty of capital cost of non-trench related labour and to reduce both the absolute time and time certainty (related to minimising disruption etc. rather than directly reducing capital cost).	Firm Selection • Scope: Core • Potential Value: High (potential to reduce significantly DHN capital cost) • Effort: Low (significant potential for quick wins, albeit achieving full potential reduction in cost will require full process redesign) • Expected Delivery Effort: High (influencing multiple actors and sustaining improvement)

Key Priority Area	Challenge	Evaluation (Scope/Value/Effort)
	System Design Architecture This will involve innovation in the overall system design. Given the client objectives, a key focus is around Reducing Capital Cost. However, there is the significant potential for improved design to address other areas as well e.g. Reducing Operational Cost.	Probable Selection • Scope: Core • Potential Value: High (potential to reduce significantly DHN capital cost) • Project Effort: Medium (will require significant system engineering input rather than product development) • Expected Delivery Effort: Unknown (very dependent on solutions identified)
Reducing Operational Cost	Reduced Network OPEX Reducing operating cost through improved networks e.g. pumping energy and operations cost	Probable Selection • Scope: Secondary (considering operational costs and not capital costs) • Potential Value: Medium (benefits accumulated over a 50 year lifetime of network, and increasing operational efficiency and reducing energy costs may be more important into the future) • Project Effort: Low (scope is naturally limited by the issues involved i.e. heat losses and pumping energy) • Expected Delivery Effort: Medium (diverse range of cost elements and potential solutions)
	Reduced Maintenance OPEX Reducing operating cost through improved approach to maintenance.	Unlikely • Scope: Secondary (considering operational costs and not capital costs) • Potential Value: Low (a minor element of Operating Cost)

Key Priority Area	Challenge	Evaluation (Scope/Value/Effort)
		• Project Effort: Medium • Expected Delivery Effort: Low (limited areas of spend and opportunity to improve) • Link to Reduced Network OPEX
	Reduced OPEX Staff & Administration Reducing the operational costs of supporting staff and administration.	Rejected • Scope: Secondary (considering operational costs and not capital costs) • Potential Value: Low (limited costs although accumulated over a 50 year lifetime of network) • Project Effort: Medium • Expected Delivery Effort: Medium • Link to Reduced Network OPEX
Reducing Time on Site	Shorter HIU Installation Reduction in time for HIU installation. Speed of HIU installation has a significant impact on Householder disruption and connection cost.	Unlikely • Scope: Core • Potential Value: Medium • Project Effort: Medium • Expected Delivery Effort: Low (single focussed activity linked to HIU development)
	Accelerate Pipe Main – Building Connections Reducing the time for installation of the main-building connections	Rejected • Scope: Core

Key Priority Area	Challenge	Evaluation (Scope/Value/Effort)
		• Potential Value: Low (value of reduced time is mainly covered in the Installation CAPEX) • Project Effort: Medium • Expected Delivery Effort: Medium
Two combined Priority Areas: **Improving the User Value Proposition Improving Investor and Developer Value Proposition**	Value Proposition Design Developing new approaches to the promotion and deployment of DHN which reduce the obstacles and sacrifices for stakeholders and improve benefits and opportunities. Improved propositions build opportunities to leverage scale and achieve critical mass. This is focussed around Users (domestic and non-domestic landlords and consumers), developers (where role includes Investors) and Local Authorities. It combines separate challenges from the WP1 report in which the stakeholders are more disaggregated.	Probable Selection • Scope: Core • Potential Value: High (reduced capital cost alone will not scale DHN deployment) • Effort: Medium (understanding and influencing multiple stakeholders) • Expected Delivery Effort: High (may require creation of new marketing, installation and operation capability)
	Improved third Party Investor Proposition As above, but focussing on improving the Value Proposition to third party investors.	Rejected • Scope: Marginal (financial investors are not core to the project) • Potential Value: Medium • Project Effort: Medium • Expected Delivery Effort: Medium
Increasing Network Revenues	New Revenue Streams This comprises potential additional income such as in-trench services (e.g. providing fibre-optics) and offsetting excavation costs (installing multiple utilities in combination).	Probable Selection • Scope: Core • Potential Value: High (potential to offset significant DHN capital cost or add new revenue)

Key Priority Area	Challenge	Evaluation (Scope/Value/Effort)
		• Project Effort: Medium • Expected Delivery Effort: High (commercial and legal complexity in achieving combined activities)
	Increased Revenue From Higher Local Take-up Achieving a viable initial system with the potential for additional local take-up either within the existing network or through expansion.	Unlikely • Scope: Core (revenue offsets OPEX) • Potential Value: High (potential to add new revenue) • Project Effort: Medium • Expected Delivery Effort: Medium (commercial and technical innovation to enable ad-hoc additions to network)
Reducing Cost and Delay of Engaging Enabling Stakeholders	Rapid External Stakeholder Engagement This includes approaches to streamline links to planners, other utilities, rail, waterways etc. Includes identifying ways to eliminate the barriers / sacrifices of combined propositions.	Unlikely • Scope: Secondary (linked to planning) • Potential Value: Medium • Project Effort: Medium • Expected Delivery Effort: High (multiple actors who have limited stake in success of heat network) Key elements can be covered with two other challenges: 'New Legal / Commercial / Risk Models' and 'Value Proposition Design'. Addressing the challenges and delays from external stakeholders will form an important part of a successful Value Proposition, but does not warrant a separately focussed challenge area.