Programme Area: Energy Storage and Distribution

Project: Heat Infrastructure Development (HID)

Title: Solution Development, Analysis and Selection Report

Abstract:

In Stage 1 of the project, work comprised assessment and synthesis of 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, from which key challenge areas were identified for targeting of cost reduction solutions during Stage 2 of the project. This report, describes the identification and development of solutions in each of these challenge areas, the assessment of the key solutions against a range of criteria, and the selection of certain solutions to have route maps developed during Stage 3.

Readers may find it useful to study the Summary Report, which summarises the entire project, prior to studying the detailed engineering reports.

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_D03

Solution Development, Analysis and Selection Report

March 2017 (updated Aug 2017)

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:

- COWI A/S supported the work for Stage 1 which was reported in its Deliverables. The work in this report builds on Stage 1. There is no additional content in this deliverable report from COWI A/S.

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

- Loughborough University Enterprises Limited supported the work for Stage 1 which was reported in its Deliverables. The work in this report builds on Stage 1. There has been no new input from Loughborough University Enterprises Limited in Stage 2.

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.	Various	DR	PW	MA	27.1.17
2	Revised final report for issue. Amendments made to previous version following minor ETI comments.	Various	DR	PW	MA	24.2.17
3	Revised final report for issue. Amendments made to previous version following minor ETI comments.	Various	DR	PW	MA	10.3.17
4	Revised final report for issue. Amendments made to previous version following minor ETI comments.	Various	DR	PW	MA	27.3.17
5	Updates to report to reflect further developments during Stage 3	Various	DR	PW	MA	24.8.17

Aldgate Tower, 2 Leman Street, London, E1 8FA
Telephone: 020 7645 2000 Website: http://www.aecom.com

Job No: 60477549 Reference: ETI: Reducing costs of DH Date Created: August 2017

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 i.e. flow temperature minus return 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 where electricity and heat are produced from a single machine
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 of 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
DHKC	District Heating Knowledge Centre
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 (see above)
DTU	Danish Technical University
ECCR workshop	The workshop systematically reviews a work activity to look to reduce cost through the following four means ▪ **E**liminate unnecessary material, capital or labour cost e.g. avoid the need for a heat exchanger (use direct HIUs) ▪ **C**ombine components or processes to reduce material, capital, operating or labour cost.

	▪ **C**ombine operations to deliver multiple activities simultaneously to save time and labour cost e.g. install longer lengths of DHN pipes simultaneously to reduce crane and labour time ▪ **R**educe time or cost of any residual operation or component e.g. use cheaper materials that still meets performance requirements
Emitters	Domestic or commercial radiators or equivalent (e.g. underfloor heating)
EN	European Norm
EPC	Energy Performance Certificate
ESCo	Energy Services Company; they provide a broad range of energy solutions which can include the construction, finance and/or operation and 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 an investment such as 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 summarises the process and results for the solution development, analysis and selection phase of ETI's Heat Infrastructure Development (HID) project. The primary objective of this project is to identify and then assess innovative solutions with the potential to deliver a substantial step change reduction in the capital cost, and contribute to overall lifecycle cost reduction, of District Heating Networks (DHNs).

The project has three stages:

- Stage 1: System review and target setting
- Stage 2: Solution development, analysis and selection
- Stage 3: Development of route maps

Stage 1 of the project is complete. It comprised a number of research and engagement activities to provide a solid foundation to this project. This included analysing key stakeholder requirements for DHNs, a literature review and horizon scanning of potential innovative solutions, an investigation of the differences in practice between the UK and leading countries where district heating is more established, the generation of an Excel-based model of current DHN costs and an analysis of these costs.

This information was used to prioritise a set of five challenges to which solutions would be identified during Stage 2 of the project. It was also used to develop a set of quantitative and qualitative evaluation criteria for the assessment of each solution and an accompanying solution template to capture and present this information in a common format.

The five prioritised Challenges which have focussed activity in Stage 2 are as follows:

- Challenge 1 - System Design Architecture
- Challenge 2 - Civil Engineering CAPEX
- Challenge 3 - Pipes and Connections CAPEX
- Challenge 4 - Internal Connections CAPEX
- Challenge 5 - New Network Income

This report presents the methodology and outputs of Stage 2 of the project summarising:

- The approach to solution development
- Solutions identified which address the challenges above
- The evaluation of solutions against the key criterion of DHN cost saving and the supporting qualitative and quantitative criteria
- The interaction of alternative solutions and how they can be applied to maximise the system level CAPEX saving
- The solutions selected for route mapping in Stage 3 and the selection rationale

Stage 3 will determine the work required to bring the selected solutions to commercial deployment. It will show the development paths for selected solutions, including anticipated timescale, investment and technical and commercial risk. It will also bring together and present the findings from across the whole project.

Stage 2 Methodology

Innovative solutions were identified, developed and evaluated in Stage 2. This built on the initial technical review of innovative solutions in Stage 1. It included significant engagement with a wide range of external parties both within and outside of the DHN industry. Regular internal meetings were held to review progress as a whole.

Each solution was prioritised as follows.

- Green – These ideas were considered to offer potentially significant DHN CAPEX cost reduction. Solution development focussed on these solutions. Most of the final set of green solutions each comprised a cluster of several individual ideas.
- Amber – These were promising ideas that were considered to have less benefit than the Green solutions. The list of Amber solutions was continually reviewed during Stage 2 as Amber could become Green, either through integrating an Amber solution into an existing Green solution or a cluster of Amber solutions resulting in more substantive benefit.
- Red – These were ideas which were considered to have little or no CAPEX benefit and significant barriers to development.

A review was then undertaken with the ETI to agree which of the Green solutions should be taken forward for route map development in Stage 3. This review considered both the detailed evaluation of each Green solution and the benefit to be gained from a route map.

Evaluation of Solutions

In total, 13 Green solutions were identified. These ranged across the five Challenges identified in Stage 1.

An estimate of the percentage saving in DHN CAPEX was made for each solution. DHN CAPEX is defined as the capital cost of the DH network and building connections including the hydraulic interface units (HIUs) from the inlet to the network at the Energy Centre to the outlet of the HIUs. Some of the solutions are mutually exclusive i.e. not all of the solutions can be applied together in a particular house or street. Table 1 summarises the cost savings predicted for each solution and the overall saving if the solutions are combined to produce the greatest CAPEX reduction. It should be noted that Solution 12 is the outcome of combining solutions 9, 10 and 11 through optimising HIU design and manufacture.

Overall, it is estimated that if the compatible Green solutions were applied together, they could achieve a 32% reduction in DHN CAPEX, with an uncertainty range from 26% to 39%. Where multiple competing solutions could apply, the one with the highest potential CAPEX saving has been assumed. Furthermore, it is estimated that the Amber solutions could generate up to an additional 6% DHN CAPEX saving.

The greatest DHN CAPEX savings originate from reducing the costs of civil engineering and Heat Interface Units (HIUs), which were the two largest components of current DHN CAPEX as identified in Stage 1. These particularly include improvements to the productivity of conventional excavation through better upfront design and planning, the widespread adoption of trenchless technologies for excavation and the reduction in the costs of HIUs, both through simplification and standardisation of components and through value engineering.

	CAPEX savings (sensitivity)	Combined
1. Knowledge Management, Research and Training	3.0% (1.0% to 5.0%)	3.0%
2. Reduced Peak Demand and Peak Flow Rate	3.4% (2.9% to 3.9%)	3.4%
3. District Heating Wall	0.9%	
4. Loft Space / Cellar Route	4.9% (3.0% to 6.0%)	2.0%
5. Trenchless solutions	11% (6% to 18%)	10%
6. Improved front end design and planning	8.7% (4.6% to 11%)	2.0%
7. Pipe crossings	1.6% (0.7% to 1.9%)	1.6%
8. Shared Civil Engineering Costs	1.4% (0.3% to 2.1%)	1.4%
9. Direct HIU System & Existing DHW Storage	4.5% (3.5% to 5.5%)	
10. HIU (1) Design for Manufacture and Assembly	3.4% (2.5% to 4.1%)	
11. HIU (2) Further Simplification & Value Engineering at Scale	5.2% (3.3% to 6.9%)	
12. HIU (3) Value Engineered Direct HIU & DHW Storage	7.1% (4.8% to 9.3%)	7.1%
13. Internal Connections — Pipework & Connections within the Property	1.8% (0.9% to 2.4%)	1.8%
Total	Central	32%
	Low	26%
	High	39%

Table 1: Summary of CAPEX savings estimated for each solution and for viable groups of solutions

Although the emphasis in the work has been to identify CAPEX savings, care has been taken to ensure that OPEX does not increase with any of the solutions. In some cases, OPEX will reduce slightly and where possible this has been quantified in the solution forms e.g. simplification of design with the use of fewer components will tend to result in lower maintenance costs. Overall, the network performance for all of the solutions will be comparable to the baseline.

In addition to the technical solution development, the analysis has identified the importance of knowledge management, research and training as a crucial enabling solution. This will provide an overarching system approach to the successful delivery of DHNs at scale.

In evaluating the solutions, a wide range of criteria were used including applicability of the solutions to different types of buildings and the potential for a more flexible future-proofed solution. Crucially, each of these solutions is envisaged to be more attractive to heat customers and potential investors in DH schemes, than the current approach to DHN delivery. Furthermore, each of these solutions should be deliverable in principle in less than 5 years with investments below £5M in research and development.

The reduced peak demand low flow rate solution will also result in cost reductions at the Energy Centre as the peak boiler capacity can be reduced.

Previous work by the ETI indicated that DH could supply around 40% of the heat market in the UK provided capital costs could be reduced by about 40%. Hence this project was challenged to identify cost savings that could result in this level of saving and hence have a significant impact in the direction of the UK's strategy for low carbon heat supply. The overall conclusion that savings of 32% (range of 26% to 39%) are estimated from combining 13 green solutions and a further 6% saving is estimated from the remaining amber solutions indicates that a 40% target is achievable with appropriate investment and so the case, on economic grounds, for developing DH networks as a significant part of the UK heat strategy is strong.

Selection of Solutions to be Route Mapped in Stage 3

It has been agreed that 11 of the 13 Green solutions should be taken forward for route mapping in Stage 3. Two of the Green solutions (numbers 7 and 13) are not to be taken forward due to the relatively small DHN CAPEX saving and/or due to the limited additional benefit which a route map is likely to provide for these specific solutions.

The Green solutions are listed in the Table below, which also identifies those which will be taken forward to Stage 3.

Solution	Selected for a Stage 3 Route Map?
1. Knowledge Management, Research and Training	Yes
2. Reduced Peak Demand and Peak Flow Rate	Yes
3. District Heating Wall	Yes (combined route map)
4. Loft Space / Cellar Route	
5. Trenchless Solutions	Yes
6. Improved Front End Design and Planning	Yes
7. Pipe Crossings	No – limited applicability and CAPEX saving
8. Shared Civil Engineering Costs	Yes
9. Direct HIU System & Existing DHW Storage	Yes
10. HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)	Yes (combined route map)
11. HIU Optimisation (2) Further Simplification & Value Engineering at Scale	
12. HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage	
13. Internal Connections – Pipework & Connections Within the Property	No – Saving mainly in terraced properties, with uncertainty due to diverse property internal layouts and décor.

Table 2: Selection of solutions for route mapping

1 Introduction to this Deliverable

1.1 Introduction

This report is Deliverable EN2013_D03 “Solution Development, Analysis and Selection Report” of ETI’s Heat Infrastructure Development (HID) project and describes the results from Stage 2 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. 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 for the purposes of this project is defined as being between: (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 has also considered 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. These Stages and Work Packages are shown in Figure 1.

Stage 1 included understanding key stakeholder requirements for DHNs, an initial technical review of potential innovative solutions, an Excel-based model of current DHN costs and an analysis of the cost breakdown. This work is reported in Deliverables EN2013_D01 and EN2013_D02. In particular, the following is noted:

- The potential innovative solutions arising from Stage 1 informed early Stage 2 workshops.
- The key stakeholder requirements informed the development and evaluation of solutions.
- The cost model was used in Stage 2 to compare the costs of the new solutions to the costs for current DHN practice.

Stage 1 prioritised five challenges to take forward to Stage 2.

- Challenge 1 - System Design Architecture
- Challenge 2 - Civil Engineering CAPEX
- Challenge 3 - Pipes and Connections CAPEX
- Challenge 4 - Internal Connections CAPEX
- Challenge 5 - New Network Income

In addition, a set of evaluation criteria was developed to assess the solutions in Stage 2 and a solution template produced to capture this evaluation.

Stage 2 objectives are to identify, develop and evaluate innovative solutions within each of the five challenges, and then select the most promising solutions for a detailed description and evaluation, some of which are then selected for further investigation in Stage 3. The work was divided into two Work Packages.

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

Stage 3 is the next, and final, part of this project. It 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. It will also bring together and present the findings from across the whole project in a clear and succinct manner.

[1] Work Package 4 is a combination of two Work Packages in the original project plan (Work Packages 4 and 5) which focussed on component/process and system-level solutions respectively. During Stage 1 it was agreed to combine Work Packages 4 and 5, with a single Work Package Lead, and an integrated approach to the development of solutions. It was also agreed to place less emphasis on developing alternative Value Propositions within this project.

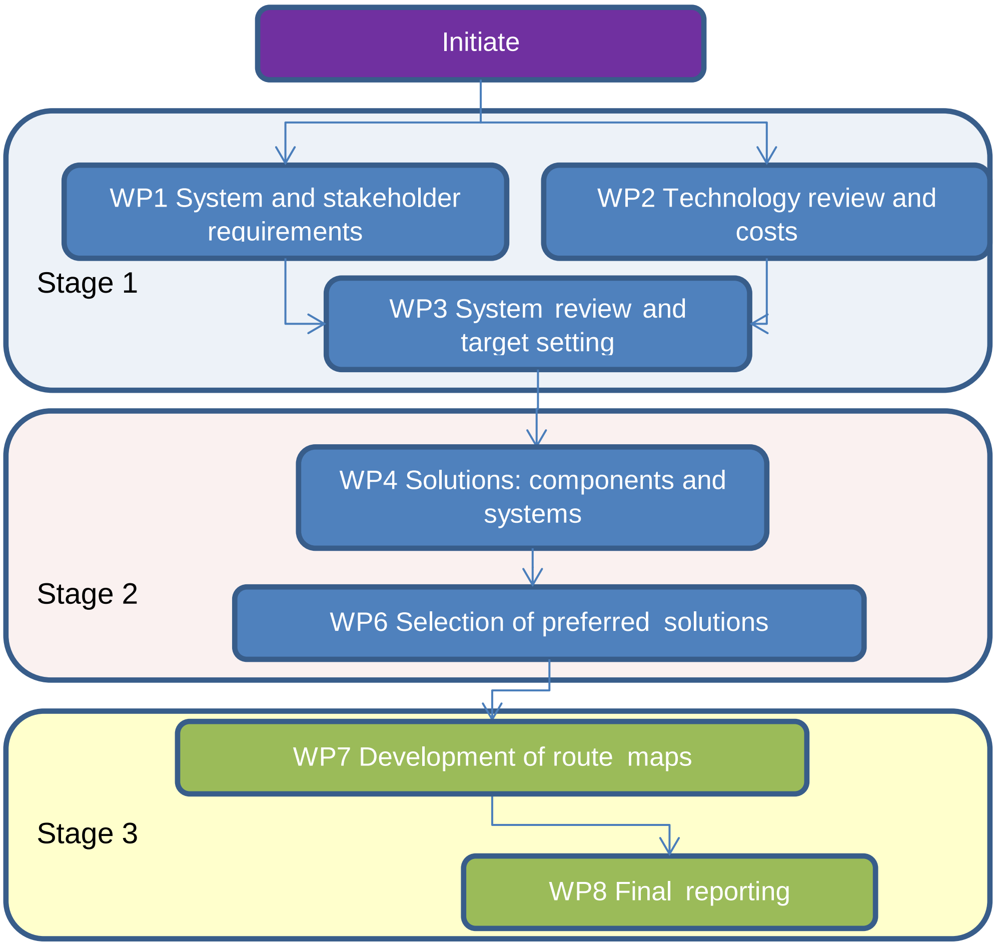


Figure 1: Overview of Stage and Work Packages

1.2 Outline of report content

Section 2 provides a summary of the process undertaken in Stage 2. This encompasses activities in both Work Packages 4 and 6. Summary notes of key meetings held are included in Appendix B.

Section 3 presents the results from Work Package 4. It contains a short description of each key solution, its estimated reduction in DHN CAPEX and a summary of other key impacts of the solution. Section 3 also highlights how the individual key solutions may conflict with or reinforce other solutions. Additionally, the completed solution evaluation form for each key solution is included in Appendix D and a list of all solutions identified is included in Appendix E.

Section 4 presents the results from Work Package 6. It includes an estimate of the overall impact on CAPEX and OPEX of the combined key solutions. It provides a summary of the decisions made in terms of which solutions should be taken forward to route map development in Stage 3 and the underpinning logic behind the decisions.

2 Methodology

The approach taken in Stage 2 is summarised here. The full list of solutions is captured in Appendix E.

2.1 WP4 – Solution Development and Evaluation

The project team identified, developed and evaluated solutions across all Challenges. Challenge 1 (System Design Architecture) commenced first to help inform the direction of the component and process level challenges (Challenges 2 to 4) and potential new network income (Challenge 5). Internal reviews and analysis were complemented by significant external engagement (including site visits) and two workshops to review in detail the cost components associated with civil engineering and HIUs respectively and look to identify solutions to reduce such costs. A list of the external organisations engaged in Stage 2 is included in Appendix A. Summary notes of key meetings are included in Appendix B.

Each fortnight, progress within each Challenge was shared with the Solutions Management Group. Each solution was prioritised as follows.

- Green – Ideas that were considered to offer potentially significant DHN CAPEX cost reduction. Solution development focussed on these solutions. A solution form was completed for each Green solution.
- Amber – These were promising ideas that were considered to have less benefit than the Green solutions. The list of Amber solutions was continually reviewed during WP4 as Amber could become Green, either through integrating an Amber Solution into an existing Green solution or a cluster of Amber solutions may result in more substantive benefit and together become a new Green solution. Some Amber solutions had more significant OPEX benefits but limited, if any, CAPEX benefit.
- Red – These were ideas which were considered to have little or no CAPEX benefit and significant barriers to development (although may be of benefit in particular circumstances).

The Solution Management Group provided a wider internal review of solutions. It also considered the impact of the Green solutions on each other and on the wider DH system (e.g. assessing the impact of system level solutions which required alternative DH network temperatures on the design of the HIU). Where conflicts existed between solutions, it led to discussions around whether better to pursue only the solution with the greatest benefit, or alternatively identify a change which would eliminate the negative impact. It also identified where the benefits of solutions would be reinforced by other solutions and hence where they would be better to be developed together.

Table 3 shows the set of evaluation criteria used to particularly assess each Green solution, the outputs of which were collected in the solution forms. This detail has been included here as it is relevant to subsequent sections[2].

[2] Further explanation can be found in the report from Stage 1, (Deliverable EN2013_D01, “Requirements, Baseline Analysis and Target Setting Report”), Part A, section 8.

Criteria		Measurement
1	Impact on DHN CAPEX	Quantified using the cost model
2	Impact on certainty of outcomes	Qualitative (-2,-1,0,1,2)
3	Impact on DHN OPEX	Quantified using the cost model
4	Impact on DHN TOTEX (whole life cost)	Quantified using the cost model
5	Impact on the operation, performance and reliability of the DHN	Qualitative (-2,-1,0,1,2)
6	Impact on the flexibility of heat networks as a method of heat supply at scale	Qualitative (-2,-1,0,1,2)
7	Impact on the attractiveness of the DHN proposition for Users and Investors	Qualitative (-2,-1,0,1,2)
8	Impact on transaction complexity and the relative difficulty of implementing DHNs	Qualitative (-2,-1,0,1,2)
9	Health, safety or environmental impacts (consideration of likelihood and impact)	Qualitative (-2,-1,0,1,2)
10	Opportunity for use at scale or constraints on deployment across the UK	Qualitative (-2,-1,0,1,2)
11	Increased revenue and value from synergies with other sub-surface infrastructure	Qualitative (-2,-1,0,1,2)
12	Benefit to UK plc from improved CO_2 and economic performance	Qualitative (-2,-1,0,1,2)
13	Technical feasibility and any implications for commonality of technical standards	Qualitative (-2,-1,0,1,2)
14	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 (0,1,2,3,4)

Table 3: Evaluation criteria

Criterion 14 gives an estimated Effort assessment of the resource, timing, technology development and likelihood of success. This gives a combined rating which is intended to assess what is required to develop the solution to a point where its viability is tested and ideally confirmed. There will then, almost certainly, be a need for further effort to develop a solution at scale so that it is adopted as business as usual. This will be explored as part of the Stage 3 route map development.

The following are particularly noted

- Three evaluation criteria were assessed quantitatively [1,3,4]. The impacts of the new solution designs on cost were assessed using the cost model initially developed in Stage 1. The evaluation of CAPEX saving also evaluated separately the impact on the five different building typologies identified in Stage 1. Appendix C includes a brief summary of the five building Typologies (A to E) that have been considered in this project.

    - Typology A: City Centre
    - Typology B: Flats
    - Typology C: Terraced housing
    - Typology D: Semi-detached housing
    - Typology E: Detached housing
- All other evaluation criteria were assessed qualitatively. Criteria [2,5,6,7,8,9,11,12,13] were rated from '-2' to '+2' where '0' denoted no significant change from current DH system, "+2" a major positive impact and "-2" a major negative impact. Criterion [10] was rated from "+2" where the solution could be applied across all typologies to "-2" where it was restricted to a single typology.
- Criterion [14] was rated from "0" where minimal effort was required to develop and commercialise the solution to "+4" denoting major effort. The evaluation of this criterion was based on a combination of four contributing sub-measures as shown in Table 4. This alternative range and colour scale is to ensure that results are not presented in a way that suggests solutions requiring more effort / greater timescale are necessarily negative.

Effort Rating	**0**	**1**	**2**	**3**	**4**
	No Effort	Little Effort	Moderate Effort	Considerable Effort	Great Effort
Investment required	<£500k	£500k-£2M	£2-5M	£5-£10M	>£10M
Technology readiness level (TRL)	9	8-7	6-5	4-3	2-1
Timescale	<18mths	18mths-3yrs	3-5yrs	5-10yrs	>10yrs
Likelihood of success	Certain	Probable	Likely	Possible	Unlikely

Table 4: Measures used to evaluate solution effort; criterion [14]

2.2 WP6 – Selection of preferred solutions

The project team and ETI agreed a list of solutions to be taken forward to Stage 3. This was based on the results of the evaluation of each solution and the benefit of the project team delivering a route map.

2.3 Testing of preliminary findings with the stakeholder community

A one day stakeholder workshop was held at the end of Stage 2 to gauge the initial level of acceptance to the preliminary findings. The attendee list and a summary of the feedback from the workshop are included in Appendix F. Some minor changes were made to the solution forms produced in WP4, and additional sensitivity analysis was undertaken for three of the solutions, based on the feedback received.

3 Work Package 4 Results

This section presents the results from Work Package 4. Solutions were identified in this project and evaluated as 'green', 'amber' and 'red' (see Section 2.1). The full set of solutions identified is shown in Appendix E. This section focusses on the evaluation of the key (green) solutions. It also highlights how these solutions may conflict with or reinforce other solutions.

3.1 Key solutions

13 key solutions were identified as part of this work. These are listed below and summary information on each solution, which is helpful to both understand the solution and subsequent analysis, is given on a single page within this section with more detailed evaluation included in Appendix D.

1. Knowledge Management, Research and Training
2. Reduced Peak Demand and Peak Flow Rate
3. District Heating Wall
4. Loft Space / Cellar Route
5. Trenchless Solutions
6. Improved Front-End Design and Planning
7. Pipe Crossings
8. Shared Civil Engineering Costs (New Network Revenues)
9. Direct HIU System & Existing DHW Storage
10. HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)
11. HIU Optimisation (2) Further Simplification & Value Engineering at Scale
12. HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage
13. Internal Connections – Pipework & Connections within the Property

In addition, detailed evaluation was undertaken on two other solutions. In these cases, the DHN CAPEX reduction was found to be very small and the project team downgraded these to 'amber'. For completeness, the solution forms with the evaluation undertaken are included in Appendix D. These solutions were:

14. Recycling Excavated Material for Backfill
15. Shared HIUs.

Solution 1: Knowledge Management, Research and Training

Description: The district heating industry is currently operating at small-scale with reports of poor experience with many new-build schemes. Some research work is taking place but is relatively small-scale in the context of the scale of the challenge. This solution proposes a comprehensive programme of knowledge management to cover: (i) research, (ii) publication and (iii) training. This would be at a national scale and organised by a committee with widespread representation from: academia, government, professional bodies and the construction industry. A District Heating Knowledge Centre would be established where research and training would be focussed so as to obtain the necessary critical mass of researchers and practitioners.

The overall aim of this solution is to establish a continuous quality improvement process where projects are evaluated and improvements identified, research carried out to develop new techniques, and designers informed and trained so that the next project is more successful (see Figure 2).

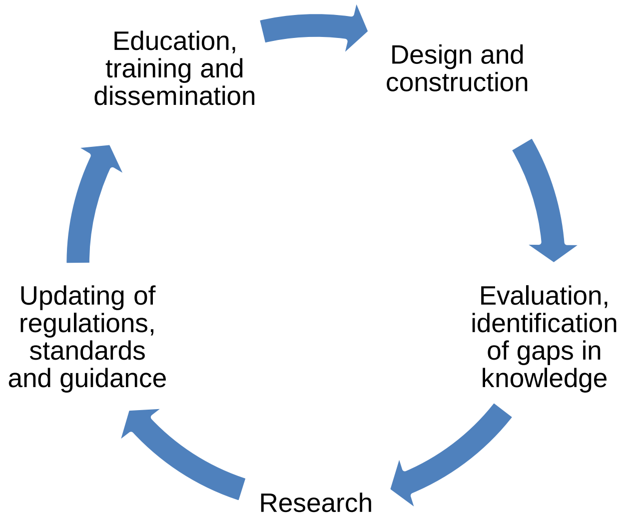


Figure 2: Continuous improvement process

DHN CAPEX savings: The baseline cost assumes a good standard of design and construction but not excellence. The CAPEX savings are difficult to quantify but predicted to be in the range of 1% to 5%, average of 3%. In practice, the benefits are anticipated to be larger as anecdotal evidence suggests that the quality of work is in many cases below a good standard and there would need to be a significant increase in the workforce if the potential of large-scale district heating in the UK was realised. It is noted that an upskilled workforce would be expected to also achieve additional total system CAPEX savings as well as OPEX savings e.g. through purchasing smaller capacity energy plants (less oversizing) and operating networks more efficiently.

Other key characteristics:

- This solution is additive to all other solutions and an important enabler as it is a means of spreading the best practice solutions that emerge.
- It is assumed that this solution can be applied across all types of heat networks.

- Potential customers and investors will have greater confidence in DHN capability with a comprehensive system of research, publications and training underpinned by Regulations.
- There is evidence that current designs are overly complex as designers are ‘playing safe’. Greater knowledge and research is likely to lead to a simpler approach.
- Health, safety and environmental (HSE) considerations should be part of this solution and therefore understanding of these issues would be enhanced and appropriate mitigation measures developed.
- Initial funding of less than £500k is expected to be sufficient to set up the structure of a new organisation and to obtain sources of funding for future years.
- The main barriers for this solution are expected to be inertia within the industry and set-up costs (albeit small in terms of the long-term benefits). There may need to be a specific grant to initiate the programme e.g. from BEIS. Once the scheme is operating it is expected that there would be a sustainable funding stream from academic research funding, industry annual contributions and training fees.
- There is some risk that this solution could result in a new DHN CAPEX increase from a more prescriptive approach to DHN delivery which might stifle innovation. Whilst recognising this, it is considered that the risk is small and the solution will deliver cost savings overall. There is benefit in embedding best practice within an industry where there are reports of widespread poor practice. In parallel, it is important that best practice is regularly reviewed to take into account the latest learning and innovation and the proposed solution would enable this review process to take place.

Solution 2: Reduced Peak Demand and Peak Flow Rate

Description: A reduced peak demand and peak flow rate system will allow smaller pipes to be used which will result in lower costs for pipe materials, pipe installation and civils. It may also mean that twin pipes and plastic pipes can be used more often in a network as these are typically only available below a certain diameter. The solution assumes a 50% reduction in flow rate through a cluster of ideas which together: (i) reduce the peak flow rate by 25% through more accurate estimates of heat demand which will be achieved by taking accurate measurements of the building, understanding the fabric of a given building and using data from smart gas and electricity meters and the use of a domestic hot water priority system, and (ii) increase the difference between the flow and return temperatures from 30C to 45C, ensuring sufficient space heating output by recognising that many radiator systems are over-sized and ensuring the radiator circuit is correctly balanced.

DHN CAPEX savings: The CAPEX savings are estimated as 3%. The cost reduction is mainly achieved through using reduced pipe sizes (one pipe size reduction assumed in all branches). However, as much of the length of the network is relatively small diameter where a reduction in diameter has a very small impact on cost (trench width is not impacted significantly), the overall saving is not as great as might have been expected. Furthermore, this calculation accounts for the additional cost from installing new radiator valves to support accurate balancing to achieve low return temperatures. There is also a benefit from the reduction in generation capacity within the energy centre. There is a relatively small additional OPEX benefit through lower pumping energy and reduced heat losses. There are also wider system benefits through smaller standby boilers necessary to meet the peak demand.

Other key characteristics:

- This solution can be applied across all types of heat networks.
- The new thermostatic radiator valves proposed are likely to be of better quality and so more attractive to residents. Residents, of well insulated homes, would be advised to use the heating more continuously in cold weather which will require some education to convince people that there is negligible additional cost in doing this.
- The solution is technically viable and has been demonstrated in a number of schemes. No significant effort is required to develop this solution – the technology is all available now but some development work on software and rapid survey techniques would speed up the design process.

Solution 3: District Heating Wall

Description: To avoid the costs of installing DH pipes in the road this solution proposes that the pipes will be surface mounted externally on the walls of the houses, typically running above the front doors and below the first floor windows. The pipes are boxed in using a pre-fabricated cover designed to match the external brickwork or render. The original intention was to apply this to terraced homes only (typology C). It has been expanded to typologies D and E which include semi-detached and detached homes through the use of a pipe bridge at about 2m height between the houses, with the pipes running on the rear elevation where possible.

The first figures below show a simple schematic of street pipe layout on the left for the baseline system and on the right for the new solution. The final figure shows the pipe layout on the front elevation of the properties.

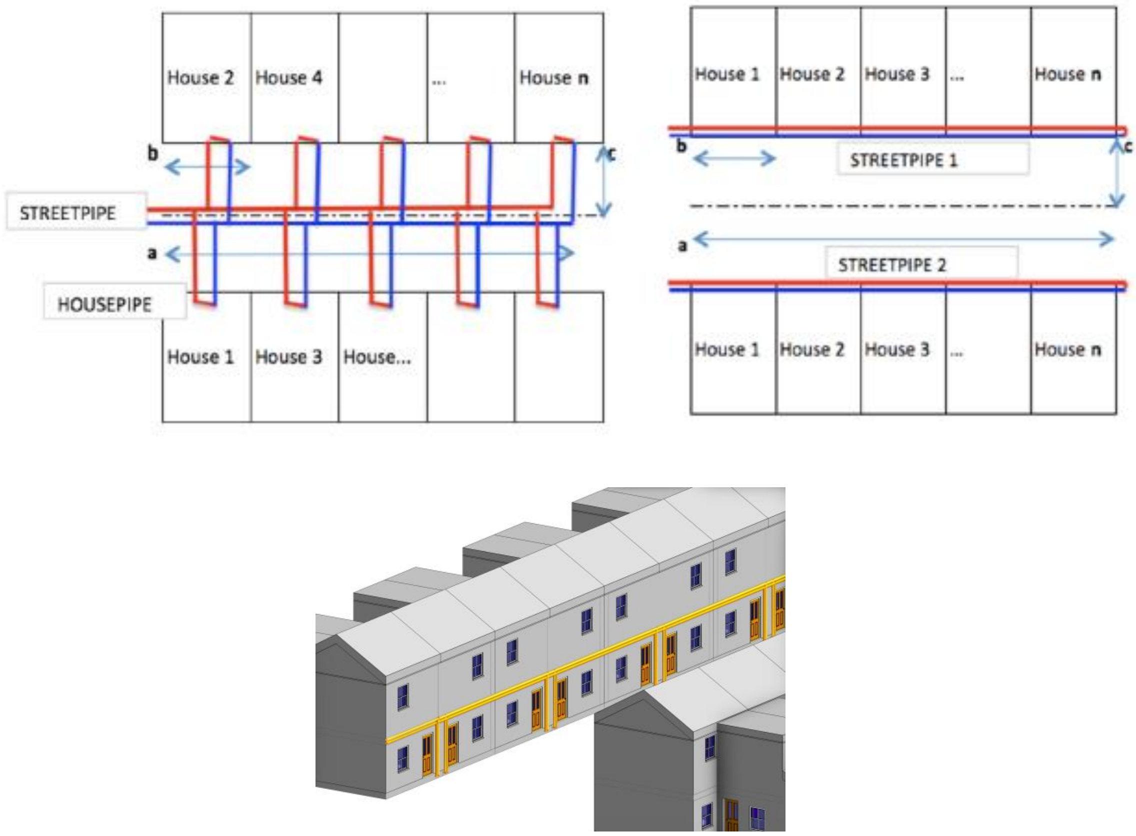


Figure 3: Schematic pipe layout for solution

DHN CAPEX savings: The CAPEX savings are estimated as 0.9% across the whole network. This is based solely on a 13% CAPEX saving for Typology C. It is estimated that there is a net CAPEX increase for Typologies D and E, particularly due to the additional pipe bridging between homes, and thus it is assumed that the solution is not implemented in these cases. It is expected that there would be no significant change in OPEX (lower heat losses from shorter branch lengths balanced by pipes now being located above ground, losing the benefit of insulation from the ground). There are not expected to be significant impacts on the wider system costs.

Other key characteristics:

- A key limitation of this solution is that it only achieves cost savings for Typology C. Furthermore, the solution depends on agreement amongst all owners to allow pipes to be installed across their property even if the DH supply is not taken - there would need to be either a significant financial incentive or regulation so that all properties in a given street would be required to allow the external pipework to be installed and ideally to also connect to the district heat supply.
- The avoidance of civils work means that the associated uncertainty of working around buried services with unknown ground conditions is removed. Furthermore, there should be reduced disruption as street excavation is avoided which allows quicker installation. Additionally, it should reduce health and safety risks, in particular by avoiding trenching work.
- The solution may be seen as too visually intrusive to Users, reducing the value of their property, and may require planning approval particularly in conservation areas. One option would be to implement this solution during installation of external wall insulation, where the pipework across the face of the property would be inserted and hidden by the insulation.
- The concept is straightforward to implement and no substantive issues identified around technical feasibility. The solution would benefit from a demonstration project.

Solution 4: Loft Space / Cellar Route

Description: To avoid the costs of installing DH pipes in the road this solution proposes that the routing of the small-sized DH branched pipework through unused spaces within the buildings themselves. This could be either utilising the ‘dead-zone’ often found within loft spaces (i.e. the eaves, where the sloped roof and ceiling joists meet) or within cellar or basement spaces. The original intention was to apply this to terraced homes only (typology C). It has been expanded to typologies D and E which include semi-detached and detached homes through the use of a pipe bridge between the houses at roof level or a small length of buried pipework between cellars.

The figures below show a schematic of the pipe layout for the new solution. The figure on the left shows the pipework between the HIU and loft space. The figure on the right shows route across loft spaces and a pipe bridge between groups of semi-detached houses.

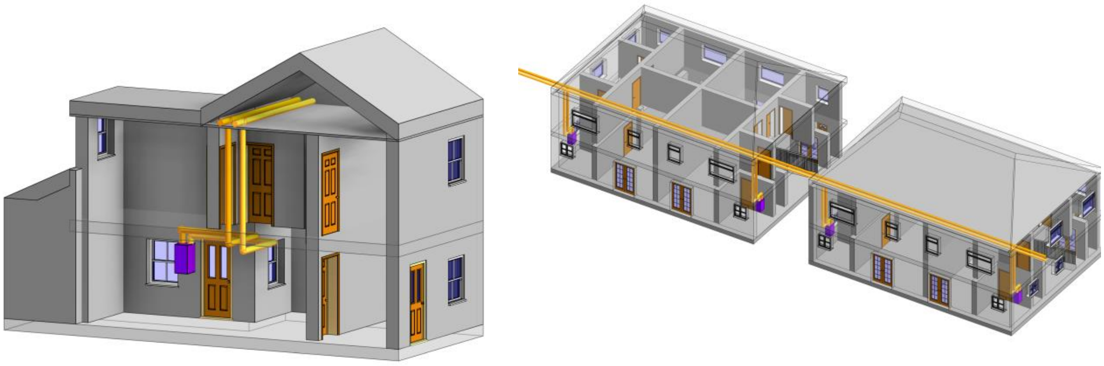


Figure 4: Schematic pipe layout for solution

DHN CAPEX savings: The CAPEX savings are estimated as 5% across the network. This is mainly because of a 10-20% CAPEX savings for Typologies C and D. It is noted that overall this has a greater cost saving than the District Heating Wall solution as: (i) the costs for fixing to the wall and cladding to make the DH Wall solution visually acceptable are higher than for this solution, (ii) the routing from the main run to the HIU is shorter and simpler. The sensitivity range of the solution is limited in that it adopts conventional technology. As a reasonable minimum, it is estimated that the cost saving could reduce to 3% accounting for unusual obstacles due to, for example, the loft design or presence of a loft-conversion. By comparison, it is expected that the maximum the solution will achieve is a 6% saving overall. No significant change in OPEX is anticipated (lower heat losses from shorter branch lengths will be balanced by some of the pipe length now being located above ground or in cold lofts). There are not expected to be significant impacts on the wider system costs.

Other key characteristics:

The Loft Space / Cellar solution has a number of characteristics in common with the District Heating Wall, namely:

- The solution is still dependent on agreement amongst all owners to allow pipes to be installed within their property even if the DH supply is not taken.
- The avoidance of disruption from civils work, consequential Health and Safety benefits as well as improved certainty of outcomes.

- The concept is straightforward to implement and no substantive issues identified around technical feasibility.
- The solution would benefit from a demonstration project.

Specifically for loft spaces:

- This solution is more widely applicable than the District Heating Wall solution in that it achieves cost savings for terraced, semi-detached and certain detached Typologies.
- Loft space routes have been used in a number of existing low rise schemes e.g. the Alexandra Park and Longsight schemes in Manchester built in the 1970s and refurbished in the 1990s.
- The loft and cellar route reduces the internal piping for terraced housing (by 40%) lessening the impact of improvement in Internal Connections – Pipework & Connections Within the Property (Solution 13). For Semi-detached properties the internal piping is increased, but this solution may not be widely applicable for such properties. Some aspects of the approach to Solution 13 would be valuable for the installation of loft space DHN pipe mains.
- In some cases, the loft will have been converted to living space however there will still be opportunities to route pipes at low level near the eaves as these areas are normally not used due to the low ceiling height or used only for storage. Nevertheless, where loft conversions have been made the work will be more intrusive and disruptive to residents.

Cellar routes may be available in some properties and would have similar characteristics to the loft solution with converted basements being analogous to loft conversions.

Solution 5: Trenchless Solutions

Description: This is a cluster of solutions with the main aim to reduce the costs of civil engineering where possible by replacing trench excavation by trenchless approaches. This particularly focusses around the use of directional drilling both within the street and for the branches between the street and the house. It is assumed particularly applicable for Typologies D and E where connection pipe lengths are greater per property and also due both to less risk of underground objects and less need for any additional trench excavation works (e.g. excavated holes to confirm safe passage of drilling past services).
Additional options have been proposed: (i) installing a GPRS sensor to the drill head to better locate underground obstacles and (ii) using the route of the gas pipes if the gas network was to be abandoned for the development

DHN CAPEX savings: The central CAPEX saving is estimated as a 11% reduction. Based on alternative scenarios, the CAPEX sensitivity is estimated to range widely between 6% and 18%. It is expected that there would be no significant change in OPEX or on the wider system costs.

Other key characteristics:

- There should be significantly greater certainty of outcomes for programme duration and cost. Particularly with the use of GPRS on the drill head, and the advantage of directional drilling in being able to steer around obstacles, there should be greater certainty of civils costs. Furthermore, there should be a significantly shorter programme of work compared to the standard approach of trench digging and reinstatement.
- Trenchless technology would be attractive to the property owner or resident. It will result in significantly less disruption both from a shorter excavation time and avoiding digging a trench from the road to the front of the property and then making good. The approach also provides flexibility through allowing for the pipe to be laid down the main street and then homes to be connected relatively easily and quickly when they sign up to district heating.
- There are improvements to health and safety by greatly reducing the need for site staff to enter a trench.
- Trenchless pipe-laying is currently applied today. Some of the trenchless technology equipment identified is still subject to development but is considered feasible i.e. a continuation of current product development rather than requiring radical new technology and innovation.

Solution 6: Improved front end design and planning

Description: This is a cluster of solutions that combines the following four elements: (i) improving the process by which designs are produced and contractors appointed to allow more detailed design work to take place prior to agreeing a price for the work, (ii) better application of survey and design techniques, (iii) obtaining consents to carry out the work earlier and (iv) better resource management through improved front end planning. This solution also highlights the benefits of an underground map of all utilities to support the design process.

The figure on the left highlights a route congested with underground services. Through greater initial survey work, as shown by the figure on the right, it should be possible to optimise the pipe route and speed up excavation.

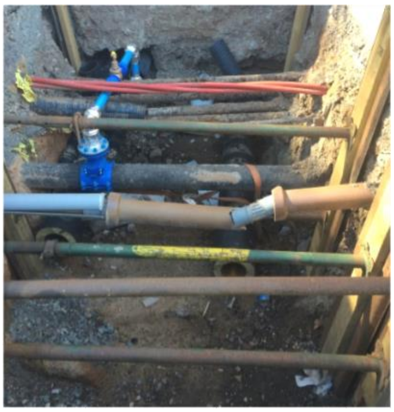


Figure 5: (a) congested DH route, (b) undertaking Ground Penetrating Radar survey[3]

DHN CAPEX savings: The DHN CAPEX savings are estimated to be 9%. This is particularly based on increasing the speed of excavation and has included feedback from contractors in this estimate. Modelling alternative scenarios provides a sensitivity range of 4.5% cost saving as a minimum and 11% cost saving as a maximum. There is no significant change to OPEX. To achieve this benefit, there are proposed significant additional upfront costs associated principally with greater design and planning.

Other key characteristics:

- This approach should be beneficial to all heat networks.
- This solution should provide much greater confidence in the civil engineering costs which is the largest and most uncertain component of the DH CAPEX. It should also result in a more certain and shorter programme of work through greater front end design and planning.
- The greater confidence in costs and timeframe, and the shorter programme of works, should be attractive to Investors and Users respectively.
- The greater certainty and ability to plan ahead, should significantly reduce the complexity in managing operations.
- Through improved underground surveying, it should be possible to undertake shallower dig for at least part of the route. This would reduce the risks associated with working in trenches.

[3] Figure 5(a) and Figure 5(b) are reproduced courtesy of AECOM Ltd.

- In general, the technical approach suggested can be applied today. The exception is the availability of an underground map in the form of a 3-D model of all existing buried services which will need to be built up over time.
- The major barrier is obtaining agreement from all parties to the improved process – albeit all key parties should benefit.
- There is potential for this solution to align with Trenchless technologies, although the savings will not be wholly additive.

Solution 7: Pipe Crossings

Description: The notional network includes three major crossings (two railways and one canal) with a tunnel for the DH pipework required in each case. A cheaper solution would be to utilise existing bridge structures to support the district heating pipes. However, the owner of the bridge often imposes onerous commercial conditions on the DH company including not only unlimited liability for any damage to the structure but also very high indirect liabilities such as interruption to flow of traffic or trains on the bridge. However, as the risks are in practice very low a more rational approach would be for the owners of the bridge and the railway to accept a lower level of liability given that ultimately it would be central government that would carry the risk whether it is for the railway or road (both are in public ownership), particularly where the DH company is also in the public sector. The current position means that heat customers are paying a higher price for heat because of the desire to minimise risk to the public sector. This solution is therefore proposing an alternative commercial arrangement where the risks are taken by the public sector and existing bridges can be used to support the pipes (as well as new bridges including suitable ducts within design where there is a marginal cost impact).

DHN CAPEX savings: The DH CAPEX savings are estimated as 2% across the network. There would of course be a variation in outcome for any given scheme depending on the details of the pipe crossings and a sensitivity of ± 1%, i.e. a range of 1% to 3%, is likely. There would be no significant change in OPEX or significant impacts on the wider DH system costs.

Other key characteristics:

- The main barrier is the difficulty of co-ordinating action amongst a large number of organisations. The Government, Highways Agency, Local Governments, Network Rail, Canal and Rivers Trust, Transport for London and other similar bodies would need to agree an approach that will facilitate the use of existing bridges for carrying district heating pipes without imposing onerous terms and conditions and excessive costs. Risks would be underwritten by central Government.

Solution 8: Shared Civil Engineering Costs (New Network Revenues)

Description: The premise for this solution is that Heat Networks are one of a range of utilities laid underground and, if the costs associated with ‘open-cut’ civil engineering of pipe trenches can be shared with other utilities, there is significant potential for cost saving.
This solution particularly focusses on a joint contract between the DHN developer and one or more other utilities to combine the trenching costs for laying new infrastructure or upgrading / repairing existing infrastructure. It also includes a refinement to set up a new business model (e.g. Joint Venture or equivalent) for the combined DHN and utility network: to own and manage the sub-soil infrastructure and lease back to the two (or more) operating companies.

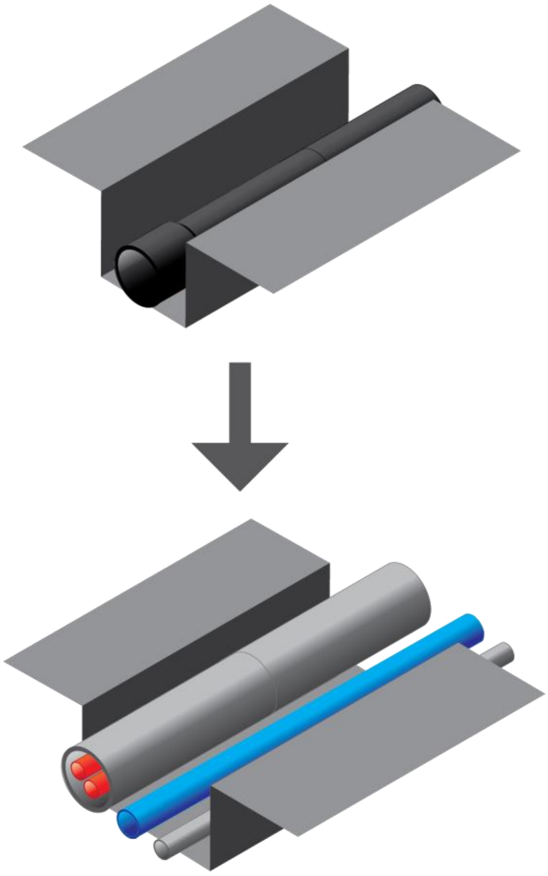


Figure 6: Example of multiple utilities sharing a trench

DHN CAPEX savings: The DH CAPEX savings are estimated as 1.4% across the network. Sensitivity analysis suggests a lower level of 0.3% and a realistic maximum potential of 2.1%. There would be no significant change in OPEX or significant impacts on the wider DH system costs.

Other key characteristics:

- From a user / householder perspective, the combined civils solution reduces the disruption of construction work in their locality i.e. combines work.
- From DH Network Investors' perspectives the solution provides a more compelling case for the Local Authority and increases the chance of a proposed DHN progressing. The solution has potential to realise synergies with water and other utilities, but the research thus far has shown that the concept is not as compelling to these organisations at the current concept stage.
- By reducing the overall level of street-works in the area, it will have a positive impact on both public and contractor safety. It will also support greater resource efficiency for construction and transport with reduced CO_2 impact from pipeline installation replacement and from traffic congestion during works.
- A significant limitation of the potential of this solution is the need to align DHN requirements with those of utilities. Hence, the cost modelling assumptions limit the scope for impact to between 4% to 20% of the baseline network length.
- This solution requires the co-ordination of civil engineering activity across at least two independent networks. Although the intention would to be to use as much of a common team to make all connections, the additional co-ordination will have a minor negative impact on certainty of outcomes. It will also significantly increase the complexity of procurement and legal agreements with multiple organisations involved.
- There is likely to need to be standard development in two areas: (i) Commercial and legal standards to ensure the responsibility is equitably allocated to all parties to the shared civils contract, or shareholders in the Joint Venture model, and (ii) Technical Standards and codes of practice for laying multiple utilities in close proximity.
- Overall there is seen to be considerable effort to take this solution to commercial deployment, particularly on a national scale.
- This effort is seen as a significant barrier, although no evidence of detailed analysis of benefits and obstacles has been identified. This lack of past research suggests that the shared civil engineering model is worthy of further exploration.

Solution 9: Direct HIU System & Existing DHW Storage

Description: This is a cluster of two integrated solutions.

(a) The baseline solution assumes indirect HIUs. By comparison a direct HIU is cheaper as it has fewer components e.g. no heat exchanger and pump for the space heating circuit. Direct HIUs could be used provided the properties' heating system pressure ratings are compatible with the proposed DH maximum pressure which is true for our notional scheme - for larger schemes it may be necessary to include, for example, additional heat exchanger substations to limit the maximum pressure. The disadvantage of this approach most often cited is that any leaks could continue in a dwelling with no limit to the volume released. A leak detection device to detect a loss of pressure on the dwelling circuit would resolve the issue. The device could be incorporated into the HIU at a small cost, although this cost has not been included in the analysis at present as it is not necessary to achieve the cost saving.

(b) The baseline assumes instantaneous hot water heat exchangers in all properties. However, in many properties the existing heating system will include a hot water cylinder heated by an indirect coil within the cylinder. In such cases, the hot water cylinder and its controls can be retained and so avoid the costs associated with the instantaneous hot water heat exchanger. The hot water cylinder coil could be supplied indirectly or, when combined with the direct connection option the HIU would then only contain a DPCV or PICV (differential pressure or pressure independent control valves) and heat meter and this equipment could probably be installed on site in any suitable location. The disadvantage of this approach is that return temperatures from the hot water heating would typically be around 60C whereas 40C and lower would be achieved with the instantaneous hot water heating. However, as the storage cylinder enables the local branch to be isolated when there is neither space heating or hot water heating demand the heat losses from the local branch main will be lower. Overall the heat losses are expected to be very similar.

DHN CAPEX savings: The CAPEX savings are estimated as 4.5% across the network. As direct connection HIU products are available in the market now the sensitivity range is relatively small – about ±1%. It assumes that all HIUs are changed from indirect to direct. It also assumes savings where existing hot water cylinders are retained (it is assumed that 50% of dwellings have existing cylinders which can be retained which is derived from survey data). No significant impacts have been identified on the wider DH system costs.

Other key characteristics:

- Direct HIUs can be applied in all networks – albeit for larger schemes it may be necessary to include, for example, additional heat exchanger substations to limit the maximum pressure. The use of hot water cylinders is dependent on those properties that have them retained and wish to keep them.
- There are advantages to the User: (i) direct HIUs will be simpler to maintain, and (ii) where cylinders are retained, work will be less disruptive to occupants.
- A disadvantage of direct connection is that it imposes pressure constraints on the network which may limit further expansion. It is best suited to schemes in a defined area where a significant further extension of the network is not envisaged.
- The solutions are all technically viable and have been demonstrated in a number of schemes. Direct connection is often perceived as having additional safety issues due to the higher pressures involved in the radiator circuits, uncontrolled leakage and probably higher surface temperatures in most cases. However the system has been extensively used in the UK and abroad and risks are well understood. Some development work could be beneficial for a system that detects leaks and automatically isolates from the DH network to help address concerns.

The main components of an HIU for the baseline and the proposed direct connection retaining the hot water cylinder are given in the tables below.

Indirect + instantaneous hot water:

- Isolating valves
- DPCV
- Strainer
- Heat meter
- PHE for space heating
- Control valve for space heating
- Secondary pump
- Power supply
- Fill loop
- Pressure vessel
- PHE for hot water
- Control valve for hot water

Direct + hot water cylinder retained:

- Isolating valves
- DPCV
- Balancing valves
- Strainer
- Heat meter

The photographs below show an indirect connection HIU on the left and a direct connection HIU on the right (both with instantaneous hot water heat exchanger).

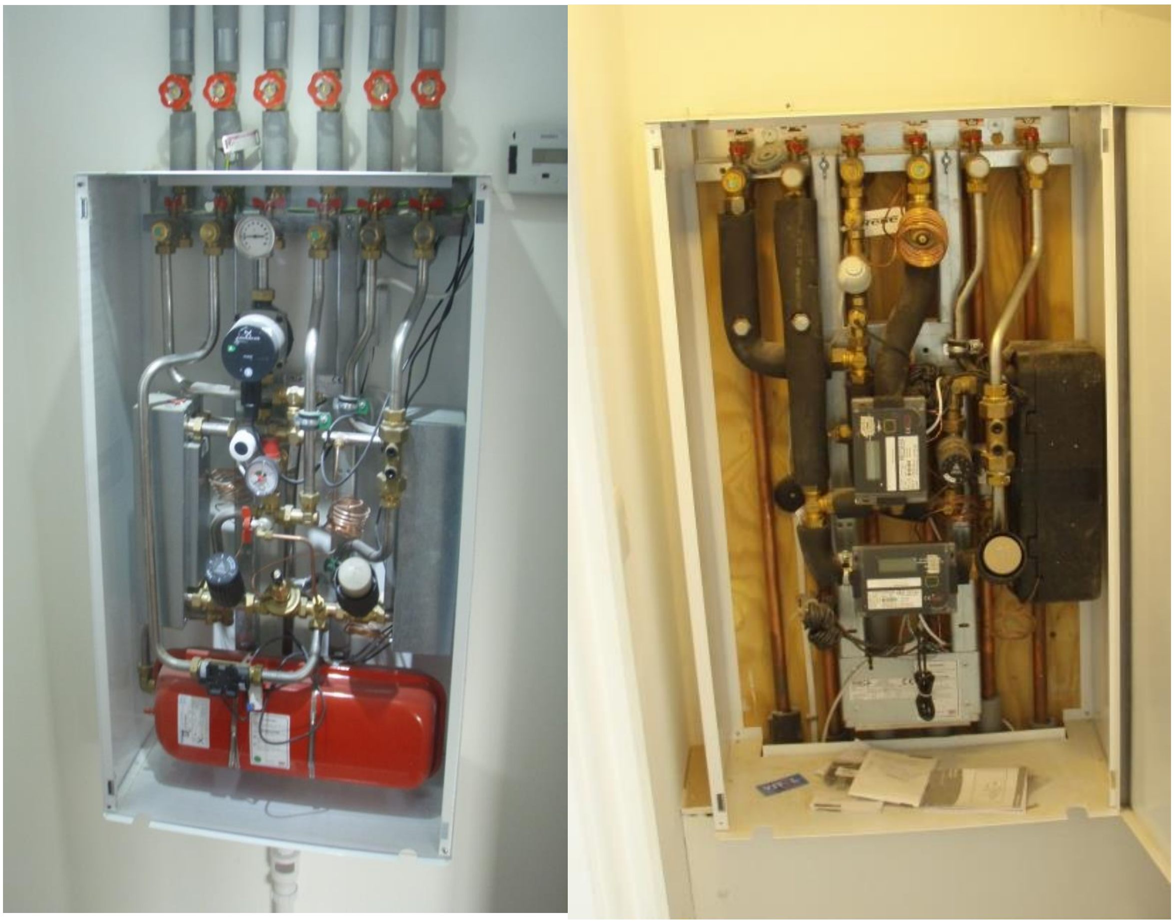


Figure 7: Typical indirect connection HIU and Typical direct connection HIU[4]

[4] Figure reproduced courtesy of AECOM Ltd

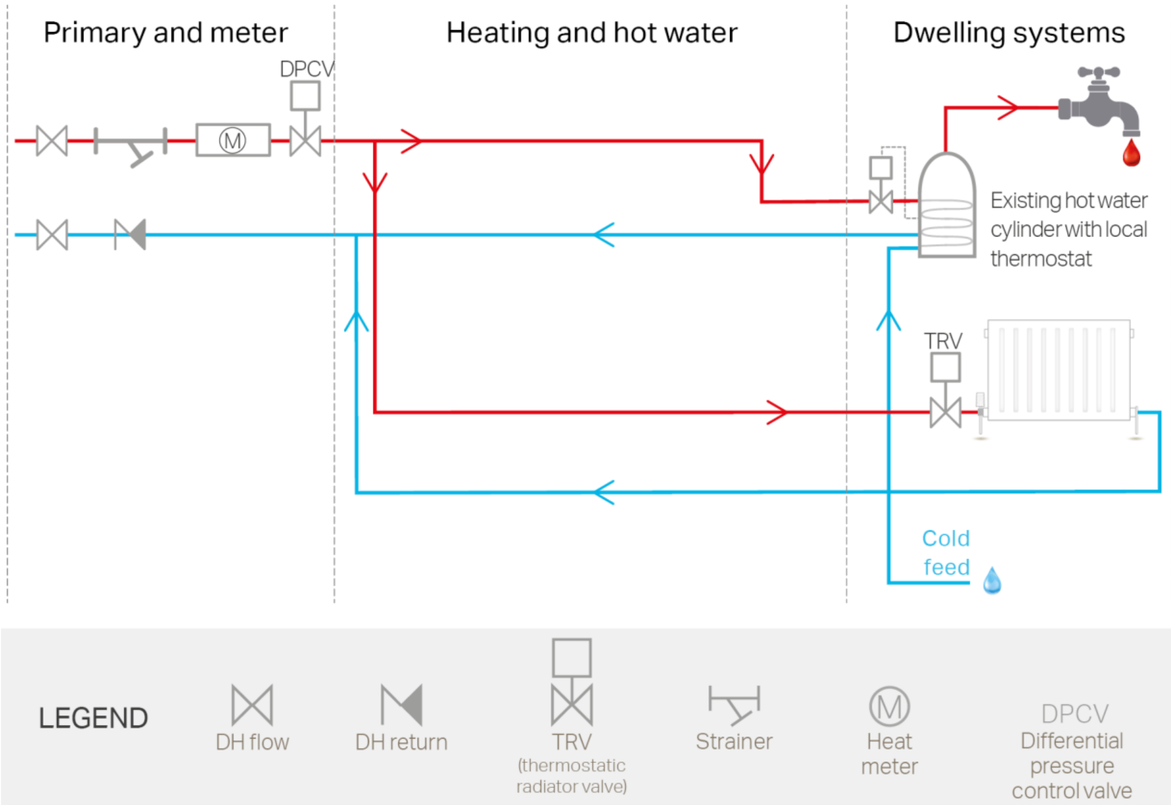


Figure 8: Direct HIU and retention of DHW cylinder

Solution 10: HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)

Description: The baseline assumption is that all domestic connections are Indirect Connection HIUs with 2 plate heat exchangers per unit. The solution, based on an ECCR[5] workshop on the 2nd September, identifies potential cost savings in HIU components and manufacturing process without significant change in unit specification and performance. This includes; (i): simplification and standardisation of components, (ii) reduction in parts count through common sub-assemblies and reduced duplication / redundancy and (iii) components that are quick and easy to install correctly to reduce labour time and joint failures.

DHN CAPEX savings: The accumulated CAPEX savings are estimated as 3% ± 1% across the network. There would be a 5% reduction in OPEX arising from lower costs to repair and replace the HIU during the DHN lifetime, including easily changed components.

Other key characteristics:

- This product can be applied across all of the residential typologies (Typology B to E).
- It is a less complex, simpler product.
- This solution is a mix of (i) low difficulty improvements which are near market and require minimal technical development, and (ii) medium/high difficulty improvements which require development. Approximately 60% of the improvements are classified as low difficulty.
- To achieve significant cost savings from control simplification (part of the solution) requires network operator, customer and system designer agreement of technical performance standards.

[5] ECCR: Eliminate components, Combine parts, Combine processes, Reduce work content.

Solution 11: HIU Optimisation (2) Further Simplification & Value Engineering at Scale

Description: This builds on the previous solution. It identifies additional cost savings by challenging existing specifications and identifying potential process cost benefits of production at scale. In particular, **c**omponents have been identified as having potential for elimination or substitution as a result of: (i) **d**uplication of functionality – within the HIU or elsewhere in the system, (ii) **o**ver-engineering – refinements or additional functionality above the basic requirement, (iii) optional items which could be designed as chargeable upgrades; enabling users to make an informed choice whether to include in their specification.

DHN CAPEX savings: The accumulated CAPEX savings are estimated as 5%±2% across the network (i.e. an additional 2% improvement from Solution 10). There would be no additional OPEX savings compared to Solution 10.

Other key characteristics:

- This product can be applied across all of the residential typologies (Typology B to E).
- It is a less complex, simpler product.
- Users should benefit from a more reliable solution increasing the mean time between failures. There is the potential for reduced user experience from simplified controls.
- This solution is a mix of (i) low difficulty improvements which are near market and require minimal technical development, and (ii) medium/high difficulty improvements which require development. Approximately 15% of the improvements which are classified as low difficulty.
- Achieving agreement on the revised heat meter improvements proposed will require alignment of multiple stakeholders: Network operators, technical bodies, consumer groups, government / regulator.
- There is the potential barrier in that HIU manufacturers may be reluctant to invest in developing a low margin product.

Solution 12: HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage

Description: This solution is a combination of the cost savings achieved through the following solutions:

- 9. Direct HIU System & Existing DHW Storage
- 10. HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)
- 11. HIU Optimisation (2) Further Simplification & Value Engineering at Scale

DHN CAPEX savings: The accumulated CAPEX savings, across Solutions 9, 10 and 11are estimated as roughly 7% ± 2% across the network (i.e. an additional 2% improvement from solution 11). There would be no additional OPEX savings compared to Solution 11 .

Other key characteristics:

- These are presented in the three individual solution summaries.

Solution 13: Internal Connections – Pipework & Connections Within the Property

Description: This solution considers the cost of the pipework and installation from the first penetration into the building to the connection to the HIU and the installation of the HIU itself. This solution focuses predominantly on reducing material and labour which account for the majority of baseline cost. In particular the solution focusses on eliminating excessive material waste and developing a programme of work which substantively reduces labour requirements.

DHN CAPEX savings: A number of alternative options have been developed for this solution. As a central case, the CAPEX savings have been estimated as 1.8% across the network. As a sensitivity, it is estimated that the savings could range between 0.9% and 2.5%. As a whole, the solution applies to all residential properties (Typologies B to E). However, the solution has the greatest impact on properties with the longest internal pipe runs and these occur most frequently in terraced properties: Typology C. There is expected to be minimal impact on OPEX or wider system costs.

Other key characteristics:

- An optimised installation process will provide greater confidence in completing home installations in the target time of a single day. From a user / householder perspective, there will be less disruption from internal works with less labour on site. From DH Network Investors' perspectives the solution provides a more compelling case for the Local Authority and increases the chance of a proposed DHN progressing.
- The solution has potential to realise synergies with the roll-out of smart meters, albeit the timing may not coincide as the replacement of meters is already well underway.
- The solution's benefit comes in the main from process optimisation and so technically there is minimal risk. New insulating trunking products proposed are an adaptation of existing solutions, rather than needing major technical development.
- Current procurement practices, with multiple layers of sub-contracting, will hinder the progress of streamlined processes.
- This solution is not unique to DHN implementation and development of streamlined piping installation or renewal processes could be driven by both new housing construction and traditional heating system renewal.
- When Solution 4 (Lofts and cellars route) is used the impact on terraced housing is to reduce the length of internal piping by 40%: Reducing the value of this solution.
  If however, the loft / cellar solution is identified as attractive for semi-detached properties there will be an major increase in internal piping (400%) and the value of the internal connections solution increases.

3.2 Holistic review of solutions

Table 5 shows which Challenge each solution addresses. It is noted that the solutions address all five Challenges with some solutions addressing more than one Challenge.

Table 6 provides a matrix of solutions showing the interactions between solutions if implemented together. The following classification has been used in the matrix.

"+" where there is a positive interaction between solutions (i.e. the cost savings of implementing both solutions together is greater than the sum of the cost savings if each solution was implemented in isolation)

"0" where there is no substantive interaction between solutions (i.e. the cost savings are simply additive)

"-" where there is a negative interaction between solutions (i.e. the cost savings of implementing both solutions together is less than the sum of the cost savings if each solution was implemented in isolation)

In the main, the interactions are neutral. However, there are some synergistic interactions.

Note that it is assumed that there is no significant interaction between Reduced Peak Demand and Peak Flow Rate and the other civil engineering related solutions. As discussed in the Reduced Peak Demand and Peak Flow Rate solution description; much of the length of the network is relatively small diameter and further reduction in diameter, as a result of reducing the flow rate, has a very small impact on the civil engineering works.

Positive interactions

- No significant positive interactions have been identified.

Negative interactions

- The District Heating Wall and Loft Space/Cellar Route solutions are mutually exclusive - they are both alternatives to trench excavation in streets and would not be applied together to the same buildings. However, in practice, the solutions could work well together as part of an overall strategy i.e. certain buildings/typologies could be more suited to one solution than the other.
- Trenchless Solutions are mutually exclusive of implementing either the District Heating Wall or Loft Space/Cellar Route - Trenchless Solutions provide another alternative to trench excavation in streets.
- Both Trenchless Solutions and Improved Front-End Design and Planning could be applied together but yield less than the total sum of the benefits as some processes and benefits would be double counted. In particular, it is assumed that the delivery of Trenchless Solutions is managed efficiently. It is also assumed that it is based on a good standard of advanced surveying and early approval consent.
- The four HIU-related solutions are connected: Solution 9 (Direct Connection) is a change of system design and Solutions 10 & 11 are iterations of improvement of the baseline indirect HIU. As a result these solutions are not additive, rather it is Solution 12 (HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage) which assesses saving from the integration of the other three solutions.
- The interaction between Loft Space/Cellar Route (Solution 4) and Internal Connection – Pipework & Connections Within the Property (Solution 13) is mixed, but

on balance negative. Shorter internal piping length in terraces reduces the saving from improved process. However, if the loft solution is widely applicable to semi-detached properties there is a significant increase in internal piping: making the interaction positive.

	Challenge 1: System Design Architecture	Challenge 2: Civil Engineering CAPEX	Challenge 3: Pipes and Connections CAPEX	Challenge 4: Internal Connections CAPEX	Challenge 5: New Network Income
1. Knowledge Management, Research and Training	✓	✓	✓	✓	
2. Reduced Peak Demand and Peak Flow Rate	✓	✓	✓		
3. District Heating Wall	✓	✓			
4. Loft Space / Cellar Route	✓	✓			
5. Trenchless Solutions		✓	✓		
6. Improved Front End Design and Planning	✓	✓	✓		
7. Pipe Crossings		✓	✓		
8. Shared Civil Engineering Costs (New Network Revenues)					✓
9. Direct HIU System & Existing DHW Storage				✓	
10. HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)				✓	
11. HIU Optimisation (2) Further Simplification & Value Engineering at Scale				✓	
12. HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage				✓	
13. Internal connections – Pipework & Connections within the Property				✓	

Table 5: Solutions which Address each Challenge

	1. Knowledge Management, Research and Training	2. Reduced Peak Demand and Peak Flow Rate	3. District Heating Wall	4. Loft Space / Cellar Route	5. Trenchless Solutions	6. Improved Front End Design and Planning	7. Pipe Crossings	8. Shared Civil Engineering Costs (New Network Revenues)	9. Direct HIU system & Existing DHW Storage	10. HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)	11. HIU Optimisation (2) Further Simplification & Value Engineering at Scale	12. HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage	13. Internal Connections – Pipework & Connections within the Property
1. Knowledge Management, Research and Training		0	0	0	0	0	0	0	0	0	0	0	0
2. Reduced Peak Demand and Peak Flow Rate			0	0	0	0	0	0	0	0	0	0	0
3. District Heating Wall				-	-	0	0	0	0	0	0	0	0
4. Loft Space / Cellar Route					-	0	0	0	0	0	0	0	-
5. Trenchless Solutions						-	0	0	0	0	0	0	0
6. Improved Front End Design and Planning							0	0	0	0	0	0	0
7. Pipe Crossings								0	0	0	0	0	0
8. Shared Civil Engineering Costs (New Network Revenues)									0	0	0	0	0
9. Direct HIU System & Existing DHW Storage										-	-	-	0
10. HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)											-	-	0
11. HIU Optimisation (2) Further Simplification & Value Engineering at Scale												-	0
12. HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage													0
13. Internal Connections – Pipework & Connections within the Property													

Table 6: Matrix of interactions between solutions

3.3 Amber and red solutions

Details of the red and amber solutions are provided in a separate Excel spreadsheet that accompanies this Deliverable. The solutions list was produced following a number of stakeholder events and brainstorming activities. All of the solutions were reviewed and classified as red, amber or green.

The rationale for classifying these as red or amber is as follows:

Red solutions were those where, when the initial idea was analysed further:
- it did not offer any capital cost saving
- it was considered to be impossible to implement.
- It would increase capital cost but in some circumstances, could reduce operating costs but not by a significant amount.

Amber solutions were those that were valid suggestions but were those where:
- the capital costs saving would be marginal or very small
- the effort in developing the solution appeared to be very significant with uncertain results
- there were other concerns over the practicality or acceptability of the solution
- the applicability was limited to particular configurations or types of schemes
- the solution was in the area of contracts or regulations rather than technology as it is the latter that is the primary focus of this project

Green solutions were those where:
- there was a good balance between the potential cost savings and the likely effort to realise these
- there was already some experience or interest in the industry providing confidence that the solution could become viable e.g. reduced peak demand and low flow rate, improved front end design and planning.

Some of the ambers were variants or sub-sets of the green solutions so the amber list will be kept under review as the route maps are developed for the green solutions and amber solutions incorporated or referred to where appropriate.

It is reasonable to assume that some further cost savings would be realised if the amber solutions were adopted. It is difficult to estimate the potential saving without further analysis of each solution. The list has a few items where significant savings could be realised (but with significant uncertainty): shallow burial, high temperature plastic pipe, more advanced equipment, routes through gardens or along the kerb line, together with a large number of smaller improvements, some of which may not be feasible if examined in detail or would not be additive in terms of savings when combined with other solutions. It is estimated that the total savings from amber solutions would provide an additional 6% CAPEX saving based on 4 amber solutions achieving 0.5% each and 20 solutions achieving 0.2% each.

4 Work Package 6 Results

This section presents the results from Work Package 6. It compares the results of the evaluation across solutions, and it prioritises solutions to be taken forward for route map development in Stage 3.

4.1 Comparison of evaluation of solutions

Table 7 summarises the evaluation of each solution against the assessment criteria set out in Section 2.1 (see Appendix D for the complete evaluation). The following is noted:

- It is expected that Solution 5: Trenchless Solutions, Solution 6: Improved Front-End Design and Planning and Solution 12: HIU Optimisation (3) will have the greatest impact on reduced DHN CAPEX. These solutions each achieve a reduction of between 7% and 11%. These solutions focus on reducing both the civil engineering and HIU costs, which Stage 1 identified as currently the largest components of DHN CAPEX.
- It is expected that Solution 1: Knowledge Management, Research and Training and Solutions 10-12: HIU Optimisation will have greatest impact on reduced DHN OPEX. Solution 1: Knowledge Management, Research and Training achieves OPEX reduction through improved design (e.g. reduced heat loss and pumping energy) as well as regular monitoring and control of operational performance. It needs to be recognised that the project's baseline position is one of good practice. As such it is estimated that up to 5% reduction in OPEX can be reasonably achieved. A 5% reduction in OPEX is expected from Solutions 10-12: HIU Optimisation as a result of lower costs to repair the HIU (easily changed components) and lower cost of HIU replacement during the DHN lifetime.
- The solutions with highest CAPEX potential (Solution 5: Trenchless Solutions, Solution 6: Improved Front End Design and Planning and Solutions 10-12: HIU Optimisation) have a difficulty score of 2 or less, and so should be able to achieve 'proof of concept' and deliver demonstration projects within 5 years, with investment below £5M each. At this point the goal is for solutions to be in a position to demonstrate their future value and attract further investment to reach commercial viability.
- Only three of the solutions are expected to require 'considerable effort' i.e. score of 3 (Solution 9: Shared Civils, Solution 13: Internal Connections and the low-cost heat meter element of Solution 12: HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage). These solutions potentially need more than 5 years and up to £10M investment to prove viability.
- Solutions which are attractive to users and investors and improve certainty of outcomes are those most likely to gain support from the industry. Both Solution 5: Trenchless Solutions and Solution 6: Improved Front End Design and Planning achieve these. Reductions in complexity will further encourage adoption.
- The scope of solution impact shows a wide range from -2 (very limited application) to +2 (applicable to the entire network). Those with limited applicability make little impact on DHN CAPEX. For example, Solution 8: Shared Civil Engineering Costs saves 20%-50% of cost but with limited applicability only 1.4% across the DHN.
- Limited opportunities have been identified for synergies or added UK value other than potential for some increase in UK manufacturing.

	Knowledge Management, Research and Training	Reduced Peak Demand and Peak Flow Rate	District Heating Wall	Loft Space / Cellar Route	Trenchless Solutions	Improved Front-End Design and Planning	Pipe Crossings	Shared Civil Engineering Costs	Direct HIU System & Existing DHW Storage	HIU Optimisation (1): DfMA	HIU Optimisation (2): Further Simplification & Value Engineering	HIU Optimisation (3): Value Engineered Direct HIU & Existing DHW Storage	Pipework & Connections within the Property
SOLUTION NO:	1	2	3	4	5	6	7	8	9	10	11	12	13
DHN CAPEX reduction (%)	3.0%	3.4%*	0.9%	4.9%	10.7%	8.7%	1.9%	1.4%	4.5%	3.4%	5.2%	7.1%	1.8%
Certainty of outcomes	1	0	0	0	2	2	1	-1	-1	0	0	-1	1
DHN OPEX reduction (%)	5.0%	1.2%	-0.3%	0.3%	0.0%	0.0%	0.0%	0.0%	2.4%	5.1%	5.1%	5.1%	0.0%
DHN TOTEX reduction (%)	3.0%	1.1%	0.1%	1.4%	2.7%	2.1%	0.5%	0.4%	3.2%	6.0%	6.4%	6.9%	0.5%
Impact on DHN performance	1	0	1	1	0	0	0	0	0	0	1	1	0
Future flexibility	0	0	0	0	1	0	0	0	0	0	0	0	0
Attractiveness to Users and Investors	2	1	-1	-1	2	2	1	1	1	1	1	1	1
Impact on Complexity	2	-1	0	0	0	2	1	-2	1	2	2	2	0
Impact on HSE	1	0	1	1	2	1	1	1	-1	0	0	1	0
Scope of opportunity	2	2	-1	-1	0	2	0	-2	1	1	1	1	1
Potential for synergies	1	0	0	0	0	0	0	1	0	0	0	0	1
Value for the UK	1	0	-1	-1	0	0	0	1	0	0	0	0	0
Technical feasibility	0	-1	-1	-1	-1	-1	0	-1	0	0	-2	-2	-1
Effort	1	1	1	1	2	1	2	3	0	0	0	1	2
HIU Medium Difficulty										1	2	2	3
New approach to heat meters											3		

* The DHN CAPEX saving for Solution 2 is 4.1%. However, there is additional CAPEX required for installing new TRVs and a reduction in energy centre CAPEX costs from reduced boiler capacity. The net impact of these two elements reduces the overall system capex benefit of Solution 2 to 3.4%.

Table 7: Solution comparison matrix

The approach to solution development was to identify a mix of solutions which, collectively, enable significant savings across the modelled DHN. Some solutions have a very broad scope across all typologies and others, although making a significant impact in specific typologies, are only applicable to a limited proportion of the network. The savings impacts are shown in Table 8.

The table uses colour to show the relative impact of each solution across the seven major elements of DHN cost (five Typologies, Primary Network and Prelims). The final row shows the proportion of total DHN cost that each element represents in the baseline modelled network. Detached and semi-detached property connections account for a significant percentage of total cost and so solutions which do not have an impact in these Typologies become less attractive at the network level.

Each solution has its own impact mix across the Typologies and only Solution 1: Knowledge Management, Research and Training is assumed to have the potential for a fairly level benefit across all areas. Other solutions are characterised as follows:

- Solution 2: Reduced Peak Demand and Peak Flow Rate has the greatest impact on large diameter pipes in the Primary Network and city centre commercial applications.
- Solution 3: District Heating Wall and Solution 4: Loft Space/Cellar Route have a significant saving for terraced properties (some potential for semi-detached), but this limits the overall impact of the solutions.
- The most likely areas for Solution 5: Trenchless Solutions to be successful are in the less dense property connections which are not currently considered viable for DHN connection. This makes the solution a good enabler of wider DHN application. The significantly reduced programme timetable from Trenchless Solutions also has a major impact on Prelims.
- Solution 6: Improved Front-End Design and Planning increases the rate at which traditional open-cut pipe laying is completed. Hence it has a major impact on Prelims and on Typologies where under-ground pipes are a significant proportion of costs.
- Solution 7: Pipe Crossings is very specific to the Primary Network and so even a 20% saving has limited impact at the whole network level. This does not mean the solution is not valuable; rather that it will be network location dependent.
- Solution 8: Shared Civil Engineering can link to both traditional and trenchless pipe-laying. Hence its impact is greatest in typologies C, D and E. It is also significant in city centre locations and this may become increasingly important for Local Authority areas which have particularly high road closure charges.
- The five remaining solutions only influence cost inside domestic properties, although there may be potential for a minor reduction in programme and hence prelims. The percentage impact for HIU cost reduction is greatest for flats where the HIU is the dominant cost, with far less piping cost as most is internal to the building. Internal Connection reductions have the greatest impact on terraced properties (generally because the pipes have to run from front door to kitchen at the rear of the property).

Table 8 is intended to provide a useful reference point for planning the roll-out of solution development and the selection of pilot projects based on local Typologies and geography.

The Dense Village is characterised by a combination of 1 of Typology C (terraced homes) and 0.5 of Typology D (semi-detached homes). Hence the impact of the various solutions on Dense Villages represents this mix of typologies (see Table 8). In particular, the most favourable solutions are as follows:

- Solution 4: Loft Space / Cellar Route - 13% CAPEX saving

  Impact achieved on both terraced and semi-detached properties which gives a greater saving than the baseline network.

- Solution 5: Trenchless Solutions - 6% CAPEX saving

  Impact exclusively on the semi-detached properties and so trenchless solutions have a reduced saving for dense villages.

- Solution 6: Improved Front End Design and Planning - 10% CAPEX saving.

  Impact is highest in terraced properties and above average in semi-detached properties. This equates to a marginally greater saving than for the baseline network.

- Solution 9: Direct HIU System & Existing DHW Storage - 7% CAPEX saving

  Without a city centre impact and primary network piping the HIU cost becomes more dominant and so the direct connection impact is greater for dense villages.

- Solutions 10-12: HIU Optimisation - 11% CAPEX saving

  As for solution 9 the HIU saving has a more significant impact for dense villages.

When tested on specific dense village networks the combined DHN saving will be greater, in percentage terms, than for the baseline network. This needs to be offset by the increased energy centre cost per connection where smaller heat generation plant, buildings and operational costs will be incurred at reduced scale.

	A: Centre	B: Flats	C: Terraces	D: Semis	E: Detached	Primary	Prelims[6]
1. Knowledge Management, Research and Training	3%	3%	3%	3%	3%	3%	3%
2. Reduced Peak Demand and Peak Flow Rate	13%	0%	1%	0%	0%	10%	0%
3. District Heating Wall	0%	0%	13%	0%	0%	0%	0%
4. Loft Space / Cellar Route	0%	0%	17%	10%	2%	0%	0%
5. Trenchless Solutions	0%	0%	0%	14%	16%	0%	37%
6. Improved Front End Design and Planning	8%	1%	12%	8%	9%	3%	38%
7. Pipe Crossings	0%	0%	0%	0%	0%	20%	5%
8. Shared Civil Engineering Costs (New Network Revenues)	2%	1%	2%	2%	2%	1%	0%
9. Direct HIU System & Existing DHW Storage	0%	11%	5%	5%	5%	0%	0%
10. HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)	0%	16%	8%	7%	7%	0%	0%
11. HIU Optimisation (2) Further Simplification & Value Engineering at Scale	0%	18%	8%	7%	7%	0%	0%
12. HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage	0%	24%	11%	10%	9%	0%	0%
13. Internal connections – Pipework & Connections within the Property	0%	5%	6%	2%	2%	0%	0%
Proportion of Model DHN Cost	5%	5%	8%	38%	20%	15%	9%

Table 8: Savings impact by typology and network section

[6] Prelims are costs associated with running a construction project, including site office, safety etc

4.2 Compatible Solution Groups

Table 9 shows a list of the key solutions and their estimated DHN CAPEX savings. Columns titled 1 to 4 show four potential "Compatible Solution Groups" that could sensibly be implemented together.

It is assumed that for all Groups certain solutions are always included. In general there is limited interaction between these and the other solutions. The solutions included in all Groups are:

1. Knowledge Management, Research and Training
7. Reduced Peak Demand and Peak Flow Rate Pipe crossings
12. HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage
13. Internal Connections – Pipework & Connections within the Property

The characteristics of the Compatible Solution Groups vary with the solution chosen to reduce civil engineering costs.

- Group 1: 'Minimum Trench': This Group is based around minimising any excavation by choosing above ground routes within the streets.
- Group 2: 'Improved Civils': This Group is based around reductions in cost to trench excavation in the streets
- Group 3: 'Trenchless': This Group is based around the adoption of trenchless techniques for excavation in the streets.
- Group 4: 'Mix': This is a combination of the above which seeks to provide an optimal mix across the typologies. In particular, it includes Trenchless Solutions for Typologies D and E and the Loft Space / Cellar Route for Typology C.

The table also shows an estimated range in DHN CAPEX savings for each Compatible Solution Group. This is based on the standard statistical approach of taking the square root of the sum of squares of uncertainties of each contributing solution. Hence if a Compatible Solution Group (Y) comprises the sum of savings of two solutions, A and B, which have uncertainties of ΔA and ΔB respectively, then the uncertainty on Y (ΔY) is calculated as follows.

$$\Delta Y = \sqrt{(\Delta A)^2 + (\Delta B)^2}$$

This equation assumes that there is no significant interaction between the uncertainties of the various solutions comprising a Compatible Solution Group. This is deemed a reasonable approximation as the solutions within a Group are generally distinct and target a different part of the DHN CAPEX. Note that for the 'Mix' Group, where the CAPEX savings have been reduced for a solution, the CAPEX sensitivity has been proportionally reduced.

In Table 9, the interactions between solutions have been taken into account by assessing which areas the solutions impact and then offsetting other solutions which impact the same area. For example:

- Solution 9: Direct HIU System and Existing DHW Storage has less impact when combined with Solutions 10 & 11: HIU manufacturing optimisation. The combined impact is quantified in Solution 12.

- For Solution 4: Loft Space/Cellar Route and Solution 13: Internal Connections – Pipework & Connections within the Property solutions there is an interaction (changing the route for internal pipework), but the length change and hence cost impact is limited.
- For Solution 6: Improved Front-End Design and Planning the bulk of benefit is in the planning phase and so does not impact other solutions.
- Solution 1: Knowledge Management, Research and Training is programme based and the impact is reduced with Solution 5: Trenchless Solutions which also have a significant impact from reduced prelims.

	CAPEX savings (sensitivity)	1. Minimum Trench	2. Improved Civils	3. Trenchless	4. Mix	Comments
1. Knowledge Management, Research and Training	3.0% (1.0% to 5.0%)	3.0%	3.0%	3.0%	3.0%	
2. Reduced Peak Demand and Peak Flow Rate	3.4% (2.9% to 3.9%)	3.4%	3.4%	3.4%	3.4%	
3. District Heating Wall	0.9%					Loft Space/Cellar Route solution gives greater benefit
4. Loft Space / Cellar Route	4.9% (3.0% to 6.0%)	4.9%			2.0%	In mix solution, only used for Typology C
5. Trenchless solutions	11% (6% to 18%)			11%	10%	
6. Improved front end design and planning	8.7% (4.6% to 11%)		8.7%		2.0%	In mix solution, only used for Typology C
7. Pipe crossings	1.6% (0.7% to 1.9%)	1.6%	1.6%	1.6%	1.6%	
8. Shared Civil Engineering Costs	1.4% (0.3% to 2.1%)		1.4%	1.4%	1.4%	
9. Direct HIU System & Existing DHW Storage	4.5% (3.5% to 5.5%)					
10. HIU (1) Design for Manufacture and Assembly	3.4% (2.5% to 4.1%)					
11. HIU (2) Further Simplification & Value Engineering at Scale	5.2% (3.3% to 6.9%)					
12. HIU (3) Value Engineered Direct HIU & DHW Storage	7.1% (4.8% to 9.3%)	7.1%	7.1%	7.1%	7.1%	
13. Internal Connections — Pipework & Connections within the Property	1.8% (0.9% to 2.4%)	1.8%	1.8%	1.8%	1.8%	
Total	Central	22%	27%	29%	32%	
	Low	18%	22%	23%	26%	
	High	25%	31%	37%	39%	

Table 9: Families of Solutions

Table 10 summarises the evaluation of each Compatible Solution Group against the assessment criteria. The relative importance of each solution within a Group has been estimated in deriving the rating for each criterion.

	Minimum Trench	Improved Civils	Trenchless	Mix
DHN CAPEX reduction (%)	22%	27%	29%	32%
Certainty of outcomes	-1	1	1	1
Impact on DHN performance	1	0	0	0
Future flexibility	0	0	1	1
Attractiveness to Users and Investors	0	1	1	1
Impact on Complexity	1	2	1	1
Impact on HSE	1	1	2	2
Scope of opportunity	0	2	1	2
Potential for synergies	0	0	0	0
Value for the UK	0	0	0	0
Technical feasibility	-1	-1	-1	-1
Effort	2	2	2	2

Table 10: Compatible Solution Group matrix

The following points underpin assessment of the solution groups in Table 10.

- The lower Certainty of Outcomes for the Minimum Trench (arising from the radical routes solutions) group is offset in the Mixed group because its impact is less crucial when solutions are combined.
- The blending of solutions in the Mixed group combines to maximise the scope and impact: (Trenchless for typologies D & E, minimum trench for typologies A,B & C)
- The significant reduction in the open-cut trenching length (particularly for typologies D and E) has a major impact on Health and Safety.
- All solution groups are set with an effort rating of 2 (Moderate Effort) as a result of a high dependency on the success in reducing the cost of HIUs (solution 12).

4.2.1 Conclusions

The conclusions from this part of the work are as follows:

- Each of the 'green' solutions has been evaluated against a wide range of criteria. The solutions which offer the greatest net benefit are: trenchless technology, front end design and knowledge management. HIU optimisation also offers significant opportunity but will be more challenging to realise.
- The solutions impact differently on each typology and part of the network and so the overall saving through implementing the solutions will vary with the nature of the scheme.
- The solutions have combined in a number of Compatible Groups depending on how the challenge of reducing civil engineering costs was addressed. Across any given network it is likely that a mix of solutions will be optimal, for example: the loft space route is very favourable for terraced housing, trenchless technology is well suited to smaller diameter branches supplying semi-detached and detached houses and improved front end design has its greatest impact with large diameter pipework.

- For the notional scheme, which was chosen to reflect the UK mix of housing in areas where DH networks might be employed, the overall CAPEX saving for a mix of solutions that is deemed optimal is 32% with a range from 27% to 39%. In addition, the remaining amber solutions are estimated to result in a further saving of up to 6%.
- These CAPEX savings compare well with the challenge set by the ETI to reduce the costs of DH networks by 40%. This level of challenge had been identified by the ETI after modelling of a range of low carbon technologies which showed that a 40% reduction in cost would mean that DH could serve 40% of the heat market cost-effectively.
- The Project Team recommends that all of the green solutions are taken forward and that the amber solutions are also kept under review during Stage 3 of the project and beyond. Some amber solutions may have limited applicability but in certain schemes could be valuable.
- The remainder of this section of the report considers which of the green solutions would benefit from a route map being produced as part of Stage 3 of the project.

4.3 Selection of solutions to be route mapped in Stage 3

The next stage in the project is to take the most promising solutions forward by creating route maps for each solution, setting out the barriers, risks, likely development requirements, commercialisation paths, routes to market, investment need and opportunities, etc.

The selection criteria applied are as follows.

- Do the solutions require route maps? This is based on which show most promise as concepts and are likely to have a high impact in reducing DHN CAPEX costs. It also depends on the extent to which the solution is already commercially available or in active development, and the extent to which any route map would be self-evident and thus add little value.
- Is the project team suitably qualified to make progress in defining the route map for development, or would a different team be better placed to do so?

Table 11 highlights which solutions are to be taken forward for route-mapping. Of the 13 ‘green’ solutions reviewed, 11 solutions were selected. Some of the route maps are to be combined as the solutions are closely linked which results in a total of 8 route maps. There will also be a review of whether particular route maps could be taken forward in combination to maximise their benefits to industry.

	Selected for a Stage 3 Route Map?
1. Knowledge Management, Research and Training	Yes
2. Reduced Peak Demand and Peak Flow Rate	Yes
3. District Heating Wall	Yes (combined route map)
4. Loft Space / Cellar Route	
5. Trenchless solutions	Yes
6. Improved front end design and planning	Yes
7. Pipe crossings	No – limited applicability and CAPEX saving
8. Shared Civil Engineering Costs	Yes
9. Direct HIU System & Existing DHW Storage	Yes
10. HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)	Yes (combined route map)
11. HIU Optimisation (2) Further Simplification & Value Engineering at Scale	
12. HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage	
13. Internal Connections – Pipework & Connections Within the Property	No – Saving mainly in terraced properties, with uncertainty due to diverse property internal layouts and décor

Table 11: Solutions to be route mapped in Stage 3

There will be interactions and synergies between the route maps and these will be identified across all solutions during Stage 3. As part of the deliverable (D04) the co-dependencies between solution route maps will be highlighted. However, the intention is not to develop a fully integrated programme, because this may discourage individual solution development. The interactions may point to the value of an integrated demonstration scheme to test multiple solutions simultaneously. Depending on timing, such a scheme could link with ETI’s Smart Systems and Heat programme.

5 Appendix A: List of organisations engaged in Stage 2

A list of the key organisations engaged with in Stage 2 is shown below (several are not included as wished to remain anonymous). In addition, the project team engaged with other specialists within AECOM and Engie. The project team appreciate the time provided by these organisations in supporting this project.

- 3D-Technical Design
- Bristol Water
- Chandler KBS
- CoHeat
- Conroy Group
- CPC Civils
- CPV Ltd
- Elgocell AB
- Guru Systems
- Lendlease
- London Borough of Islington
- National Grid
- National Joint Utilities Group (NJUG)
- OFWAT (Former Director)
- Options Energy Services Ltd
- Orchard Partners London Ltd
- Ormandy Group
- PT Contractors
- Radius Systems
- Rehau
- Severn Trent Water
- Southern Water
- United Kingdom Society for Trenchless Technology (UKSTT)
- Thermal Integration
- Tracto-Technik
- Trent Energy
- United Utilities
- University of Nottingham
- Various trenchless technology providers at "No Dig Live" exhibition
- Various suppliers of options for reducing the cost of backfill

6 Appendix B: Summary Notes of Key Meetings

This Appendix includes summary notes of the following key meetings. These are the views of the attendees and, where appropriate, were considered further in subsequent analysis.

- The initial System Design Architecture Workshop
- The initial Component Design Workshop
- The two ECCR Workshops

Title: Project Team System Design Architecture Workshop

Location: AECOM, Holborn

Date: 20th June 2016

Attendees: David Ross, Paul Woods, Tim Hall, Andrew Cripps, Rob Boyer, St John Ager, Simon Box

1. Type of fluid for heat transport

Early DH schemes used steam supply and condensate return but modern systems have used water. Are there any other options? And what would be the potential benefits?

- Additives to the water to increase the specific heat capacity. This includes micro capsules of phase change materials to transfer more heat in a given volume. Challenges may include problems with pumping, filtration, leakage of a solution that may not be environmentally friendly. It was noted that existing water in DHN is a pollutant - water treatment leads to a highly alkaline solution.
- Heat transmitted as a batch delivery of High Heat Capacity or Phase Change Material which is transported to a local area network or individual homes by road, rail, canal or drone. This has the benefit in reducing/eliminating civil engineering. Could use, say, rail for periods when under-utilised such as at night. It was noted that the highways agency may be concerned with road congestion. It was also noted that it can be difficult to get the heat out of PCMs. (Further discussions of bulk heat batteries further on).

2. Heat production

In the longer term, large-scale heat pumps may be the preferred low-carbon heat source for DH and this has led to the desirability of lower operating temperatures (see later). However as the main alternative will be individual building heat pumps the benefits of DH will become harder to demonstrate as economies of scale and efficiencies of central heat pumps may be outweighed by the cost of distribution and the need for higher temperature operation to keep pipe sizes reasonable. Alternative solutions?

- Circulate the heat source via DH and for each building to have a local water to water heat pump. The benefits of this arrangement are:
  - Compared to local air source heat pumps potentially a higher temperature heat source could be used and less space needed outside, less noise.
  - Compared to conventional DH, much lower network temperatures and so lower heat losses, also less energy to be transported as some energy is supplied via the electricity for the local heat pumps. The temperature difference will be smaller but there is the potential to also use the network as a heat rejection sink from commercial buildings. There was also a discussion around the potential of better utilising roof-space for domestic and non-domestic buildings with solar thermal. The building heat pumps can utilise low temperatures in the building heating circuits so will be more efficient.
  - This is the system used at Kingston Heights with heat pumps not for each dwelling but for groups of dwellings in each block.

  Implications for DH could be:

- Lower temperatures mean that pipes will not need as much insulation or could even be omitted on the return pipe
- Could the gas network be utilised for return water?
- May be limited to where there is an elevated temperature heat source to make the DH worthwhile
- It may be limited to small schemes as the small delta T will make the DH too expensive to transmit energy far
- Glycol mix may be needed to increase delta T by dropping return temperature close to 0’C which may have safety implications in the event of leaks
- Relatively high cost system at the building level for numerous small heat pumps.

3. Peak boilers and storage

Linked to above, there was a discussion around peak boilers and storage.

It was agreed that domestic customers would be unwilling to accept a solution with a delay in delivery. They want to have, for example, hot water when they turn on the shower. They do not wish to wait a significant amount of time before it becomes hot or only use their shower at a specific time which they select in advance. Hence, the capacity needs to be such that it can meet people’s needs when they want it; or there is locally stored heat. (3 options: Capacity, Stock, Leadtime)

Most DH systems use a combination of low carbon plant (CHP or heat pumps) supplemented by peak boilers. The peak boilers are used to supply perhaps 20-30% of the annual heat demand. However to meet the peak demand, their capacity may be significantly greater than the CHP plant (e.g. CHP capacity may only be 30% of peak demand but still meet 70% of the annual heat demand).

- There would be benefits if this peak demand was met by more local boilers in both saving on Energy Centre plant capacity and reducing pipe sizes further as the full peak demand of the dwelling need not be supplied from the DH. As most properties already have gas boilers there could be a fairly low cost in having such a hybrid system. But would it be sustainable in the long term? Could be an easier sell than replacing the gas boiler, at least for the owner-occupier (in rental sector, can be advantage in removing boiler to reduce maintenance access and costs). It could be sustainable if the peak gas use was small and available from biomethane sources (note IGEM conference recently on decarbonising gas supply).
- Top up with heat pump or direct electric heating using the capacity in the electricity network at times of peak heating demand (note: this capacity is very limited)
- It may be possible for a single local boiler to be shared by multiple residents i.e. sharing top-up boiler. Is there spare space? Could one resident be paid for renting out space in house, garage say or paid for supplying heat to the locality? Could this be done on the street, part of a scalable network idea? This is easier to envisage on a block of flats.
- Spreading heat demand by using weather forecast to start heating early so that the peaks do not occur simultaneously and the thermal storage of the buildings themselves is exploited. This may result in a cost saving in the most local parts of the network i.e. at a street level.

There was also a discussion around the better use of thermal storage to help meet peak capacity and reduce overall size of heat generation plant. Where do we put the storage in the network in order to optimise the total system cost?

- Pre-heat the building as a form of thermal store. Or simply allow for the fact that given the heat capacity of a building, having the heating turned down (or possibly off?) for a period of time may not be noticed by the occupants.
- Include storage at a building level. It may be sufficient to have one in a block of flats or one for a group of homes. It may be possible somehow to link into the building structure (probably most feasible for new-build developments).
- Need to link above to the required heat up time for systems. Can the heat-up time be reduced without impacting on customers and reduce need for storage.
- Can Phase Change Material (PCM) be used for storage (There was a discussion that the volume to take water from 40-80C is equivalent to volume of PCM to take roughly from 40-50C).
- (Heat pumps may also need to have some storage to avoid the peaks on the electricity network).
- Potential for inter-seasonal storage.

4. Operating temperatures

A fundamental design issue for any DH system is the selection of operating temperatures.

- Low temperature district heating: The latest research programme within the IEA is developing the concept of 4th generation DH (4GDH), seeing a trend from steam (1GDH), high temperature systems 120C (2GDH), low temperature systems c90C (3GDH) to systems with flow temperatures up to 70C but operating most of the year at around 50C and with very low return temperatures 20C-40C. The driver for 4GDH is particularly to enable the introduction of efficient heat pumps as heat sources for existing heat networks and for new networks serving low density areas where heat losses would otherwise be considered excessive. The disadvantage of 4GDH is that the delta T is smaller than it could be. To maintain the high delta T one solution is to install a micro heat pump working between flow and return which lowers the return temperature at the expense of some electricity use but this can be partially recovered through lower pumping energy and improved heat recovery or heat pump efficiency at the production plant.

- Low flow district heating: There is a countervailing view that 4GDH may make sense for networks that already exist where the lower delta T can be accommodated within the existing networks as these are proving to have spare capacity as the building heat demands are generally falling, but is less suitable for new networks to supply existing buildings in high density areas (as in the UK) where the priority should be to minimise capital costs. This leads to a design which seeks to minimise flow rates (high delta T) using very low return temperatures but retaining flow temperatures at c90C at times of peak demand. The pipes are then as small as possible which saves on materials, reduces trench dimensions and heat losses can be comparable as the smaller pipes have lower heat losses even though the flow temperature is higher. (There was some discussion around potentially going higher than 90C – up to 160-170C previously in Russia and Heathrow – albeit larger heat losses).

- Comments on both low temperature and low flow district heating:
  - In both of the above cases the lowest possible return temperature is envisaged and so this is a clear objective for the overall design of DH.
  - Our baseline design assumes temperatures is 90C/60C and it is quite possible that a shift to 4GDH (say 70C/30C at peak) or a shift to low flow design (say 90C/30C) will both be lower cost than the baseline assumptions. Hence it is possible to take forward both of these system design concepts rather than having these as either/or choices. Our baseline assumes that flow temperatures

are reduced to around 70C in summer with 90C only used in cold weather thus allowing the use of plastic pipes for branches to individual dwellings.

In selection of operating temperatures there are a number of constraints:

a) The temperatures used for existing heating systems and the extent to which these can be modified, or if not then will the cost of installing additional surface area of heat emitters (radiators) be more than offset by the benefits of using lower temperatures
b) The temperature needed to heat domestic hot water (DHW) which is determined both by comfort requirements and legionella risks especially if DHW is stored.

- For both low temperature design and low flow design, the domestic hot water provision proves to be an important aspect and so is discussed separately below. Some possible implications on other aspects of DH design for these system architectures are:
  - Low return temperatures may mean that insulating the return pipe is not necessary
  - Can the gas pipe be used for the return if not required in the future? Would people be willing not to use gas for cooking etc?
  - The low flow strategy means smaller pipes and the potential for greater use of twin pipes (noted up to 200mm diameter standard, with 250 special production, and nothing above).
  - The low temperature strategy means potential for lower operating costs – more efficient heat pumps and lower heat losses
  - Does there need to be different HIU designs for the different options? Would a single HIU design be too inefficient by needing to work for worse case scenario? (It was suggesting that many domestic HIUs used in the UK are designed for a detached house in Denmark and used in a new apartment unit in London – hence not tailored).

5. Domestic hot water production

The most common form of domestic hot water production is the instantaneous heat exchanger as this is seen to benefit from low return temperatures when water is drawn off, low heat losses compared to a hot water cylinder and saving on internal space. It is similar to a gas combi boiler which has proved popular in the UK. This is our baseline design.

There are a number of other options that could be explored within system design or HIU design. There are pros and cons with all of these. Improved performance can be obtained but with the potential also for greater complexity and cost.

- In apartment blocks hot water can be produced centrally and distributed around the building (apartment block, row(s) of houses). This is a common Scandinavian system. It is a 4-pipe system with flow and return for each of space heating and DHW. Could be reduced to 3-pipe with common return.
- A hot water cylinder can be used either with a heating coil within the cylinder or with an external plate heat exchanger
- A primary side heat store can be used in conjunction with an instantaneous heat exchanger
- An instantaneous heat exchanger can be used supplemented by a small store to avoid the need to maintain the heat exchanger in a keep warm condition

The need for individual metering needs to be considered as this is a requirement under the Energy Efficiency Directive and this makes the 4 pipe system less attractive as two meters will be needed.

The main disadvantage of instantaneous heat exchangers is the need to keep the heat exchanger warm so that there is no delay in getting hot water at the taps. This keep warm condition results in a return temperature at about 40C and high heat losses from the local branches to the dwelling. A storage system will in principle result in smaller pipes especially if there is an element of control from the DH company so that peaks can be managed. The local branch pipe can be allowed to cool down when the cylinder is not calling for heat. So this could be a good system for a lower density housing area with long branches.

6. HIU design

The HIU design and cost are partly a function of the type of hot water production but also whether there is an indirect or direct connection. An indirect connection is normally used in the UK and is our baseline design. There are both engineering and contractual reasons why indirect connection is used but it adds a significant cost and complexity to the HIU.

- A direct unit means that the internal heating system needs to be able to operate at the same temperature and pressure as the heat network. Quite common in Scandinavia to use a direct connection e.g. Jutland in Denmark but also the ENGIE scheme in Southampton uses direct connection extensively for commercial buildings. A requirement on the HIU design could be to find ways of addressing the concerns on direct connection so that it can be more widely used e.g. currently in the UK, social landlords do not wish the safety risks associated with direct units (high temperature, potentially high volume of water without adequate isolating valves) and private builders do not like such schemes (e.g. risk of new householder having high volume of water flow during leakage). It may be, at least in some cases, more a perceived than actual risk. May be lower risk at lower operating temperatures. Direct connection helps with keeping return temperatures low, as it avoids the temperature drop across a heat exchanger. Costs are reduced as there are fewer components – no need for secondary pump, control valve, expansion vessel etc
- Another option is a mixing connection which has the same pressure but can deliver a lower temperature to the radiator circuit than the network temperature. This also requires a pump and mixing valve so the saving over indirect connection is not as great.
- There was a discussion around what temperature hot water is needed to be at and whether it can be reduced. Paul reported that below 48C one operator was reporting complaints. Can use thermostatic mixing valves (TMV) to avoid scalding. NHBC say 60C must be provided at kitchen taps, which is a problem as it is not in line with other guidance from the DH industry and the 4GDH concepts. Need to ensure legionella risks are controlled for any of the designs.

7. Pumping

Conventional approach is to have a single set of pumps at the Energy Centre. This can lead to sub-optimal pipe design with too much pressure difference available in some legs which then has to be taken out by DPCVs.

- Would we get a better design with smaller pipes if pumps were distributed perhaps on a street by street basis?
- Would this result in a lower total pressure making direct connection more feasible?
- Where would such distributed pumps be located? Constructing local pumping cubicles similar to BT cabinets may be possible but will be costly especially for power supplies.

8. Routes

The conventional design assumes the DH pipes are buried in the street with branches into each building also buried. Other utilities have generally taken the same approach in the UK although in other countries electricity supplies are frequently above ground. In the UK it is mainly the national grid system and rural electricity supplies that use above ground distribution.

There may be opportunities for DH pipes to be installed above ground. The main disadvantage is visual impact however other low carbon technologies also have visual impact such as solar PV and air source heat pumps (and chimneys!). If the pipe size can be reduced enough then installing pipes on the external walls of buildings could be acceptable.

- The DH wall solves the problem of visual impact by combining the DH pipework with external wall insulation.
- It may be assumed that each dwelling requires a separate branch from the street main but an alternative is to have one branch supplying two houses in the case of semis or 3 or 4 dwellings in the case of terraces.
- Could place pipes within the kerb zone replacing kerb with a purpose made kerb incorporating ducts for pipes.
- There could be other novel routes e.g. loft spaces, external on roofs, rear gardens, front gardens, hanging from poles. May be legal implications i.e. can get approval from local authority for social housing but what about privately owned properties – consent needed for allowing services supplying other properties through their land?
- Could advertise on the pipes to get revenue.
- Need for air venting valves as the pipes go up and down.
- Opportunity to combine sewers with DH, potentially also electricity – a major integrated upgrade facility

9. Pipe location in ground

The preference is for underground apparatus to be in the footpaths (pavements) as cheaper than the road to excavate. There was a discussion around the current NJUG rules for pipe depths in terms of where all the other things are placed (http://www.njug.org.uk/wp-content/uploads/V2-New-Development-Sites-Issue-4-29-10-2013.pdf). Anecdotally, whilst the depths in practice were broadly correct, the lateral location can differ. The implication is that DH needs to be located in the road and at sufficient depth so that the main run and the branches are below the other utilities.

- A possible solution is to install pipes shallower than current (i.e. above typical underground obstacles). However, this can prove a challenge as cable tv typically at 250 mm. Also concerns from utilities that DHN is placed on top of in terms of maintenance etc – may need to pay to move existing utilities.
- Suggestion that better to have depth than breadth. Key cost is digging the blacktop and reinstatement. Hence better to have pipes one above each other rather than side-by-side.

10. Other ideas

- Do we need a return pipe? Why not pass water through the system and back in the river afterwards or some other use? Suggested that some shopping centres do this for cooling.
- Can cascade down temperature i.e. take return from high temp loop to supply low temp loop

- Heat nodes and transport using a bulk heat battery (see PCM earlier) through routes which are under-used like rail network, river, canals. Could be at a huge scale – e.g. heat from Hinckley Point.
- Taking heat out of train / tube tunnels
- Use Crossrail and other underground caverns as heat stores (avoid London centric solutions)
- Could we use fibre optic to distribute heat instead?? Heat driven laser…
- Split return pipe into 4 that sit around a central supply pipe. Return pipes externally will reduce supply heat loss. Multiple chambers are easier to manufacture than a torus – also gives an opportunity for simpler branch connections. Multiple return flows give an option for balancing return heat paths depending on the connection point (unclear whether this has a network value).
- (Need to take care with solutions to share network installation and revenues as heat pollution from DHN could impact on e.g. telecoms and cold water (increase legionella risk)).
- (It was noted that horizontally drilling does not go always in the right direction. Also noted that GPR is not that accurate – need to have existing records to help decipher what is seen by GPR and need to back-up by trial holes)

Title: Project Team Component Design Workshop

Location: AECOM, Holborn

Date: 4th July 2016

Attendees: David Ross, Paul Woods, Simon Box, Rob Boyer, St John Ager

Part 1 – Civil Engineering

1. Providing better information on the complexity of existing services

Background

Pre-insulated DH pipes are relatively large in terms of buried services and currently two pipes are needed. Other utilities have already made use of much of the road and pavements and in a typical street layout will also have services to buildings running perpendicular to the main run. As a result new DH pipework often has to be laid below these service crossings at considerable depth. The ideal depth of c600mm cover to the top of the pipe is rarely achieved.

Although the costs of civil engineering are very dependent on the route and depth of trench often, due to the way the design and construction process is tendered, there is limited survey work carried out in advance and limited opportunity to excavate trial holes. Often existing services record drawings are insufficiently accurate to provide confidence in the route selected.

The CDM Regulations 2015 imply that such investigation works should be carried out early as part of the preparation of Pre Construction Information. Or the Client must allow the designer/contractor sufficient time and resource to do so instead. To not fully explore the existence of existing services may be a contravention of the Regulations.

Tenders are often priced on limited information and a key assumption is the rate of trench excavation which tends to be a matter of judgement rather than specific design.

When work commences without detailed information on other services, progress can be slow and some abortive time may be incurred.

Hence any techniques which enable better information on the location of existing services together with the use of advanced design techniques using 3-D modelling are likely to result in both cost reductions as lower risk margins will be applied and greater certainty of outcomes.

Much DH work has been carried out in city centre areas where services are most congested. It is possible that in lower density areas the same cost base may be inappropriate and lower costs can be predicted for these areas.

Discussion
The National Joint Utilities Group (NJUG) Volume 1 GUIDELINES ON THE POSITIONING AND COLOUR CODING OF UNDERGROUND UTILITIES' APPARATUS (2013) provides guidance on the position and depth of different utilities.

The Guidelines do not implicitly state a minimum depth of cover but requires that 'Installers of district heating should consider the location, spacing and depth of cover to avoid potential conflict with other existing underground apparatus'. And before DH is laid contact must be made with all appropriate existing apparatus owners.

As other utilities companies will be unlikely to agree to waive their reserved space down to a depth of minimum 1.2m in both footways and carriageways, in all likelihood DH pipework shall need to be deeper. Where other utilities exist, it will not be practicable to install within the footway.

- The NJUG guidance is helpful in understanding where utilities are located. However, the guidance is only relevant to newly installed utilities – existing utilities may not follow these recommendations although generally electricity and communications ducts are found in the pavements and water services will be at a greater depth to ensure pipes do not freeze. Gas pipes often found below pavements as well.
- Each utility company has records made in accordance with the requirements of the New Roads and Street Works Act 1991, Section 79. Data is stored in accordance with the Street Works (Records) (England) Regulations 2002. Records are normally only supplied in 2D plan drawing format and are issued with disclaimers regarding accuracy – hence they are informative but cannot be relied upon.
- The poor accuracy of records is an issue that would benefit from investment and improvement. Recent government mandates and new standards requiring the adoption of Building Information Modelling (BIM) will improve the future recording of new services, but will not necessary improve the traceability of the huge number of existing services.
- Each utility company (Statutory undertaker) keeps its own records and does not record other operator's apparatus when encountered. One solution is to build-up central records over time as underground apparatus is installed. So in 50-100 years may be very helpful as central database gets better but not immediately.
- St John took us through a typical process from his experience of civil engineering (not necessarily DH)
  - The designer obtains ordinance survey mapping for the works area – this typically shows roads, legal boundaries and buildings etc.
  - The designer obtains utility company records from each provider – these show services routes but with poor accuracy/reliability
  - The designer manually transcribes the individual utility company records into a combined utilities drawing or CAD model.
  - Where possible the designer arranges for the utility companies to mark the location of the services on the site and ensures that the locations are recorded. (Eg BT dial before you dig service).
  - If there are known to be significant number of potential services in the area under consideration, then an accurate topological survey is often required to record all surface covers, manholes, chambers and the like. Topographical surveys provide much greater accuracy than the OS mapping and provide accurate 3D locations of the existing ground levels.
  - Further to the receipt of the topographical survey the designer ensures that a further site inspection is carried out to look at and positively identity the different apparatus found e.g. BT pits, trench scars, man-hole covers etc– this helps better correlate the utilities locations shown for each service on the company records with identifiable features on the ground. After this exercise the designer updates the combined utilities drawing or CAD model.
  - The designer then arranges for Ground Penetrating Radar Survey (GPRS) – The surveyors need good information on the likely services present to be able to satisfactorily interpret the data (i.e. if starting from scratch without a reasonable understanding of services routes, get poor results out). Essentially GPRS is being use to validate or amend expected knowledge of routes.
  - Upon receipt of the GPRS data the designer again updates the combined utilities drawing or CAD model.

- As a final stage, the designer arranges for slit trenches across carriageway, or specific trail excavations to confirm knowledge is correct.

- The above process is necessarily iterative and relies on the experience of both the designer and GPRS operators. Many subjective decisions are required to be made to produce the combined utilities drawing or CAD model. And often the service records obtained from the utility company may be proven to be incorrect.
- Normally this process ensures a combined utilities drawing to around 90% accuracy. However, upon excavation, it is still possible to find an unmarked pipe unconnected to any of the utility drawings.
- Ideally GPRS is undertaken before any route is agreed – it should be brought forward to initial design i.e. pre-tender. This needs to be done for the whole route and, indeed, all alternative routes considered at design stage. No central records currently as commercially sensitive i.e. someone has gone to the expense of determining underground services routes and does not see benefit of sharing knowledge gained.
- It was noted that there are no records of what is in front gardens as this is people’s own property and not subject to Public Highway requirements (which cover public footpaths and roads etc). Need to hand dig as unsure where things are.
- Services using small bore plastic piping will be difficult to see by survey tools, e.g. GPR, and cannot be traced by other below ground locating techniques.

2. Process improvements

Background

One of the weaknesses in the current process is that contractors are asked to price projects on limited information. This tends to lead to higher costs. The reason for limited information being available at time of tender is that the decision of when the project proceeds may itself be dependent on the cost of the network and so any work carried out pre-tender is at risk and is generally restricted as a result. If a more comprehensive DH programme was initiated then projects would have greater certainty of proceeding and more design time would be justified. This might involve producing a 3-D model of all existing services, verified by ground penetrating radar, trial holes and other techniques so that an optimised route can be selected. This may involve a different longer route than might be considered initially but that would still be cheaper overall.

This upfront design work would need to be carried out by specialists who are familiar with the installation of DH. At present this experience rests mostly with the contractors. Hence involvement of the contractors in this design process will be of value. Or the contractor needs to be appointed competitively on the basis of a bill of quantities against which the work will be re-measured so that there is the opportunity to involve a contractor at the earliest possible stage. This approach would not provide an incentive to design to reduce costs though so a combination of a re-measurement against rates with a lump sum profit may be appropriate (a similar methodology was adopted for the construction of Heathrow Terminal 5 where contractors and designers were appointed at the start of the project).

Discussion

- It was noted that contractors are sometimes employed in two stages. There is a smaller initial contractor to help support the design. There is then a subsequent larger contract for the civil engineering works. There is a risk in this approach in that the initial contractor is assumed to be best placed to win the latter work and others then do not tender i.e. it is not a competitive process. Possibly multiple contractors could be involved at an early stage. Or, as per the Heathrow example, there is an

incentive for the contractor to keep cost low e.g. the contractor is part of a joint venture where they benefit from the overall profit of the scheme.
- More generally, it was suggested that (similar to Denmark, say) processes are standardised and roles and responsibilities of different people involved are clear.

3. Re-use of excavation material for backfill

Background

The current approach is to excavate the trench and remove all excavated material which is disposed in landfill. The backfill around the pipes is typically imported sand and the rest of the excavation is backfilled with graded fill suitable for road construction. This involves significant cost especially in central London as suitable landfill sites are some distance away and transport costs are high.

One of the benefits of the above approach to the local area is that there is no excavated material or backfill stored on site.

On many major construction sites there has been a drive to minimise the amount of material sent to landfill by sorting material produced on site e.g. from demolition works.

Studies have shown that the pre-insulated pipe material is unlikely to be affected by the reuse of excavated material provided there is a measure of processing, i.e. removing large stones, bricks etc.

The main difficulty is the need to process excavated material on a typical street based site where there is limited space, but some specialised machinery could be the answer.

Discussion

- It is normal when undertaking civil engineering for sewers to re-use backfill - so not new.
- Logistically it can be a challenge – where to locate the excavated material before re-use for backfill. The soil could be used for another construction project (AECOM previously run [may still do] a brokering service between people who wished to get rid of waste from construction and those that required it). Or possibly could do as a conveyor process – if sufficient length of trench open, can be excavating from one part and backfilling in another.

4. Shallow burial

Background

Conventional design requires DH pipes to be buried at a minimum depth of c600mm to avoid excessive force from traffic on the pipes. This typically means installation at much greater depth to avoid existing services and this in turn leads to higher costs for excavation, disposal of materials, import of backfill materials, trench shoring, supporting of existing services etc. These costs would be reduced if the pipes could be buried within the thickness of the road sub-base i.e. in the range 200mm-400mm cover. To achieve this may require a stronger pipe material or the use of a structure that spreads the load around the pipes. This could be in the form of a duct with the pipe pulled through afterwards.

Discussion

- Need to take care to avoid “reflective cracking” or humps appearing over time. Perhaps change shape to minimise risk of cracking. Agreed the need to create stronger pipe or strong box around the pipe.
- Could use a different road material to inhibit cracking/hump. For example could concrete road – but more expensive to build and maintain. Also cannot have two materials adjacent (e.g. concrete and roads with normal material) as it results in cracking.
- The Highway Authorities are likely to object to any change in current practice regarding the form of construction of road or footway pavements.

5. Micro-tunnelling

Background

Micro-tunnelling is an established technique for installing services in constrained locations where an open trench is not feasible is the use of micro-tunnelling machines. The general view in the DH industry is that the equipment hire is not justified except in special circumstances. Could it be used more widely?

Discussion

- Perhaps the costs would be lower if the machinery could be used at a much higher utilisation rate that might be the case with widespread adoption of DH. Need to understand the components of price better.
- Given the concern around underground obstacles, could micro-tunnelling go down 2-3m as unlikely to be any obstacles there? It would be assumed that depth is less of a cost penalty for micro-tunnelling compared to trench digging.
- Still have the issue of knowing the presence of underground services. At the front of the machine could have a radar to check that nothing is in front.
- It was noted that micro-tunnelling does not go in a straight line – would need to look to improve this if delivering long lengths.
- Could add 3D printer to produce pipe materials at the same time as tunnelling.

6. Co-ordination with other street works

- At present there is limited co-ordination of work on buried services either with other utilities or with general road maintenance. This is due to the relatively ad-hoc nature of both utility repairs and road maintenance.
- If DH was to be introduced at large scale across a given city there would be the opportunity to plan this such that road surfacing works followed closely after the DH pipe installation. This could lead to significant cost savings as the DH contractor could make a cheaper temporary reinstatement.

7. Speed of construction

- Much of the cost of the civil engineering work is related to the speed of excavation (labour cost, plant cost). So any innovation which increases the rate of work on site is likely to result in cost savings in civil engineering.
- The use of pre-fabricated pipework & fittings would reduce the overall site time and beneficial for civil engineering costs.

- Another option could be to move to 24 hour work. It reduces time. It would increase labour cost (unsociable hours) but would reduce plant cost. Highways agency may like 24-hr working and place less onerous terms.

8. Alternative routes

- Could use the gas routes if not needed in the future. Excavate where the gas route is. Shallower dig (than 1.2m) and less chance of other services being located in the same place as space is usually provided around gas pipes. Typical gas pipe is 63-200mm – so could not get both the flow and return pipes down the existing pipework (only one).
- Use the space typically taken up the kerb and its concrete support. The concept is to excavate and remove the existing kerb and replace with a specially cast kerb containing ducts where DH pipes can be pulled through. Could potentially be a problem with kerb-dropping at various places and circuits for traffic lights located within existing kerbs. Needs to be larger than existing kerbs to install pipes. A further alternative could be to place another utility in the kerb (e.g. media cables which have smaller dimensions) and re-use their space for DH pipes.
- There was a discussion around using the loft space to pass pipes through in homes. Most suitable for smaller lofts i.e. those which are not suitable to convert to loft rooms. On semis there would be a pipe bridge between the lofts. Another option discussed was locating the pipework below the eaves. Would it be a visual problem?
- There was a discussion around using 1 pipe solution. Flow and return pipes to the group of housing. However only a single flow pipe going down the street around the housing itself. Previously this solution has been delivered for radiator circuits but has not been effective. However, with digitally controlled HIUs, say, can control the system such that each house gets sufficient heat input and it does not result in the need to oversize the system or that the houses at the end of the route get inadequate heat input.

Part 2 – Hydraulic Interface Unit

The fundamental functions that the HIU provides
The HIU typically provides the following functionality (assuming indirect connection). These may be achieved by direct acting mechanical controls or by electronic controls – the latter providing increased sophistication.

- Transfer of heat to a space heating circuit via a heat exchanger and its control valve
- Transfer of heat to a hot water circuit via a separate heat exchanger and its control valve
- Limiting maximum primary flow rate through use of a differential pressure control valve (DPCV) or a pressure independent control valve (PICV)
- Secondary pump for space heating circuit
- Heat meter
- Isolation valves

9. Direct connection HIU

- Use of a direct connection where the DH water flows through the building space heating system results in a simpler interface saving costs.
- The current challenge is one of perception – a leakage in the home could in theory result in all of the water from the DH network pouring into the one property. This can be addressed through education to address perception of risk and, if necessary, additional technical safeguards.

10. 4-pipe system

- An alternative network design more typically used in apartment blocks, but could in principle be used for other groupings of homes (Cowi previously highlighted widespread use in Denmark). The hot water is generated for the block and distributed by a flow and return hot water circuit with the space heating provided by a separate flow and return circuit, typically with direct connection to each dwelling. This potentially saves significant cost as it reduces the number of HIUs required. The exception is the regulated need for heat meter for each property - which is more complex in this design as a separate volume meter is needed for the hot water (i.e. 2 meters per property rather than 1). There is also additional cost for a 4-pipe system rather than the 2-pipes needed for a system with HIUs in each dwelling. There is also the cost for the central hot water production plant.
- An advantage of the 4-pipe system is that you can use weather compensation on the space heating circuit so that you need only supply at quite low temperature most of the year which reduces heat losses within the block. Furthermore, the space heating can be turned off entirely at times reducing heat losses further. In contrast, with a 2-pipe system it is necessary to keep the system running 24/7 in case someone wants to take a shower at any time of day or night.
- Could potentially turn it into a 3 pipe solution – share return for space heating and DHW.

11. Hot water store

- A hot water store shared between multiple dwellings avoids the need for a DHW heat exchanger for each dwelling and its control valve and potentially reduces the flow rate required in the local branch. These savings are offset by the cost of the storage cylinder and any cost for the space of this store. This hot water store could be located for, say, a block of flats on each floor supplying all of the flats on that floor.

12. Diversity and Demand response

- Diversity factors are used to estimate peak network design – both for DHW and space heating. More impact on peak network design on new-build as limited amount of space heating and DHW more dominant and subject to time-variable household demand.
- Could operate demand response whereby at times of peak demand, as a network of properties, heating can be reduced to space heating to meet DHW demand (i.e. hot water priority). Again this helps limit peak network design.

13. Volume production and standardisation

- The high cost of HIUs, compared to say individual gas boilers, is expected (to be confirmed) to be largely a result of the limited volume of production and this would change if there was more widespread take-up of DH. Major cost reductions were realised in solar PV technology largely as a result of mass production to meet global markets.
- Higher volumes of production of the same product could be delivered even in the current market if there was more standardisation of products. It is noted that there may still need to be differences between international markets to reflect different usage/social patterns.
- It was noted that currently the UK imports HIUs from Denmark which are designed for detached homes in Denmark and then used in flats in the UK. Good equipment but not engineered for the actual heating loads in the UK.

14. Heat metering

- There has been a recent requirement for a heat meter for each property. Providing an individual dwelling heat meter has a significant initial cost and ongoing costs for individual meter reading and billing. As the cost of producing heat is relatively low for DH the benefits realised from reduced consumption as a result of household response to meter readings are expected to be limited.
- Metering on a block or street level and then sharing the costs by means of a fixed charge related to floor area and occupancy could be a lower cost solution overall even if consumption is higher. This is particularly appropriate in apartment blocks where space heating demand could be limited using the four-pipe system (the 4-pipe system allows for weather compensation hence the space heating delivered can be centrally controlled – this reduces the risk of people using excessive heat because they are not metered) and where heat demand may vary with the position of the flat in the block (i.e. a fairer solution would be for the charge to be independent of factors such as the intrinsic energy efficiency of the flat due to its location in the block).
- A further option is to use volumetric metering rather than heat metering which reduces the cost. Volumetric metering also encourages people to take as much heat out of a given volume of water as possible i.e. lowering the return temperature. The same amount of heat is used but with less volume of water which helps the network. The heat meter will be more accurate but if the flow temperature is kept constant and return temperatures are all low (around 30C) then the volume will be closely related to energy take anyway.
- Use a positive displacement pump instead of a separate heat meter. The pump combines pressure control, isolation valve and heat meter (i.e. 3 key functions of a HIU in one). Known as the Orchometer and proposed by William Orchard.

15. Other

- Traditionally, HIU internal pipework was insulated. Now people are looking to insulate the whole HIU cover instead.
- People use copper/stainless steel for HIU pipework. Alternatives?
- Could use hot water store integrated with external plate heat exchanger. Called an Exergenious and proposed by W Orchard. Results in good OPEX because low return temperatures achieved and so lower heat losses. Additional CAPEX for the hot water cylinder – although the heat exchanger is smaller you still need a heat exchanger, control valve and circulating pump.
- Use of two separate HIUs - heat meter, isolation valves, DPCV in external meter box, hot water production near bathroom. May be lower CAPEX as less disruption from installation inside the property to décor, kitchen fittings etc, but higher CAPEX as two parts need to be made and handled.

Part 3 – Pipes and Connections

16. Materials

- Use of plastic materials has cost advantages for appropriate temp and pressure
- At lower network temperatures could consider Glass Reinforced Epoxy (GRE) pipes - have long life and robust.
- At lower network temperatures could consider braided hose – albeit friction losses in practice could be a problem due to kinks in hose
- There was a discussion that if using micro-tunnelling, could earth be fused in some way to act as a sealed pipe

17. Use of twin pipe

- Option discussed at the System Design Architecture workshop. Impacts more on civils costs

18. Pre-fabricated tees – especially with plastic pipe

- Pipework including connections can be pre-fabricated, rolled-up and ready to install as one unit on-site.
- Would reduce the overall site time and beneficial for civil engineering costs.
- Hot tap concept for t-s on buildings. The concept is that you make the tees on site by drilling a hole into the main pipe wherever required. This could be cheaper in some circumstances but site work is generally more costly so unsure what the balance is. Normally hot taps are considered less reliable than factory made tees. However, necessary when adding a connection to an existing network where you can do the work without a shutdown (hence hot tap).

19. Mechanical joints – avoidance of welding

- It was noted that it can take an hour for each weld to deliver the quality required. For a flow and return pipe, this results in 2 welds. For t-junctions it results in 6 welds per T (for 3 sets of flows and returns) plus temporary support for pipework within the trench being provided (sand bags or the like).
- For lower temperature networks can use plastic pipes with push fittings. Could use standard water pipes or gas pipes.
- Non-welding of steel pipes e.g. http://www.victaulic.com or go back to flanges.

20. Heat loss and insulation

- As an estimate, it was suggested that heat losses for new build are around 35% for the DH network of which 10% is from the main underground pipework and 25% between connection to the building and the HIU (including associated fixtures and fittings). Designs should go for more risers and less laterals to reduce the length of pipework. Furthermore, where possible, use smaller diameter pipes where possible. Losses will be lower as a percentage for existing buildings but will depend on heat density.

21. Above ground construction

- Leave trench open for longer which allows welding etc to be done above ground. This reduces cost (e.g. save need to excavate space for welding to take place in the trench, needs to be dry for welding to take place and may not take place on wet days). Then drop down welded pipe in trench.
- However, Local Authority limits the amount of trench that can be open at one time.
- Also challenge to thread between underground services present.

22. Asymmetric pipe sizing

- A more efficient system would be to use smaller pipes for the flow pipe to limit heat losses and compensate this with a larger return pipe whilst achieving the same overall pressure drop. It is not clear how this might impact on capital costs but there would be an OPEX saving.

23. Return pipe uninsulated

- If return temperatures could be consistently reduced to c20C then there would be a case for a system that did not insulate the return pipe at all and this could result in a new design concept. One possibility might be to use the gas pipe for the return water assuming that the gas network would become redundant in the future.

General

- Suggestion that the industry needs to be better educated especially designers who tend to oversize and commissioning engineers who tend to concentrate on maximising heat output not reducing return temperatures. Business rates on DH (say from the GLA) should be used to fund a skills academy. Business rates are much higher for DH than for the gas network.

Title: ECCR Workshop (civils, pipes, internal connections)

Location: AECOM, Holborn

Date: 21st September 2016

Attendees: David Ross (AECOM), Andrew Cripps (AECOM), Rob Boyer (AECOM), Simon Box (Total Flow), Paul Woods (Engie), Andy Simms (Engie), Mervyn Chapman (CPC Civils), Craig Groberty (3D Technical Design Ltd)

Introduction

These minutes record the proposals suggested and other key comments to reduce the cost of civil engineering, pipes and connections, and internal pipework in buildings.

These minutes also record post-meeting categorisation of the effort and reward in implementing the solutions.

- Impact – a measure of the overall CAPEX savings to heat networks in the UK. A higher level of impact is most attractive
- Effort – a measure of the level of resources (time, money) to bring about the solution to commercial deployment. A lower level of effort is most attractive. Note that many of the solutions requiring stakeholder engagement are classed as high effort as we are considering solutions to be implemented across the UK rather than an individual scheme e.g. if solutions require planning officers buy-in, we are considering the effort to obtain wide-scale buy-in.

High Impact, Low Effort

- At some point in the future, follow line of abandoned gas network. Should be relatively free of obstacles and lower depth.
- UK stock of pipes
  - Could manufacture in the UK but cheaper to important from Eastern Europe with lower labour cost
  - Could stock in the UK. Reduce time lost waiting for pipes for unplanned route changes. Also could reduce compound size with Just-in-Time deliveries. More cost-effective with volume – what scale would be viable?
- Should feed the outcome back to the start of the process to enable learning. It was noted that in Denmark there is much more a culture of sharing and learning.
- A number of ideas were highlighted that not all schemes adopt today but are treated as good practice in this project
  - Cost of labour in London is high. Some contractors transport in labour from other regions where day-rates are cheaper (e.g. Wales). Even accounting for transport and accommodation, still cheaper.
  - Intelligent design of number of bell-holes (space to weld around). Realistic assumptions.
  - Wireless heat meters – save on wiring.
  - Minimise the total length of pipework installed in apartment buildings. Where feasible avoid long runs of lateral pipework in unventilated corridors, by increasing the number of risers. Fewer larger pipes provide less heat gain than a greater number of smaller pipes.
  - Client specifies outcomes – leaves network developer/contractor to specify best solution.

High Impact, Medium Effort

- For many of the DH practitioners in the meeting, improved up-front design was seen as the solution that would deliver the greatest reward. The common approach in the DH industry is for contractors to be employed to design and build the network. The contractor is provided with an outline design based on limited survey information to determine their fee. Based on this limited information, the contractor needs to provide a price and include risk to account for uncertainty e.g. presence of underground services. If a better design is provided by the client up-front based on more comprehensive and accurate survey information, the risk to the contractor and the fee would be reduced. Furthermore, a more cost-optimum route may be identified at the start and the project more cost-effectively managed i.e. less surprises. The view in the room was that the additional design cost upfront would result in a significantly greater reduction in contractor fee.
- Solutions for better up-front design included the following which are relatively straightforward to implement
- Ensuring the client has the necessary expertise to carry out a more detailed design. This could include expertise in-house or a specialist third-party (which could include contractors who undertake DH civils and thus perhaps best understand the design information necessary to inform a subsequent tendering process)
    - Utilising PAS128 Specification for Underground utility detection, verification and location (desktop study, site survey, GPR focussed areas, trial holes in focussed areas)
    - [Also discussed use of 3D scanning and ideally if scanning provide greater certainty/reassurance in future could eliminate trial holes. This links also to involving a framework contractor in develop the design. Also the concept of simultaneous engineering i.e. designing with a cross-functional/organisation team, with the design prepared DFM (design for manufacturing)]
- The reason for medium effort is the need to also address the wider context as to why greater upfront design does not currently happen. A key reason is that the detailed design costs 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, for example by local planning authorities. Solutions suggested to help address these issues included the following.
    - Regulating the district heating industry
    - Requiring more detailed design, including following PAS128, at the start of the project.
    - Wider-scale take-up of district heating
- It was noted that there are alternative approaches to contracting. In particular, the two main forms of contracting were as follows.
    - Fixed price: The contractor provides a fixed price and takes on all of the risk. The fee will be higher to account for the risks but the developer has cost certainty.
    - Variable price: Here the contractor provides a base price based on design information provided. Contract variations are agreed where actual conditions differ from the outline design
- Improved design information would help in both cases. However, in particular, it should reduce fixed fee as there the element of risk is a higher proportion of the fee.
- Look to keep digging – rather than all stopping for lunch etc (i.e. the digging is the slowest part – the bottleneck – so keep working all of the time). Could have rotating crew. To be cost-effective, likely need to align with larger works.
- More generally, linked to above, can be benefits where possible to have multiple excavations happening in parallel on-site as takes the longest time. Pipe-laying and welding etc is quicker and can shuttle from one part of excavation to another.

- Put pipes above ground where possible. This could include going through rather than around buildings (even if not connected to network). Could make payment to building owner for use of their space if cost-effective to do so.
- Take pipe out of road and put into verges – soft dig.
- Look to apply moling (tunnel and pull pipe through). It was suggested that for a water pipe of 150mm diameter, the cost is £150 per meter. Diameter would be expected to be larger for DH. Would likely need still to dig branches from pipes in road to buildings. Challenge again around services. Could mole deeper and would need to weigh against deeper excavation trenches for branches.
- Avoid overspecifying. In particular for heat load and HIU size. Specify for the real heat load. Need to be confident of real heat loss and address risk of legal action for under-specifying e.g. have code of practice people can follow, appropriate training, study tours. Have an association for operators to learn from one another.
- A number of pipe-related solutions
  - Buy lengths from Europe (possibly via UK stockist for overnight delivery – as per earlier solution). Call off welded junctions overnight for delivery to site next morning. Alternatively could create t-junction on-site – need sufficient expertise on site.
  - Pre-fabricate pipe connections beside the road whilst digging. Drop in when ready. This will reduce time and size of trench. If time free when waiting for civils, can go between multiple excavations if on same time. Likely to be more relevant when linked with other ideas e.g. high temperature plastic solutions and reduced pipe diameter. May need to enter trench to get around obstacles. If civils team could unroll the pipe and join – avoid the need to welders and insulation joiners and remove skills for joints.
  - Use more flexible steel pipe or high temperature plastic on a roll.
- Place HIU outside of the dwelling – reduce internal pipe connections & easier for access for maintenance
- National register of all surveys below ground.
  - Who owns / who pays?
  - Could be pay per use.
  - Regulated for?
  - Google below ground.
  - May need higher-volume for market to take-up?

High Impact, High Effort

- There would be significant benefits if there was greater co-ordination of works at a local authority / city level. However, this is rated as high effort as it would need wide buy-in across cities in the UK to deliver the benefits to UK as a whole, albeit may be able to commence with one LA and it benefits demonstrated and grow from there.
  - Through implementing larger-scale networks, could better ensure higher utilisation and lower costs for staff e.g. if bottleneck on one job could support another job.
  - Through co-ordinating contracting of multiple utilities in different locations in a city, a contractor could work on multiple jobs at the same time (e.g. DH and water) and move staff between sites as bottlenecks occur etc.
  - Through co-ordinating multiple utilities in the same location in a city, it would avoid digging up the road multiple times.
- The current culture of contractors is to accommodate the highways agencies and obtain approval to the highways agencies terms. If possible, a better approach would get highways agencies to consider the cost impact of alternative traffic management options and agree pragmatic work around. For example, there would be significant benefits in closing the complete road and being able to excavate along the length at

one time (or more generally, increasing the length of trench that can be opened should enable cost savings). Hence, could better employ staff. For example, a welder's cost may be relatively high if not needed for the day (would need to allow for transport to another job if there is one sufficiently local). However, if multiple civils crews working in tandem on different parts of the road, should be able to attend when a full day's work. This could also significantly reduce pre-lims as work can be completed quicker.

- Reduce temperature of the system. This affords the use of flexible plastic pipework instead of metal pipes. Potentially less insulation at lower temperatures.
- Create framework whereby DH installation has authority to divert other utilities if cheaper than going around it. Issues here around other utilities acceptance and risk.
- Trenching machine with intelligence to know what is below ground. Make intelligent decisions as you go. This could include, for example, sensor in the bucket.
- Shallower trench through using base/sub-base. Need to spend more on protecting DH piping. Save considerable amounts from shallower dig.
- Plastic pipe that comes flat and only inflates when in place and filled with water. Enables longer roll and easier to lay.
- Steel pipe solutions with no welds e.g. vitriolic which is a mechanical joint. Current concerns that joints could be a week point e.g. more susceptible to expansion than welds. Due to general concerns of risk would need proven research of lifetime of joint.
- Able to obtain emergency sections of pipe quicker than special order from abroad
    - Make emergency sections of pipe on site as needed e.g. in compound. Would need appropriate expertise (or equipment to de-skill).
    - UK stockist. Could be made off-site at stockist. Alternatively standardisation assists stock requirements.
- In general, greater standardisation through industry
    - Of components e.g. standard bends, standard fittings. Reduce cost of components and time for familiarity. Also standardise any pipe joint system used in future – pick and mix manufacturers components.
    - Of process. Reduces time as repeat similar activities. This also includes rarer events which could stop process whilst resolved. Get pre-approval (client, local council etc) should certain standardised issues occur to avoid time wasted.
- Regulate minimum performance. The Code of Practice is currently voluntary.
- Eliminate/substitute expansion loops.
    - Previously used bellows but excessive failures. Alternative designs?
    - Pre-heat system to avoid expansion joints – done before welding.
- Better planning for reinstatement. Full width reinstatement by combining with other plans e.g. bring forward council plans to re-lay road surface.
- Machine to dig, lay pipe, process material, reinstate.

Medium Impact, Low Effort

- The typical approach in the UK is to tender separately for each DH project. Frameworks with call-off contracts can reduce the cost of bidding for both the client and contractor. Note that due to the variation in works between locations, it may not be possibly to agree fixed day-rates etc.
- In some cases, the depth may be deeper than actually required to accommodate potential future connections. Look to reduce where possible now e.g. different zones at different depths.
- Currently there are several weeks at the start of the programme for traffic management plan. Could be undertaken earlier and reduce time
- Using redundant pipework, e.g. gas pipes, where possible. Use route. Use mains bursting.

- Service level agreement for pipe delivery etc (some may already happen).

Medium Impact, Medium Effort

- Typically the current process is for excavating a length of trench before laying the pipe etc. An alternative is for continuous operation where you slowly roll along doing all processes (excavation to reinstatement) as you go along. This could allow all staff to be continually involved and less issues around traffic management etc. It is dependent on the use of coiled pipe to be rolled out as go along – probably plastic. Need to address potential regular service obstacles and relatively slow speed of civils (Note also the idea elsewhere of a machine that would drive along the route slowly, digging trench, dropping pipe and then backfilling).
- Vacuum excavators are used around services to remove earth. Work can progress quicker if faster i.e. removes soil at higher rate (and cheaper). Also looks at ways to run continuously rather than need to stop to move earth collected e.g. suck into a dumper. Vacuum excavators also need to be quieter – some civils teams are not using them because the noise is too high and it disturbs people working in offices along the route. Innovation needed – faster and quieter machines.
- Reduce the number of welds if know location of obstacles. For example, could use longer lengths of pipes (assuming no intervening services). Also, if we know where obstacles are then the system can be designed to avoid them rather than having to react by cutting pipe and creating welded sections on site.
- Better identification of redundant pipe that contractor can remove, say, rather than going around. Need better information up-front.
- Put risers outside of apartment buildings (the riser can be made part of the architectural feature of the building). Locate HIUs close to risers.
- Currently have to reinstate as found. However, this can add significant cost in some cases (e.g. if specialised surface) and may not really be necessary. Opportunity is to challenge the spec and also to design intelligently.
- Re-use excavated soil – save landfill costs and potentially some transport costs depending on solution. Both would need a (new) machine/processing unit. For the site solution it could be on wheels or in a 20ft container.
  - Re-process and re-use on site e.g. in compound.
- Use local central location (e.g. local rubbish centre) to take backfill which is reprocessed for any utilities to use.

Medium Impact, High Effort

- There would be significant benefit if there was a planning portal with details of all highways works planned. Hence the contractor could see other works planned along the proposed DH route (e.g. gas DH, etc). Could co-ordinate works and reduce costs. This has been classed as medium reward as without central planning, the opportunities for linkage between works would be ad-hoc.
- Prepare consistent traffic management standards by region.
- Eliminate costs for shoring if sufficiently shallow depth trench and no need for anyone to enter trench. Suggestion could go around 1.2m depth. If man in trench would need to be shallower before no shoring and depth would depth on variables such as make-up of ground. Alternatively, only shore at points where someone does need to enter trench e.g. for welding. Innovation needed to design a load-bearing pipe that can go close to the road surface.
- Eliminate welding to save trench pits. Drop in pipes. Note less welding, less issues for flushing.
- If hit other services need to fix. Can you get a license to fix? How do you know what is redundant? Need to minimise time not working.

- Corgi have a system where engineers can phone up about installing gas boilers. Could reduce cost of installation. Similar approach for HIUs? Could link to more standardised HIU?
- Reverse vacuum to pipe in sand backfill. Suggested expensive to do as need to be dry to reverse pump whereas sand purchased today and dropped in is not dry.
- Create governance body for all projects to ensure the scheme delivers intended outcomes. Governing body would include residents/users, ESCO, contractors, etc. More OPEX benefit – although some learning for designing future scheme

Low Impact, Low Effort

- Safety, Health and Environment planning earlier – include in contract
- Reduce the number of joints e.g. use 16 m pipe where possible. Designers default to 12m Note that with underground services may have limited use. Also in inner city centres may have difficulty transporting artic with such long length of pipe.
- Use of foam concrete to reduce costs
- Eliminate flushing (seen as relatively small cost and thus reward)
  - Prefabricated clean pipes
  - Roll of pipe
  - Pipe with shield at end which dissolves when water passes through for first time.
  - Pigging (or something to clean pipe in sections)
  - Use something akin to chimney sweep
  - Change filters more often – reduce CAPEX but increased OPEX in first few months.
- Retain water used in flush test for use in DH system for heating

Low Impact, High Effort

- There can be impacts from the general public when undertaking schemes (they want minimum hassle). This could be reduced by more general education in the UK. The level of effort can range from low (e.g. TV advert) to high for a more systematic awareness campaign. Note that if the public are anxious to get the DH installed rather than fighting it. - this pull allows many barriers to be moved aside faster.
- Develop standards for flushing. However, considered to have limited reward. (See link to Code of Practice. More value in good practice approach for commissioning to, say, maximise system efficiency and reduce cost).
- Standard for water quality into DH system – low reward – is it really a problem on good quality schemes today?
- Reduce cost of flushing by using rigs which taken on site which filter mains water etc to produce right quality of water.

Other Comments

- Hydraulic separation between network and pipework in building adds cost
- Welding standards existing. Tough to challenge (may be over the top). Denmark follow same welding standard.
- Discussed reducing the amount of (or eliminating) weld testing. However, the integrity of the welds is seen as crucial and developer would want not wish to take increased risk of need to retrofit latter. The upfront cost is seen as outweighing the risk.
- Discussed eliminating wires for leak detection. They tell fault but not accurately in terms of location – so how useful are they? However, the general response appeared to be that leak detection is needed (i.e. could not eliminate cost) but needed to be

implemented better. For example, eliminate wires by using modern technology to pinpoint exact location. Perhaps more an OPEX issue.

- Final hydraulic test. Rare to find faults. However, client keen to keep it to minimise uncertainty and potential redig later. [This may be driven by the need for the designer/specifier to feel comfortable rather than a real need. Could challenge this view with facts – e.g. 99.9% pass rate (if true - made up number) – if this exists – and overcome the need?

Minutes

Meeting name	Project name	Circulation list	Attendees	Apologies
ETI Workshop			Ewan Jones (AECOM) Simon Box (Total Flow) Paul Woods (Engie) Marko Cosic (CoHeat) Tim Hall (Total Flow) Phil Cooper (Ormandy) Charles Mobray (Ormandy) David Dutch (Ormandy)	
Subject	**Project number**			
Hydraulic Interface Units	60477549			
Meeting Date	**AECOM project number**			
02 September 2016	60477549			
Time	**Additional information**			
9:30				
Venue	**Prepared by**			
Ormandy Bradford	Ewan Jones			

Company Overview

Ormandy is an offshoot of Rycroft focused on offsite manufacture large range of products:

- Tanks
- Immersion heaters
- Heat exchangers
- Boilers
- Calorifiers
- Package plant rooms
- Aquatherm plastic pipework – have UK licence for wall/ceiling heating system

ISO 90001

ISO 140001

Wholly owned business – no parent company

Hydraulic Interface Unit (HIU)

Tenant Interface Unit (TIU)

General Comments

Could we use a TIU for a whole floor of flats rather than separate HIUs for each flat – which is cheaper and what are the other impacts?

Code of Practice says needs leak detection but it means primary side not secondary. Many stakeholders have misinterpreted this as secondary side and so incur unnecessary cost.

COP says things such as “HIU can be tested using a pressure standard such as X” – this can and has been interpreted as “must be tested using X”.
On one recent project, putting the demarcation of primary and secondary

through the middle of the HIU has led to 2 separate HIUs being installed and very poor coordination in general. Opportunity to standardise designs and educate specifiers.

Ormandy produce a utility cupboard module combining HIU, MVHR, Washing Machine etc.

Study focus is on retrofit rather than new build.

Ormandy not cheapest HIUs but they can tailor the product to suit a wide range of specifications.

Ormandy are often asked for fault monitoring – but not much/anything to monitor.

Shop Floor

Pipes are pre-brazed, bent and have fittings assembled in Poland except when less than 50 units are needed, in these cases the work is done in the UK.

Some manufacturers who were using stainless steel pipes are now reverting back to copper – because it is cheaper/easier for runs of under 10,000 units.

Some systems have primary, secondary and tertiary circulation loops; this is often contractually driven.

More clients are demanding pressure tests offsite – adds factory costs, does it save on commissioning? ELIMINATE?

Cost Reduction ECCR (Eliminate, Combine Components, Combine Processes, Reduce) Process

General Notes

The design for the Ormandy HIU currently has infinite variability, this reflects the range of different requirements that each client may have. Standardising the requirements could reduce costs. REDUCE

How closely/quickly do we need to control temperature? Currently the unit controls respond in just 3 seconds. General opinion was that this could be 6 seconds?

The base plate – could be replaced by a frame. ELIMINATE – only if cheaper.

Does the expansion vessel need to be metal – unit used is mass produced so design and manufacture is probably optimised already.

Do we need expansion vessel? System is sealed, not if existing system has header tank. Could we recommend externalising the expansion vessel?

Combine pump with pressure relief, temp sensor air vent. ELIMINATE the need for multiple components and COMBINE components.

Plastic pipes for lower temps:

- Cold feed DHW
- DHW flow

But moulded plastic pipes with bends are expensive for small scale. Could plastic pipes be used for straight sections? REDUCE cost

The material costs of a heat meter are around £50, but the meter needs to be certified and recertified every 5 years; this adds costs.

Temperature/pressure gauge is combined. Temperature is arguably not needed – could use pipe surface temp. Only used by maintenance team. Pressure needed by anyone topping up system, but could be reduced to 3 LEDs. REDUCE

Combine junctions, valves sensors onto a single manifold. COMBINE

How to manage the size of heat exchangers:

- Primary temperatures being variable makes this very challenging.
- Legionella management can also be a problem because people assure temperature regime is the only solution. Could the COP address this issue better?

Heat exchangers with 6 connections do exist but are expensive and unusual. Using such a unit would mean that only one heat exchanger is required, but the additional cost and complexity is likely to outweigh this benefit.

Using direct primary flow for space heating would exclude 1 heat exchanger. But there are many issues:

- Leaks in properties
- Water quality – tenants adding unsuitable chemicals.

Regarding leaks we live with this risk in some traditional systems.

Paul Woods suggested Temperatures

	DHW Peak	DHW Norm	LTHW Peak
Primary Flow	70	70	90
Primary Return	40	30	45
Secondary Flow	10	10	80
Secondary Return	55	55	40

David Dutch will write to PW with excel file on this topic.

<u>Hydraulic Controls</u>

Do we need variable flow control on LTHW? Removing this would reduce complexity of control to on/off. Unrestricted flow (on/off) may create noise issues, so need some form of flow restriction; this might be done in blocks of 10 dwellings rather than for each individual dwelling. COMBINE

DHW control could be changed to a standard TRV but at the cost of reduced reaction time (currently 3 seconds). How much does this matter if the dead-legs in the existing system mean that the total system reaction time is much longer than 3 seconds. REDUCE spec

Change probe from gas filled to liquid filled – cheaper but somewhat slower response. REDUCE cost

TRVs fail open – scald risk with DHW at 80°C. Could the install TMV to restrict DHW, Combined cost of TRV and TMV is probably less than the current solution. COMBINE

The network operator needs the facility to read meters and to cut customer off, e.g. pre-payment customers. Can we eliminate the power supply from the unit? This would require batteries for valve controls and meters. But if customers are cut off frequently then battery is going to flatten. ELIMINATE?

Pressure testing: Units could be air tested rather than hydraulically tested. This is quicker; 30 mins rather than 60 mins. All leaks found so far have been in Polish braced joints. Testing in Poland would cost more.

Eliminating joints would eliminate this problem. ELIMINATE/COMBINE – manifolds?

Lagging

Can get pre insulation heat exchangers but costs more. REDUCE labour time/cost?

Lagging is 25% of assembly time.

Insulation fish crate solution is likely to be the best solution. This would replace the back plate and casing with a single insulated box (probably polystyrene like a fish crate) and would avoid the requirement for pipe lagging. It may be possible to identify a standard insulated box size that can be used, rather than having one custom-made. COMBINE

Electronics must be kept cool i.e. isolated from heat. Not inside insulation.
Marker Hot Wire cutting fish crates would be cheaper than custom moulding.

Packaging

Currently the HIU is simply put in a box with a little bubble wrap and protection around the valves.

The unit is over 15kg and so is classified as a two-man-lift. This adds to the cost of packaging the unit and during installation. However it is debatable that this is a real cost, because it is thought that most installers treat it as a one-man-lift.

Do we need insulation in the unit at all? Industry and standards are becoming more demanding. This implies the insulated box solution is best option and is future-proof. ELIMINATE?

Current unit price is £1,000-£1,300

Direct system target cost £350 at 50,000 units/year

Indirect system target cost £700 > £400 at 50,000 units/year

Categorised Notes

The following table summarises the solutions arising from the ECCR workshop session. Ideas highlighted in green were incorporated in the solution category in the right hand column. Red ideas were rejected. Amber ideas needed adaptation to be viable. Categories are as follows

(1) Eliminate: Items not critical to HIU which can be eliminated without loss of performance.
(2) DfMA: Design for Manufacture and Assembly: Ideas to speed up and reduce cost of assembly.
(3) Value Engineering: Reducing component cost as a result of lower specification and/or scale of demand.
(4) Minimal solution: Savings as a result of a direct connection.

High impact, low effort	**Solution Category (1-4 or rejected)**
Pressed back plate for system support. A thermal break would be needed i.e. insulation between the base and the bracket. Or eliminate bracket entirely and use moulded insulation.	(2) DfMA
Eliminate back plate, replace with frame, press out and cradle the components. Is it cheaper?	(Rejected)
Make current safety valve drain into a new bucket. Current safety valve or a new bucket may be cheaper; this is seldom if ever used. The bucket would need to be between a cup and 3L in volume. [applies to indirect only]	(1) Eliminate
Combine. Saddle/ridge in foam shape for holding pipes. Clamp at each end. Self-drilling block. Clip fit.	(2) DfMA
First fix rail gives full support. Unit can be either top or bottom hung.	(2) DfMA
Indirect Simplest. Time control pump. Return temperature limiter (RTL) on primary. Re always hot primary. Rtemp renew drops lower (or internal logic). Positive is that the primary is always hot. Negative is that the return temperature never drops below set point. Alternative to TRL is internal logic in the HIU.	(4) Minimal Indirect
Combine hot water and (Mech) heating (elec) controllers? Y/N design is it possible?	(2) DfMA
Heat exchanger – uniblock cheaper then threaded fixings.	(2) DfMA
H-Exchanger Power is a range – capable of alternative ratings of a standard format by varying thickness. Step change is required at a point – but not within a domestic range.	(3) Value Engineering standardisation
DHW controls – reaction time is key. If not concerned	(1) Eliminate

then can use a cheap TRV. Issues include speed of response, scale in heat exchanger (fast shut off), mix valve to limit maximum temperature. Controls – the actuator is expensive and includes some redundancy but no current alternative is available. Potential saving (mechanical vs. electrical) £168 - £80 if reduced performance is acceptable. [applies to direct only] Reduce – clip in pipework instead of screw fixings. Probe for hot water could replace with cheaper liquid filled rather than gas-filled. How much would this bring the cost down? Liquid filled has a slower response time; how much slower? Eliminate all power to the unit (This possible for direct units which do not require a pump, perhaps using Peltier effect for powering DC digital controls.) Controls could be specifically designed for production volumes (cost down by 50%). Packaging – target 15kg max lift. 1 man install – template for drilling etc. to be on box. • Make the HIU a two-component system, i.e. expansion vessel as a separate add-on component – quick fit expansion vessel and pump. [applies to direct only]	((3) Value Engineering (1) Eliminate (3) Value Engineering (1) Eliminate (3) Value Engineering (2) DfMA
Medium impact, low effort	
Pump and manifold could be designed using an off the shelf unit. Less solder points, labour, improved leak testing, pre-insulate. [applies to indirect units only]	(1) Eliminate
Low impact, low effort	
Eliminate drain/valve option on 1st fix rail Polystyrene box (high density) frames the guts – off the shelf boxes are available. System inlet – do we need all valves? or such a high spec.? Ownership demarcation needs to be clear and valves are an obvious point.	Eliminate (5) VE / Scale (1) Eliminate Obstacle be addressed

Valves:	
Cold in	optional
DH Flow	☑
DH Return	☑
CH Flow	☒
CH Return	☒
DHW	☒

Expansion Vessel Fixing; combine jubilee clip with power box. Clip and fix. [applies to indirect only] Make the expansion vessel external [applies to indirect only]: • On radiator • Under sink Cost/Vessel = £14 Heat Exchanger issues - orientation needs to be consistent (vertical & fill from the base) otherwise performance is affected. Heat exchanger; two standard options would be ideal to reduce variability in heat exchangers (but note that some participants believed there was already considerable standardisation) Testing – air test instead of hydraulic/wet test. This is quicker, cleaner, cheaper. Leak test – most failures have been identified on brazing joints. If we can eliminate brazing then most faults would be eliminated. – Link with Uni-Block Manifold Pressure temperature gauge: temperature gauge could be eliminated if maintenance team use a surface temperature probe. Pressure gauge could be replaced with an LED showing good/bad pressure. Alternatively the pressure gauge could be combined with the pump. Pre-lag heat exchangers if not in fully insulated box. Likely to cost more than current solution.	(2) DfMA Rejected 2) DfMA (2) DfMA Standardisation (2) DfMA (1) Eliminate (1) Eliminate (2) DfMA
High impact, high effort	
Design unit to be suitable for external mounting e.g. meter cabinet outside dwelling. User OPEX increased cost, easier install. Piping: pre-manufacture hydro-block manifolds including pressure relief, air valve, sensors.	
Medium impact, high effort	
Unit rather than component Pre-insulation: e.g. Fit into existing Meat crate clam shell. Electrical components should be kept external to avoid reduced life. Bespoke tooling approx. £50k. Use cheap meat or cool box cost to test the principle. Avoid back plate and cover. Pre-made enclosure, polystyrene, standard width (kit cupboard)	

Low impact, high effort	
Expansion Vessel – lighter weight material and lower cost. High volume vs. £14 for current solution. [applies to indirect only] Secondary expansion vessel. Domestic system could use existing system boiler header tank (un-pressurised) or remote expansion vessel (hidden). Simplified control $1m^3$ cost vs. network. Single heat exchanger for DHW & CH combined: 6-ports • Heat exchangers with 6 connections do exist but are expensive and unusual. Using such a unit would mean that only one heat exchanger is required, but the additional cost and complexity is likely to outweigh this benefit. [applies to indirect only] Heat meter could be ultrasonic. 5yr testing cycle and Test in situ to avoid removal vs. £100 certification of system (euro market). Longer term solution – Engie performance monitoring. An alternative to a standard heat meter would be to simply measure the DHW draw off with a flow meter and then allocate the space heating on the basis of combined radiator output for each dwelling. Current costs of heat meter are £100 but could go as low as £60.	(4) Indirect Suitable for direct connection with re-use of current DHW cylinder Heat Meters a key priority in (1) Heat Meters a key priority in (1)
Principles	
Piping costs are a combination of raw material costs, a price per bend and a price per solder/brazed joint. Cold = Plastic issues: Diameter: wall-thickness ratio Fittings bulky Brass issues: Brass bulky and compression fittings take both time and skills to avoid weeps /leaks – still challenges of post-installation leakage over time. Copper is reliable but takes longer. Eliminate complexity caused by the current approach of making each batch of units made-to-order on a project by project basis. Eliminate all lagging. Don't insulate at all? Maybe only hot water heat exchanger? Direct Connect Issues: • Leak detect or shut off • Identify abnormal usage • Water treatment • Quality of service to other customers (if a leak occurs in one dwelling others will be affected)	

• Safety of primary temperature and pressure. Controls: simplest options DPC valve and TRV. (+time via 2 port) Direct connection. [applies to direct only]	

Cost Reduction System Thinking

Process

Marco: DHW diversity use radan curve:

- <100 dwellings use Danish standard
- >100 dwellings use Swedish standard

HIUs are the best solution for individual houses, but for flats a cheaper solution maybe to have an onsite packed plant room with heat exchangers, buffer vessel, pumps etc. Then each flat only needs a heat meter costing around £150.

Direct connection can work for several thousand dwellings. Therefore we can create several small networks of a few thousand dwellings to ensure that direct connection is always possible.

Consolidate & Next Steps

Ormandy have offered to put some thought into what annual volumes are needed for industrialised manufacturing to be feasible, and what the cost reductions could be at these volumes.

They will also send some of product and component specifications where available and not commercially sensitive.

7 Appendix C: Summary of the Five Building Typologies

7.1 Introduction

This Appendix summarises the five building typologies which form the basic building blocks of the network design which are used in the project to evaluate the innovative solutions in comparison to current practice. A typology is based around a standard “block” which represents a sample area and, in the case of housing, is limited to a set number of houses. Where an area to be modelled is larger than the limit set for a typology (for example, 400 terraced houses rather than 200), then it is assumed that multiples of the same typologies are neighbouring each other, with a section of primary pipework used to connect them.

The network design is shown as below. The schematic shows:

- Five local distribution networks each based around one of the five typologies (A to E), each comprising one or more blocks.
- The primary network which links together the five local networks and the heat source at the energy centre (EC).
- A railway crossing (the network included 2 rail crossings and 1 canal crossing).

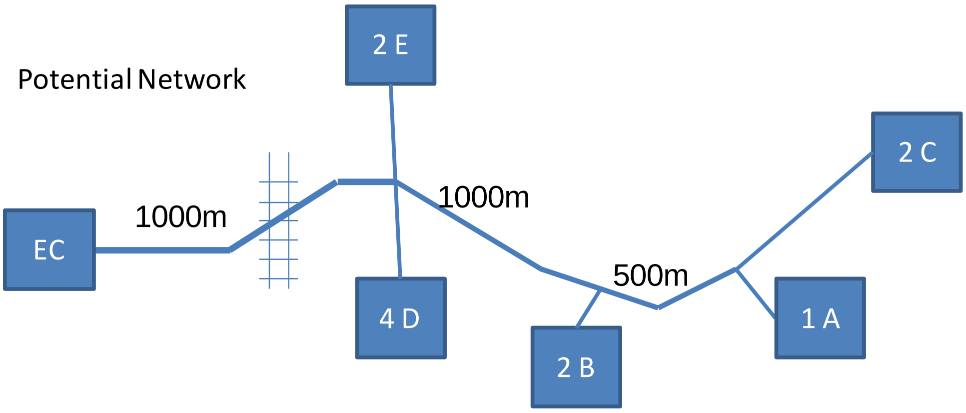


Figure 9: Schematic showing network construction concept for the cost model

7.2 Typologies

A summary of each of the typologies is given below. Further details are provided in the Stage 1 report, “Deliverable EN2013_D01: Requirements, Baseline Analysis and Target Setting Report”.

Typology	Description	Number of properties in each typology block
A	City Centre - Commercial / Institutional This typology is used to represent a broad range of non-domestic areas where heat networks may be developed. Examples could include commercial offices, public sector buildings, hotels, large retail stores or complexes, etc.	9 buildings with combined peak demand of 21 MW
B	High Density Residential – Flats 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. • Medium rise. Typical of the mansion-type blocks found around London, or newer medium rise developments. The buildings often have more than one core.	256
C	High Density Residential – Terraced Terraced housing is characterised by long runs of identical homes, often with a regular grid pattern.	200
D	Medium Density Residential – Semi Detached Semi-detached housing is the second most common housing format in the UK, and found across many towns and cities.	400
E	Low Density Residential – Semi / Detached The low density typology is predominantly made up of detached housing and semi-detached housing.	400

In addition, a dense village has been modelled as a 50:50 mixture of Typologies C and D. It has been treated as a stand-alone typology (i.e. not part of the network). It has been used to assess the impact of the various solutions on the DHN capital cost for dense villages.

8 Appendix D: Solution Evaluation Forms

This appendix comprises evaluation forms for the following key /'green' solutions:

Solution 1: Knowledge Management, Research and Training
Solution 2: Reduced Peak Demand and Peak Flow Rate
Solution 3: District Heating Wall
Solution 4: Loft Space / Cellar Route
Solution 5: Trenchless Solutions
Solution 6: Improved Front-End Design and Planning
Solution 7: Pipe Crossings
Solution 8: Shared Civil Engineering Costs (New Network Revenues)
Solution 9: Direct HIU System & Existing DHW Storage
Solution 10: HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)
Solution 11: HIU Optimisation (2) Further Simplification & Value Engineering at Scale
Solution 12: HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage
Solution 13: Internal Connections – Pipework & Connections Within the Property

It also includes evaluation forms for the following 'amber' solutions:

Solution 14: Recycling Excavated Material for Backfill
Solution 15: Shared HIUs (Heat Interface Units)

Further information relating to each solution can also be found in Appendix F which summarises the feedback from the stakeholder workshop at the end of Stage 2.

Solution name:	**Knowledge Management, Research and Training**	Evaluation Rating
Name of evaluator(s):	Paul Woods	
Solution ID:	1	
General		
Description of solution	The district heating industry is still operating at small-scale with reports of poor experience with many new-build schemes. Common failings include: • Oversizing of central plant and equipment, especially due to cautious views on diversity factors • High heat losses from local networks, partly due to oversized pipes, poor specification or poor construction standards • Early failure of buried heat mains due to poor quality installation • High return temperatures due to poor specification of controls and poor commissioning, leading to high heat losses • Poor heat distribution between customers due to poor commissioning • Unreliable metering systems An analysis of the inefficiencies in one recent new build scheme was analysed under the Innovate UK Energy Performance of Buildings Programme with a paper presented at the CIBSE Technical Symposium 2015 (see http://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I73h). In response to the perceived deficiencies, a Code of Practice for Heat Networks was commissioned by CIBSE and the Association for Decentralised Energy. This has been supported by a training programme and a proposed checklist to monitor schemes. The BRE has published a Technical Guide to District Heating updating a previous guide (Good Practice Guide 234). BSRIA have produced a draft guide to Hydraulic Interface Units and new UK testing procedures. In addition the UK District Energy Association has commissioned a new guide from BSRIA as well as individual technical notes. Despite this work CIBSE and BSRIA would need to take an even greater role in promoting good design as in many cases it is the building services design that is critical for the successful DH scheme. Some research work is taking place within universities and sponsored by the International Energy Agency and the Department for Business, Energy and Industrial Strategy (BEIS), through the Small Business Research Initiative (SBRI) projects, but the research programme is relatively small-scale in the context of the	

	potential size of the heat network industry. The recent report issued by BEIS on the consultation on the Heat Networks Investment Project noted that some respondents identified the need for further research and training (page 52 – responses to question 31). The cost benefit analysis (Annex 1) referenced the Technology Innovation Needs Assessment (TINA) work that suggested a 3% reduction in capital cost from 'learning by doing' and a further net 5% reduction from an R&D programme. This solution proposes a comprehensive programme of knowledge management to cover: • Research • Publications • Training This would be at a national scale and organised by a committee with widespread representation from: academia, government, professional bodies and the construction industry. A District Heating Knowledge Centre (DHKC) would be established where research and training would be focussed so as to obtain the necessary critical mass of researchers and practitioners. Further detail of a proposed structure for the DHKC has been developed in Route Map A in Stage 3 (Deliverable EN2013_D04 "Solution Route Maps Report". **Research** would be undertaken to fill gaps in knowledge and to monitor established schemes so that operating data can be used to improve future designs. Examples might be: to establish design guidance for diversity factors on a range of different types of scheme with different groups of buildings so as to avoid oversizing, to take forward some of the solutions developed within this ETI project by means of further R&D and demonstration projects, and to optimise the control of building heating systems to provide benefits both to building owners and the DH schemes. A more comprehensive set of **publications** would be produced covering all aspects of district heating from design through to operation. This would take account of the research findings and also lead to the identification of gaps in knowledge and potential areas for further research. There would be detailed guidance and standardised designs to support the CIBSE/ADE Code of Practice CP1. There would be a standing committee to review the CP1 at regular intervals to ensure continuous improvement and to potentially move the 'Best Practice' requirements to the 'minimum requirements'. Useful learning should be taken from the Danish Technical Guide which is being translated into English for BEIS. Consideration should also be given to issuing essential information quickly rather than relying solely on comprehensive publications which can	

	take a long time to prepare and publish; this information could be issued through short focussed guides via a website and other alternative formats. A **training** programme would be provided for designers and for the construction industry to raise standards of design, construction and commissioning. This would be targeted not just at professionals designing schemes but all trades involved especially technicians commissioning heating systems in buildings. There would be a range of courses offered – 5 day short courses, more comprehensive two month courses (may be spread over a year) and full or part-time MSc courses on district energy. The training would be offered nationally but co-ordinated by the District Heating Knowledge Centre. There would be a closer link with the Building Regulations to improve the standards of design and provide a way of enforcing compliance with standards. For example: providing more specific rules for compliance with minimum standards (via the compliance guides) or requiring designers to be part of an accredited scheme where members are required to complete regular CPD and have their work independently quality assured. Potential customers would be provided with greater confidence in district heating as a result of the trained workforce and the use of the CP1 to set minimum requirements, underpinned by the Building Regulations, together with the consumer protection already afforded by the Heat Trust.	
How the solution was identified	In the course of all of the Challenge Area 1 workshops there was a general view that costs would come down when schemes are designed better and when there is more data published on existing schemes so that a less conservative design approach can be followed.	
Capital cost		
Change relative to baseline CAPEX	Costs of the DH **Network** The baseline cost assumes a good standard of design and construction but not excellence. There would be two impacts from this solution: Providing a route for the other solutions identified in this project to be disseminated widely and taken up more rapidly. This solution is an enabler for the others and so no additional cost saving can be attributed to this aspect of the solution Developing better designs over time, including identifying further solutions and ensuring feedback to designers on what has worked well so that the overall standard and cost-effectiveness of schemes improves. An example would be monitoring of schemes to establish better understanding of diversity of demand which could lead to a reduction in demand and hence reductions in pipe sizes and a consequent reduction in cost.	

	It would be reasonable to assume that by the measures outlined in this solution design and construction practice would be improved and costs would fall. This has been estimated to be in the range of 1% to 5%, average of 3%. This is a conservative figure but is assumed to be additive to all other solutions such as the Reduced Peak Demand and Peak Flow Rate design which will also require a skilled workforce to deliver. Hence this solution is an important enabler for all other solutions as it is a means of spreading the best practice solutions that emerge. This figure is assumed to be net of costs for setting up the various elements of the solution as these will be very low compared to the potential benefits. Costs of the DH **System** The proposed solution will also impact on the cost of the DH system especially if it leads to a reduction in the degree of oversizing as the cost of the Energy Centre plant is more closely related to capacity than the DH network. For example, boilers, CHP plant, pumps and gas supplies are frequently oversized leading to unnecessary cost. Often there is additional complexity introduced as well. A range of 1% to 5% is similarly proposed for the impact on the DH system.	
Certainty of outcomes		
Certainty of outcomes	Greater understanding of the technology and the potential impact of costs from different design and construction approaches will also lead to greater certainty in outcome	1
Operational cost		
Change relative to baseline OPEX	Costs of the DH **Network** Improved design and construction is likely to lead to a more efficient network with lower heat losses and pumping energy. Whilst difficult to quantify at this time, it should significantly reduce DHN OPEX. It needs to be recognised that the project's baseline position is one of good practice. As such it is proposed that up to 5% reduction in OPEX can be reasonably achieved. Costs of the DH **System** Improved design and construction is likely to lead to a more efficient energy centres and more optimal operation. Whilst difficult to quantify at this time, it should significantly reduce DHN OPEX. It needs to be recognised that the project's baseline position is one of good practice. As such it is proposed that up to 5% reduction in OPEX can be reasonably achieved.	

Lifecycle costs		
Change relative to baseline lifecycle costs	Costs of the DH **Network** No additional cost reductions from above. Costs of the DH **System** No additional cost reductions from above	
System performance		
Impact on DHN performance	Improvements will result but difficult to quantify. Lower heat losses, lower pumping energy, more optimal operation of heat production plant, higher reliability and greater customer satisfaction are likely to result.	1
Future flexibility	Improved knowledge such as a better understanding of peak heat demands would enable schemes to build in flexibility without excessive costs. On the other hand greater standardisation of designs to reduce costs may limit flexibility in overall design approach and inhibit innovation.	0
Attractive to Users & Investors		
Attractiveness to Users and Investors	Potential customers and investors will obtain reassurance from a comprehensive system of research, publications and training underpinned by Regulations in a similar way that the micro-generation certification scheme (MCS) has been valuable for encouraging small-scale renewables. This solution would provide a similar structure to improve confidence.	2
Reduced Complexity		
Complexity	There is evidence that current designs are overly complex as designers are 'playing safe'. Greater knowledge and research is likely to lead to a simpler approach.	2
Health, Safety and Environmental Impacts		
HSE	HSE issues could and should be part of the programme of research, guidance and training so understanding of these impacts would be enhanced and mitigation measures developed	1
Opportunity to scale		
Scope of opportunity	This solution will be of benefit to all typologies.	2
Increased Revenue		
Potential for synergies	The knowledge management aspect of this solution will enable best practice to be shared through publications and case study examples. Some of this best practice could include designs which exploit synergies such as shared trenches with other services, combining heat networks with fabric upgrades etc	1

	This is turn will mean that future schemes will be better placed to exploit such synergies.	
UK plc external Stakeholder Value		
Value for the UK	This solution will help enable the industry to deliver projects at a faster rate and to a higher quality so will provide faster CO_2 savings and other benefits to the economy. More qualified workforce could lead to potential export of professional services as has been the case with Danish DH engineering and other UK engineering services e.g. civil engineering.	1
Technical feasibility		
Technical feasibility	The proposal is technically feasible and the type of approach has been demonstrated in other industries in the UK and abroad.	0
Effort to Implement Solution		
Effort	• Investment capital and research required: <£500k (0). Expect initial funding of less than £500k to be sufficient to set up the structure of a new organisation and to obtain sources of funding for future years • Level of technological innovation (uncertainty): Technology readiness level (TRL 9) (0). There is no real technology innovation to set-up knowledge management, research and training • Anticipated timescale to the point where the solution is delivering value: <18 months (0). • Likelihood of success: Probable (1)	0
Other		
Any additional equipment required	None	
Barriers	The main barriers would be inertia within the industry and the set-up costs involved. Once the scheme is up and running, a sustainable funding stream would be expected from: • Academic funding – EPSRC etc • Contributions in the form of membership subscriptions from industry • Fees payable for training courses by participants There may need to be a specific grant from BEIS to initiate the programme.	

Solution name:	**Reduced Peak Demand and Peak Flow Rate**	Evaluation Rating
Name of evaluator(s):	Paul Woods, David Ross	
Solution ID:	2	
General		
Description of solution	A reduced peak demand and peak flow rate system will allow smaller pipes to be used which will result in lower costs for pipe materials, pipe installation and civils. It may also mean that twin pipes and plastic pipes can be used more often in a network as these are typically only available below a certain diameter (c150mm). As an illustration, to reduce the flow rate such that a smaller pipe size can be used in each part of the network, a reduction in flow rate of c50% is required. This means that pipe diameters can be about 70% of the base case for the same velocity, e.g. 300mm drops to 200mm, 150mm to 100mm, 80mm to 50mm etc. Even with the same velocity, pressure drops will be slightly higher across the network so pumping energy may increase (pump energy is the product of volume flow which will be reduced and pressure difference which will increase. Pumping energy is around 1% of heat sales so this potential increase is not deemed significant, although the maximum pressure would be a consideration in this design if direct connection of buildings is to be employed. Our cost model analysis showed that costs do not vary significantly with flow rate. This is because for the same flow velocity a 10% reduction in flow leads to a c5% reduction in diameter (the cross sectional area of the pipe will be proportional to the flow rate so proportional to the square of the diameter). Also, most of the pipework length is found in the smaller diameters including the branches from the street mains to individual houses. Here a reduction from 32mm to 25mm or 25mm to 20mm would be possible. However the cost model rates were almost the same for these diameters as the civils work and the pipe installation work is almost the same (the trench width would not be significantly different in practice). The 50% reduction in peak flow rate (this is for illustrative purposes and a higher or lower figure could be used in an actual design) can be achieved by implementing two changes together: • Reduce the peak heat demand that the building connections are designed for • Increase the difference between the flow and return temperatures (base case assumes 90C flow 60C return)	

A design approach to achieve a 25% reduction in peak heat demand and an increase in temperature difference from 30C to 45C is presented below giving an overall reduction in peak flow rate of 0.75 x 0.667 = 0.50. The changes needed to the baseline design are given below.

Sensitivity Analysis

It is possible that further reductions in peak demand and even lower temperatures could be achieved. As a sensitivity, a 30% reduction in demand and an increase in temperature difference from 30C to 50C could be assumed with further optimisation and taking into account developments in Scandinavia to achieve low return temperatures following 4^{th} generation DH principles. This would lead to an overall reduction in peak flow rate of 0.7 x 0.6 = 0.42, i.e. a further reduction of about 16% in flow rate.

If the degree of overestimating is less than expected so that only a 20% reduction is achieved and the temperature difference can be increased only from 30C to 40C then the overall reduction in peak flow rate would be 0.8 x 0.75 = 0.6 which is 19% higher than the central case.

Peak heat demand reduction of 25%

The base line assumes that peak space heating demands will be estimated without reference to actual energy use data and are likely to be over estimates. To achieve the flow rate reduction required, more accurate estimates of heat demand will be obtained by taking accurate measurements of the building, understanding the fabric and using data from smart gas and electricity meters (see below). A typical design approach will be to add 20%-30% to the heat loss estimate so that short heat-up times are obtained as intermittent heating is assumed. The margin added will be reduced to 10% as it will be assumed that residents will operate the system continuously on the coldest days so that the requirement for rapid heat-up time is not required. This is the way systems in Denmark are operated and provides benefits for the DH operator as high peaks in the morning period are reduced.

The two approaches outlined above will be supported by developments in software for calculations and automated surveying techniques the costs of which will be very small when spread over the large number of dwellings envisaged.

There will also be a process of sharing operational data with the designers so that the peak demand estimates can be further refined in the light of experience.

In addition, at present a domestic hot water demand is calculated and added to the space heating demand. A diversity factor is applied but an allowance of c2-3kW per dwelling is typical. Some designs of HIUs have a function which shuts off the space heating when the hot water is being drawn off - a hot water priority system. (The benefit of this functionality is taken in this solution as it is generally available in the market but not always used in designs). As this occurs for a relatively short time in any one dwelling the internal temperature will not reduce significantly, especially for well-insulated dwellings. As a result there is no need to add the hot water demand to the space heating demand. This reduces the peak demand by about 6%-13%, depending on assumptions made on diversity, the relative demand of space and hot water heating and the location in the network.

For example a pipe sized to supply 100 dwellings each with a 10kW space heating demand and a 35kW hot water heat exchanger would be conventionally sized for:

- 100 dwellings at 10kW for space heating = 1000kW
- 100 dwellings at 35kW with 10% diversity = 350kW
- Total demand on network 1350kW

(note: the diversity factor used above is taken from the ADE/CIBSE Code of Practice Figure 9 using the curve from the Danish standard DS439)

A hot water priority system would assume that the diversity factor means that 10% of dwellings are calling for hot water at any one time but these dwellings would have the space heating shut off so:

- 90 dwellings at 10kW for space heating = 900kW
- 10 dwellings at 35kW = 350kW
- Total demand on network = 1250kW, reduction of 100kW or 7.4%

If the same calculation is repeated for 10 dwellings the reduction in demand is 13.3% and for 1000 dwellings it is 6.3%.

It is therefore considered that it is reasonable to assume a 25% reduction in demand can be achieved from a combination of the above approaches. e.g. 10% reduction from better estimates of peak demand, 10% from reduced margin and 7% from hot water priority system. This is further substantiated from experience in the new build sector where typically designers allow 5kW per dwelling and the peak demands actually experienced by the DH operator are about 3kW per dwelling.

Increase temperature difference from 30C to 45C

The base case model assumes 90C flow 60C return, a ‘delta T’ of 30C, as these are typical temperatures that result when connecting existing buildings without significant intervention in the building heating systems. It is proposed to increase the delta T to 45C by maintaining the flow temperature at 90C and reducing the return temperature to 45C. The 4th generation DH systems proposed use return temperatures of 30C or below so 45C is not unreasonable. It does however require significant interventions to achieve lower return temperatures.

Selecting a radiator return temperature of 40C will result in a primary network temperature of 45C as a 5C approach temperature is typical when designing the plate heat exchanger. With direct connection the return temperature would be 40C.

To achieve the low return temperature from the radiator the circuit flow rates need to be correctly balanced. This can be done by installing high quality thermostatic radiator valves (TRVs) with an adjustable flow setting or a return temperature limiter or both. Such radiator valves are available in the UK but from a limited number of suppliers. In some cases, valves that are available in continental Europe are not marketed here due to lack of demand. The position is expected to change if the UK market for DH products expands and more suppliers become active in the UK.

The cost model includes a cost of £50 per radiator to supply and install these valves and an average of 6 radiators per dwelling i.e. £300 per dwelling. This will typically be a half day’s labour at £50/hour plus £15 material cost for each radiator valve. This cost is set against the saving in the network costs from reducing a pipe size. Whilst achieving a 40C delta T is challenging in new build properties where the radiators are relatively small, for existing houses with radiator outputs of c1kW the required flow rate can be set up provided a TRV specifically designed for district heating with low flow rates is used. Part of the work in fitting the valves would be draining down and flushing the system to remove suspended solids to reduce the risk of fouling of the TRVs.

The baseline instantaneous hot water heat exchanger is typically designed for a 25C return temperature when cold water is drawn off and a 45C keep warm set point. On average we would therefore expect return temperatures from the hot water element of the demand to also be below 45C.

	Radiators operating at 80C/40C would have an output 65% of that obtained with 82C/71C temperatures or 75% of that obtained with 80C/60C, the latter being commonly used when sizing radiators. Given that the peak space heating demand is assumed to be reduced by 20% (see above) and that radiators are typically oversized by at least 10% (especially where fabric improvements have been made after the radiators were installed) an 80C/40C system would be feasible in terms of maintaining comfort levels. It will be important that the DH company is responsible for the changes to the radiator systems to deliver the required return temperature so that a holistic view is taken of the issue. In new build schemes the designer of the building services is often a separate entity to the designer of the DH system and this can cause difficulties. It will be important to explain to the resident the function of the TRVs and the fact that one end of the radiator will be relatively cool. The resident may see this as a fault with the system is they have been used to a conventional system with much higher return temperatures. Further benefits could be obtained by the use of smart controls that could for example, self-learn and adjust the flow temperature to the radiators to minimise the return temperature thus automatically compensating for radiator oversizing. The smart controller could also manage the requirement to shift to continuous heating in cold weather automatically by overriding user time control preferences under certain weather conditions. The main additional cost associated with this would be the installation of the additional internal and external temperature sensors (not included in our cost estimates but additional costs for smart control would be justified also on energy savings).	
How the solution was identified	A number of research programmes are investigating the potential for low temperature district heating with the aim of improving operational efficiency for an existing network especially where large-scale heat pumps are to be used as the heat source. However for new networks, the requirement to reduce capex means that using low flow rates is more important than low temperatures. This means keeping the flow temperature at around 90C under peak demand conditions and exploiting many of the initiatives proposed for low temperature DH to obtain low return temperatures, a large temperature difference and hence a low flow rate system. Discussions with other system designers confirmed this approach with the understanding that in practice flow temperatures can be reduced for most of the year to reduce heat losses, with the 90C flow temperature only used on the coldest days. Designers also identified oversizing of networks as being a major problem both from experience in operating schemes and a lack of understanding of hot water diversity. The functionality of HIUs to prioritise hot water	

	production so that the hot water demand does not need to be added to the space heating demand is currently available but is not always used. As a result of these discussions the solution was developed which aims to reduce the flow rate as far as possible to minimise the pipe sizes which will clearly have benefits in both pipe material cost, installation cost and civils costs as the trench is narrower and shallower.	
Capital cost		
Change relative to baseline CAPEX	Costs of the DH Network The main cost reduction is achieved as all of the pipe sizes reduce by one size. However, as much of the length of the network is relatively small diameter where a further reduction in diameter has a very small impact (trench width is not impacted significantly) the overall saving is not as great as might have been expected. In addition, the savings are offset by the additional cost assumed from new radiator valves as detailed above – these costs are allocated to the Total System Capex. The cost model results in the following:	

Typology	Network Costs		Domestic Costs	Saving due to innovation	
	Baseline cost (£k)	Innovation cost (£k)	Householder side of the HIU (£k)	(£k)	(%)
A	£1,953	£1,708		£246	12.6%
B	£1,038	£1,038		£0	0.0%
C	£1,706	£1,696		£10	0.6%
D	£3,871	£3,871		£0	0.0%
E	£4,113	£4,096		£17	0.4%
Primary Network	£6,476	£5,808		£667	10.3%
Prelims	£3,748	£3,748		£0	0.0%
Total DHN Capex	£45,190	£43,327		£1,863	4.1%
Total system Capex	£62,602	£61,079	£896	£1,524	2.4%
Dense village Capex, no prelims	£3,641	£3,633		£8	0.2%

OPEX	£3,320	£3,280		£40	1.2%
TOTEX non-discounted	£184,090	£181,010		£3,080	1.7%

N.B. TRV costs have been excluded from the DHN CAPEX but included in System CAPEX and in the TOTEX. Cost of TRVs is included in typologies CAPEX, reducing the savings shown.

It can be seen that the main saving is in the typologies where larger pipes are used, especially the primary network. Overall this solution represents a 4.1% saving on the DHN cost.

The sensitivities discussed above indicated:

- A positive case that a further 16% reduction in flow rate below the central case may be possible in which case the DHN capex saving could increase from 4.1% to about 4.9%.

- A negative case that the flow rate would be 19% more than the central case in which case, it is estimated that the saving will decrease from 4.1% to about 3.4%.

In addition there are more minor OPEX impacts:

- A reduction in flow rate of 50% will lead to a cost reduction in the operating energy of the central pumps. Pumping energy is proportional to flow rate. However the smaller pipes will lead to higher pressure drops for the same velocity. We anticipate a small saving in CO_2 emissions associated with pumping (the quantification of this saving will also depend on the electricity emission factor in the future which will reduce as the grid decarbonises)
- The smaller pipe size and lower return temperatures will reduce the heat losses on the network by about 20%. This will result in lower OPEX estimated at £7,300 p.a. or £93,000 when capitalised, assuming a heat production cost of 1p/kWh.
- The smaller pipes will result in less water volume and so reduced water treatment costs

Costs of the DH System

A reduction in demand of 25% would result in smaller standby boilers to meet the peak demand. This is expected to result in a saving of approximately £0.55m.

	TRVs required at householder level are expected to result in an additional cost of £896k.	
Certainty of outcomes		
Certainty of outcomes	The level of cost certainty is unchanged as the same technology is used but with smaller diameter pipes. In some cases this may assist in navigating existing services especially where plastic pipe can be used which otherwise would not be possible as the diameter would have been too great. This potential advantage only impacts a small part of the network.	0
Operational cost		
Change relative to baseline OPEX	The overall operational costs are expected to improve marginally as the lower return temperature will result in lower heat losses and pumping energy. In addition the lower return temperature may result in additional heat recovery from CHP plant or more efficient heat pumps or steam extraction from a steam turbine system. The customer heat use will increase during cold weather as continuous heating will be required. Overall the impacts are small and are considered neutral overall.	
Lifecycle costs		
Change relative to baseline lifecycle costs	As the OPEX changes are considered negligible overall, the reduction in the lifecycle cost is the same as the capex saving.	
System performance		
Impact on DHN performance	Impacts on DHN performance are expected as follows: • The lower return temperatures will result in lower network heat losses, and the 50% reduction in volume will reduce pumping energy. • Reducing peak flow capacity will reduce the pipeline's ability to meet increased demand (additional buildings or colder winters), but this is an unplanned benefit which is probably not relevant for most schemes and in many cases demand will reduce over time as building fabric improves • Reduced radiator return temperatures may impact consumer perceptions of system performance and the radiators will respond more slowly when turned on. However these perceptions will reduce when it is realised that room temperatures are being maintained	0
Future flexibility	There is expected to be no major difference to the baseline.	0

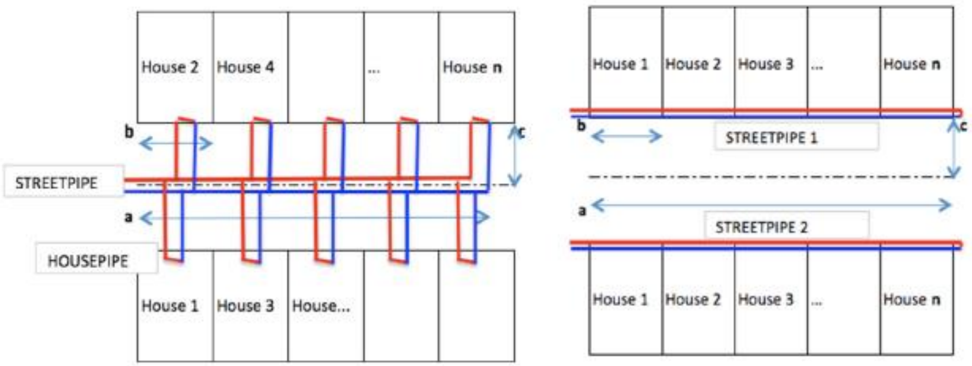
Attractive to Users & Investors		
Attractiveness to Users and Investors	Impacts are expected as follows: • The new thermostatic radiator valves proposed are likely to be of better quality and so more attractive to residents, and the old ones would need replacing or maintaining at some point. • Residents would have to be advised to use the heating more continuously in cold weather which will require some education to convince people that there is negligible additional cost in doing this.	1
Reduced Complexity		
Complexity	The will be some additional complexity needed in design and commissioning of the system.	-1
Health, Safety and Environmental Impacts		
HSE	There is expected to be no major difference to the baseline.	0
Opportunity to scale		
Scope of opportunity	The proposed system is in line with the best performing continental schemes. The solution would apply to all typologies.	2
Increased Revenue		
Potential for synergies	No change in revenue streams.	0
UK plc external Stakeholder Value		
Value for the UK	No significant impacts specific to this solution.	0
Technical feasibility		
Technical feasibility	The solution is technically viable and has been demonstrated in a number of schemes. However, there will be some additional complexity needed in design and commissioning, and it will benefit from some further research to maximise its potential.	-1
Effort to Implement Solution		
Effort	• No significant effort required to develop this solution. The most useful approach would be through a demonstration scheme. • There is a need to develop software to take smart meter data and estimate peak demands. This would entail the following. ○ Smart meters provide access to half-hourly metered data and should allow a good estimation of the actual peak heat load. To better estimate the peak space heating load, it is necessary to first	1

	separate out the space heating load component from the energy data which comprises an accumulation of several energy end uses (e.g. space heating, domestic hot water, cooker use, lighting, small power electrical load). It is envisaged that intelligent software can be produced that would isolate to a good approximation the peak space heating load based on, for example, typical usage patterns. If necessary, further information can be obtained about each household (e.g. heating sources, timer controls) during an initial visit to the property by the DH company to, for example, assess the installation (i.e. not necessary to pay for the expense of a separate, specific visit). One approach here could be for research funding to develop appropriate algorithms to analyse the data to be shared amongst the software companies and provide confidence by the design teams in the use of smart meter data for peak load estimation. ○ It will be necessary to size the system based on a design external temperature. If the peak load data is based on an alternative temperature (e.g. the smart meter data could be for mild winters), a calculation approach would need to be developed to make such a conversion e.g. a regression analysis of peak load vs external temperature. ○ There is a need for development of design software to assist a rapid assessment of radiators and flow settings for each. ○ Training in the approach would be required both for designers and installers. • Investment capital and research required: £500k- £2M (+1). • Level of technological innovation (uncertainty), technology readiness level (TRL 8-7) (+1). • Anticipated timescale to the point where the solution is delivering value: 18 months-3yrs (+1) • Likelihood of success: probable (+1)	
Other		
Any additional equipment required	None.	
Barriers	No major barriers to implementation. Technology is all available now but some development work on software and rapid survey techniques would speed up the design process.	

<table>
<tr><td>Solution name:</td><td>District Heating Wall</td><td rowspan="3">Evaluation Rating</td></tr>
<tr><td>Name of evaluator(s):</td><td>Paul Woods, Andrew Cripps</td></tr>
<tr><td>Solution ID:</td><td>3</td></tr>
<tr><td colspan="3">General</td></tr>
<tr><td>Description of solution</td><td>

To avoid the costs of installing DH pipes in the road this solution proposes that the pipes will be surface mounted externally on the walls of the houses, typically running above the front doors and below the first floor windows. It is particularly straightforward to do this for houses without bay windows. The pipes are boxed in using a pre-fabricated cover designed and finished to match the external brickwork or render or to blend in with existing architectural features.

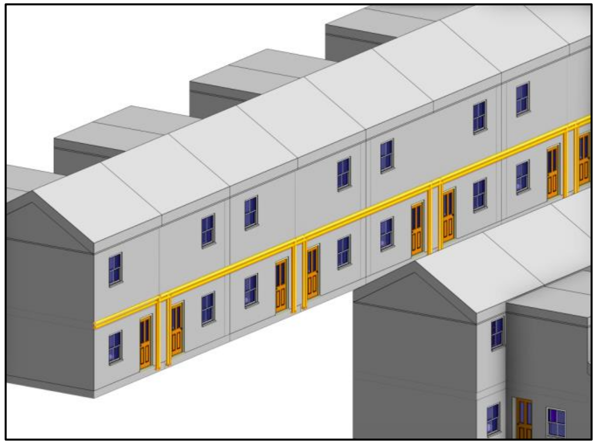
The figure below shows a simple schematic of street pipe layout on the left for the baseline system and on the right for the new solution.



The original intention for this solution was to apply this to terraced homes only. However, this comprises one typology only (typology C) and thus has limited impact in reducing overall DHN costs. As a result, this solution has been expanded to typologies D and E which include semi-detached and detached homes through the use of a pipe bridge at about 2.5m height between the houses. This would allow pedestrians and vehicles to

</td><td></td></tr>
</table>

	pass under this as required. The original solution (as developed by Paul Woods et al – see reference below) was for the DH wall to be installed in conjunction with external wall insulation which covers the pipes entirely. One clear advantage from a householder perspective with this option is that the DH pipes would be hidden. There would also be a cost saving as not necessary to box in the pipes. However, the cost of the DH organisation funding the external wall insulation as part of the solution would result in a significant increase, rather than reduction, in CAPEX and thus is not evaluated separately below. However, there is a clear synergy if the intention is separately to improve the energy efficiency of the property through external wall insulation e.g. through a separate funding route. Although the solution has been developed and costed assuming that the front elevation is used in some cases the rear elevation may be preferable. This would make it easier to connect to an existing heating system as the gas boiler is often installed in a kitchen area at the back of the house. Disadvantages of this route are the likelihood of rear extensions which may be difficult to route around and a greater likelihood of conflict with other services such as drainage pipework. It is likely that with further development a range of model designs would be produced to suit the various house types and designs. One option could be to incorporate with the guttering i.e. a one piece solution. Frost, C, Wang, F, Woods, P & MacGregor, R. (2012). 'The 'District Heating Wall': a synergistic approach to achieve affordable carbon emission reductions in old terraced houses' *Low Carbon Economy*, vol 3, no. 3A, pp. 115-129. DOI: 10.4236/lce.2012.323016	
How the solution was identified	Paul Woods identified this potential solution prior to this project. Paul owns the background IP but it has been widely published. DECC supported this concept and a feasibility study was produced under the SBRI programme.	
Capital cost		
Change relative to baseline CAPEX	Costs of the DH **Network** • The cost of excavation, backfilling and reinstatement for the street main and branches to each dwelling is avoided. These costs have been removed from the cost model for this solution. • Although there are two street pipes, one for each side, the diameters will be smaller and the length of branches from them is reduced. • There is additional cost for fixing to front wall, boxing in and making good (around £170 per m). This assumes £40 for material, £130 for labour and £0 plant (assuming the power tools required are included in the overheads of the labour rate, 3.4 hours labour). In addition, for typologies D and E there is a requirement to construct a pipe bridge from home to home. This has been costed by the AECOM QS at	

	around £250 per metre, assuming £160 material, £80 labour and £10 plant (cherry picker hire). Based on 2.1 hours labour per metre. • To establish these changes in CAPEX costs, AECOM produced and costed an outline design (see below) for the modification from the baseline scenario. • Note these costs are probably high as these are not standard installations; cost savings from optimisation are likely to be achievable.  	

Costs of the DH **System**

- No additional change in CAPEX of the DH System has been identified

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£1,038	£0	0.0%
C	£1,706	£1,491	£214	12.6%
D	£3,871	£3,871	£0	0.0%
E	£4,113	£4,113	£0	0.0%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£44,761	£429	0.9%
Total system Capex	£62,602	£62,174	£429	0.7%
Dense village Capex, no prelims	£3,641	£3,630	£11	0.3%
OPEX	£3,320	£3,330	-£10	-0.3%
TOTEX non-discounted	£184,090	£183,912	£179	0.1%

With the current costs there is only a saving showing from Typology C. This reflects the relatively high cost assumed for fixing to the front wall and the cost of the pipe bridge which is comparable with the costs of trenching in typologies D and E, where half of the ground is assumed to be soft. As a result of the detailed cost modelling of this solution for each typology this solution currently shows a net benefit only for Typology C.

Additional sensitivity analysis was undertaken to assess the impact of households within a street opting out from this solution. This analysis is presented after Solution 4. It shows that 9% of households would need to

	opt out for there to be no net savings based on a lifecycle cost assessment. This reflects additional capital costs in routing around the households that opt out and a loss of income from heat sales.	
Certainty of outcomes		
Certainty of outcomes	• The avoidance of civils work means that the associated uncertainty of working around buried services with unknown ground conditions is removed. • The solution is only viable if there is agreement amongst all owners to allow pipes to be installed and access to be provided, even if the DH supply is not taken. This means a higher marketing risk than for the conventional approach. A precedent is often seen with other services e.g. drainage where several houses will feed into a local sewer before discharging to the street sewer. • It also raises further uncertainty on market risk if it is seen to be too visually intrusive, although the assessment has allowed for the boxing of the pipes to be to a high standard and painted to blend into the existing building. • On balance this solution is seen as having greater uncertainty than the baseline.	-1
Operational cost		
Change relative to baseline OPEX	Costs of the DH **Network** • OPEX on heat losses will reduce because the branch length from the street main to the houses is much shorter, but the pipes are above ground so losses per m will increase slightly. In addition there are two street mains of smaller diameter rather than one. Overall a small reduction in heat losses is expected, but this is not significant and so has not been estimated. • Repair costs will be lower than for buried pipe as the pipe is more accessible however the risks of damage to above ground pipe are greater than for buried pipe. In both cases repair costs are very low so have not been estimated. Costs of the DH **System** • No additional change in OPEX has been identified.	
System performance		
Impact on DHN performance	• The thermal efficiency of the network should improve slightly through lower heat losses as a result of reduced pipe length as described above, but this has not been quantified. • System reliability should improve as there is reduced risk of failure as pipes are less subject to third party damage from work within the road or corrosion from ground water. • The pipe bridge solution may bring operational risks if not designed with care e.g. third party damage (e.g. repairs to fabric, fixing of satellite dishes etc), impact on existing building structures from expansion.	+1

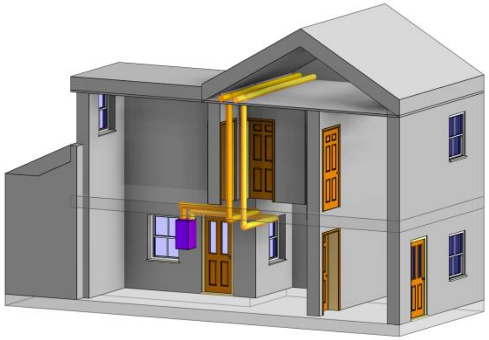
	• The shorter branch lengths should improve response times to heat demand. • The solution means that faults are easier to detect and much simpler to repair.	
Future flexibility	• No direct impact on the future flexibility of the system. • It is noted that if external wall insulation was also installed as part of the works, it would reduce the heat demand of the properties, increasing the potential for a lower temperature network and increasing the range of input heat sources e.g. efficient heat pumps. In addition, the insulation and its cladding would remove the need for boxing and so lower the cost of this solution.	0
Attractive to Users & Investors		
Attractiveness to Users and Investors	The key issues identified are as follows • The solution may be seen as being too visually intrusive to users and reducing the value of their property. • The solution is only viable to Investors if there is agreement amongst all owners to allow pipes to be installed even if the DH supply is not taken. This means a higher marketing risk than for the conventional approach. • It is anticipated that there is reduced disruption time as street excavation is avoided which allows quicker installation.	-1
Reduced Complexity		
Complexity	• The solution has reduced complexity as there is a reduction in the need for trenching where ground conditions and location of existing services cannot be exactly determined in advance. • An accurate pre-construction survey could be carried out with all parts pre-fabricated using standardised products – tees, fixings etc. • However, individual agreements will need to be reached with each householder to provide permission for pipes to be installed on their property that supply other houses, with long-term rights for access to maintain the pipes irrespective of whether a heat supply is taken. Although standard forms of agreement will be used the process may be time consuming.	0
Health, Safety and Environmental Impacts		
HSE	• Rapid and straightforward installation with avoidance of safety risks of trenching work, less dust and noise, no landfill, less transport of materials. • Risks remain from working at height on front or rear elevations however these risks are well understood and relatively low if suitable platforms are used.	+1
Opportunity to scale		
Scope of opportunity	• This solution can be applied to Typologies C to E. However, if the detached houses are too far apart the pipe bridge is too expensive and so the solution is most suited to terraces or closely spaced semis (Typology C and D).	-1

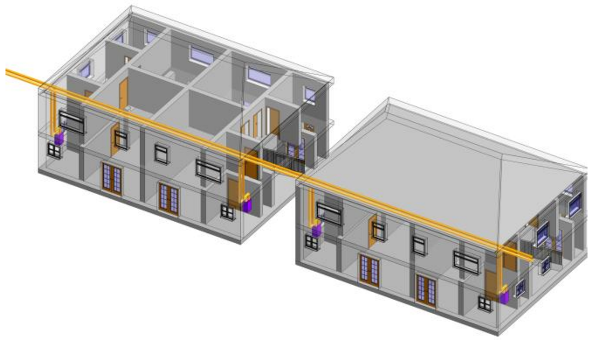
Increased Revenue		
Potential for synergies	• The solution could incorporate a duct for communications cabling, within the boxing on the wall and within the pipe bridge. For areas where high speed broadband could most easily be supplied with new cabling this could be a significant benefit. The potential for this enhanced revenue has not been included.	0
UK plc external Stakeholder Value		
Value for the UK	• There would need to be policy change to enable this solution. There would need to be either a significant financial incentive or regulation so that all properties in a given street would be required to allow the external pipework to be installed and ideally to also connect to the district heat network. • In terms of jobs, there would be a reduction in civils work compared to the conventional solution. • Although the concept could be used outside of the UK, specific exports of products are unlikely as the components needed are readily available in local markets. • There is no explicit additional CO_2 saving from this solution.	-1
Technical feasibility		
Technical feasibility	• Whilst the concept is straightforward, in comparison with conventional DH installation, there will be some minor reduction in technical feasibility associated with installing the piping across the front of the house and the associated pipe bridge and allowing for different dwelling characteristics.	-1
Effort to Implement Solution		
Effort	Estimates of effort as follows • Investment capital and research required: £500k- £2M for both a development phase and a demonstration project • Level of technological innovation (uncertainty), technology readiness level: TRL 8-7 • Anticipated timescale to the point where the solution is delivering value: 18 months to 3 years. • Likelihood of success – qualitative assessment (probable, possible, unlikely): Probable	+1
Other		
Any additional equipment required	• No additional equipment required as the solution uses standard components for pipes and fittings. However, it is possible that as a result of further development specialised tools or fittings may be developed.	
Barriers	• No additional barriers identified. • The concept has already been published by Paul Woods et al and so does not raise IP issues.	

Solution name:	**Loft Space / Cellar Route**	Evaluation Rating
Name of evaluator(s):	Tristram Royce, David Ross, Andrew Cripps, Paul Woods	
Solution ID:	4	
General		
Description of solution	To avoid the costs of installing DH pipes down the centre of roads this solution proposes the routing of the small-sized DH street level pipework through unused spaces within the buildings themselves. This could be either utilising the 'dead-zone' often found within loft spaces (i.e. the eaves, where the sloped roof and ceiling joists meet) or within cellar or basement spaces. All building-to-building interfaces would be core-drilled and fully fire and acoustically sealed. All pipework routed through properties would be clad and contained so as to minimise issues surrounding heat loss, accidental damage and fire-rating issues. The solution, where appropriate, could be combined with improving roof insulation as part of a package of work This solution was generated as complementary to the district heating wall solution (RR/1) and has the benefit of less visual impact. The original intention was to apply this to terraced homes only. However, this comprises one typology only (typology C) and thus has limited impact in reducing overall DHN costs. As a result, this solution has been expanded to typologies D and E which include semi-detached and detached homes through the use of a pipe bridge between the houses. This would allow pedestrians and vehicles to pass under this as required, allowing greater pipework continuity and a greater number of buildings to be served, without multiple level changes and minimising branching.	
How the solution was identified	This idea was presented by Paul Woods at an initial Stage 2 workshop on the 4th July. It is based on his general knowledge of potential routing options.	
Capital cost		
Change relative to baseline CAPEX	Costs of the DH **Network** • The cost of excavation, backfilling and reinstatement for the street main and branches to each dwelling is avoided. These costs have been removed from the cost model for this solution. • Although there are two main pipes, one for each side of the street, the diameters will be smaller and the	

length of branches from them is reduced.

- There is additional cost for drilling through external and internal walls, and modified costs in each case for the connection to the HIU, which must pass through a different route to reach the HIU. In addition, for typologies D and E there is a requirement to construct a pipe bridge from home to home.
- To inform these changes in CAPEX costs, AECOM produced and costed an outline design for the modification from the baseline scenario. These are shown for Typologies C and D in the figures below. The lengths and number of joints and walls to be drilled through were derived from these models and a similar version for Typology E





- The following costs were applied to estimate the cost of this solution, based on information from the AECOM QS:
- Boxing in, support structure (trays, mounts etc.), making good: £100/m (£35 material, £65 labour, £0 plant, based on 1.76 labour hours).
- Core drilling and make good (int. wall): £100 (£2 material, £98 labour, £0 plant, based on 2.6 labour hours).
- Core drilling and make good (ext. wall): £140 (£30 material, £110 labour, £0 plant, based on 3 labour hours).
- Cut through ceiling, floor, make good: £90 (£0 material, £90 labour, £0 plant, based on 2.35 labour hours).
- Fire-stopping and internal drilling between properties: £150 each (£60 material, £90 labour, £0 plant, based on 3.3 labour hours).
- Pipe bridge: £250 per m (£160 material, £80 labour, £10 plant, based on 2.1 labour hours and 2 hours hire of a cherry picker).
- Handheld power tool plant costs are included in the overhead for labour.

- It is possible that some additional features may need to be considered to minimise the risk of leaks that might cause damage to property, this might include leak detection systems linked to automatic isolating valves or pipe in pipe pre-insulated systems to provide a further protection. These enhancements have not been included in the cost estimates at this stage.

Note these costs are probably high as these are not standard installations; cost savings from optimisation are likely to be achievable.

Costs of the DH **System**

- No additional change in CAPEX has been assumed.

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£1,038	£0	0.0%
C	£1,706	£1,413	£293	17.2%
D	£3,871	£3,494	£377	9.7%
E	£4,113	£4,043	£70	1.7%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£42,956	£2,234	4.9%
Total system Capex	£62,602	£60,368	£2,234	3.6%
Dense village Capex, no prelims	£3,641	£3,160	£481	13.2%
OPEX	£3,320	£3,310	£10	0.3%
TOTEX non-discounted	£184,090	£181,606	£2,484	1.3%

This solution only applies to Typologies C, D and E. With the current costs there is large saving from Typology C, and a significant saving for Typology D. The main differences here are due to the cost of the pipe bridges needed for typologies D and E, with E also having more external walls to drill and make good, and more pipe bridges.

	Additional sensitivity analysis was undertaken to assess the impact of households within a street opting out from this solution. This analysis is presented after this solution form. It shows that for typologies C, D and E, it would require 8%, 3% and 0.5% respectively of households to opt out for there to be no net savings based on a lifecycle cost assessment. This reflects additional capital costs in routing around the households that opt out and a loss of income from heat sales. In particular this suggests that typologies D & E do not appear viable unless 100% participation (or at least consent for routing) can be achieved.	
Certainty of outcomes		
Certainty of outcomes	• The avoidance of civils work means that the associated uncertainty of working around buried services with unknown ground conditions is removed. • The solution is only viable if there is agreement amongst all owners to allow pipes to be installed even if the DH supply is not taken. This means a higher marketing risk than for the conventional approach. • It also raises uncertainty on market risk if it is seen to be too intrusive. • The need to gain access to the house on the planned day will be important, so this solution is a little more uncertain than the DH Wall solution where most of the work is external to the property	0
Operational cost		
Change relative to baseline OPEX	Costs of the DH **Network** • OPEX on heat losses will reduce because the branch length from the roof main to the HIU is much shorter, but the pipes are above ground in the loft so losses per m will increase slightly in winter and be less in summer. In addition there are two mains down the street (on each side within the lofts) of smaller diameter rather than one. Overall a small reduction in heat losses is expected, but this is not significant and so has not been estimated. • Repair costs will be lower than for buried pipe as the pipe is more accessible however the risks of damage to above ground pipe are greater than for buried pipe. In both cases repair costs are very low so have not been estimated. Costs of the DH **System** • No additional change in OPEX has been identified	
System performance		
Impact on DHN performance	• The thermal efficiency of the network should improve slightly through lower heat losses as a result of reduced pipe length as described above, but this has not been quantified. • System reliability should improve as there is reduced risk of failure as pipes are less subject to third party damage from work within the road or corrosion from ground water. • The pipe bridge solution may bring operational risks if not designed with care e.g. third party damage (e.g. repairs to fabric, fixing of satellite dishes etc), impact on existing building structures from expansion.	+1

	• There is a risk of damage to the pipes from residents working on the loft space. • The shorter branch lengths should improve response times to heat demand. • The solution means that faults are easier to detect and much simpler to repair. • On balance the DHN performance will be enhanced.	
Future flexibility	• No direct impact on the future flexibility of the system	0
Attractive to Users & Investors		
Attractiveness to Users and Investors	The key issues identified are as follows: • The solution may be seen as too intrusive to users and reduce the value of their property. • Some homes may have been modified in a way to make this impractical to deliver, e.g. some loft conversions (although in most cases a route close to the eaves in a space typically used for storage is likely to be feasible). • The solution is only viable to Investors if there is agreement amongst all owners to allow pipes to be installed and access to be provided even if the DH supply is not taken. This means a higher marketing risk than for the conventional approach. • It is anticipated that there is reduced disruption time as street excavation is avoided which allows quicker installation.	-1
Reduced Complexity		
Complexity	• The solution has reduced complexity as there is a reduction in the need for trenching where ground conditions and location of existing services cannot be exactly determined in advance. • An accurate pre-construction survey would need to be carried out with all parts pre-fabricated using standardised products – tees, fixings etc. • The survey would also need to assess access and the need to move personal property. Particular issues will arise where there is a loft or basement conversion. • However, individual agreements will need to be reached with each householder to provide permission for pipes to be installed within their property that supply other houses, with long-term rights for access to maintain the pipes irrespective of whether a heat supply is taken. Although standard forms of agreement will be used, the process may be time consuming.	0
Health, Safety and Environmental Impacts		
HSE	• Rapid and straightforward installation with avoidance of safety risks of trenching work, less dust and noise, no landfill, less transport of materials, no hot works etc • However, other safety risks arise from working in a restricted space and the need to take materials and tools through a property and up a ladder to the loft. • There is a risk from working at height to install the pipe bridges between properties for which a scaffold tower will be required.	+1

Opportunity to scale		
Scope of opportunity	• This solution can be applied to Typologies C to E. However, if the detached houses are too far apart the pipe bridge is too expensive and so the solution is most suited to terraces or closely spaced semis (Typology C and D). It has therefore been assumed that 100% of terraces and semi-detached in the notional scheme can have this solution but none of the detached houses. In practice across the UK it is expected that 100% of terraces, 70% of semi-detached and 30% of detached within urban areas could adopt the solution.	-1
Increased Revenue		
Potential for synergies	• The solution could incorporate a duct for communications cabling including within the pipe bridge between houses. For areas where high speed broadband could most easily be supplied with new cabling this could be a significant benefit however any financial benefit from additional revenue has not been included. • However, no significant benefit compared to baseline where communication cabling, for example, could be included in the trench.	0
UK plc external Stakeholder Value		
Value for the UK	• There would need to be regulatory changes to enable this solution. There would need to be either a significant financial incentive or regulation so that all properties in a given street would be required to allow the pipework to be installed (and for access to be given on request) and to also be incentivised or required to connect to the district heat network. • In terms of jobs, there would be a reduction in civils work compared to the conventional solution. Although the concept could be used outside of the UK, specific exports of products are unlikely as the components needed are readily available in local markets. • There is no explicit additional CO_2 saving from this solution.	-1
Technical feasibility		
Technical feasibility	• The concept is straightforward and no particular issues identified around technical feasibility or the need for common technical standards. • The pipes are assumed to be supported by conventional pipe hangers from the roof rafters. In older property there will be a need to assess the stiffness and strength of roof timbers from which the pipes are to be suspended. The solution may be to either support at greater intervals or to support from the ceiling joists rather than the rafters. • Overall the solution has some additional technical challenges compared to the baseline.	-1

Effort to Implement Solution		
Effort	Estimates of effort as follows • Investment capital and research required: £500k- £2M for both a development phase and a demonstration project. • Level of technological innovation (uncertainty), technology readiness level: TRL 7-8. • Anticipated timescale to the point where the solution is delivering value: 18 months – 3 years. • Likelihood of success – qualitative assessment (probable, possible, unlikely): Probable.	+1
Other		
Any additional equipment required	• No additional equipment required as the solution uses standard components for pipes and fittings. However, it is possible that as a result of further development specialised tools or fittings may be developed.	
Barriers	• Although a leak in the pipework is a very low risk the consequence for damage to a property would be significant and the DH company may have to insure against this risk which would be an additional cost compared to the baseline and the DH Wall solution (this cost has not been estimated at this time).	

Sensitivity analysis on Solutions 3 and 4

Introduction and Scope

This report relates to the additional cost associated with some households not agreeing to take part in the district heating wall and loft space solutions (3 and 4).

The agreed scope for each was as follows.

For Solution 3, "District Heating Wall", conduct sensitivity analysis to assess technical impact, costs and solution benefits in the event that one or more home-owners (a) fail to sign up to take heat and/or (b) fail to provide consent for pipework routing across the property, and therefore that one or more properties need to be bypassed. Scope to comprise:

1. Set out the design changes needed to bypass one house, including sketch drawing;
2. Estimate value of lost heat sale for each property not signing up to take heat;
3. Estimate additional capex cost for bypassing each house;
4. Apply costs to Typology C, and analyse impacts on network cost, DH scheme income and therefore the benefits of the solution, as the proportion of houses either failing to sign up and/or failing to consent is increased, and in each case determine the critical point at which this solution no longer delivers any cost benefit;
5. Prepare text and table(s) to be used in Stage 2 report to take account of these findings; and
6. Agree text with ETI and update Stage 2 report (deliverable EN2013_D03).

For Solution 4, "Loft Space / Cellar Route", conduct sensitivity analysis to assess technical impact, costs and solution benefits in the event that one or more home-owners (a) fail to sign up to take heat and/or (b) fail to provide consent for pipework routing across the property, and therefore that one or more properties need to be bypassed. Scope to comprise:

1. Set out the design changes needed to bypass one house, including sketch drawing, for each of Typologies C, D and E;
2. Estimate value of lost heat sale for each property not signing up to take heat;
3. Estimate additional capex cost for bypassing each house;
4. Apply costs to Typologies C, D and E, and analyse impacts on network cost, DH scheme income and therefore the benefits of the solution, as the proportion of houses either failing to sign up and/or failing to consent is increased, and in each case determine the critical point at which this solution no longer delivers any cost benefit for each Typology;
5. Prepare text and table(s) to be used in Stage 2 report to take account of these findings; and
6. Agree text with ETI and update Stage 2 report (deliverable EN2013_D03).

Solution 3: District Heating Wall

One of the key concerns raised about this potential solution is that there is a likelihood that some homeowners or residents will not want to connect to the scheme. Unless powers are available to force them to take part this could lead to additional costs for the scheme. These could impact on the scheme in two ways:

- Consumers permit the DH pipes to run on the wall of their property but do not contract to take the heat. This would result in a loss of income, but no additional network costs. In fact there would be a small saving in cost as the internal works and branch connection would not be needed in that house. This will have a small impact on the network financial case - equivalent to what would happen in the base case if one customer opted not to join the scheme.

- Consumers do not agree for the pipe to run across the front of their house and also do not take the heat. In this case the pipe route needs to be diverted off the front wall to below ground, away from the building line to the public space, along the street to bypass the 'missing' house, and then back to the house line to continue the system.

The second scenario is the more important as the additional costs are significant. The implications for the pipe route is shown in sketch form below. It is noted that if many homes chose to opt out the impact of additional bends would need to be accounted for in the design because of the additional pressure losses. The use of large radius bends might be appropriate in some cases, but generally if just a few customers opt out the impact of additional bends on overall pressure loss for the scheme will be very small.

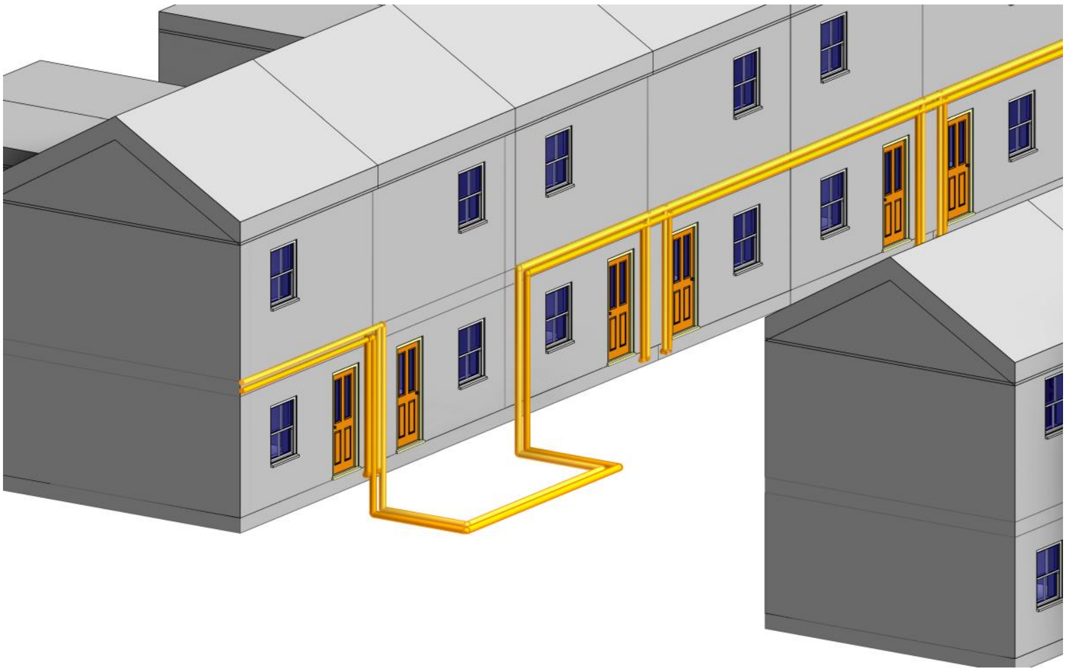
The analysis below considers the second scenario only, as this is the worst case, and is in two parts:

Firstly, an analysis of the additional capital costs to determine the point at which the additional costs for houses that do not agree to the route offset the potential saving in cost from employing this solution.

Secondly, a life-cycle cost analysis that takes account of the loss of net income from heat sales as well as the additional capital cost, again to determine the point where there is no net benefit from using the solution.

It has been assumed that the comparator is a street where there is 100% take-up of heat and the only reason for the owner to opt out of the scheme is because of the proposed DH Wall route.

Typology C (terraced houses) has been analysed as the solution was found to offer a significant saving for this typology but not for the others.



Analysis of capital costs only

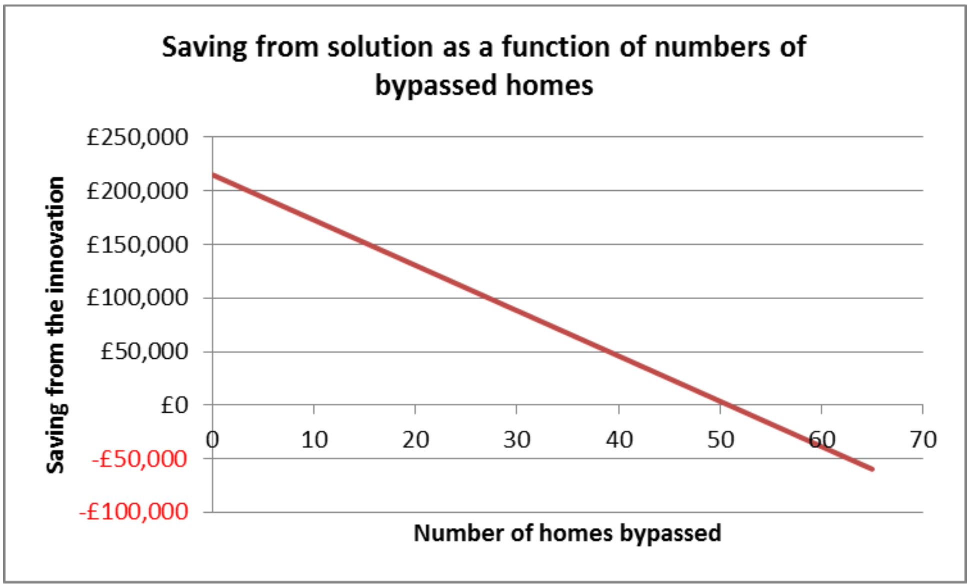
The following estimates have been made from the dimensions in this drawing of the additional requirements in terms of components external to the home to divert the pipe route and their expected typical cost.

Item	Number / length	Rate	Sub-total
Trench (m)	9	£381	£3,425
Pipe (m)	11	£268	£2,949
Bends	6	£463	£2,777
Fittings	-1	£863	-£863
Pipe 25mm (m)	-2.5	£90	-£225
Boxing in (m)	-4	£170	-£680
Total			£7,383

However, in addition, there is a saving within each house which would apply to any house that chose not to opt in. This covers the internal pipe work, its fitting and the HIU. The cost per house for this in the model is £3,158.

Hence the net additional cost is £7383 - £3158 = **£4,225** for each house that refuses to have pipes routed across the property.

The original analysis of the District Heating Wall solution estimated a saving of around £214k within Typology C. This typology consists of 200 houses assumed to be within 4 terraced streets of 50 houses each. On this basis, if more than 51 or 26% of non-contiguous houses were to refuse to have pipes routed across the property then this solution would no longer deliver a capital cost saving. This represents a worst case; if several homes in a row did not allow access then the impact would be slightly reduced. The graph below shows this point where the saving reduces to zero just above 50 homes out of the 200 in Typology C.



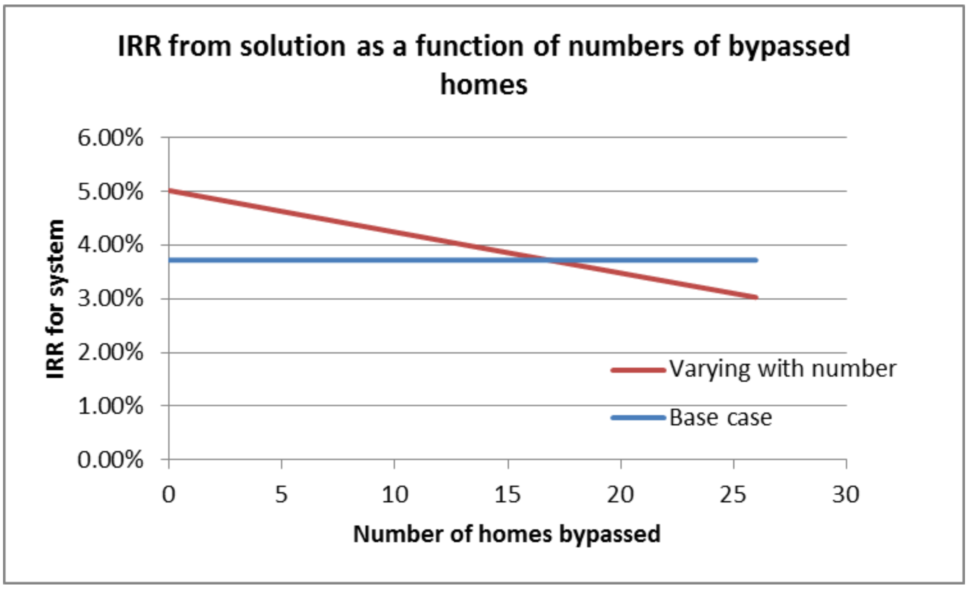
It is worth noting that the model has a cost in Typology C of around £8500 per house in the base case, and just under £7500 in the District Heating Wall solution.

Life-cycle cost analysis

A comparison on the basis of capital costs is not sufficient to establish the impact on the project financial case as each house lost to the scheme results in an expected loss of heat sales of 9.4MWh (the assumed heat use in the cost model), with a value of just over £500 per year as well as a typical £250 per year standing charge. This is partly balanced by reduced operating costs for producing the heat, maintenance and metering and billing.

To estimate the impact of this loss of income, a simplified model has been applied of the life cycle cost of a portion of a network. In this model, the District Heating Wall solution is assumed to give an IRR (Internal Rate of Return) of 5%. In the same model the base case solution is modelled, with the same operating cost but the higher capital cost. This gives a lower IRR, in this case 3.7%. This model was then used to see how many houses have to refuse routing to return the IRR to the same level of 3.7%, taking account of both the increase in capital cost and the loss of income from heat sales. In this case the result is that if 17 houses out of 200 opted out the IRR would reduce to 3.7% with no net benefit.

This is shown in the figure below with the IRR reducing from the 5% level to the base case outcome around 17 homes.



<u>Solution 4: Loft Space / Cellar Route</u>

For this solution, Typologies C, D and E were each modelled as they all showed savings against the base case, although Typology E was more marginal. In each typology it is assumed that the base case involves 100% connection and the reason for opting out is only because of the proposed route. It is assumed that where individual properties opt out and need to be bypassed these properties are not adjacent to each other as this is a worst case assumption and for small numbers opting out is also the most likely scenario.

The case where the owner allows the pipe route through the loft space but does not take heat has not been analysed as the impact will be marginal and the scenario appears unlikely.

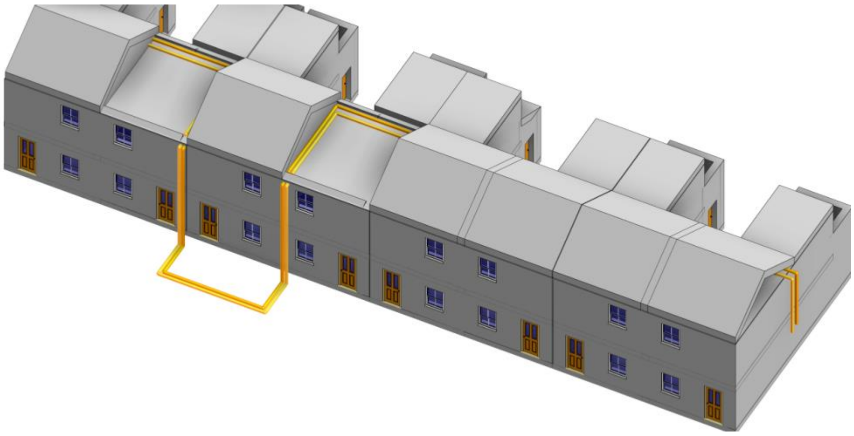
The solution in each typology is slightly different reflecting its layout. The analysis is based on the loft space route, as this is expected to be the more widespread application. The impact on the cellar route is expected to be similar but the additional costs would be lower.

The analysis for each typology is in two parts:

Firstly, an analysis of the additional capital costs to determine the point at which the additional costs for houses that do not agree to the route offset the potential saving in cost from employing this solution.

Secondly, a life-cycle cost analysis that takes account of the loss of net income from heat sales as well as the additional capital cost, again to determine the point where there is no net benefit from using the solution.

Typology C: Terraced Home



Capital cost analysis

In the loft space solution the expectation is that the run of pipes is towards the back of the house, for shorter access to the connection point, typically where the boiler was before. This means the route to by-pass the opted out house must do the following:

- turn 90^o to the route to reach the front of the house
- exit the house through the eaves if possible
- drop down the front of the house into a trench dug in the pavement or front garden of the neighbour
- move far enough from the house line to safely dig a trench along the pavement
- reverse the process to re-enter the next home via the eaves

It should be noted that this process brings considerable extra disruption to the neighbours of the opted out house.

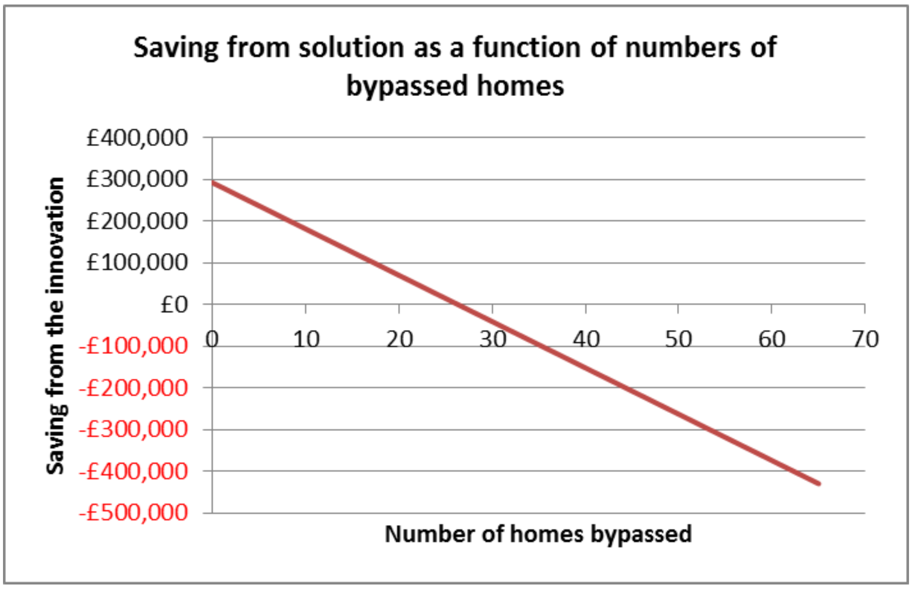
This process, based on the dimensions used through the project, results in the following expected changes.

Item	Number / length	Rate	Sub-total
Trench (m)	9	£381	£3,425
Pipe (m)	27	£268	£7,238
Bends	8	£463	£3,703
Fittings	-1	£863	-£863
Drill through eaves	2	£140	£280
Boxing in within loft (m)	7	£100	£700
Total			£14,482

However, in addition, there is a saving in cost for any house that chose not to opt in. This covers the internal pipe work, its fitting and the HIU. The cost per house in the loft space solution in the model is £3,375.

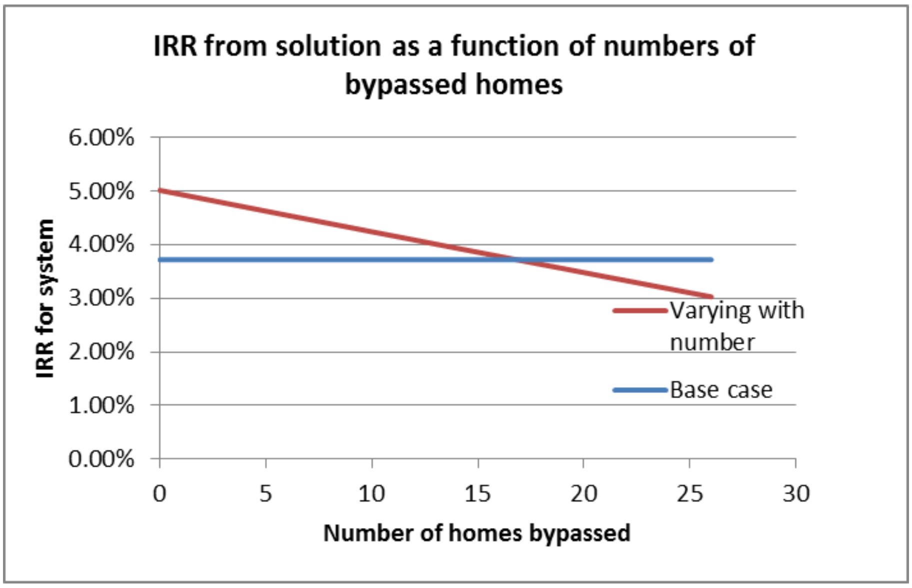
Hence the net additional cost to the scheme is £14,482 - £3375 = **£11,107** for each house that opts out of joining the scheme.

The original analysis of the Loft Space solution estimated a saving of around £293k within Typology C. This consists of 200 houses assumed to be within 4 terraced streets of 50 houses each. On this basis if more than 26 or 13% of houses were to opt out then this solution would no longer deliver a capital cost saving. This is shown in the graph below.

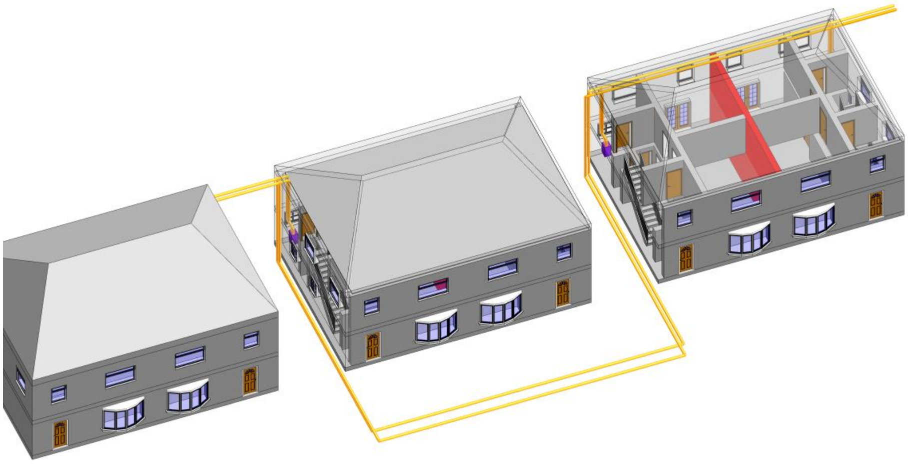


Life cycle cost analysis

As for the DH Wall case the analysis has been extended to include the impact of loss of heat sales income from the houses that do not connect. Each house lost to the scheme results in an expected loss of heat sales of 9.4MWh, with a value of just over £500 per year as well as a typical £250 per year standing charge. This is partly balanced by reduced operating costs for producing the heat, maintenance and metering and billing. The results show that if more than 15 houses were to opt out (7.5%) then there would be no overall saving.



Typology D: Semi Detached



Capital cost analysis

In the case of the semi-detached layouts, modelling has been undertaken based on the right hand of the middle pair of houses opting out. On this basis the work needed is as follows:

- enter the left hand side of the building - just to supply that house but no continuation across its loft
- add a tee-piece within the pipe bridge
- drop down to ground level and enter a trench dug from the side of the last connected home to the street. In the model this is costed at an intermediate rate between hard and soft dig
- continue the trench along the pavement to the next pair of houses
- return to the line of the pipes near the back of the homes and continue with the solution

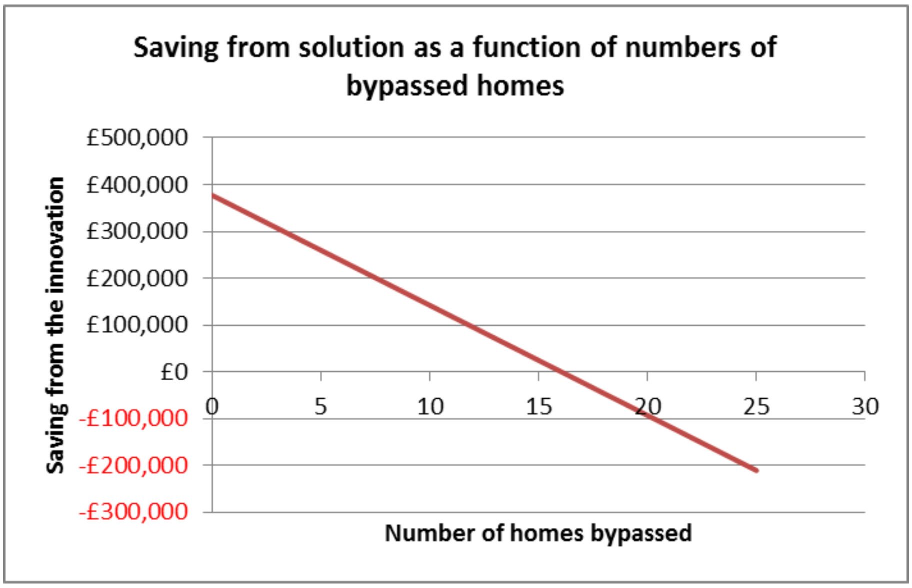
Taking into account a number of elements which are no longer needed, particularly one pipe bridge, the estimated additional costs are presented in the table below.

Item	Number / length	Rate	Sub-total
Trench intermediate (m)	30	£263	£7,896
Trench hard (m)	18.5	£381	£7,040
Pipe (m)	43	£268	£11,527
Bends	5	£463	£2,314
Fittings	0	£863	£0
Internal wall drilling	-1	£150	-£150
External wall drilling	-1	£140	-£140
Pipe bridge (m)	-5	£250	-£1,250
Boxing in loft space (m)	-7	£100	-£700
Total			£26,537

However, in addition, there is a saving within each house which would apply to any house that chose not to opt in. This covers the internal pipe work, its fitting and the HIU. The cost per house in the loft space solution in the model is £3,039.

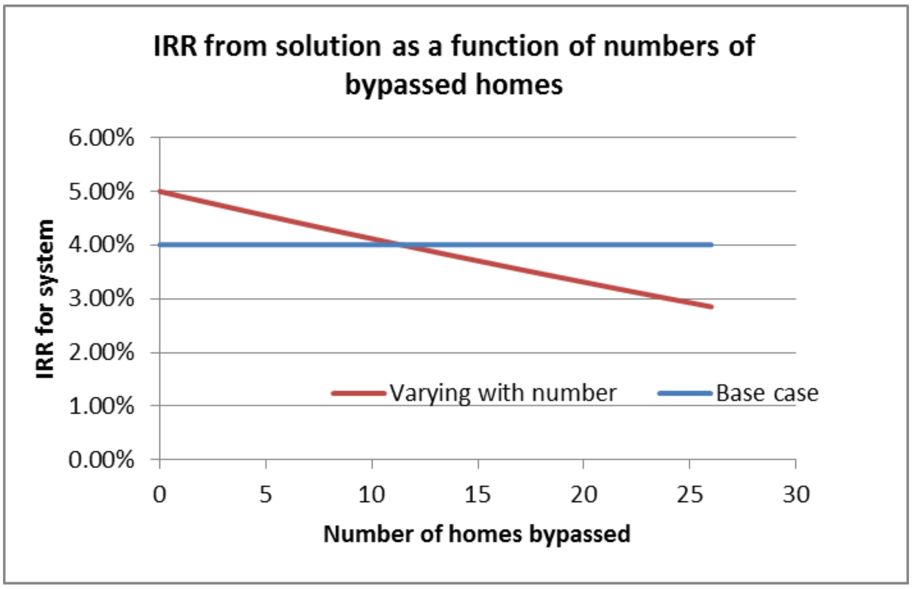
Hence the net additional cost is £26,537 - £3,039 = **£23,498** for each house that opts out of joining the scheme.

The original analysis of the Loft Space solution estimated a saving of around £377k within Typology D. This consists of 400 houses. On this basis if more than 16 or 4% of houses were to opt out then this solution would no longer deliver a capital cost saving. This is shown in the graph below

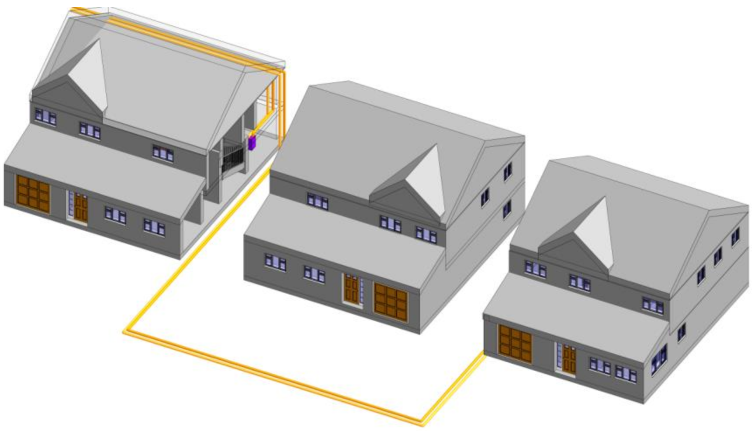


Lifecycle cost analysis

To estimate the impact of loss of income, a simplified lifecycle cost analysis has been undertaken similar to that discussed for the District Heating Wall Solution. Each house lost to the scheme results in an expected loss of heat sales of 13.9MWh, with a value of just over £750 per year as well as a typical £250 per year standing charge. This is partly balanced by reduced operating costs for producing the heat, maintenance and metering and billing. The results show that if more than 12 houses were to opt out (3%) then there would be no overall saving.



Typology E: Detached



Capital cost analysis

In the case of the detached layout, modelling has been undertaken based on the diagram above. On this basis, the work needed is as follows:

- serve the house to the left in the normal way.
- drop down to ground level and enter a trench dug from the side of the last connected home to the street. In the model this is costed at an intermediate rate between hard and soft dig
- continue the trench along the pavement to the LHS of the house beyond the opted out one
- return to the line of the pipes near the back of the homes and continue with the solution

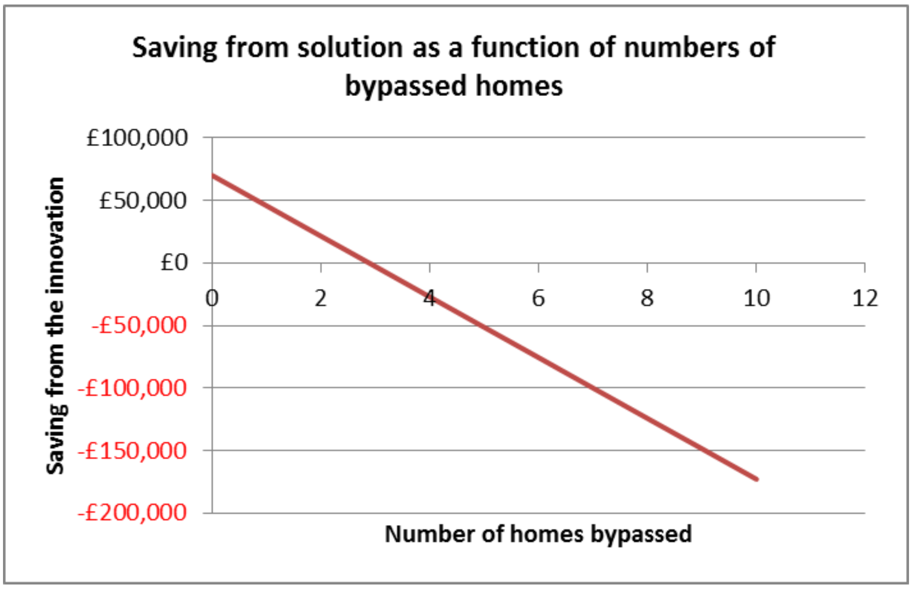
Taking into account a number of elements which are no longer needed, particularly two pipe bridges, the estimated additional costs are presented in the table below.

Item	Number / length	Rate	Sub-total
Saved tee	-1	£863	-£863
Trench intermediate (m)	36	£263	£9,475
Trench hard dig (m)	19	£381	£7,230
Pipe (m)	49	£268	£13,135
Bends	6	£463	£2,777
Fittings	-1	£863	-£863
External wall drilling	-2	£140	-£280
Pipe bridge (m)	-8	£250	-£2,000
Boxing in loft space (m)	-11	£100	-£1,100
Total			£27,511

However in addition there is a saving within each house which would apply to any house that chose not to opt in. This covers the internal pipe work, its fitting and the HIU. The cost per house in the loft space solution in the model is £3,235.

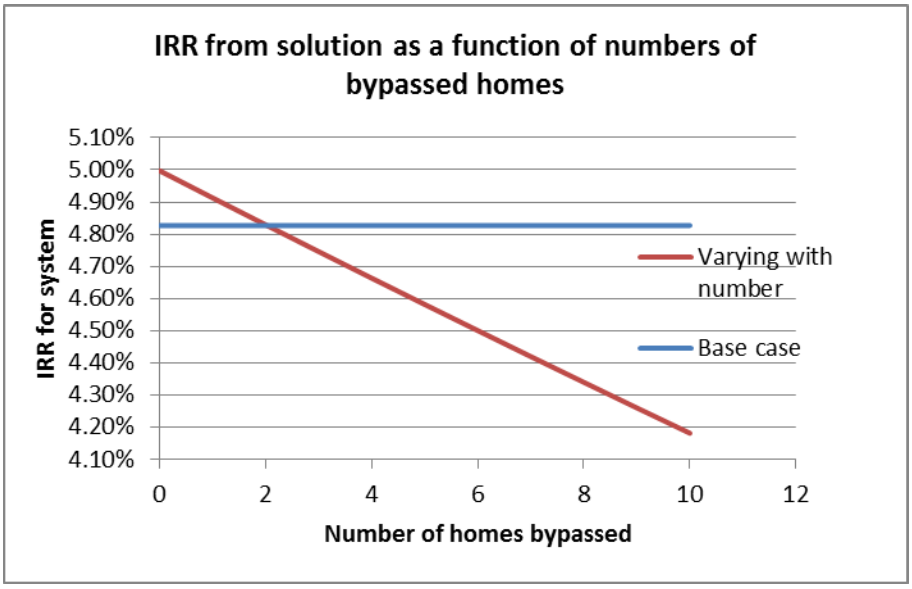
Hence the net additional cost is £27,511 - £3,235 = **£24,277** for each house that opts out of joining the scheme.

The original analysis of the Loft Space solution estimated a saving of around £70k within the Typology E. This consists of 400 houses. On this basis if more than 3 or 0.75% of houses were to opt out then this solution would no longer deliver a capital cost saving. This is shown in the graph below.



Lifecycle cost analysis

To estimate the impact of loss of income, a simplified lifecycle cost analysis has been undertaken similar to that discussed for the District Heating Wall Solution. Each house lost to the scheme results in an expected loss of heat sales of 19.8MWh, with a value of nearly £1100 per year as well as a typical £250 per year standing charge. This is partly balanced by reduced operating costs for producing the heat, maintenance and metering and billing. The results show that if more than 2 houses were to opt out (0.5%) then there would be no overall saving.



Summary of all Solutions

The following table summarises the key findings from the life cycle cost analysis as this approach represents the impact on a business case for adopting the solution. This shows the percentage of houses that need to opt out for no net savings across the solutions and typologies. The smaller percentages for typologies D and E reflect the longer additional lengths of pipes and trenching to bypass the house that has opted out.

Option analysed	Typology	Saving per home of the measure	Extra cost per home of a diversion	% of houses to opt out for no net savings
District Heating Wall	C	£1,075	£4,225	9%
Loft Solution	C	£1,465	£11,107	8%
Loft Solution	D	£943	£23,498	3%
Loft Solution	E	£175	£24,277	0.5%

The conclusion of this study is that the savings from the DH Wall and loft space solutions in Typology C appear relatively robust. The solutions' benefits have sufficient margin and/or insensitivity to some properties refusing consent to the proposed routes for the solution to remain valid.

However the loft space solution in Typology D & E, by contrast, do not appear viable unless 100% participation (or at least consent for routing) can be achieved. This primarily reflects the longer connection lengths involved in the bypass option. These typologies were also less attractive for this solution in the original calculations.

<table>
<tr><td>Solution name:</td><td>Trenchless Solutions</td><td rowspan="3">Evaluation Rating</td></tr>
<tr><td>Name of evaluator(s):</td><td>David Ross, Tim Hall, Andrew Cripps, St.John Ager</td></tr>
<tr><td>Solution ID:</td><td>5</td></tr>
<tr><td colspan="3">General</td></tr>
<tr><td>Description of solution</td><td>This is a cluster of solutions that fit together. The main aim is to reduce the costs of civil engineering where possible by replacing trench excavation with trenchless approaches.

<u>Main street</u>

The approach is to use Horizontal Directional Drilling (HDD) that combines a specialist piece of steerable underground drilling equipment with an electronic walkover detection system.

• Excavation pits are formed at, say, 100m distance apart – the ‘entrance’ and ‘receiving’ pits.
• A pilot bore is first drilled with a radio sonde located near the bore head. The drill is steered, supported by the walkover detection system, along the planned bore path.
• Once the pilot bore is installed, a reamer is pulled back from the receiving pit to open the bore hole to a larger size. It may be that more than one pass is required if the pipe to be installed is large.
• On the last reamer pass, the district heating pipe will be pulled in directly behind the reamer on an attachment. This could be a single twin-core pipe or multiple pipes can be attached. It is possible to also include, for example, a pipe or duct for another utility to share costs.
• The flow and return pipe can be separately attached to the reamer on the last pass, reducing the pipe diameter and increasing flexibility.

It is noted that both the pilot bore and reaming require the use of a drilling fluid to act as a coolant for the control of temperature on the radio sonde, transportation of bore cuttings to the exit pits and lubrication to reduce friction when pulling in the pipe or ducting – the fluid is generally bentonite, a polymer or both. A vacuum tanker will be needed (daily) to remove the inert drilling fluid and soil.

It is assumed that plastic pipe is used – hence relatively simple and quick to do long lengths, ideally from a 100m reel. Polyethylene (PE) pipe is successfully pulled in HDD applications in the water sector and there are limited development examples used in European DHN installation. There is a risk that significant damage could be caused to the DHN pipe through pulling it behind the reamer although research [UKSTT] shows that stone scratches are very limited in HDD applications where the reamer is necessarily larger than the pulled</td><td></td></tr>
</table>

	pipe. The worst case is where 'pipe bursting' is used (not suggested in this proposal) and here scratch depths are limited to 7-10% of typical pipe wall-thickness which is deemed to be acceptable to National Grid. Currently 180mm is the largest diameter of uninsulated pipe which can be installed from a reel [UKSTT]. For insulated pipe this will be reduced further, but trials have not been conducted to establish the size limit. Note that the vast majority of the pipework in the baseline network is small or medium bore plastic, where long lengths can be provided without welds. Pulling steel DHN piping has the potential, in particular, for the welds to be damaged when pulling the pipe in the last reamer pass. Casing sleeves can be provided to protect the joint. It is noted that steel pipes also have the disadvantages of needing an exit pit of the same length as the pipe (likely 12m) and space to weld connections below ground, with associated safety implications. Two alternative solutions were identified that, for completeness, have been captured here. • Instead of increasing the specification of the existing pipe, an additional pipe liner could be pulled through with the last reamer pass followed by the operating pipe as a second stage. The pipe liner is a relatively cheap product sold by pipe suppliers. However, this has cost and installation speed implications, likely to be greater than the durable pipe option. Including the additional time to pull through the operating pipe and the need to cut through the pipe-liner for making branch connections to the house and for future access. This approach has been used in Scandinavia [Logstor], but where a very high degree of outer casing integrity is specified. The use of liners for gas or water piping replacement is reducing in the UK as confidence in the process and integrity of pulled pipe in stony ground increases [UKSTT] • The project team have also considered inserting un-insulated plastic pipes into the pipe-liner and spraying in insulation, such that the pipe-liner now forms the outer wall of the pipe system. This option is intended to overcome the limited flexibility of larger diameter pipes (100mm insulated pipes are expected to be the largest insulated pipes usable on a reel). As yet it is unclear whether this will result in a net cost saving compared to factory produced insulated pipework which may then need to be installed in lengths as described for steel pipe. There are other trenchless dig techniques that can be used, but Horizontal Directional Drilling allows the key element of steering the path. With other techniques, the contractor points broadly in the correct direction at the start. However, depending on the resistance along the path, the final location can vary significantly both in terms of depth or position from that originally intended. This increases the risk of hitting known obstacles as well as not following the network route down the street.	

	Street to house This approach is built as a combination of the 'core and vac' technique (e.g. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/383712/tal-2-14-core-and-vac.pdf) and directional drilling. Again there are alternatives to directional drilling – in particular 'moling' is commonly used, which is a forced displacement solution used over shorter distances and the equipment is significantly cheaper (more than an order of magnitude less than HDD) and requires smaller teams to operate than conventional trenching, saving labour costs. However, the equipment is not steerable and may require more than one pass to achieve the correct path (thus offsetting the potential labour cost saving) with increased risk of hitting obstacles in its path. This solution is widely used in the gas and water sector for replacement of domestic connections. Further developments have been made recently to use steerable drilled solutions (mini-HDD) giving a keyhole option. The proposed process is as follows: i. An initial "keyhole" is created above the DH pipeline running down the street. This is achieved through first cutting a circular plug of up to 1.5m in diameter in the road surface using a core bore unit. A vacuum extractor is then applied which excavates the soil down to the DH pipeline. This technology is currently available and has been applied in the UK over the last few years to, for example, maintain utility pipes - guidance on this technology is provided by the Government (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/383712/tal-2-14-core-and-vac.pdf). ii. Long handled tools would need to be developed to drop down through the "keyhole" and make a connection between branch pipe and street pipe. For example, SGN and Tracto-technik are currently developing a tool to be inserted down a "keyhole" to allow connection and disconnections of gas pipework to support a pipework replacement programme (https://www.sgn.co.uk/iCore/iCore-What-are-we-doing/) iii. Something akin to the Grundopit mini directional drill rig (http://www.tracto-technik.com/GRUNDOPIT-Keyhole-230.html) is then placed inside of the keyhole. This rig contains drilling rods which are pivoted into the bore direction (assumed upwards from the street pipe to the building) and driven to create a pilot bore hole to the building. This creates the hole for the pipe to be pulled through. Currently, the maximum outside diameter pipe that can be applied is 90mm and further research would be needed to roughly double this pipe diameter assuming a plastic twin-pipe solution. The manufacturer of the current product agrees it is feasible subject to further development and sufficient demand. An alternative solution has been taken for costing purposes which is a separate drill for the flow and return pipes i.e. two separate drills of 90mm are used in the cost model for each street to home connection. iv. An excavation pit (or further keyhole) is required outside the property. This has two purposes: Firstly, the	

pipe to be installed is anchored to an oversized reamer at the end of the drill rod, which is pulled back through the hole dragging the pipe along back to the main street pipe. The pit also allows connection between the branch pipe and the pipe network in the building. For buildings with cellars or basements the need for this pit is eliminated as the bore emerges directly within the building.

v. The keyhole is re-filled with the excavated soil, the soil compacted during re-fill, and the previously extracted asphalt core is fixed back into place using a special mortar. The keyhole has the added benefit of more reliable and durable road reinstatement than traditional techniques.

This approach is applied to connect from the street main to individual properties along the length of the street. It is assumed that the keyhole in (i) can be used to branch to houses in several directions e.g. in a terraced street, branches may connect to four houses – two on each side of the road. (In the cost model two connections per keyhole are assumed to take a cautious approach).

- Based on advice from UKSTT It is proposed that trenchless technology will not be applied to Typologies A (City Centre – Commercial) and B (High Density Residential - Flats) as most are subject to high densities of subsurface utilities, increasing the potential for hitting underground objects as well as challenges in navigating a suitable route. In addition to underground utilities, inner cities may be built over historical structures. Experienced equipment providers and contractors cannot envisage trenchless solutions becoming viable in heavily congested city centres. However, if at some point, a mechanism for using such solutions was developed for the primary network: a similar 10% saving might be achievable, reducing the total DHN cost by a further 1.5%. This would also have a major impact on the renewal costs of all pipeline infrastructure in city centres.
- Trenchless technology is less suitable to be applied to Typology C (High Density Residential – Terraced Housing). This is because of the shorter main to home connections, the potential need to excavate both a ‘keyhole’ per two homes and a connection hole per home. It is expected that either the district heating wall or loft solutions would be more cost-effective for typology C.
- For the purposes of demonstrating the potential value, the following analysis assesses the savings from trenchless technology fully applied to Typologies C, D and E. These typologies account for >90% of the baseline piping.

It is noted that despite better surveying upfront, there is still a risk of hitting an obstacle. As part of research for this solution, a relevant research project called ‘Orfeus’ was identified with the aim of inserting GPRS into the drill-head of Horizontal Directional Drilling equipment. It comprised two consecutive European-funded research projects (http://www.orfeus-project.eu/ and http://orfeus.org/). Key challenges included the development of robust electronics to survive the significant vibration inherent in the drilling process, as well as coping with heat build-up as the drill string goes through the ground. A member of the Orfeus team confirmed

	the intention that Orfeus would be commercially deployed but the price is currently commercially sensitive and could not be shared. The expectation is that the additional cost of the 'Orfeus' solution will be significantly less than £100k/unit. It is unlikely to need an additional site operator as someone is already present to control the direction of the drill bit and the GPRS output could be another part of the computer dashboard. The cautious cost estimate has been accommodated in the cost model and the £100k (max.) figure contrasts with current GPRS equipment with software which can be purchased for £9-15k (e.g. http://surveyequipment.com/detection-safety/ground-penetrating-radar/).	
How the solution was identified	The original idea of using trenchless technologies was identified in Stage 1 of the project. This solution was developed in Stage 2, particularly through discussions with: • Don Wilkinson, Tracto-Technik – A company which develops specialised trenchless technology equipment, including participating in research projects directly with clients (e.g. with SGN as above) as well as European funded projects (such as Orfeus). • Matthew Izzard, Vice Chairman of the UK Society of Trenchless Technology (UKSTT). When Matthew was originally approached he was also Trenchless Technology Manager for Vermeer UK but moved to Tracto-Technik. In his role in the UKSTT, he provided a broader picture of trenchless technology and potential solutions. • Simon Conroy, Conroy's Group – Contractors who specialise in civil engineering, trenchless solutions and extraction including Horizontal Directional Drilling.	
Capital cost		
Change relative to baseline CAPEX	**Central Case** Critical costing assumptions for trenchless solutions: • Target street drilling rate using HDD will be 100m / day – but with geography, street layouts and a level of aborted drills due to ground conditions an assumed average of 30m / day. • Trenchless Capital equipment to a value of £1.9M purchased (including the cost of the GPRS), operated by the DHN delivery contractor directly and used for 40 days /year. (1x HDD Rig, 8x Core machine, 2x Vacuum excavator, 8x Keyhole drilling rig.) • Capital assets depreciated over 3 yrs + (typically) 20% of CAPEX Operating expense per year. • Street to House: 3 keyhole cores vacuum excavated, drilled from the street-main to the house and pits reinstated each day. For the purposes of the Central Case cost model Trenchless solutions have been applied to 50% of Typology C (Terraced) and fully utilised across Typologies D & E. The significant savings below are based on directly operated construction assets, scheduled to be in use one day per week over 40 weeks. An alternative of using specialist contractors on a 'spot hire' basis would be a multiple of the cost.	

Further research and pilot projects will give a more accurate picture of whether trenchless solutions are viable in approaching 100% of situations.

Trenchless, Central (100% applicability in D&E, 50% C) Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£1,038	£0	0.0%
C	£1,706	£1,706	£0	0.0%
D	£3,871	£3,329	£543	14.0%
E	£4,113	£3,467	£647	15.7%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£2,380	£1,368	36.5%
Total DHN Capex	£45,190	£40,358	£4,832	10.7%
Total system Capex	£62,174	£57,771	£4,832	7.9%
Dense village Capex, no prelims	£3,641	£3,435	£206	5.7%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£179,258	£4,832	2.7%

With the **Central Case** potentially delivering a 10.7% saving across the DHN on its own this solution looks to be compelling.

The **Optimistic Case** stretches the applicability of trenchless technology to the maximum level that industry experts will support without testing and significant product development. Changes to the cost summary are based on

- 100% applicability to Typology C as well as typologies D & E.
- Also higher productivity per day (4 core - house drills / day vs. 3).
  This requires less machinery and labour to achieve the installation of the pipe network.
- Street drilling using HDD is assumed to be more productive achieving an average of **40m** per day in this optimistic case (vs. 30 m/day in the Central case).
- Higher productivity means that less Trenchless Capital equipment is required. Reducing plant capital to a

value of £**1.5M**

- The equipment is operated by the DHN delivery contractor directly and used **50** days /year. (1x HDD Rig, **6x** Core machine, **1x** Vacuum excavator, **6** x Keyhole drilling rig.)

Trenchless, Optimistic (100% applicability in C,D&E) Typology	NETWORK COSTS		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£1,038	£0	0.0%
C	£1,706	£1,643	£62	3.6%
D	£3,871	£2,825	£1,046	27.0%
E	£4,113	£2,923	£1,191	28.9%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£2,020	£1,728	46.1%
Total DHN Capex	£45,190	£36,955	£8,235	18.2%
Total system Capex	£61,489	£54,368	£8,235	13.4%
Dense village Capex, no prelims	£3,641	£3,056	£585	16.1%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£176,037	£8,053	4.4%

However with the uncertainty of applicability to ground conditions in crucial residential areas and a need for confirmation of the modelled levels of asset productivity and utilisation, a more **Pessimistic Case** is prudent. This takes a cautious approach reducing the applicability of Trenchless solutions to 50% of pipework in Typologies D & E only. Also making an estimate of 20% higher operating costs as a result of reduced success rate for drilling (i.e. increased number of re-drills required to achieve the desired path).

Trenchless, Pessimistic (0%application in C, 50% D&E) Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£1,038	£0	0.0%
C	£1,706	£1,706	£0	0.0%
D	£3,871	£3,573	£298	7.7%
E	£4,113	£3,764	£350	8.5%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£2,740	£1,008	26.9%
Total DHN Capex	£45,190	£42,473	£2,717	6.0%
Total system Capex	£62,174	£59,886	£2,717	4.4%
Dense village Capex, no prelims	£3,641	£3,492	£149	4.1%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£181,555	£2,535	1.4%

At the **Optimistic Case**, where the number of cores per day approaches the level achieved in the best examples of water and gas industries [National Grid]; there is potential to deliver an **18.2%** cost saving across the DHN with this solution alone.

Even the **Pessimistic Case,** which is expected to achieve **6.0%** reduction in DHN costs overall, makes a significant impact in Typologies D & E which are currently the areas of the DHN network least likely to be viable on a cost per connection basis.

This warrants road-mapping and significant further research and development.

Certainty of outcomes

Certainty of outcomes	Particularly with the use of Orfeus, and the advantage of HDD in being able to steer around obstacles, there should be greater certainty of civils costs. Furthermore, there should be a significantly shorter programme of work compared to the standard approach of trench digging and reinstatement.	+2
Operational cost		
Change relative to baseline OPEX	No impact on OPEX – although the equipment developed for the solution will enable cost-effective connections after the initial commissioning.	
Lifecycle costs		
Change relative to baseline lifecycle costs	No additional costs assumed for the wider DH system	
System performance		
Impact on DHN performance	It is not envisaged to significantly impact on DHN system performance. Although the civil engineering and pipe-laying is undertaken by an alternative approach than standard; the performance of the eventual system is expected to be the same.	0
Future flexibility	Where DHN connection is not mandatory, this approach allows for the pipe to be laid down the main street and homes to then be connected relatively easily and quickly when they sign up to district heating. This is an advantage for the solution although costings are based on mandatory connection. In principle, a conventional trench digging could connect each home to the main pipe down the street when the home signed up. However, this would be more time consuming and of greater disturbance to the occupant.	+1
Attractive to Users & Investors		
Attractiveness to Users and Investors	It is considered that trenchless technology would be particularly attractive to the user. It should result in significantly less disruption both from a shorter excavation time and avoiding digging a trench from the road to the front of the property and then making good.	+2
Reduced Complexity		
Complexity	No significant change in complexity is envisaged.	0
Health, Safety and Environmental Impacts		
HSE	This approach should greatly reduce the need for site staff to enter trenches.	+2
Opportunity to scale		

Scope of opportunity	It is currently envisaged that this approach would be applied fully to Typologies D and E only, though these two typologies account for more than 80% of the baseline network piping. However, research may prove that there are limitations on the use of the solution reducing the proportion of each typology which can benefit from the solution. This may be conservative. As part of future research, it would be valuable to look to identify whether costs can be reduced for Typology C as compared to District Heating Wall and Loft solutions (see initial Description). Furthermore, there may be specific parts of routes through Typologies A and B where trenchless technology is suitable and beneficial on a case by case basis. Once the technology is proven and widely adopted, the opportunities to scale in other DHN applications will increase.	0
Increased Revenue		
Potential for synergies	This solution provides the opportunity for significant synergy in that other utility pipes, for example, can be connected to the reamer in its final pass. It is noted that the baseline approach of conventional trench digging also allows additional utility pipes to be installed. Hence, there is not a significant improvement upon the baseline.	0
UK plc external Stakeholder Value		
Value for the UK	Trenchless technology is already available worldwide and no major manufacturers are UK based. The need for some new specialised equipment has been identified and this may provide the UK with development potential and, in future, opportunities in overseas markets.	0
Technical feasibility		
Technical feasibility	Trenchless digging is currently applied today in other sectors but requires proving for DHN delivery. Some of the trenchless technology equipment identified is still subject to development but is considered feasible i.e. continuation of current product developments rather than something radical.	-1
Effort to Implement Solution		
Effort	• Investment capital and research required: £2M- £5M (+2). This particularly relates to product development as well as standardising upon the most robust and cost-effective process. • Level of technological innovation (uncertainty), technology readiness level (TRL 6-5) (+2). Whilst there is some technology development needed, it is not considered to be radical but builds upon existing solutions. • Anticipated timescale to the point where the solution is delivering value: 2-5yrs (+2) • Likelihood of success: probable (+1)	+2
Other		

Any additional equipment required	Equipment development has been discussed above. In summary, this includes the following: • Long handled tools would need to be developed to drop down through the “keyhole” and make a connection between branch pipe and street pipe. • A larger diameter mini directional drill rig to connect between the street mains and the home • GPRS installed in the HDD drill head (desirable, but not essential for solution deployment)	
Barriers	No significant barriers considered	

Solution name:	**Improved Front-End Design and Planning**	Evaluation Rating
Name of evaluator(s):	David Ross, Paul Woods, Rob Boyer, Andrew Cripps	
Solution ID:	6	
General		
Description of solution	This is a cluster of solutions that fit together. The main aim is to improve processes prior to on-site construction, particularly around the detailed design of the network route to reduce delays on-site and increase site productivity. This is achieved through improved survey and design techniques and a modified procurement strategy that allows the front end design to be fully developed using the appropriate level of expertise. <u>Current approach</u> At an early stage in the process, the network developer agrees a contract sum with a contractor for the works associated with civils and pipe-laying. This is needed to assess the viability of the scheme. It is based on an outline network design, which can simply be a route line on a map between heat source and buildings with limited route optimisation and knowledge of underground conditions. As a result the contractor needs to price risk into the contract based on many unknowns, in particular in relation to underground services and other buried features or obstructions related to the historical layout and use of the site. Contract negotiations between the network developer, and commonly the local authority, can be lengthy (e.g. around commercial and legal issues). During this period, typically no detailed design is undertaken by the developer as there is the risk that the heat network may not be implemented, e.g. due to commercial issues or changes in central or local Government energy policy, and hence the network developer wishes to minimise any additional cost until the Energy Supply Agreement is signed. Energy Supply Agreements typically have a fixed Operational Start Date for heat supplies to commence and may contain penalties for delays. Funding including grants may have specific time limits by which the money must be spent. Hence, once signed, there is immediate pressure on delivery (albeit few of the actual delivery risks will have been identified). Hence, whilst more detailed design work is undertaken prior to construction, it is typically limited in terms of its scope. Furthermore, it is a specialist activity and may not be carried out to high enough quality and thoroughness. The consequences of this are typically delays and reduced productivity throughout the excavation process where, for example, unknown underground services or other obstructions are identified, resulting in delays in	

	redesigning pipe routes, transporting pipework from abroad if special fittings are required and gaining any permissions if needed. The additional costs incurred may be covered by the Contractor but often these lead to claims for additional costs which will add to the total costs of the project and there will be further costs in considering and negotiating the claims. All of these costs feed into the general level of costs in the industry. This is particularly an issue with installing rigid pipe in areas with a high level of complexity and density of existing services. Even where plastic pipes are used, although these are more flexible, there is still potential for inefficient working and additional costs unless the design is fully defined and proven in advance of construction. Solution This solution contains four inter-related strands: 1. Improving the process by which designs are produced and contractors appointed to allow more detailed design work to take place prior to agreeing a price for the work The traditional contractual process needs to be modified such that there is greater focus up-front on efficient project delivery. In particular, more detailed design work should be undertaken which will afford better planning and higher productivity. There is clearly benefit to both the client (e.g. the local authority) and the network developer to implement this work properly e.g. lower costs, affords better traffic management planning. It is assumed that there is no additional cost associated with an improved process itself – indeed there could be cost savings if the commercial and legal negotiations can be shortened as part of the solution. The new contractual process might involve appointing one or more contractors early to carry out the design or support the design process with the contractor(s) then also asked to tender at a later stage. The development costs are therefore higher than in the current approach. This is often difficult to justify as it is seen as investment at risk until there is a final decision to proceed with the network. This risk would be reduced if there was a stronger policy in favour of district heating - say in particular zones of a city – so that any front end design investment would be considered a valuable investment to reduce costs rather than an investment at risk and hence something to be minimised as far as possible. In addition, alternative contractual frameworks should be considered. It is most common for a fixed-price contract to be agreed with the contractor where the risk is accounted for, at least to some degree, in a higher price. Alternative approaches, such as a target-cost contract with a pain/gain sharing mechanism, may be better. This form of contract is intended to drive a collaborative approach to seeking lower costs which benefits both parties and is more common in other utilities e.g. the water industry.	

	2. More comprehensive survey and detailed design work is necessary up-front. <u>Scope of works:</u> It is proposed that the scope of works would include the following activities. This may be subject to future refinement and detail. (i) Provide early design and dimensioning of alternative route options based on accurate plan view of the area, with involvement from a contractor (ii) Overlay plans from of utility service providers (gas, water, electricity) of their existing underground infrastructure (pipes, cables etc) over the route options to help select preferred route(s) (iii) Desk top study to gain insight into history of the site. This includes identifying, for example, any defunct buried structures (e.g. tunnels, bridges, foundations, previous buildings) and any issues around the ground conditions (e.g. if contaminated) (iv) Site reconnaissance to identify physical features that support the existence and location of utilities and other buried risks within the survey area. (v) Underground surveying (e.g. Ground Penetration Radar) and 3D post-processing to enable the production of a 3D model which identifies and tracks both the services shown on the C2 drawings and identified unrecorded utilities and other adverse buried issues. (vi) Detailed design of the route. A 2D route design will be produced which will ideally run in the areas clearest of services, with involvement of a contractor. (vii) Trial holes to provide further investigations before breaking ground. Assuming the above activities are undertaken, the location of trial holes can be better targeted and minimised compared to current practice, particularly to establish pinch points/complexity, and in locations where there could be a bank of ducts and the depth of the service at this point is critical. (viii) There will be benefits of 3D design of certain parts of the route, for example to modify the network depth to avoid other services. (ix) (It is noted that PAS 128:2014 “Specification for underground utility detection, verification and location” provides further details of the approach to be undertaken on some of the above activities related to buried utilities). <u>Quality of works:</u> Each activity highlighted above needs to be undertaken both comprehensively and accurately. Furthermore, the information needs to be integrated together to build a complete map of the underground and design the network route. In the discussions with DH practitioners, all have particularly highlighted the need for involvement of someone with significant experience in civils works, with anecdotal evidence of cases where this has not happened and resultant delays and route redesigns. This expertise can be from the network developer, a specialist third party DH design company or the contracting	

	organisation itself (an example was given of a contractor being employed to undertake the initial design work prior to competitive tendering of the main civils works). In addition, a solution identified in Stage 1 was to develop an underground map of all existing utilities to support the design process. For example, this map could be maintained independently or with the data shared between utilities. This would modify the scope of works above and could result in some upfront design savings (expected to be of the order of £100-300k based on current design costs). This saving in development time and cost upfront would be expected to make it more likely that the necessary front-end design work would be carried out. It is noted that there is currently significant activity in this space. For example: (i) the EPSRC project "Mapping the Underworld" is looking into the feasibility of a multi-sensor location tool, mapping and position data integration to yield a single repository for records, and RFID tags to assist future pipe location, (ii) a standard is currently being developed to improve the collection and storing of data related to buried assets as well as the sharing of this information (PAS 256 "Buried services – Collection, recording and sharing of location information data – Code of Practice"), (iii) the Greater London Authority (GLA), as part of its Smart London Infrastructure Network, recently held a competition to link together utilities and smart technology organisations to help the utilities to accurately identify the position of their own and others' underground assets and/or determine their condition (http://smarterlondon.co.uk/news/competition-winners-pitch-tech-innovations-to-map-londons-utilities-underground/#more-1105) and (iv) Ordnance Survey's 2016 Geovation challenge is looking to support business ideas to address the biggest challenges of the utility industry in managing their underground assets including better mapping of utilities below ground (https://www.ordnancesurvey.co.uk/blog/2016/10/going-underground-geovation/) 3. Obtaining consents to carry out the work earlier Complementary to better design is obtaining appropriate permissions in a timely fashion. This includes obtaining all upfront permissions such as the Section 50 traffic management plan (http://www.legislation.gov.uk/ukpga/1991/22/section/50). It also includes developing good communication routes with the local council and other utilities at an early stage to quickly address any unexpected issues identified whilst excavating e.g. during one site visit there was a delay due to a significant underground void being identified adjacent to the trench which, whilst not affecting the DH works themselves, needed to be rectified prior to reinstatement. It is assumed that there is no additional cost in implementing this part of the solution – these activities will typically happen but often not in a timely fashion resulting in delays in delivery.	

	4. Better resource management Improvement to up-front design and obtaining permissions early affords better management of staff on-site. Currently, if there is a delay, contractor staff will be standing idle which adds to costs unless a contractor is able to deploy staff elsewhere on the same site or on another project. This solution should enable greater certainty of works and encourage contractors to look at ways to employ staff more efficiently e.g. if there is greater certainty as to the route of the network, the contractor could start at both ends and meet in the middle which would significantly reduce the site 'preliminaries' (site staff, site accommodation and facilities, fencing, lighting dewatering pumps etc). The potential benefit would increase for larger developments – e.g. installing DH across a whole district of a city - where there is a greater number of activities and thus potentially efficiencies can be gained through better front end planning.	
How the solution was identified	This solution originated from many separate discussions with DH practitioners who highlighted the need for greater project risk management through better front end design and ensuring that the necessary permissions are obtained early. This solution was developed based on a series of discussions, as well as desktop studies. • Discussions with three contractors (CPC civils, PT contractors, Trent Energy) • Discussions with an ENGIE site manager • Discussion with specialist in network route designs (3D Technical Designs) • Discussion with specialist in underground mapping (Technics) • The civils ECCR event which, in particular, included DH practitioners from AECOM, ENGIE, CPC civils and 3D Technical Designs • Discussion with Cowi • Two site inspections in the UK and one in Denmark	
Capital cost		
Change relative to baseline CAPEX	In order to predict the potential savings associated with improved design, a separate model has been prepared of the costs of trenching which has built upon the series of discussions with contractors listed above. This model contains three elements: • A fixed element reflecting a base cost for any trenching work • An element relating to materials that depends on the width and depth of the trench, and the cost of disposing of materials and replacing them with new aggregate • A speed related element for labour and plant, that uses a figure for the average number of metres of	

trench dug per day for a normal gang.
- Note that each typology assumes a different percentage of hard and soft dig. This solution speeds up hard dig – soft dig is significantly faster already.

The trench model has been adjusted to give a reasonable fit to the costs that have been used previously in the main cost model, and provided by contractors.

The base case assumes a depth of 1.8m for trenches and the following rates of excavation for hard-dig:

Trench width (mm)	500	750	1000	1500
Rate per day (m)	7	6	5	4

<u>Central Case</u>

The following key assumptions have been made:
- It has been assumed that improved process, design and surveying and obtaining necessary consents up-front (solution components 1 to 3) will result in a significant increase in the excavation rate per day. This was based on feedback from 3D-technical design (a design team with significant experience in commercial projects from working previously at Engie) and three contractors (CPC Civils, Trent Energy, PT Contractors). In the discussion, the example taken was a 1.8 depth trench at 1m wide. Three of those interviewed estimated 100% increase in excavation rate. One contractor estimated only a 20-30% improvement, albeit the contractor suggested that their current dig rate was significantly higher than the other two contractors. For the purpose of the central scenario, a 70% increase in excavation rate was taken based on 3 of the 4 consulted estimating a 100% increase and derating somewhat as the improvements may not be fully realised in practice.

This results in the following improved rates for hard dig:

Trench width (mm)	500	750	1000	1500
Rate per day (m)	12.612	10.210	7.88	6.16

In addition, it has been assumed that better front end design would further improve efficiencies by minimising prelims. As an illustration of the benefits, cost savings have been derived based on two teams working simultaneously starting from opposite ends of the trench. This would effectively half the time-related element

	of the pre-lim costs as the overall programme duration for a given site would be halved. Currently, contractors would typically start at one end only as there is uncertainty as to underground obstacles and the potential need to change the route during the dig would make multiple start points a high risk of abortive work. However not all of the prelim costs will reduce proportionally (e.g. whilst the site compound may only need to be used for half of the time, it will likely need to be a larger size as greater work is being undertaken in parallel) so it is assumed that only 20% of the time-related element of the prelim costs are saved. <u>Pessimistic Case</u> It has been assumed here that the benefits in the Central Case have been reduced by one half. Whilst the feedback on improved excavation rates has been received from experienced contractors, it is possible that there is some bias in the feedback and it is noted that one contractor assumed a significantly smaller improvement. Furthermore, whilst the solution involves significantly greater effort upfront on surveying and obtaining consent approval, it is expected that some issues will still arise which will result in a delay to the project and not fully achieving the improved rates estimated in the Central Case. <u>Optimistic Case</u> This accounts for the additional benefits in being able to excavate at shallower depth for part of the route. The current approach is to both quote for and excavate to a depth of 1.8m to try to avoid obstacles. However, with better knowledge of the underground, it would be possible to plan to excavate for a shallower depth for part of the route and only dig to 1.8m (or deeper) where obstacles are identified. The flexibility of plastic or corrugated steel pipes aids this solution in more easily varying the depth of the excavation. Furthermore, as most of the pipework in the streets is within the less dense residential neighbourhoods, the density of other utilities would be expected to be less too. The assumption here is that 50% of the route remains at 1.8m and 50% of the route is now 1.5m depth. This is particularly based on discussions with 3D Technical Design who suggested that 80% of the route at 1.5m may be feasible. In addition, CPC civils confirmed that a significant proportion of the route could be shallower if the underground was well mapped beforehand. (Modelling was also undertaken with 50% at 1.8m and 50% of the route at 1.2m, which achieved a further ~1% DHN CAPEX reduction). The resultant extraction rate for hard-dig is shown below. This improvement was based on discussions with the contractors, and results from the reduced material to be extracted and replaced, and reduced requirements for shoring as a result of the shallower depth.	

Trench width (mm)	500	750	1000	1500
Rate per day (m)	16.1	14.4	12.7	11.7

All cases

The additional costs for doing the work to prepare the improved design have been estimated at around £305k. These have been included in the total system cost below. This is based on the following.

- Based on approximate rates provided by 3D-Technical Design, it has been estimated that detailed design services would be around £90k. However, some of this work would already have been undertaken currently and hence the additional cost has been estimated at around half of this.
- The number of trial holes depends on various factors. It has been assumed that a trial hole is required every 100m on average for the scheme. Given a street length of approximately 17km and a cost per trial hole of £2,800 (from Engie), this gives £840k. Again, it is assumed that some trial holes have been undertaken currently and hence the additional cost has been estimated at around half of this.
- An estimate was provided of £3500 per 1.5km for GPR surveys (Technics). Based on 17km length, this equates to £40k. Again, it is assumed that some GPRS is undertaken currently and hence the additional cost has been estimated at around half of this.

<u>Overall results</u>

The results of the Central Case are given below:

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,793	£160	8.2%
B	£1,038	£1,025	£13	1.2%
C	£1,706	£1,509	£197	11.5%
D	£3,871	£3,566	£305	7.9%
E	£4,113	£3,748	£365	8.9%
Primary Network	£6,476	£6,277	£198	3.1%
Prelims	£3,748	£2,344	£1,404	37.5%
Total DHN Capex	£45,190	£41,240	£3,950	8.7%
Total system Capex	£62,602	£58,653	£3,950	6.4%
Dense village Capex, no prelims	£3,641	£3,292	£349	9.6%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£180,323	£3,768	2.1%

The results of the Pessimistic Case are given below:

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,873	£80	4.1%
B	£1,038	£1,032	£6	0.6%
C	£1,706	£1,607	£98	5.8%
D	£3,871	£3,719	£152	3.9%
E	£4,113	£3,931	£183	4.4%
Primary Network	£6,476	£6,376	£99	1.5%
Prelims	£3,748	£3,046	£702	18.7%
Total DHN Capex	£45,190	£43,124	£2,066	4.6%
Total system Capex	£62,602	£60,537	£2,066	3.4%
Dense village Capex, no prelims	£3,641	£3,466	£175	4.8%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£182,024	£2,066	1.1%

	The results of the Optimistic Case are given below: (table follows)	

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,699	£254	13.0%
B	£1,038	£1,019	£19	1.8%
C	£1,706	£1,468	£238	13.9%
D	£3,871	£3,507	£364	9.4%
E	£4,113	£3,677	£437	10.6%
Primary Network	£6,476	£6,151	£325	5.0%
Prelims	£3,748	£2,020	£1,728	46.1%
Total DHN Capex	£45,190	£40,222	£4,968	11.0%
Total system Capex	£62,602	£57,634	£4,968	8.1%
Dense village Capex, no prelims	£3,641	£3,221	£420	11.5%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£179,304	£4,786	2.6%

Certainty of outcomes		
Certainty of outcomes	This solution is considered to have the following significant benefits • Much greater confidence in the civil engineering costs which is the largest and most uncertain component of the DHN CAPEX • More certain and shorter programme of work through greater front end design and planning.	+2
Operational cost		
Change relative	No expected significant change in operational costs	

to baseline OPEX		
Lifecycle costs		
Change relative to baseline lifecycle costs	No significant change in lifecycle costs other than the CAPEX costs reported above	
System performance		
Impact on DHN performance	This solution should make civil engineering and pipe laying more efficient. It is not expected to impact on DHN performance.	0
Future flexibility	This solution is not expected to impact on future flexibility.	0
Attractive to Users & Investors		
Attractiveness to Users and Investors	The significantly greater certainty of outcomes should similarly be significantly attractive to Investors. Users will be attracted by a shorter programme of work and thus less disruption.	+2
Reduced Complexity		
Complexity	The greater certainty and ability to plan ahead, should significantly reduce the complexity in managing operations.	+2
Health, Safety and Environmental Impacts		
HSE	Through improved underground surveying, it should be possible to undertake shallower dig for at least part of the route. This would reduce the risks associated with working in trenches and minimise the amount of material transported.	+1
Opportunity to scale		
Scope of opportunity	This approach should be beneficial to all heat networks. It is most beneficial where civils is a greater proportion of the cost and/or where traffic management costs are higher. As can be seen from the cost analysis, significant cost savings have been identified for four of the five typologies.	+2
Increased Revenue		
Potential for synergies	On its own, this solution is not envisaged to substantially increase revenue through synergies with other works. There may be some benefit in a clear, shorter programme in terms of encouraging sharing of civils etc.	0
UK plc external Stakeholder Value		
Value for the UK	This approach is not considered to have export potential – other countries such as Denmark already have greater focus on upfront design and planning. Greater resource efficiency could result in job losses. However, this is balanced by greater attractiveness to Investors and Users which should lead to more developments taking place.	0

Technical feasibility		
Technical feasibility	In general, the technical approach suggested can be applied today. The exception is the availability of a multi-utility underground map. PAS 128:2014 "Specification for underground utility detection, verification and location" provides various options and information is also included in the Heat Networks Code of Practice. It is worth reviewing with industry that Best Practice is agreed and clearly defined.	+1
Effort to Implement Solution		
Effort	The estimated effort is as follows: • Investment capital and research required: £500k - £2M. The overall solution needs relatively little technical development. There would be additional costs (and benefits) to the utility industry as a whole in developing an underground map. In addition, a more standardised contractual framework would help maximise the value of this solution, including standardised scopes of work for each stage of the design process. (1) • Level of technological innovation (uncertainty), technology readiness level: TRL 8-7. This takes account of some quasi-technological development required in the systems to map the underground in a useable manner, and so insofar as TRL applies, the technical solution is not fully proven through completed missions. (10) • Anticipated timescale to the point where the solution is delivering value: 18 months – 3 years. This solution should deliver value is less than 18 months through developing case studies to demonstrate in more detail potential cost savings and developing any additional technical guidance needed. To maximise the value of this solution, there is the need for a more standardised contractual framework as highlighted above which will take longer (potentially more than 3 years). This would benefit from Government and Local Authority Leadership including, ideally, a stronger policy in favour of district heating so that any front end design would be considered a valuable investment. A middle timeframe has been proposed here. (1) • Likelihood of success – qualitative assessment: It is expected that there is a high likelihood ("probable") of delivering significant value. However, maximising the value here would be expected to require central	+1

	Government and local authority leadership which is less certain. Hence, an overall rating of “Likely” (2)	
Other		
Any additional equipment required	None	
Barriers	Currently, the contract negotiations between the network developer, and commonly the local authority, can be lengthy and the Energy Supply Agreements typically have a fixed Operational Start Date for heat supplies to commence. Together they are disincentives to upfront design and planning. The uncertainty on whether a project will actually come to fruition means that all pre-contract costs are minimised as far as possible as it is seen as expenditure made at risk. A more certain overall development plan for DH across a city would mean a greater willingness to invest in the advanced design work. The process should be reviewed and improved upon. There should be benefits to all key stakeholders from greater upfront design and planning which reduces cost, improves cost certainty and reduces the programme of work.	

<table>
<tr><td>Solution name:</td><td>Pipe Crossings</td><td rowspan="3">Evaluation Rating</td></tr>
<tr><td>Name of evaluator(s):</td><td>Paul Woods</td></tr>
<tr><td>Solution ID:</td><td>7</td></tr>
<tr><td colspan="3">General</td></tr>
<tr><td>Description of solution</td><td>The baseline includes costs for major crossings of a railway and a canal. This is not unusual for district heating systems being constructed across densely built up areas often with an industrial history.

The cost plan assumes that there are three crossings:

• Two rail crossings using tunnels at a cost of £220,000 each
• One canal crossing using a tunnel at a cost of £840,000 (higher cost due to the depth of the tunnel)
• Total cost: £1.28m.

It is often recognised that a cheaper solution would be to utilise existing bridge structures to support the district heating pipes and this may well be explored by the design team. The main problem with this approach is usually not an engineering one but a commercial and legal one, especially given the DH company's limited leverage as a non-statutory utility (despite having to compete financially against them).

The owner of the existing bridge will not see any benefit from the installation of district heating as typically the same charge would be levied by them for an independent bridge crossing or a tunnel and in any case the DH company is unlikely to be able to pay a significant amount for the crossing rights.

As a result, the owner of the bridge often imposes onerous commercial conditions on the DH company including not only unlimited liabilities for any damage to the structure but also very high indirect/consequential liabilities such as interruption to flow of traffic or trains on the bridge. Also the owner will not guarantee the permanence of the bridge and will not compensate the DH company for costs if the bridge is removed in the future. Where there is a crossing of a road over a railway and the DH company wishes to use the road bridge as a support, consents would generally be required from two parties, the bridge owner and the railway owner. Although the likelihood of these risks are perceived as very low, the DH company is often unwilling to accept these risks and the high liabilities imposed and so building a separate bridge or a tunnel is seen as the only viable option, even though the costs of the crossings are then higher.

However, as the risks are in practice very low, an alternative approach would be for the owners of the bridge,</td><td></td></tr>
</table>

	canal, road or railway to accept a lower limit of liability from the DH company as standard practice. As all of this infrastructure is in public ownership and if local and national policy is to promote cost-effective district heating it would be reasonable for a lower limit to be agreed as a way of enabling cheaper pipe crossings. This approach is particularly appropriate where the DH company is also in the public sector as in this case the risks are being passed from one public sector body to another and in the process a more expensive crossing would result. Even where the DH company is in the private sector, the result of the more expensive crossings would be passed on either by higher heat charges to customers or in the need for a higher subsidy from the public sector through subsidy. This solution is therefore proposing an alternative commercial arrangement where the risks are as standard (i.e. not subject to negotiation and potentially onerous commercial terms as at present) taken by the owners of the existing bridges (normally within the public sector) which can be used to support the pipes. Furthermore, new bridges should include suitable ducts within design where there is a marginal cost impact.	
How the solution was identified	Experience of ENGIE on the Olympic Park has informed this discussion where new crossings have been complex to negotiate for rail and canals. However, when the pipes were installed as part of the original bridge design there were no particular technical difficulties.	
Capital cost		
Change relative to baseline CAPEX	Costs of the DH **Network** The costs of utilising existing bridge structures are estimated to be about a third of the cost of using tunnelling, a saving of £853,000 on the notional scheme. This cost has been derived from a project on the Olympic Park which reused an existing bridge to carry the pipes over a canal. As a sensitivity test, it may have been possible to reach reasonable commercial terms with one or more of the three crossings. As such the cost savings would have been less for this solution. For example, if one of the rail crossings could have been used, the savings would be reduced by around £145,000. If the canal crossing could have been used, the savings would be reduced by around £560,000. Costs of the DH **System** No additional change to DH System costs.	

Certainty of outcomes		
Certainty of outcomes	Attaching the pipes to an existing bridge has an inherently lower risk than deep tunnelling.	1
Operational cost		
Change relative to baseline OPEX	Costs of the DH **Network** No additional change Costs of the DH **System** No additional change.	
Lifecycle costs		
Change relative to baseline lifecycle costs	Costs of the DH **Network** As the pipes will be more accessible any repairs and replacements will have a lower cost than if the pipes are installed in a tunnel. Costs of the DH **System** Change only as a result of Capex change on DH network.	
System performance		
Impact on DHN performance	No change.	0
Future flexibility	No change.	0
Attractive to Users & Investors		
Attractiveness to Users and Investors	No change.	0
Reduced Complexity		
Complexity	No change.	0

Health, Safety and Environmental Impacts		
HSE	Carrying out work above ground will generally have a lower risk than above ground. However suitable access to the pipes will need to be considered where the pipes are attached to existing structures to enable maintenance work to be carried out safely.	1
Opportunity to scale		
Scope of opportunity	The issue of crossings of rail, road, river or canal is likely to occur for transmission mains in most cities.	2
Increased Revenue		
Potential for synergies	No additional potential for synergies identified.	0
UK plc external Stakeholder Value		
Value for the UK	No significant additional value identified.	0
Technical feasibility		
Technical feasibility	No significant difference in technical feasibility compared to tunnelling. Generally the solution will be technically feasible as the weights of pipes are normally much less than the design loads for the bridge - however structural surveys and checks will be needed. The most challenging route may be between the buried part and the bridge itself where substantial footings are likely at the bridge landing points.	0
Effort to Implement Solution		
Effort	The main effort is for Government, Highways Agency, Local Government, Network Rail, Canal and Rivers Trust, Transport for London and other similar bodies to agree an approach that will facilitate the use of existing bridges for the carrying of district heating pipes without imposing onerous terms and conditions and excessive costs. Risks would be underwritten by central or local Government. This is likely to take time for new policies to emerge rather than specific resources. • Investment capital and research required: <£500k (0). • Level of technological innovation (uncertainty), technology readiness level: TRL 9 (0). • Anticipated timescale to the point where the solution is delivering value: 3-5yrs (+2) • Likelihood of success: likely (+2)	2
Other		
Any additional equipment required	None	
Barriers	Main barrier relates to the difficulty of co-ordinating action amongst a large number of organisations.	

Solution name:	**Shared Civil Engineering Costs (New Network Revenues)**	Evaluation Rating
Name of evaluator(s):	Tim Hall, Paul Woods, Simon Box, David Ross	
Solution ID:	8	
General		
Description of solution	The premise for this solution is that Heat Networks are one of a range of utilities laid underground and, if the costs associated with ‘open-cut’ civil engineering of pipe trenches can be shared with other utilities, there is significant potential for cost saving. To emphasise this there is a rule of thumb in the water industry that 80% of the cost of laying a new water pipe is in the excavation and reinstatement of the carriageway and only 20% for the pipe and connections [United Utilities / Southern Water]. DHN pipes are significantly more expensive per metre (when including insulation), but Deliverable D1 and Deliverable D2 show that they still represent less than 30% of the total pipe installation cost across the residential typologies in the base case. The challenge for this solution has been to identify and evaluate mechanisms to share the costs of excavation, reinstatement, road closure and traffic management across two or more parties that have a programme of significant street-works or other underground works. Four approaches were initially identified of which, following initial evaluation, progress focussed on the first and last items. • 8/01 A contract between the DHN developer and one or more other utilities to combine the trenching costs for laying new infrastructure or upgrading / repairing existing infrastructure. • 8/02 Pre-arranged installation of ductwork by the DHN developer for sale or rent to a 3rd party on completion. Examples (without financial details) were cited [Lend Lease / National Grid] for provision of ducting for new data services, although both were linked to a full brownfield re-development rather than retrofit. Further attempts to link with digital infrastructure providers were unsuccessful and this approach was not progressed further due to a lack evidence to suggest the solution could achieve significant scale for existing buildings. • 8/03 Resurfacing alignment: Agreement with Local Authorities to offset cost of road closure with the DHN developer repairing / resurfacing the carriageway. This was identified as unviable early in the research based on the significant cost (and on-going liability) for road resurfacing compared to the savings from waived road closure. Even with additional local authority funding the synergies between carriageway paving and trenching are limited [National Grid, Options]. • 8/04 Setting up of a new business model (e.g. Joint Venture (JV) or equivalent) for the combined DHN	

	and utility network: The JV owning and managing the sub-soil infrastructure and leasing back to the two (or more) operating companies. This is a refinement of the first approach which adds an ongoing shared interest in DHN roll-out between the utility provider and DHN developer, as opposed to ad hoc contracts. The additional advantage is that further stakeholders (e.g. Local Authority or a 3rd utility) can be included in the business model to widen the impact. The precise contractual framework is beyond the scope of this analysis. The initial research made clear that there is significant potential in this area, but also a wide range of different opportunities and a spectrum of willingness to engage with the research from utilities, their contractors and partners. To develop and evaluate this outline concept, the project team focused on data and insight from a single utility [Bristol Water] which can then be tested for wider applicability. The larger water companies approached to participate (3) have indicated that they would want a more developed technical and commercial proposal before engaging further and investing time. This solution is supported by the regulatory requirement for utility companies to maintain and upgrade their networks in line with their regulators' determinations of necessary investment to achieve customer service standards. The water sector works on a 5 year Asset Management Period (AMP) and the appeal of this approach, for the water company, is the potential to both improve their Assessment ranking and increase profitability at the same time. For the remainder of this evaluation all opportunities, for combined DHN delivery with other utilities, are considered a single solution. **Key aspects of the solution are as follows:** Aligning the trenching for the installation of a Heat Network with the renewal or upgrade of water supply (in this case) provides the opportunity for a single team sharing costs of the following: • Open cut trenching and reinstatement (or the alternative trenchless technology). • Road closure costs (Local Authority Charge £300-£3000/day) [Chandler KBS / Technics]. • Traffic Management (typically £500/day) [Technics / Options]. • Site management and some aspects of Prelims cost; reducing overall time on site. • Water supply replacement projects are generally for sections of 2km in total and this aligns well with a continuous section of a DHN. [Bristol Water] • There is a significant operational benefit to water companies from optimising the network routing of a system which has been extended, in iterations, over a century or more. An optimised DHN routing can provide the opportunity to make the change which would not be viable in isolation.	

	How the solutions applies to different sections of the network: • Typology A: In City centre areas the solution helps defray the cost of road closure, which is at its greatest in certain London boroughs and other city commercial districts. However, this typology accounts for only 3% of the sub-soil pipe-laying. • Typology B: Minimal impact: connections to blocks of flats have the lowest % of street-works. • Typology C: Some impact for terraces where a loft or wall solution is not viable. • Typology D: Major impact with semi-detached properties accounting for 56% of sub-soil pipe. Early – Mid 20th Century properties in particular are likely to be at the right stage for cast iron and asbestos cement main renewal [Bristol Water]. • Typology E: Significant impact from longer pipe runs per Detached property accounting for 27% of sub-soil pipe, with clusters of older properties needing replacement of mains as above. • Primary network: Limited length at only 5% of the network and large specialist pipes coming from the energy centre, where there may not be a need for upgrading other existing utilities. However, where CHP is the energy source electrical network upgrade may be needed. • In areas suitable for trenchless technology (Solution 5) there is a major impact where a water pipe can be added to a Horizontal Directional Drilling route at minimal additional cost. **Challenges and obstacles** • The key concern for the water company is to avoid a negative impact on water quality from an increased temperature due to heat transfer from the DHN pipes. This can be achieved by higher performance insulation on the DHN pipework, which is already being promoted to reduce system heat loss. There is a need for further cost benefit analysis of the detailed water sector requirements versus the cost of providing sufficient insulation. • The OFWAT determination prescribes the sections of the network to be upgraded for a 5 year period (with some opportunity to influence / renegotiate) and so timing of the DHN delivery and planning is crucial. • Some sections due for replacement will be in areas unsuitable for DHN reducing the overlap. • There will be sections of the DHN where the water system is already modernised to a high standard and so there is no value in upgrading and no opportunity for shared costs. • Once the opportunity is agreed between the two Network Providers there is the additional complication of ensuring compliance with the 50 or more technical requirements for works in the Public Highway [National Joint Utilities Group]. • Trench installation depths may differ creating unstable working conditions for one of the service providers, but this will be resolvable with a new standard for trenching and working conditions.	

Potential further Opportunities

- In addition to pipeline replacement there is a requirement for 'renovations' to reduce leakage and improve customer service. The level of renovations is three to four times the required length for pipe renewal. If the cost of replacement, compared to renovation, can be reduced with a shared civils approach, this brings a much greater scope for potential overlap with DHN installation.
- Water companies have significant registers of 'redundant / abandoned assets' where new pipelines have been installed to increase capacity and the original pipes abandoned once the route has been switched. This gives an opportunity for a known route for DHN piping in sections of the network. The scale of such assets is considered to be 'significant' [Chandler KBS], but only quantifiable on a case by case basis. Applicability is likely to be towards the low end of a 1% to 10% proportion of the total DHN network and focused in older town and city centre locations [Bristol Water]. Further research is needed to quantify potential for specific networks.
- A suggestion from one stakeholder was to take advantage of spare capacity in water companies' drainage and sewage systems.
- Above ground assets for water pumping stations (and potentially electrical sub-stations) require less space for modern technology and are increasingly underutilised assets. There is potential to repurpose them (or parts) as DHN substations linked to HIU Sharing (amber solution). This is an unanticipated opportunity and has greater impact with solution families than shared civils alone.
- Water companies are seen as more innovative than other utilities and are working on increasing the use trenchless technologies and 'down the hole' keyhole connections and repairs to their live network; this aligns well with the trenchless technology solution (Solution 5).
- Collaboration and partnership with the Local Authority. DHNs are often driven by, or at least supported by, the Local Authority and forming a partnership with both the utility and Local Authority for DHN delivery brings potential for further alignment of street-works. Bristol Water see this as having value to help develop their relationship with Bristol City Council and are planning to organise a workshop to explore the opportunity further.

These additional opportunities are expected to be supportive of the core idea rather than generating a significant increase in the applicability for shared civils beyond the cost assessment values below.

General conclusions from the research were as follows:

- There is broad recognition of the value of shared / combined civils works across multiple utilities.
- Contractors [Clancy Docwra / Options] cited instances when they had delivered works in the same streets, within a few weeks of each other, for different utility companies.

	• Legal complexities for shared works are a major challenge to align contracts to the satisfaction of legal and operational teams of multiple parties. • With current regulatory pressure, a drive for increased sustainability in the utilities sector and greater priority given to customer service and corporate social responsibility, utilities and their contracting partners are becoming more open to innovation in their approach to street-works. • The Major Infrastructure - Resource Optimisation Group [AECOM] has infrastructure clients focusing on resource efficiency and sustainable construction. This has potential for DHNs where new infrastructure is city based (e.g. Crossrail 2) or where a DHN is looking to provide heat from a more remote source. These examples are beyond the scope of current analysis. • For the larger utility companies it has proven both difficult to find the correct individual to engage with from a research perspective and contacts approached have been reticent to share insight. The research shows that organisations across the DHN value chain recognise significant, but unquantified, potential value of shared civils. However, current consensus is that the benefits are not worth the effort to address commercial and technical challenges. This is not backed up by analysis and project findings confirm that there is merit in detailed case studies as part of the road-mapping.	
How the solution was identified	The core solution of shared street-works to reduce public disruption is clear, even becoming the theme of an iconic Heineken advert (https://www.youtube.com/watch?v=dg3StO-7zZY). The cost of the civil engineering is the most significant proportion of DHN CAPEX as shown in Stage 1 work (~40% of total DHN cost excluding pipes & fittings). This solution evaluation has taken the basic premise of reduced cost and disruption and explored the practical implications, opportunities and obstacles to shared civil engineering works. Significant contributors to the solution development, beyond the Project Team were: • Michelle Ashford – Head of Network Asset Planning, Bristol Water plc • Patric Bulmer - Head of Water Resources & Environment, Bristol Water plc • Les Guest – Former CEO, National Joint Utilities Group (NJUG) • Paul Gerrard - Strategic Street Works Manager, National Grid • David Port – Director, Options Energy Services – Specialist Utility Contractors • John Gavigan – Partner, Chandler KBS - Utility project management and cost consultancy • Werner Panton – General Manager, Clancy Docwra (Heat Network Delivery Group) • Andrew Dunn – former Director of Consumer Protection, OFWAT • Claire Hebbes – Head of Infrastructure Development, Lendlease	

	• James Bisco, Principal Consultant, Business Sustainability, AECOM • Chris Edmondson, Construction Director, United Utilities (retired)	
Capital cost		
Description of Change relative to baseline CAPEX	**Basis for the Cost Analysis** The cost analysis which follows is built on an initial top-level case study developed with Bristol Water to assess the potential value of combining DHN delivery with their regulated water network Asset Management Plan (AMP). The key data are: • Overall network length of 6,800km serving 500,000 customers. • The current AMP6 requirement is for 65km of water main replacement over the 5 year period. (This is approximately 0.2% of the network and a very low level compared to OFWAT norms which are typically 1% - giving pipework a 100yr expected life) • Budget costs for replacement are £385/m of which £250/m is attributed to labour and plant costs. • In addition there is a requirement for 230km of renovations to reduce leakage and improve water quality. These give greater scope for alignment with DHN installation, but at a lower price point. Key assumptions for the modelling: • For the Pessimistic case we assume the current low level of 65km of renewal over 5 years. An alternative is to assume the typical OFWAT 1% renewal rate per year giving higher potential: This is the Central case in the following cost analysis. • The savings opportunity is Bristol Water’s pipe renewal labour and plant cost (£250/m) less 20% for water pipe connections and any additional trenching labour. These connections are then completed by the DHN installer, using free issue pipe materials for an additional £50/m charge. • This gives a net system saving of £200/m. This is an averaged price paid by a specific water company and there will be geography and pipe size factors which influence the precise cost. • The saving is attributed 50/50% between the water and DHN installation: giving £100/m saving to each, which is sufficient to be attractive to both parties. Detailed analysis of DHN and Water network typologies will identify the most attractive location and specification opportunities. • A cautious 50% of the network is anticipated to be too rural to fit with the DHN typology model. Only 10% of the urban replacement delivered is a suitable match with DHN delivery; the low correlation arises from areas of low housing density and potential congestion of utilities in some areas reducing the benefit. This assumption has high sensitivity on the result and should be validated during any further development of this concept. A workshop, leading to a pathfinder project is proposed as a mechanism to explore the range and sensitivity. • As a cross-reference to test the previous assumption is to consider what proportion of the 50km heat	

network piping could potentially link with water main renewal. This is highly dependent on the age of current pipes and the OFWAT determination, but a range of 5% to a stretching 25% was agreed as viable [Options].

- Renovations will not be factored in as an additional benefit, but as an alternative mechanism to achieve the higher level Central Case calculation.
- The DHN pipework is rolled out over 3 years, giving an opportunity to overlap with main renewal over an extended period. This may not have an impact as the sequence of renewal is not prescribed in the AMP determination. As a result this assumption takes a cautious perspective.

Change relative to baseline CAPEX

Solution Summary

For the cost model analysis the assumptions from the previous section are built into an algorithm as follows for Central and Pessimistic scenarios (shown in table format). These are then fed into the cost model to provide the common presentation of the impact of the solution.

	Pessimistic Case	Central Case
AMP Pipe main replacement rate	0.2% /yr = 13km/yr	1% /yr = 65km/yr
Over a 3yr DHN installation programme	39km	195km
Assume 50% rural (unsuitable for DHN)	19.5km	97.5km
Assume 10% geographical match	1.95km	9.75km
Apply £100/m saving: Approximate Network impact	**£195k**	**£975k**

As described in above, irrespective of the rate of pipeline replacement, there is an expectation that 30% is the upper limit for potential overlap between DHN and other utilities. The following table is a cross-check to establish the level of the overlap for the two cases.

	Pessimistic	Central
As a proportion of the 50km DH Network	1.95km ≡ **4%**	9.75km ≡ **20%**

Central Case

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,924	£29	1.5%
B	£1,038	£1,032	£6	0.6%
C	£1,706	£1,668	£38	2.2%
D	£3,871	£3,795	£76	2.0%
E	£4,113	£4,027	£86	2.1%
Primary Network	£6,476	£6,426	£50	0.8%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£44,548	£642	1.4%
Total system Capex	£62,602	£61,961	£642	1.0%
Dense village Capex, no prelims	£3,641	£3,565	£76	2.1%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£183,448	£642	0.4%

Optimistic Case

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,910	£44	2.2%
B	£1,038	£1,029	£9	0.8%
C	£1,706	£1,649	£57	3.3%
D	£3,871	£3,757	£114	2.9%
E	£4,113	£3,984	£129	3.1%
Primary Network	£6,476	£6,401	£75	1.2%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£44,227	£963	2.1%
Total system Capex	£62,602	£61,640	£963	1.6%
Dense village Capex, no prelims	£3,641	£3,527	£114	3.1%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£183,127	£963	0.5%

Pessimistic Case

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,948	£6	0.3%
B	£1,038	£1,037	£1	0.1%
C	£1,706	£1,698	£8	0.4%
D	£3,871	£3,856	£15	0.4%
E	£4,113	£4,096	£17	0.4%
Primary Network	£6,476	£6,466	£10	0.2%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£45,061	£128	0.3%
Total system Capex	£62,602	£62,474	£128	0.2%
Dense village Capex, no prelims	£3,641	£3,626	£15	0.4%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£183,962	£128	0.1%

As outlined above there is significant sensitivity in the assumptions of the proportion of DH Network overlap with water main replacement geography.

The figures presented above are seen as a realistic range by the project team, Bristol Water and other stakeholders. The figures can be tested and uncertainty reduced with a proposed workshop between Bristol Water, Bristol City Council, contractors and the Project Team if the solution is taken forward for road-mapping in Stage 3.

There is additional potential for adding in pipes run alongside semi & detached properties linked with the revised baseline layout which replaced internal pipework with DHN pipework underground, below driveways and paths. This would have the impact of adding 140m – 1,000m of additional shared civils with additional savings £14k - £100k.

	This solution is inherently site specific. However, given the number of utilities and the large-scale potential for DH deployment, there is a high probability that the necessary overlap of activity can be achieved with sufficient co-ordination effort. The expectation is that, if additional utilities were combined with the solution summary above, the impact would be increased benefits, but with a corresponding increase in complexity of co-ordination. Although the potential for overlap would increase, benefits would not do so pro rata. In fact it would be difficult to envisage the potential for combining costs for more than 30% of the network under any circumstances: This limit is presented as the Optimistic case above. However, it must be stressed that this level of integration would require considerable alignment of works including: • Aligning programmes with utilities which have not yet engaged with this research • A fortunate alignment between geographic priorities for new or upgraded utility networks and a suitable DHN network proposal. To support the alignment of utility renewal with DHN delivery there is a need for mapping tools which are capable of overlaying existing services (including condition) in order to reduce the barriers to Shared Civils work.	
Certainty of outcomes		
Certainty of outcomes	This solution requires the co-ordination of civil engineering activity across two independent networks. Although the intention would be to use as much of a common team as possible to make all connections, the need for additional co-ordination adds complexity will have a minor negative impact on certainty.	-1
Operational cost		
Change relative to baseline OPEX	No significant impact on Operating costs.	
Lifecycle costs		
Change relative to baseline lifecycle costs	No significant impact on lifecycle costs.	
System performance		
Impact on DHN performance	No significant impact on DHN performance	0
Future flexibility	No significant impact on DHN flexibility	0

Attractiveness to Users & Investors		
Attractiveness to Users and Investors	From a user / householder perspective, the combined civils solution reduces the disruption of construction work in their locality. From DH Network Investors' perspectives the solution provides a more compelling case for the Local Authority and increases the chance of a proposed DHN progressing.	+2
Reduced Complexity		
Complexity	Minor impact on the complexity of the DHN product and a slight increase in the complexity of process. Significant increase in complexity of procurement and legal agreements with multiple organisations involved.	-2
Health, Safety and Environmental Impacts		
HSE	Reduces the overall level of street-works in the area which has a positive impact on both public and contractor safety; assuming that the installation is carried out by a combined team (as proposed by Clancy Docwra) rather than multiple teams operating in the same workplace.	+1
Opportunity to scale		
Scope of opportunity	The shared civils solution is not limited to any particular typology so the scope can include all parts of the network and building types. However, in our assumptions, we have limited the scope to impact on between 4% & 30% of the baseline network length. This is a result of a need to align DHN requirements with the regulated plans of Utility AMP (or equivalent). This is a significant limitation on the impact at scale.	- 2
Increased Revenue		
Potential for synergies	The solution has potential to realise synergies with water and other utilities, but the research thus far has shown that the concept is not compelling to these organisations at the current concept stage. The scale of the commercial and legal complexities is seen as a barrier, but the larger water companies contacted declared an interest, provided a successful case study could be cited. This suggests that there would be value in an industry of government funded pathfinder project.	+1
UK plc external Stakeholder Value		
Value for the UK	The solution will support greater resource efficiency for construction and transport with reduced CO_2 impact from pipeline installation replacement as a result of: less material and energy usage for civil engineering and	+1

	reduced traffic congestion during works. There is unlikely to be an opportunity to export the solution directly.	
Technical feasibility		
Technical feasibility	Combined civils is technically feasible with some need for innovation to lay DHN pipes and other services in close proximity without risk to the performance of either. In particular ensuring mains water is not heated by the DHN. This can be achieved by increasing levels of high performance insulation on the DHN pipework, which is technically feasible albeit at increased cost. There will be a need for new standards in 2 areas: • Commercial and legal standards to ensure that responsibility is equitably allocated to all parties to the shared civils contract, or shareholders in the Joint Venture model. This will apply to any interruption of the utilities involved, but also to 3rd parties including the local highways department for performance of the reinstatement and the public risk issues during the works. • Technical Standards and codes of practice for laying multiple utilities in close proximity.	-1
Effort to Implement Solution		
Effort	Investment capital and research required: • <=£500k to develop a business case across a range of potential sites in towns and cities (0) • £2M - £5M to support and analyse a pilot of solution, as funded within an existing DHN (+2) • Technology Readiness Level (commercial equivalent): TRL 3-4 (Proving feasibility) (+3) • Anticipated timescale to the point where the solution is delivering value: 3-5 yrs (+2) • Likelihood of success – Possible (+3)	3
Other		
Any additional equipment required	No development of equipment required	
Barriers	Development of commercial and legal documentation to support the shared civils model.	

<table>
<tr><td>Solution name:</td><td>Direct HIU System & Existing DHW Storage</td><td rowspan="3">Evaluation Rating</td></tr>
<tr><td>Name of evaluator(s):</td><td>Paul Woods, Lucy Pemble, Andrew Cripps</td></tr>
<tr><td>Solution ID:</td><td>9</td></tr>
<tr><td colspan="3">General</td></tr>
<tr><td>Description of solution</td><td>The baseline design assumes that an indirect HIU with instantaneous hot water production is installed in each dwelling i.e. using two plate heat exchangers, one for space heating and one for hot water heating. This is the most common system being installed in the UK at present (mainly for new build market). In blocks of flats a substation is also used at ground floor level to avoid creating additional static pressure on the network.

There are a number of ways in which this baseline solution can be challenged from a system design architecture view. The optimal solution is likely to depend on the particular circumstances of the scheme. The type of HIU used also depends on the existing method of hot water generation i.e. whether there is a combination boiler generating hot water as well as heating for space heating or a conventional boiler with a hot water cylinder.

A) Use of direct connection in all typologies

The indirect HIU is more expensive than the direct HIU due to the additional complexity of heat exchanger, control valve, pressure vessel and pump. It would be possible to use direct connection on all dwellings in all typologies provided the heating system pressure rating is compatible with the proposed DH maximum pressure. For our notional scheme it was found that assuming a relatively flat topology the system pressure did not need to exceed 6 bar which is normally acceptable for typical radiator systems. For larger schemes it may be necessary to include additional heat exchanger substations within the system or to use distributed pumps to limit the maximum pressures. These additional costs will be dependent on the actual scheme and have not been included within the assessment of this solution as they do not apply to the notional scheme. In any case these costs will be relatively minor.

The benefits will be lower capex for the HIU, lower return temperatures and lower maintenance costs for the HIU. The potential disadvantages are – risk to the main network from unauthorised drain downs, in blocks of flats a leak could continue in a dwelling with no limit to the volume released with the potential to damage other properties.</td><td></td></tr>
</table>

	This risk could be mitigated by having a leak detection system that would detect a leak on the dwelling circuit by automatically isolating the dwelling's heating circuit at regular intervals and detecting a fall in pressure which would then automatically isolate the dwelling. Such a system would add to the cost but could be developed as a further feature of an electronically controlled HIU at relatively low cost. However, leaks are in any case very rare and such a system could be considered unnecessary for this solution. In the low rise dwellings the impact of a leak would only affect one dwelling and would be no different to the risk of a leak from say a cold water service. It would be good practice for the resident to isolate the incoming DH mains if the resident was away from the property for an extended period to reduce the risk of damage from a leak. A further issue is unauthorised drain downs which would lead to a loss of water. If the heat meter is placed in the flow then this drain down would result in an abnormally high energy use which would act as a deterrent to this interference and also enable early detection if the amount of draining down was significant. The existing heating system will require flushing however this is also the case with the baseline to avoid fouling of the heat exchanger. Direct connection has been used extensively in some cities in Denmark, for example Odense and is well suited to the low temperature 4^{th} Generation DH schemes being proposed. In the UK, most, older residential systems use direct connection and it is also used to connect commercial buildings in the Southampton geothermal scheme. For this option it is assumed that direct connection is feasible for all typologies and a cost reduction is given below. For the blocks of flats the block substation is retained for this solution so that the static pressures can be kept low enough for direct connection to be viable in other parts of the network. This cost reduction reflects the baseline cost of HIUs and a smaller reduction in the HIU cost would be realised if the cost of the HIU itself is reduced through the improved design and manufacture solutions (see solutions 10, 11, 12). In most cases the peak pressures on the network can be limited by suitable pipe sizing and layout of the network. On very large networks and especially where there is significant variation in ground level the peak pressures could become too high. There would be various ways to overcome this issue including separating the network into different sections so that the static pressure from parts at a higher ground level do not impact on parts at lower levels. This will incur some additional cost however the net impact is still expected to result in a capex saving even in this worst case. Replacing existing radiators with higher pressure rated radiators may be another option but is only likely to be a viable approach if the radiators need replacing anyway due to	

	age or condition. B) Retain existing hot water cylinders in the system The baseline assumes that hot water will be produced from instantaneous hot water heat exchangers in all properties. However, in many properties the existing heating system will include a hot water cylinder heated by an indirect coil within the cylinder. To reduce costs further it would be possible to retain the hot water cylinder and its controls and so avoid the costs associated with the instantaneous hot water heat exchanger. The hot water cylinder coil could be supplied indirectly (option B1) i.e. off the secondary heating circuit where indirect connection is used or, when combined with the direct connection option (option B2) the HIU would then only contain a DPCV or PICV (differential pressure or pressure independent control valves) and heat meter and this equipment could probably be installed on site in any suitable location. The disadvantage of this approach is that return temperatures from the hot water heating would typically be around 60C whereas 40C and lower would be achieved with the instantaneous hot water heating. However, for existing buildings the hot water is a small component of the total demand and the additional heat loss cost would be relatively small cost penalty especially if the heat source had a low cost of production. It is possible to use an external plate heat exchanger with the hot water cylinder which would result in lower return temperatures but there would be an additional cost for the heat exchanger, control valve and circulating pump (a development of this concept - the Exergenius by Orchard Partners – is designed to be an efficient retrofit for systems where the existing hot water cylinder is retained). The cost benefit for the notional scheme will of course depend on the proportion of hot water cylinders that are assumed to exist. Research indicates that the likely proportion is 50% hot water cylinders, 50% combi boilers (from English House Condition Survey).	
How the solution was identified	The cost model showed that HIUs were a significant cost element. It is known that there are differing views in the industry about the use and type of HIUs. HIUs were therefore seen as a separate challenge area. However the fundamental way in which HIUs are used and the various types available can also be considered as part of the system design architecture challenge area. The issues of HIU design and system architecture were discussed at a number of workshops with industry representatives. The subject was also discussed with COWI in Denmark.	
Capital cost		
Change relative	Costs of the DH **Network**	

to baseline CAPEX	Advice from HIU suppliers indicates a cost reduction of £460 per HIU for direct connection instead of indirect connection. The system where existing hot water cylinders are retained would save an additional £300 per HIU as the hot water heat exchanger and control valve would be omitted and the interface would be simply the heat meter, control and isolating valves and strainer. It has been assumed that installation costs and labour costs remain the same as it is still necessary to connect to all the dwelling circuits. There would need to be a specific survey of the property in advance of doing the work so that the correct equipment is provided to the site. However it is envisaged that this survey to be carried out at the same time that heat sales contracts are negotiated so that there is no significant additional cost.	

Typology	NETWORK COSTS		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£882	£156	15.0%
C	£1,706	£1,584	£122	7.2%
D	£3,871	£3,627	£244	6.3%
E	£4,113	£3,869	£244	5.9%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£43,169	£2,020	4.5%
Total system Capex	£62,602	£60,582	£2,020	3.3%
Dense village Capex, no prelims	£3,641	£3,397	£244	6.7%
OPEX	£3,320	£3,240	£80	2.4%
TOTEX non-discounted	£184,090	£178,204	£5,887	3.2%

	The cost savings are seen in all Typologies with residential HIUs, and as these are a significant share of the cost, the overall reduction is large. Note: the above cost savings are also incorporated in Solution 12 which is for the improved HIU design with direct connection so these savings are not be additive to the savings from Solution 12. This solution was presented at the stakeholder event at the end of Stage 2. The main outcome was a recognition that customer choice and preference will be a critical part of determining the best solution for any given dwelling. Additional sensitivity analysis was undertaken using direct HIUs but for various options with and without DHW storage tanks depending on whether the dwelling had an existing DHW storage tank and customer preference. This is presented after this solution form. The sensitivity analysis investigated the following options: (i) retain existing DHW tank, (ii) replace existing but ageing DHW tank with new tank, (iii) remove existing DHW tank, (iv) install new DHW tank where there is no existing tank, (v) do not install new DHW tank where there is no existing tank. The analysis showed that there is a net cost saving for the three options where a DHW cylinder does not need to be replaced or a new cylinder installed where not present previously (Options i, iii, v). Where an existing cylinder needs to be replaced (Option ii), the cost is very similar to the baseline resulting in no net savings. However, this option retains the advantages to the home owner of an alternative supply from an electric immersion heater. Where a new cylinder is added that is not present previously there is a significant extra cost (Option iv). The homeowner would need to value the additional benefits to pay the additional cost e.g. greater hot water flow rate.	
Certainty of outcomes		
Certainty of outcomes	The costs of HIUs are well understood. The decision on whether direct connection is feasible is mainly dependent on the pressure rating of the existing heating system and the peak pressures experienced on the network. The acceptance of the solution by the customer is also uncertain. These uncertainties mean that the scoring is lower than for the baseline solution.	-1
Operational cost		
Change relative to baseline OPEX	Costs of the DH **Network** Direct connection will result in lower operating temperatures by 3-5C which will have a positive but very small	

	impact on heat losses, e.g. a reduction from 10% heat loss to 9.3%. The direct connection systems are simpler and a small operational saving could be achieved in maintenance costs as the potential cost for replacement of failed parts is less. This is estimated at a saving of £25 per dwelling p.a. Costs of the DH **System** No changes to the DH system costs are identified.	
Lifecycle costs		
Change relative to baseline lifecycle costs	Costs of the DH **Network** Equal to CAPEX saving Costs of the DH **System** No change	
System performance		
Impact on DHN performance	These solutions reduce the complexity of the systems within the dwelling and would be expected to improve reliability of service. Direct connection would result in lower return temperatures and so lower network heat losses. However, retaining hot water cylinders may increase return temperatures in some cases and the flow temperature may need to be higher in summer than for the instantaneous option.	1
Future flexibility	One of the disadvantages of direct connection is that it imposes pressure constraints on the network which may limit further expansion. However this can be overcome with pumping stations at key points as the network extends and these have limited cost implications. Retaining localised storage in cylinders increases the diversity factor of the demand increasing DHN capacity.	0
Attractive to Users & Investors		
Attractiveness to Users and Investors	The direct connection systems will be simpler to maintain and so less impact on residents. Where cylinders are retained this will also be attractive as this will result in less installation disruption within the dwelling. The change from a cylinder system to an instantaneous system will result in higher water pressures which could be seen as a benefit for showers and the option to remove the cylinder can be given to the householder. Ultimately it may be customer preference that determines how this solution is adopted as customers may be willing to pay more to have cylinder removed.	1

	From an investor perspective the retention of a proportion of domestic cylinders on the network will smooth hot water demand at peak times - increasing resilience and increasing the number or properties that can be served by the network. So this solution may be seen overall as slight improvement to the baseline.	
Reduced Complexity		
Complexity	The solution reduces technical complexity compared to the baseline HIUs.	1
Health, Safety and Environmental Impacts		
HSE	Direct connection could be seen to have additional safety issues due to the higher pressures involved in the radiator circuits and probably higher surface temperatures in most cases. However, the system has been extensively used in the UK and risks are well understood.	-1
Opportunity to scale		
Scope of opportunity	The solution is applicable to all residential typologies although will be more complex to deliver in areas where there is significant variation in ground level across the scheme.	1
Increased Revenue		
Potential for synergies	No difference	0
UK plc external Stakeholder Value		
Value for the UK	No significant impacts on policy, jobs or exports.	0
Technical feasibility		
Technical feasibility	The solutions are all technically viable and have been demonstrated in a number of schemes. There is no impact on standards as the ADE/CIBSE Code of Practice CP1 allows for direct connection. With direct connection the total pressure will need to be limited to that of the majority of the radiators installed. However, if necessary a hydraulic break can be used further back in the system. With most schemes without significant variation in ground level, the peak pressures are unlikely to be high enough to prevent direct connection being used.	0
Effort to Implement Solution		

Effort	• Investment capital and research required: No significant effort required – the most useful approach would be through a demonstration scheme. Linking to Solution 1, training of designers to ensure they choose the most appropriate design of HIU would be of value. Furthermore, published reports on costs and benefits, in-use performance and user experience of different systems would also assist the designer in the selection. <£500k (0). • Level of technological innovation (uncertainty), technology readiness level (TRL 8-7) (+1). • Anticipated timescale to the point where the solution is delivering value: < 18 months (0) • Likelihood of success: probable (+1)	1
Other		
Any additional equipment required	A system that automatically detected a leak and isolated the dwelling before damage could occur would be of value but is not essential for the direct connection solution.	
Barriers	No major barriers to implementation, although it is noted that some developers and ESCos may be reluctant to use direct connection due to perceived risks from leaks. Technology is all available now but some development work on a system that detects leaks and automatically isolates from the DH network would be of value in addressing the above concerns.	

Sensitivity analysis on Solution 9

Project brief

The variation instruction brief is as follows:

For Solution 9, "Direct HIU and Existing DHW Storage", conduct sensitivity analysis for variant of solution using direct HIUs but other options with and without DHW storage tanks. Scope to comprise:

1. Set out potential options and associated customer offers, and the alignment of each option/offer with the requirements of likely customer types; Provisionally, options could include: (i) retain existing DHW tank, (ii) replace existing but ageing DHW tank with new tank, (iii) remove existing DHW tank, (iv) install new DHW tank where there is no existing tank, (v) do not install new DHW tank where there is no existing tank; though it is anticipated that certain options would be attractive to only a particular type of customer (e.g. installing a new DHW tank where there is no existing tank, in addition to installing a new HIU, is likely to be attractive only to wealthy customers with very large DHW requirements);
2. Identify changes that would result from direct connection using each of these options, both for individual properties and for the network;
3. Use model to calculate the impact of change;
4. Prepare text and table(s) to be used in Stage 2 report to take account of these findings; and
5. Agree text with ETI and update Stage 2 report (deliverable EN2013_D03).

Options

The five options for hot water provision and how they might align with different customer types are discussed here. This analysis has been undertaken assuming that all customers will have a direct connection installed when converting to district heating. Note that the baseline network in this project assumes the adoption of an indirect connection with instantaneous hot water, with any existing DHW cylinders removed.

Where there is an existing DHW cylinder

Option (i) - Retain the existing DHW cylinder

This option has already been modelled as part of Solution 9, and it avoids the cost of a new DHW heat exchanger and allows the use of a lower power heat connection. This is likely to be attractive to many home owners who have an existing cylinder. The disruption will be at a minimum and the home owner will retain the backup capacity due to having an electric immersion heater within the cylinder. This option will also typically allow a higher rate of hot water flow.

Option (ii) - Replace the existing but ageing DHW cylinder with a new cylinder

This is the same as Option (i), but with the additional cost of a replacement cylinder which may be needed if the condition of the existing cylinder is poor. There is the additional advantage that it should reduce heat losses compared to an older cylinder. This option should be attractive to the same customers as with Option (i), but with the additional resource to pay to replace the cylinder.

Option (iii) - Remove the existing DHW cylinder and install a new instantaneous DHW heat exchanger

This is similar to approach in the project's baseline which includes the removal of any DHW cylinder present and accounts for any subsidiary plumbing work needed to support this. The exception is the adoption of a lower cost direct connection rather than using an indirect connection.

This option is likely to be most attractive to home owners who particularly wish to make use of the space that would be freed up by removing the cylinder. Many modern homes in particular have limited storage space and removing a cylinder can free up significant useful space.

Where there is an existing combi boiler and no existing DHW cylinder

Option (iv) - Install a new DHW cylinder where there is no existing cylinder

This allows the use of a lower power connection and the potential for intermittent (programmed) supply of heat. However, it also requires the addition of the cylinder and any necessary changes to the hot and cold water services plumbing. If the cylinder is to be located near the combi boiler these additional changes will be limited, but there is likely to be a need to construct a cupboard if there is no suitable space available.

As noted below this is a relatively expensive option. However, some home owners may be dissatisfied with the hot water flow rate that is delivered by a combi type boiler, and prefer the enhanced provision that comes with a cylinder. They may also like to know that the presence of an immersion heater will enable hot water to be provided in the event of heat network failure. As a result there may be a number of customers who are content to pay the extra cost of this option.

Option (v) - Do not install a new DHW cylinder where there is no existing cylinder

This option has been modelled as part of Solution 9. It would be expected that most customers with combi boilers would favour this option as it is the lowest cost option and has the least disruption.

Cost information

In Stage 2, the key costs were estimated as follows:

- For the baseline solution, the cost of an indirect connection and instantaneous hot water HIU was estimated to be £1518 with £400 allowed for installation.
- There is a cost reduction of £460 per HIU for using direct connection instead of indirect connection which applies to all options for hot water production.
- The cost of installing the indirect HIU was assumed to be £400. It is assumed that these labour costs are the same for a direct connection as the same plumbing connections are required.
- Where existing hot water cylinders are retained, there would be an additional £300 per HIU saving as the hot water heat exchanger and control valve would be omitted and the interface would be simply the heat meter, control and isolating valves and strainer.

The key capital costs associated with each option are as follows.

- **Option (i) Retain existing hot water cylinder:** This results in capital costs for the direct connection with the DHW cylinder retained of £758 (£1518 - £460 - £300).
- **Option (ii) Replace existing hot water cylinder with new:** The basic system costs are the same as Option (i). In addition, there is the need to cost for the supply and fitting of the replacement cylinder.

  Replacement domestic hot water cylinders are available at a wide range of costs, from as little as £200 for copper cylinders with a 2 year warranty, through to stainless steel cylinders at around £500 with 25 year warranty, and up to £1000 or more for large cylinders. For this work, a cost of £500 has been assumed.

  Replacing a cylinder is a straightforward job for a plumber. However, it will involve draining down the system, removing controls and electrics, cutting pipes, replacing the cylinder and then reconnecting everything. It will be at least a full day’s work for a plumber (or half days for two). This is modelled as having a cost of £300.

- **Option (iii): Remove existing hot water cylinder.** This is the same as the project baseline with the exception that the lower cost direct connection is used. This results in a capital cost of £1058 (£1518 - £460).
- **Option (iv): Install new cylinder where none existed before.** The basic system costs are the same as Option (i). In addition, there is the need to cost for the supply and fitting of the new cylinder.

  This requires installing a cylinder where there was no cylinder before (i.e. prior use of an existing combi boiler). It will be the most complex job and will only be possible if an appropriate space is available for the cylinder. The cost will then depend on the location of this space and whether extensive work is needed to make it acceptable e.g. constructing a cupboard. Further, the extent of additional plumbing needed will depend on the location of the connection point, the chosen cylinder location and how it will then connect to the hot water circuit.

The cost of the cylinder and its basic installation is taken to be the same as in Option (ii), i.e. £800 in total. Additional plumbing works are assumed to be 1.5 person days' work (£450). The cost of boxing in the new cylinder is likely to vary significantly between homes and an allowance of £500 has been made. This makes a total of £1750 for this option.

- **Option (v): No new cylinder installed – combi boiler existing** The capital costs are associated with replacing the combi boiler with a direct connection HIU i.e. £1058 (£1518 - £460).

These costs are summarised in the following table.

Action	Cost estimate for use of direct connection		
	Direct connection	Install connection	Other work
Option (i): Retain the existing DHW cylinder	£758	£400	£0
Option (ii): Replace the existing but ageing DHW cylinder with a new cylinder	£758	£400	£800
Option (iii): Remove the existing DHW cylinder	£1058	£400	£0
Option (iv): Install a new DHW cylinder where there is no existing cylinder	£758	£400	£1750
Option (v): Do not install a new DHW cylinder where there is no existing cylinder	£1058	£400	£0

Notes:

i) The above costs are average costs across all typologies. It is likely that in practice there will be significant cost variations depending on the layout of the property and the locations of: the existing boiler and hot water tank, the new HIU and the DH entry position.

ii) Option (iii) may involve some additional labour in removing the cylinder and adjusting hot and cold water services to suit the location of the HIU.

The project baseline cost including installation is £1918, comprising the HIU at £1518 plus £400 for installation. The following table summarises the cost saving per home for the five options based on the adoption of direct connection.

All assume direct connection	Solution total cost	Saving compared to baseline	Comments
Option (i): Retain the existing DHW cylinder	£1,158	£760	This is the saving from retaining the DHW cylinder and the lower cost direct connection. This is the main option modelled in Solution 9.
Option (ii): Replace the existing but ageing DHW cylinder with a new cylinder	£1,958	-£40	This is slightly more than the baseline as the cost of the new DHW cylinder is significant. The home owner may prefer this solution (e.g. for immersion heater back-up).
Option (iii): Remove the existing DHW cylinder	£1,458	£460	This is the saving from adopting the lower cost direct connection, but with instantaneous hot

			water.
Option (iv): Install a new DHW cylinder where there is no existing cylinder	£2,908	-£990	This option is significantly more expensive compared to the baseline due to the cost of the new DHW cylinder, plumbing modifications and builders work to box in the new cylinder.
Option (v): Do not install a new DHW cylinder where there is no existing cylinder	£1,458	£460	This is the saving from adopting the lower cost direct connection.

Discussion

There is a net cost saving for the three options where a DHW cylinder does not need to be replaced or a new cylinder installed where not present previously.

Where an existing cylinder needs to be replaced, the cost is very similar to the baseline resulting in no net savings. However, this option retains the advantages to the home owner of an alternative supply from an electric immersion heater.

Where a new cylinder is added that is not present previously there is a significant extra cost. The homeowner would need to value the additional benefits to pay the additional cost e.g. greater hot water flow rate.

The following table summarises the outcomes in each case. Whilst noting that home owners can take whichever option they prefer, it would be expected that there would be a strong preference for Option (i) where they currently have an existing cylinder and Option (v) where they have currently a combi boiler.

Option	Cost (-) or saving (+)	Connection type	Space required for DHW cylinder	Electricity back-up	Level of disruption
Baseline	0	Indirect	Space released if existing DHW cylinder present Neutral if combi and no existing DHW cylinder	No	Medium if removing existing cylinder Low if combi and no existing cylinder
Option (i): Retain the existing DHW cylinder	+£760	Direct	No change	Yes	Low
Option (ii): Replace the existing but ageing DHW cylinder with a new cylinder	-£40	Direct	No change	Yes	Medium
Option (iii): Remove the existing DHW cylinder	+£460	Direct	Space released	No	Medium
Option (iv): Install a new DHW cylinder where there is no existing cylinder	-£990	Direct	Additional space needed	Yes	High
Option (v): Do not install a new DHW cylinder where there is no existing cylinder	+£460	Direct	No change	No	Low

Solution name:	**HIU Optimisation (1) Design for Manufacture and Assembly (DfMA)**	Evaluation Rating
Name of evaluator(s):	Tim Hall, Paul Woods, Simon Box	
Solution ID:	10	
General		
Description of solution	The starting point for this solution is the baseline assumption that all domestic connections are Indirect Connection HIUs with 2 plate Heat Exchangers (HEx) per unit and include a compliant Heat Meter. From the users’ perspective the system provides domestic hot water (DHW) on demand and the central heating control is a timer equivalent to typical programmable combi-boiler system. (Typical specification http://ormandyltd.com/wp-content/uploads/2015/04/Ormandy-MINIBREEZE-OM-rev.10.pdf) The DfMA approach in the ECCR Workshop is a ‘bottom up’ analysis and examined the potential for cost saving in HIU components & manufacturing process without significant change in unit specification and performance. This included: • Simplification and standardisation of components • Reduction in parts count through common sub-assemblies and reduced duplication / redundancy • Plug & play components to reduce labour time and joint failures	
How the solution was identified	The multiple cost saving innovations were developed during the ECCR* Workshop with the project team, a UK HIU manufacturer and other system specifiers. The potential cost savings shown below were calculated by contrasting the workshop solution ideas, with a bill of materials and costs which was confidentially shared by the manufacturer. The ideas and innovations were further developed during discussions with other manufacturers and network operators. (*ECCR – Eliminate non-essential items, Combine Functions, Combine Processes, Reduce Content)	
Capital cost		
Change relative to baseline CAPEX	**Design for Manufacture & Assembly (DfMA)** This solution group focuses on opportunities which are not dependent on major volume increases and have minimal technical performance impact (from the users’ or network operators’ perspectives). For each solution idea the team also assessed the: • Value of the solution: How much capital saving and other benefits; including installation labour saving and/or operating / repair cost. For CAPEX alone: Low <£10, High >£50 • Difficulty to implement: A qualitative assessment base on the time and effort needed.	

	Each solution element is given an assessment of the likely savings vs. the typical unit used in the Baseline cost model. The individual savings are summed and the impact range on the HIU cost and total Network cost are summarised below. **Solution elements.** **£ Material Saving vs. baseline** • Simplified HIU back-plate and other pressed components revised with pre-formed pipe mounts. • Reduced material & brackets (and labour accounted for below) £ 22 • 'Click fit' pipe support brackets linked to above (30 minute labour saving is the key aspect) £ - • 'First-Fix' rail to align pipework prior to fitting the HIU with matching click-fit installation (impacts installation speed & quality labour saving summarised below) £ - • Eliminate isolating valves on domestic HW & Central Heating (Flow & Return) £ 6 • Make isolating valve for cold infeed optional (valves required for DH Flow & Return) £ 2 • Simplify / eliminate other valves & brassware (e.g. 2nd Air Vent, drain) £ 10 • Eliminate compression fittings on Heat Exchangers (HEx) & other core components: Replace with pin connections to save assembly time and repair cost £ 24 (This also reduces installation & maintenance time from weeping union joints). • DfMA of internal pipes, brackets & supports to achieve assembly with minimal threaded connections. Reduced cost of parts & also assembly time saving of 30 minutes £ 40 • Common manifold(s) for: Pump, 2x HEx, heat meter, control valve & expansion vessel. This requires volume to offset tooling cost (say 50,000 units total). A combination of the two above aims to achieve a 60% reduction in current cost of £100. £ 20 Also a labour reduction of an additional 30 mins and reduced leak risk from brazed joints, • Simpler control and flow regulator valves to eliminate redundant features. This may require a change of valve manufacturer or product development. (Current cost £330 → £275) £ 55 • Standardise on 2 or 3 sizes of heat exchanger, with identical boss locations. £ 24 Also reduces complexity, stock holding and assembly time. Improved spares service. • Air instead of water pressure test: Faster, cleaner cheaper (10 minute time saving) £ - • Pre-insulated key components (HEx, pipes etc.). This eliminates 40 minutes of assembly, although there is an expectation of a £2 net increase in component costs. +£2 • Packaging design as a template for rapid packaging and subsequent installation £ - • Design for <15kg (one man lift) for indirect HIUs which are currently 2 man lift. £ - This has an impact on installation cost. This might be achieved by separating the Expansion tank in transit. • Standardised / simplified heat meter at scale £ 70	**Value / Difficulty** M M M L L L L L L L M L M L M L M M H L M L L L M M L L H L H L/M

	£ Labour & Margin Saving vs. baseline All Labour saving associated with above changes 240mins → 100mins £ 54 Labour based on £23.35/hr) Margin: Significantly reduced design and procurement overhead from standard product: £170 **Solution Cost Summary:** HIU Baseline Cost: £1,800 Evolved Market Price HIU: £1,500 including a contractors margin of 14% (the evolved market price reflects the downward price trend since the creation of the cost model) Ex-Works cost including delivery £1,320 (removing contractors mark-up) Low difficulty solutions impact: £285 Medium difficulty solutions impact: £210 **Solution Total Saving: £495 Range estimate: £300-£495 Saving** Revised Indirect HIU Cost [Solution 10]: £825 Including Contractors Margin: £948	H M

Network Impacts:

The 1st Phase Optimisation of HIUs aims to reduce the cost of the HIUs as follows:

Typology	Network costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£920	£118	11.3%
C	£1,706	£1,614	£92	5.4%
D	£3,871	£3,687	£184	4.8%
E	£4,113	£3,929	£184	4.5%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£43,666	£1,524	3.4%
Total system Capex	£62,602	£61,079	£1,524	2.5%
Dense village Capex, no prelims	£3,641	£3,457	£184	5.1%
OPEX	£3,320	£3,150	£170	5.1%
TOTEX non-discounted	£184,090	£173,235	£10,855	6.0%

This shows a significant impact in high density typologies in particular.

Certainty of outcomes		
Certainty of outcomes	Standardised design & first fix rail will improve certainty of installation quality and reduced time. Minor risk of system performance degradation through changed valve components. Avoiding this must be a priority; in order to challenge the perception that lower cost means an inferior product.	0
Operational cost		
Change relative to baseline OPEX	REPEX: Repair and maintenance savings from: • HIU replacement / repair will be cheaper, based on revised cost and easily changed components • Rapid replacement of the HIU as a whole, or components with quick-connect fittings. • The assessment is that this will achieve a 33% saving in the £150/yr baseline cost. • Reduced system leaks from quick connect fittings vs. Compression fittings.	

Lifecycle costs		
Change relative to baseline lifecycle costs	Change as a result of lower capital, repair and maintenance costs as described above.	
System performance		
Impact on DHN performance	(i) No direct impact on thermal efficiency (ii) Minor improvements in system reliability (iii) No direct impact on system temperature (iv) No direct impact on supply certainty at times of peak demand *(v)* Potential minor reduction in responsiveness to demand – from reduced control sophistication	0
Future flexibility	(i) Supply agnostic – Able to operate with multiple DHN heat sources. (ii) Temperature agnostic – HIU design solutions can adapt to all delta T supply temperatures. (iii) No direct impact on options to extend and interconnect	0
Attractiveness to Users & Investors		
Attractiveness to Users and Investors	Rapid installation and repair will be a minor improvement in the user proposition. Simple and fast repair and replacement will be an advantage for landlords to minimise disruption to tenants and the cost of repair, whilst also minimising the need for spare parts stockholding and reducing complexity for the service technicians.	+1
Reduced Complexity		
Complexity	(i) Design for Manufacture and Assembly simplifies product (ii) Standardised designs simplify procurement (iii) Bespoke systems can also make training harder and limits the amount of training that takes place	+2
Health, Safety and Environmental Impacts		
HSE	No change identified – unless the revised unit becomes smaller and easier to lift.	0
Opportunity to scale		
Scope of opportunity	Impact across the five typologies: (i) Typology A - City Centre commercial buildings – No HIU impact (ii) Typology B - High Density Flats – Applicable to all (iii) Typology C - High Density Terraced Houses – Applicable to all (iv) Typology D - Medium Density Residential – Applicable to all (v) Typology E - Low Density Residential – Applicable to all	+2

	Can apply to all domestic typologies. Potential to apply to European and Scandinavian domestic markets.	
Increased Revenue		
Potential for synergies	No direct impact	0
UK plc external Stakeholder Value		
Value for the UK	Potential to scale manufacturing and installation Possible opportunity for export	0
Technical feasibility		
Technical feasibility	All low difficulty solutions are near market and require minimal technical development. Medium difficulty solutions require development of low-cost items (valves / meters) and iterative development. This solution can therefore be classed as close to the baseline HIU for feasibility.	0
Effort to Implement Solution		
Effort	**Low difficulty solutions:** • Investment capital and research required: Approx £100k Score: 0 • Level of technological innovation, technology readiness level: TRL 9 Score: 0 • Anticipated timescale: <18months Score: 0 • Likelihood of success: Certain Score: 0 **Medium Difficulty Valve Development:** • Investment capital and research required: £500k - £2M Score: 1 • Level of technological innovation, technology readiness level: TRL 7 Score: 1 • Anticipated timescale: <18months Score: 0 • Likelihood of success: Probable Score: 1 Feedback from HIU manufacturers at the stakeholder workshop at the end of Stage 2 (see Appendix F) was that a focus on cost in Solutions 10 to 12 risks a 'race to the bottom' on performance and margin and undermines investment in high quality capacity.	0 1
Other		
Any additional equipment required	All solutions are applications of existing technology and processes.	
Barriers	Potential for market push-back (technical specifiers) against simplified controls vs. current solutions.	

Solution name:	**HIU Optimisation (2) Further Simplification & Value Engineering at Scale**	Evaluation Rating
Name of evaluator(s):	Tim Hall, Paul Woods, Simon Box	
Solution ID:	11	
General		
Description of solution	The outcomes of solution [10] are the starting point for this solution, which extends the potential saving by challenging existing specifications and identifying where there are potential process cost benefits of production at scale. This includes components identified as having potential for elimination or substitution as a result of: • Duplication of functionality – within the HIU or elsewhere in the system • Over-engineering – refinements or additional functionality above the basic requirement • Optional items which could be designed as chargeable upgrades; enabling users to make an informed choice whether to include in their specification	
How the solution was identified	The multiple cost saving innovations were developed during the ECCR Workshop with the project team, a UK HIU manufacturer and other system specifiers. The potential for cost savings shown below were developed from cost model confidentially shared by the manufacturer. These ideas and innovations were added to during discussions with other stakeholders.	
Capital cost		
Change relative to baseline CAPEX	**Simplification and Value Engineering** Opportunities in this solution group are focused on those areas of the HIU cost model which either: • Provide additional functionality above basic requirements which not all users and operators value. For example: - Pressed metal casing which can be substituted for insulation and concealed in a cupboard. - Pressure and Temperature gauges which are normally only used in set-up and fault finding. • Attract disproportionate cost relative to the cost of the overall unit. For example:	

<u>Control Valves</u>: Although a key element of the HIU, the control valve initial cost is equivalent to the ex-works price of a domestic gas boiler. However, it is widely acknowledged that there is significant redundancy and over-specification in these precision valves (by specifying engineers and suppliers). To achieve the saving will require product development in collaboration with manufacturers. By contrasting the functionality of control valves within healthcare showers [Kohler-Mira] a target cost of £75 is expected to be achievable.

<u>Heat Meters</u>: There is some contention about both the cost and the value of heat meters in an HIU. There is a regulatory requirement to measure the energy being delivered to the home, even though the marginal cost of the heat may be low. To meet current requirements the proposed approach is to press for the development of a low cost meter with a step change in technology. Although an ultra-low-cost heat meter has eluded designers to date, the proposed solution is that an ultra-low cost sensor, or an alternative contactless design can be developed within 5 years based on the need for HIUs at scale. An equivalent step change in technology cost was achieved in the 2000's for Carbon Monoxide testing when demand (arising from litigation) encouraged cost evolution from laboratory equipment costing a few $100's in 1990s, to around $90 in the early 2000s and units which can be bought today for $10 or less (Quantum inc. US).

Solution elements.	**£ Material Saving vs. Solution 10**	**Value / Difficulty** (Low <£10, High >£50)	
• Pre-formed polystyrene insulation as a push-fit case and frame for pipes and components.			
• The insulation replaces the decorative cover to become the external shell within a cupboard.		M	M
• Needs volume (□10,000) to justify dedicated tooling – minimises pressed metal, saving	£18		
Additional labour saved: 20 minutes (Already been adopted by some HIU manufacturers.)			
• Control and flow regulator valves simplified to the equivalent of Return Temperature Limiters and TRVs to reduce over-engineering whilst providing sufficient temperature and flow control.		H	H
• This will require manufacturer investment and scale to develop new products.	£200		
• (The target cost at this stage is £75 by comparison with the temperature and pressure			
• regulating 'engine' of a healthcare standard shower system of c£60, or c£20 for domestic [Mira].)			
• Eliminate Pressure & Temperature Gauges, or replace with red/green LEDs, for users.		M	L
• Service engineers use a temperature probe or pressure tap if needed for fault finding.	£13	M	M
• Value engineering of valves & electrical components:	£13		
• Simplification of Diverter valves & brassware (linked with common manifolds)			
• Electrical box minimised to simplify control logic (pump on/off. Diverter: DHW or CH)		M	H

- Heat Meter – Further reduced cost with simplification and scale (£50 target cost) £30 — M L
- Eliminate the expansion vessel from the HIU: £14

Either by using existing expansion capability in the home (system boiler installations)
or including a separate vessel somewhere unobtrusive in the property (this may not save cost). –

£ Labour & Margin Saving vs. Solution 10

- Labour saving from above 100mins □ 50mins £ 20 — M L
- Margin: Fixed manufacturers margin, reduced in cash terms, but a higher as a % of sales. £ 30 — M M

HIU manufacturers' margins are assumed to reduce and the reduction is based on a highly standardised product offer, limited technical advice and minimal aftersales support: This can only be sustained as a viable business with limited basic designs at manufacturing at scale.

Solution Cost Summary:

Revised Indirect HIU Cost [Solution 10]:		£ 825	
Low difficulty solutions	Total:	£47	
Med / High Difficulty	Total:	£ 291	
Solution Total Saving:		**£338**	**Range estimate: £100-£338 Saving**
Revised Indirect HIU Cost [Solution 11]:		£486	Including Contractors Margin: £559

Network Impacts:

Successful 2nd Phase Optimisation of HIUs achieves reductions in the cost of the Network as follows:

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£855	£183	17.6%
C	£1,706	£1,563	£143	8.4%
D	£3,871	£3,586	£285	7.4%
E	£4,113	£3,828	£285	6.9%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£42,828	£2,361	5.2%

<table>
<tr>
<td></td>
<td>
<table>
<tr><td>Total system Capex</td><td>£62,602</td><td>£60,241</td><td>£2,361</td><td>3.8%</td></tr>
<tr><td>Dense village Capex, no prelims</td><td>£3,641</td><td>£3,356</td><td>£285</td><td>7.8%</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>OPEX</td><td>£3,320</td><td>£3,150</td><td>£170</td><td>5.1%</td></tr>
<tr><td>TOTEX non-discounted</td><td>£184,090</td><td>£172,397</td><td>£11,693</td><td>6.4%</td></tr>
</table>
Reducing the ex-works cost of an HIU to below £500 saves 23% of the connection cost in flats (typology A) and has the potential to act as a ‘disruptive’ proposition with an opportunity to shift the viability of some marginal heat networks.
</td>
<td></td>
</tr>
<tr><td colspan="3">Certainty of outcomes</td></tr>
<tr>
<td>Certainty of outcomes</td>
<td>Changes to HIU design should not have significant impact on certainty of DHN outcomes. Design changes need to be managed to ensure system reliability / performance are at least maintained.

Concerns were raised by stakeholders and reviewers that the process of optimising HIUs necessarily means a reduction in quality and/or product lifespan. The project team stand by their experience that there is significant wasteful activity in all but the very best manufacturing processes. The ECCR review carried out for this solution reinforces the potential for the significant cost savings described above, without degrading HIU or system performance.</td>
<td>0</td>
</tr>
<tr><td colspan="2">Operational cost</td><td></td></tr>
<tr>
<td>Change relative to baseline OPEX</td>
<td>REPEX: Repair and maintenance savings from:
Cost of replacement / repair will be cheaper, based on easily substituted sub-assemblies and faster on-site repair. The assessment is a £50, 33% saving in the £150/yr baseline cost.
The bulk of the benefit arises from solution 10 (DfMA) and should not be double-counted.
OPEX: If the revised heat meter can be read remotely, and the unit as a whole can be shown to be reliable enough to perform without an annual service, there is potential for further OPEX saving. For landlords the annual boiler safety check and service is a major cost and organisational burden (tenants unwilling to permit access) [Islington B.C.]. For Engie DHN developments each Heat meter is tested every 3 years on a risk based approach to assess reliability of the units: If very few need recalibration or replacement the interval will be extended. If the 3 yr cycle can be achieved an additional saving of £50/yr per unit ≡ 4% of OPEX can be achieved. (this is not modelled above)

A 3yr maintenance cycle for a DHN HIU would give landlords a significant impetus to migrate their</td>
<td></td>
</tr>
</table>

	stock to DHN solutions where they are proposed. However, at this stage is would be speculative to factor this potential in OPEX calculations.	
Lifecycle costs		
Change relative to baseline lifecycle costs	Change as a result of lower capital, repair and maintenance costs as described above.	
System performance		
Impact on DHN performance	(i) No direct impact on thermal efficiency. (ii) Simpler more reliable solution to reduce Mean Time Between Failures. (iii) Improved Mean Time to Repair: Estimate 40% reduction in maintenance time vs. baseline. (iv) Will accommodate variable system temperatures. (v) No direct impact on supply at times of peak demand. There are concerns from some contributors and reviewers that simplification will have a negative impact on the user experience (unstable temperature or flow): With good engineering design there is no reason to expect reduced quality or lifespan. The ECCR approach is focused on eliminating waste.	+1
Future flexibility	(i) Supply agnostic – Able to operate with multiple DHN heat sources. (ii) Temperature agnostic – HIU design solutions can adapt to all delta T supply temperatures. (iii) No direct impact on options to extend and interconnect.	0
Attractiveness to Users & Investors		
Attractiveness to Users and Investors	**Users:** Reduced repair & replacement cost will appeal to users. Potentially offset by perception of more limited performance; which must be addressed in advance for HIUs to be seen as attractive heating solutions. **Investors***:* Attractive reduced CAPEX and OPEX for Network Investors and operators. HIU Manufacturers may be reluctant to invest in developing a low margin product: Higher cost and margin bespoke solutions may be preferred by some engineering focused manufacturers. This may give an opportunity for new entrants from FMCG or domestic appliance markets.	+1
Reduced Complexity		
Complexity	Further simplification to the product	+2

	Standardised designs & common components simplify procurement and servicing.	
Health, Safety and Environmental Impacts		
HSE	No change identified.	0
Opportunity to scale		
Scope of opportunity	Impact across the five typologies: (i) Typology A - City Centre commercial buildings – No HIU impact (ii) Typology B - High Density Flats – Applicable to all (iii) Typology C - High Density Terraced Houses – Applicable to all (iv) Typology D - Medium Density Residential – Applicable to all (v) Typology E - Low Density Residential – Applicable to all Can apply to all domestic typologies. Potential to apply to European and Scandinavian domestic markets.	+2
Increased Revenue		
Potential for synergies	No direct impact	0
UK plc external Stakeholder Value		
Value for the UK	Potential to scale manufacturing and installation. Possible Opportunity for export.	0
Technical feasibility		
Technical feasibility	Technical feasibility is high for the simplification of the main product including manifold development. The step change in Control Valves and Heat Meters is likely to be more challenging. Achieving agreement on a revised Heat Meter solution will require alignment of multiple stakeholders: Network operators, technical bodies, consumer groups, government / regulator. Agreement from government on the frequency of Heat Meter calibration is important to quantify potential savings and any obstacles.	-2

	This solution can therefore be classed as being less technically feasible than baseline HIU.	
Effort to Implement Solution		
Effort	With multiple elements to this solution there will be a series of parallel development projects, each with their own timing. Grouped by difficulty the anticipated timing and effort requirements follow: **Low difficulty solutions:** • Investment capital and research required: Approx £100k Score: 0 • Level of technological innovation, technology readiness level: TRL 9 Score: 0 • Anticipated timescale: <18months Score: 0 • Likelihood of success: Certain Score: 0 **Medium / High Difficulty Valve Development:** • Investment capital and research required: £2M-5M Score: 2 • Level of technological innovation, technology readiness level: TRL 6 Score: 2 • Anticipated timescale: 3-5yrs Score: 2 • Likelihood of success: Probable Score: 1 **New Approach to Heat Metering** (Potentially high difficulty): This is added as a separate element of the solution on the basis that a significant number of reviewers and stakeholders had concerns whether the development of a much lower-cost and more reliable heat meter was achievable, particularly in the short-term. As a result of the uncertainty of outcomes; the development effort was increased as follows: • Investment capital and research required: £5M-£10M Score: 3 • Level of technological innovation, technology readiness level: TRL 4 Score: 3 • Anticipated timescale: 5-10yrs Score: 3 • Likelihood of success: Likely Score: 2	0 2 3
Other		

Any additional equipment required	Alternative heat metering technology or methodology will be required to deliver the full potential of the solution as described above.	
Barriers	Changes to heat metering regulations or guidance may be needed to maintain consumer protection with new approaches to measuring heat. Although the cost per kWh of heat is a minor element of the cost of a DHN; current EU regulations require metering. No IPR issues identified: (Pre-moulded insulation is unlikely to be patented).	

Solution name:	**HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage**	Evaluation Rating
Name of evaluator(s):	Tim Hall, Paul Woods, Simon Box	
Solution ID:	12	
General		
Description of solution	This solution combines the saving potential of HIU solutions [9, 10, & 11] as follows: • [10] HIU Design for Manufacture and Assembly & Simplification • [11] HIU Value Engineering and production at scale • [9] Simplification from direct connection to the DHN - Direct connection with single Heat Exchanger for properties with Combi-boilers - Direct connection without heat exchanger for properties with existing Hot Water tanks. Direct connection HIUs can provide a cheaper and greatly simplified solution than indirect HIUs by: • Eliminating one plate heat exchanger (space heating) • Eliminating the need for a local pump • Reducing HIU complexity, size & footprint • Reducing pressure drop and so system pressure and pumping cost. Using existing DHW storage tanks with the DHN brings the following additional benefits: • Eliminates the second (larger) DHW Heat Exchanger • Further simplifies controls and valves • Increases DHW demand diversity – reducing peak load on the network A further development has been to separate the supplier's metering and flow control aspects of the	

HIU from the domestic Central Heating and DHW elements. This gives 2 distinct assemblies to form the HIU:

Primary Metering Module

- Heat Meter
- Isolation valves (2 or 4)
- DH non-return valve
- Temperature sensors (2)
- Electrical controls
- Strainer
- Return Temperature Limiter
- Flow Limiter
- Primary flow isolation
- Fail-safe shut-off

Domestic System

- DHW Heat Exchanger or Tank/Coil
- Heating Heat Exchanger (if required)
- Diverter valve (DHW / Heating)
- Heating controls
- Pump (if required)
- Expansion Vessel (if required)

The proposal is that the Primary Metering Module (PMM) is the responsibility of the DHN Operator and the Domestic System is the responsibility of the resident. This gives a clear delineation and also means that the PMM can be largely standardised – irrespective of customer choice or property type. The Domestic system will allow consumer / landlord choice of Direct / Indirect connections and Instantaneous / Stored DHW. The PMM can be incorporated within the HIU enclosure, or can be a separate unit:

- as an internal meter box
- as an outside wall meter cupboard
- in the street below ground (akin to a water meter)

The standardisation in the PMM will support rapid development of low cost components and HIUs

A full discussion of the system implications is in solution [9] Direct HIU & existing DHW Storage.

The following challenges need to be considered as part of the combined solution:

1. Risks of leaks and system contamination.
   Leak detection & auto shut-off to avoid system pressure / volume loss and property damage.
2. Risk of degraded system performance arising from HIU Optimisation:
   This is mitigated with a robust Product and Process Failure Modes and Effects Analysis (FMEA)
3. Challenge of demarcation points and legal responsibility changes within the property and system.

	4. Feedback from each property to identify abnormal usage and protect other user's supply 5. Concerns that poorly maintained heating systems will increase water treatment requirements. 6. Limit maximum temperature (=<90ºC) & pressure (<6bar) to protect consumers from scalding. Assessing the likelihood and severity of risks and their mitigation will be part of the road-mapping. Consideration is also given to where there may be a need for local sub-stations to balance system pressures due to hilly topology or high-rise buildings. These costs are already part of Typology B: High density flats, but added for a proportion of other buildings as a result of topology (the causes and implications are discussed in more detail in Solution 9).	
How the solution was identified	This solution brings together the insight from three previous solutions [9, 10, &11] to assess the ultimate potential for cost reduction associated with HIUs. Solution [9] identifies the saving from moving from Indirect (2 Heat exchangers per HIU) to Direct (1 Heat exchanger for DHW only) connection. This solution combines that thinking with the savings from Solutions [10] and [11] developed in the ECCR Workshop with the project team, HIU manufacturer and other stakeholders.	
Capital cost		
Change relative to baseline CAPEX	This solution builds on the Indirect HIU solutions [10 & 11] and so the starting point is the target outturn costs of Solution [11]: Revised Indirect HIU Cost [Solution 11]: **£486** Including Contractors Margin: **£559** Two solutions have been identified for changing from the baseline case of Indirect HIU with instant hot water to a Direct connection with either: 1. Instantaneous hot water. 2. No heat exchanger and a connection to an existing DHW tank with appropriate heating coil. **12a. Direct Connection with instantaneous hot water £ Material Saving vs. Solution 11** The following savings are achieved in a unit which provides instantaneous domestic hot water (DHW) • Minimal control valves: Simplified requirements to act as an on/off flow control for demand and as a diverter valve from Heating to DHW with temperature control. (Target cost £40 per unit) £35 • Pumps are not required with direct connection so the entire cost can be saved. £76 • Direct connection requires only a single heat exchanger as heating flow is direct from the DHN (the larger DHW heat exchanger is still required) £28 • Reduced piping / washers / valves from the simplification of parts in direct connections £13 • Reduced size for the HIU backplate & insulation as a result of a smaller simpler unit £ 8	**Value / Difficulty** (Low<£10,High>£50) M M H L M L M L L M

	• Simplified plug & play manifold for direct connections (4 less manifold connections as a result of eliminating the CH Heat Exchanger) £30	M	M
	• Reduced requirement and specification for cold water flow switch £ 8	L	L
	• Significant impact on installation complexity / time & cost		
	£ Labour & Margin Saving vs. Solution 11		
	• **Margin:** Fixed margin based on minimal aftersales: (Quick replacement vs. fault repair) £35		
	• **Labour:** saving impact from the above (50mins → 25mins vs. baseline 240mins) £10	M	M
	Direct Connection HIU with Instantaneous Hot water: Total Saving: £243	M	L
	Revised Indirect HIU Cost [Solution 12a]: **£243** Including Contractors Margin: **£278**		
	12b. Direct Connection using existing hot water tank £ Material Saving vs. Solution 11		
	The following are additional savings above those identified for the instantaneous solution (1) as a result of connection to a pre-existing DHW tank with a suitable coil.	**Value / Difficulty**	
	• Eliminate DHW heat exchanger (alternative valves and connections required £10) £33		
	• Minimal control valves (£20 per unit) £20	M	L
	• Eliminate mains voltage requirement: Controls may be run via battery or Peltier effect. £ 11	M	M
	(achievable when there is no need for a pump)	M	M
	£ Labour & Margin Saving vs. Solution 11		
	• **Margin:** Fixed margin based on minimal aftersales: (Quick replacement vs. fault repair) £10		
	• **Labour:** saving impact from the above (25mins → 18 mins vs. baseline 240mins) £3	M	M
	(NB: Thus simplified unit may incur additional installation cost vs. the instantaneous solution)	L	L
	Direct Connection HIU with Instant Hot water: Additional Saving (vs.12a): £77		
	Revised Indirect HIU Cost [Solution 13b]: **£165** Including Contractors Margin: **£190**		
	Research indicates that the likely proportion of systems in existing UK properties is 50% hot water cylinders, 50% combi boilers.		
	Solution Evolution (from baseline) & Ranges		
	• HIU Baseline Cost: £1,800		
	• Evolved Market Price HIU: £1,500		
	• Ex-Works cost including delivery £1,320		

- Post-Solution [10]: DfMA £ 825
- Post-Solution [11]: Value engineering £ 486

Low difficulty solutions impact: [12a] £ 135 [12b] £36
Medium difficulty solutions impact: [12a] £ 108 [12b] £41
Solution Total Saving: [12a] £ 243 [12b] £77
Range estimate: [12a] £150-£243 Saving [12b]: £36 - £77 Saving

Revised Indirect HIU Cost [Solution 12a]: **£ 243** [Solution 12b]: **£ 165**
Including Contractors Margin: [12a] **£ 278** [Solution 12b]: **£ 190**

These costs draw together the range of improvement ideas from solutions [9, 10 & 11]. This gives a target HIU cost of £190, for systems utilising pre-existing domestic hot water cylinders, if all solution elements are successful.

Network Impacts:
The 3rd Phase Optimisation of HIUs achieves reductions in the cost of the network as follows:

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£789	£249	24.0%
C	£1,706	£1,511	£194	11.4%
D	£3,871	£3,483	£389	10.0%
E	£4,113	£3,725	£389	9.4%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£41,972	£3,218	7.1%
Total system Capex	£62,602	£59,385	£3,218	5.2%
Dense village Capex, no prelims	£3,641	£3,253	£389	10.7%
OPEX	£3,320	£3,150	£170	5.1%

<table>
<tr><td></td><td>
<table>
<tr><td>TOTEX non-discounted</td><td>£184,090</td><td>£171,541</td><td>£12,550</td><td>6.9%</td></tr>
</table>
This table summarises the combination of impacts of solutions [9, 10, 11 and 12] assuming all Low, Medium and High difficulty solutions are achieved. As described above, there is an expectation that the actual savings achieved will be within a range, rather than an absolute value.
The table above includes the value of OPEX savings (repair and maintenance) and the TOTEX covers one replacement of the HIU during the 25 year time model.
The following assessments are based on the likelihood and impacts of the changes of the combination of solutions, assuming all previous solutions have been successfully achieved.
An additional summary of the impacts and effort to deliver all the savings is presented at the end.
</td><td></td></tr>
<tr><td colspan="3">Certainty of outcomes:</td></tr>
<tr><td>Certainty of outcomes</td><td>With direct connections there is marginally increased uncertainty as a result of potential:

System water quality issues from the commissioning process of old domestic radiator systems
Potential for the risks described above to undermine the perception of direct connections.
Also individual engineers and specifiers have a negative view of the potential failure modes of direct HIUs, despite their successful deployment in Scandinavia.
Increased requirement for network balancing to ensure all users receive the required service levels
</td><td>-1</td></tr>
<tr><td colspan="2">Operational cost</td><td></td></tr>
<tr><td>Change relative to baseline OPEX</td><td>REPEX: Repair and maintenance savings from:

Cost of replacement / repair will be cheaper, based on easily replaced sub-assemblies and faster on-site repair. The assessment is a 33% saving in the £150/yr baseline cost.
The bulk of the benefit arises from solution 10 (DfMA) and is not be double-counted here.

Other savings from:

Reduced efficiency heat loss across heat exchangers (not quantified)
Marginally reduced pumping energy (not quantified).
</td><td></td></tr>
<tr><td colspan="2">Lifecycle costs</td><td></td></tr>
<tr><td>Change relative to baseline lifecycle costs</td><td>Reduced TOTEX in the table above, as a result of the HIU being replaced with lower unit and installation cost. The cost model assumes one HIU replacement in the 25yr DHN life expectancy.

However, the pipework is expected to have a greater than 40yr lifespan so, in reality, the HIU may be</td><td></td></tr>
</table>

	replaced twice or more within the life of DHN.	
System performance		
Impact on DHN performance	(i) Thermal efficiency improved by reducing heat losses across heat exchangers. (ii) Rapid replacement of parts significantly reduces mean time to repair (plug / play replacement not on-site diagnostics and trial & error repair). (iii) Potential to be effective at lower system temperature with lower losses across heat exchangers. Also a DfMA design will allow easy retrofit of a re-sized heat exchanger if different thermal / flow properties are needed. (iv) The direct system needs to be well-balanced to ensure no properties suffer from poor supply. (v) This solution gives marginally improved domestic response	+1
Future flexibility	(i) Supply agnostic – Able to operate with multiple DHN heat sources. (ii) Temperature agnostic – HIU design solutions can adapt to all delta T supply temperatures. (iii) No direct impact on options to extend and interconnect.	0
Attractiveness to Users & Investors		
Attractiveness to Users and Investors	**Users:** Reduced repair and replacement frequency, time and cost will appeal to users. A smaller direct connection HIU is likely to appeal to users who have space limitations, or who would like to relocate the HIU from a current boiler location. **Investors***:* Attractive reduced CAPEX and OPEX for Network Investors and operators. Potentially more attractive than the indirect HIU to property rental companies based on simplicity which should improve reliability and both Mean Time Between Failures and Mean Time to Repair. The stakeholder workshop held at the end of Stage 2 (see Appendix F) highlighted the value in making units last longer than the typical combi boiler (10-15yrs); housing associations ideally want 30-60yrs lifetime with no moving parts.	+1
Reduced Complexity		
Complexity	Further simplification of the product (direct vs. indirect). Procurement of units and replacement parts should be straightforward.	+1
Health, Safety and Environmental Impacts		
HSE	Reduced weight of HIU without expansion vessel and other parts from the indirect solution. This should eliminate the need for 2-man lifts by reducing weight below 20kg.	+1
Opportunity to scale		
Scope of opportunity	Impact across the five typologies: (i) Typology A - City Centre commercial buildings – No HIU impact	+2

	(ii) Typology B - High Density Flats – Applicable to all (iii) Typology C - High Density Terraced Houses – Applicable to all (iv) Typology D - Medium Density Residential – Applicable to all (v) Typology E - Low Density Residential – Applicable to all Can apply to all domestic typologies. Potential to apply to European and Scandinavian domestic markets.	
Increased Revenue		
Potential for synergies	No direct impact	0
UK plc external Stakeholder Value		
Value for the UK	No policy change required but there will be a need to convince individuals and groups that the risks of direct connections (outlined above) can be mitigated. Potential to scale manufacturing and installation with a UK benefit for jobs and *p*ossible opportunity for export.	0
Technical feasibility		
Technical feasibility	Technical feasibility – Direct connections have been used successfully in a multiple countries but so far have only been adopted to a very limited extent in the UK. The challenge is to develop a solution acceptable to the UK market. One approach is to adapt existing Scandinavian designs to avoid re-inventing a solution. Or develop a wholly new design to draw together the best aspects of previous designs. Either way a process of industrialisation and further development will be needed to achieve the cost savings identified above. Standards – There will be a need to update guidance from technical bodies (e.g. CIBSE) to ensure system designers and customers are comfortable with direct connection performance standards.	-1
Effort to Implement Solution		
Effort	**Effort for both Instantaneous & Stored DHW solutions** **Low difficulty solutions:** • Investment capital and research required: Approx £100k Score: 0 • Level of technological innovation, technology readiness level: TRL 7 Score: 1	1

	• Anticipated timescale: 18months- 3 years Score: 1 • Likelihood of success: Probable Score: 1 **Medium Difficulty Solutions:** • Investment capital and research required: £500k - £2M Score: 1 • Level of technological innovation, technology readiness level: TRL 6 Score: 2 • Anticipated timescale: 18months- 3 years Score: 1 • Likelihood of success: Likely Score: 2	2
Other		
Any additional equipment required	Development of robust and simple thermostatic control valves at scale. Setting the requirements of these valves will form part of the road-map if the solution is taken forward.	
Barriers	Possible objection / resistance from existing DHN operators based on the perception of reduced specification. This needs to be mitigated but assuring technical equivalence. No IPR issues foreseen.	

This table summarises the qualitative and quantitative data from the four HIU related solutions.

- For the quantitative OPEX & Lifecycle cost savings the summary column takes the combined total, which is the highest estimate of saving potential.
- For the qualitative data the lowest value has been taken for the summary to indicate the areas where obstacles need to be overcome or improvements made.
- For the effort evaluation the summary column takes the highest effort ranking, albeit that this will only apply to an element of the total solution.

	[9] Direct HIU	**[10] DfMA**	**[11] VE / Scale**	**[12] Combined**	**Summary**
Certainty of outcomes	0	0	0	-1	-1
Change relative to baseline OPEX	0% Saving	4% Saving	4% Saving	4% Saving	4% Saving
Change relative to baseline lifecycle costs	7% Saving	7% Saving	8% Saving	9% Saving	9% Saving
Impact on DHN performance	0	0	+1	+1	0
Future flexibility	-1	0	0	0	-1
Attractiveness to Users and Investors	+1	+1	+1	+1	+1
Reduced Complexity	+1	+2	+2	+1	+1
Health, Safety and Environmental Impacts	-1	0	0	+1	-1
Opportunity to scale	+2	+2	+2	+2	+2
Increased Revenue	0	0	0	0	0
UK plc external Stakeholder Value	0	0	0	0	0
Technical feasibility	0	0	-2	-1	-2
Effort: Investment	0	0 1	0 2 3	0 1	3

Effort: Technology	0	0	1	0	2	3	1	2	3
Effort: Time	0	0	0	0	2	3	1	1	3
Effort: Likelihood of success	0	0	1	0	1	2	1	2	2

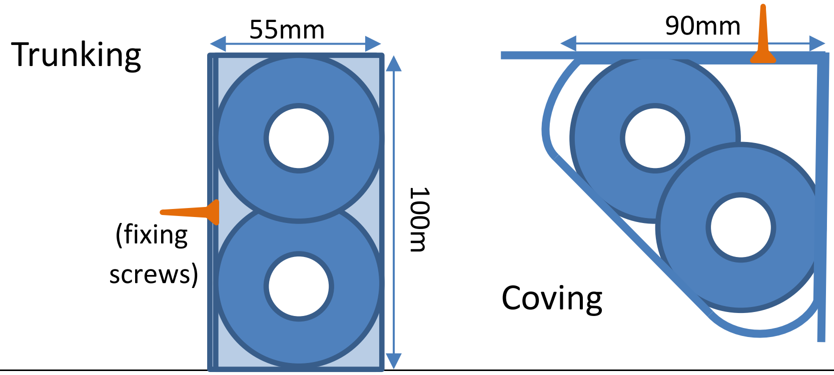
Solution name:	**Internal Connections – Pipework & Connections Within the Property**	Evaluation Rating
Name of evaluator(s):	Tim Hall, Paul Woods, Simon Box	
Solution ID:	13	
General		
Description of solution	This solution considers the cost of the pipework and installation from the first penetration into the building to the connection to the HIU and the installation of the HIU itself. A key consideration for this aspect of DHN delivery and the baseline cost model is that there are very few examples of DHN connections in existing buildings other than Typology B, apartment blocks. The internal connections also appear to have had less focus from the network developers, despite accounting for a significant proportion of cost in the baseline model. There are four main elements of cost within internal connections • **Material**: Pipes, fittings, insulation and materials for making good post installation. The goal is to minimise material use and cost without degrading performance or reliability. • **Labour**: Installer labour from removal of the existing boiler to final DHN system commissioning. An opportunity to reduce task time and balance labour across the programme to ensure teams have a steady workload to maximise productivity. • **Plant:** The cost of hire, lease or depreciation of capital assets such as core drills and generators. If products and processes can be designed for easy fitting: efficiency is improved by avoiding the need for specialist plant. • **Overhead**: Organisational costs, including contingency and rework, as well as genuine overhead. Significant overhead costs arise from factoring-in costs due to errors, delay and poor planning. In addition multiple layers of profit and overhead accrue with layers of sub-contracting. This solution focuses predominantly on material and labour which account for 63% of baseline cost. Overhead, often concealed as a mark-up on labour and materials, is a significant cost but more closely linked with procurement and contractual solutions deemed outside the scope of this project. There is also a broad diversity of connection pipework lengths across and within building typologies	

which will have a major impact on the material cost and installation labour. These range from an apartment with the HIU to be located adjacent to a vertical riser (Therefore needing less than 3m of pipe for flow/return), to a heavily extended London terraced house where the pipe makes multiple detours through the property to connect to the current boiler location. This diversity is accounted for in the cost model and is described analysis that follows.

Material

A key insight from Liverpool Warmer Homes (part of the UK Government's CERT programme) [AECOM] is that for heating system installation or renewal there is often a policy of over-supplying pipe and fittings for jobs to keep within standard pack quantities and ensure jobs are not delayed by material shortage. The excess material (free-issued by the main contractor) is deemed a benefit in kind for the installers. This is frequently at a level of 30% excess material at the end of a job. Such practices are confirmed as common, but not universal, by [National Grid Transco]. Although the cost of having a team of four installers waiting for material is also costly, this systemic over-supply is a burden on installation cost. Creating more realistic 'DHN home kits', in say 3 sizes, will more closely match the range of dwelling sizes, whilst avoiding the need for a more complex system of survey, order-pick and deliver a bespoke pack to site. This will minimise the endemic material waste and shortages are avoided using a 'pull-flow' supply approach from the warehouse. The precise number and content of the kits will be developed in pilot programmes. The assumption used in the analysis is that there is potential to save an average of 20% of material for installations. Particularly valuable for longer runs of internal pipework (terraced houses and a proportion of other Typologies).

For boxing in pipework standard plastic trunking is commonplace (without insulation) and this



	enables rapid installation and a consistent aesthetic finish. Where this is not suitable gas teams add a carpenter to the team to 'box-in' pipework from scratch materials – adding considerably to cost. Disguising pre-insulated pipes will create a bulky and intrusive installation and so it will be important to develop a new DHN trunking solution to minimise the visual impact, whilst also enabling rapid installation. The provisional concept, in the example sketches below, is for a co-extruded (or assembled) trunking or coving back-plate and insulation. This is fixed to the wall and the pipework inserted into the insulation, simultaneously supporting and insulating the pipe. A decorative top cover is then clipped to the back-plate to finish the installation. For the HIU a crucial enabler for rapid installation is a 'first-fix' bracket to which all incoming pipes are routed before installing the unit itself. This allows the installer much easier access to make the pipe runs and connections, knowing that the HIU will fit in a few minutes as a later step. (Solution HID 10). For pipework itself plumbers have a preference for using copper rather than plastic. However, when installed in floor voids (which is the preference for householders where it is not intrusive) plastic has the advantage of being easier to install through joists without notching. The failure points of plastic pipes tend to be at joints and so a continuous pipe run through floor voids is a good use of the product. Making good is often an afterthought of the installation, but needs to be well handled if the user perception of DHN installation is to be kept positive. Finishing around holes and blocking up of the original boiler flue are important details: Simple to use products in common sizes will need to be developed as a step-change improvement, in speed and finished quality, on the current '*half a brick and some sand / cement'* common solution [National Grid Transco] currently used for blocking boiler flues. **Labour** In heating system installation / upgrades the focus is on getting the job complete in a single day [AECOM]. This meets with the householders' tolerance for disruption and aligns with previous ETI research as part of the Smart Systems and Heat programme [ETI SSH]. The example labour contrast was with a new installation of gas heating: All radiators, pipework and a combi-boiler are planned to be installed and commissioned in a day using a four man team for 10 hours [AECOM]. This works up to a 3 bedroom property. Timing is very tight, but teams are incentivised to get the job done in a day. This may lead to a speed rather than quality focus and as a result some installations	

	are prone to post-completion defects or complaints. [Islington Council] [AECOM]. Labour only cost for full system installation of boiler, gas supply and 7 radiators is typically £1,800 outside London [AECOM] and this is for a team of four working from 8am – 6-pm. The costings for pipework and HIU installation which follow require less labour content (no gas or radiators) and the baseline programme assumes three installers working for 10 hours. For HIU installation the only need for gas work is to cap-off the existing gas supply: This means that there is an opportunity to use semi-skilled installers in future reducing labour cost by 20% or more [ETI SSH]. **Plant** Within the cost of labour the team will typically bring all the tools they need for pipe installation. The exception may be a core drill, for cutting holes through masonry walls, which can be hired for £142/wk for a high specification product with dust collector [HSS]. There may be a need for a generator if the householder objects to providing power, or has insufficient electrical credit. Current assumptions of £50/day have been reduced in the latter stages of solution development in line with the reduced labour content – keeping plant costs at around 5-6% of total. **Overhead** An important aspect of construction is the layering of contractors' margin through the practise of multiple sub-contracts. This is the profit, administration burden, contingency for quality and delay errors and risk for each organisation. Overhead is commonly levied as a mark-up on material (≈ 20%) and labour (which may be up to 300%) [AECOM], [ETI SSH]. This means that a plumber earning £100 per day could be charged at £400/day after the mark-up of fitting gangs, M&E contractor & main contractor. The resolution of this contracting challenge is beyond the scope of this project, but it does mean there is a multiple benefit of reducing material and particularly labour cost. Review of the contracting model will form part of the roadmap. **Challenges and obstacles** Although there is limited experience of DHN installation in existing buildings, there is significant learning from gas heating installation and replacement and the following list covers some of the areas which will need to be addressed during future development of this solution.	

- Householder objections to pipe location – for visual or space / access reasons.
- Fitted furniture in the pipe route which can be problematic to pass through without damage.
- Significant post-completion snag-list – Complaints from customers require a second team to complete the rework. The original install team then has a proportion of their income docked.
- Clutter, poor hygiene & difficult access to the property sometimes mean the installation cannot be completed and extra costs are incurred – Approximately one in 30 visits is abandoned [AECOM]
- Risk of damage to the occupiers delicate items and (sometimes false) claims – commonly Hoover, carpet and decoration damage.
- Slow & dusty hole cutting.
- Risk of damage to electrical cables when lifting / replacing floorboards and when using a standard power drill to put holes through joists (striking cables as it breaks through uncontrolled).
- Cost based on building condition or non-typical construction in some typologies: e.g. DHN pipework costing £12k per connection in one block of old pipes with asbestos [Islington]
- Balancing radiators takes time [Islington / AECOM] easy to ignore and crucial to the user experience with low temperature systems in particular.

Solution Option Development :

1. <u>Eliminate excessive material.</u>
   When delivering at scale there will be significant volume of material supply to set up a more sophisticated but simple to manage logistics operation (with a merchant) to prepare material kits, right-sized to the property type rather than, for example, supplying two 30m packs of copper pipe to a house which may only need 32m [AECOM]. Safety stock is made available for genuine errors in estimating or installation. This will enable a 20% reduction in material usage which has a significant impact in terraced properties which require longer internal pipe runs.

2. <u>Develop a single day programme for installations with a crew of one or two (up to 10hrs).</u>
   Two top level programmes for HIU installation were developed with Dan Young [AECOM]; an experienced former fitting team member. These programmes aim to optimise labour to install the pipework and HIU within a single day for all domestic typologies. There are two scenarios to achieve this:
   - For short internal pipe runs where the DHN piping comes in to the property close to the planned HIU location; typically flats and also semi-detached / detached properties.
   - Longer internal pipe runs where the DHN connects at the front of the property and needs to be taken through the house to the kitchen (usually at the rear)

   Time studies from previous research [ETI SSH] show that retrofit labour is only 30% productive

	during installation. This is due to inadequate process design and unreliable material supply. With process design and optimisation, supported by product development and an ‘industrialised’[7] process significant labour savings can be achieved. The expectation is to improve productivity form 30% to 50% and, in so doing, reduce labour content by one third. This will have the effect of achieving: o For short internal pipe runs: 1 operator for 10hrs vs. current 2 operators for 7.5hrs. o Longer internal pipe: 2 operators for 10hrs vs. current 3 operators for 10hrs. This will achieve a repeatable result with the development of specialist HIU trunking or coving products and a focus on robust processes to alleviate the quality challenges. The use of plastic (cross linked Polyethylene - PEX) push-fit pipes, increasingly common in traditional domestic heating, will also enable faster installation. To achieve the 40 years design life required, PEX pipe needs to operate below 80’C [Polypipe]), if higher DH Network temperatures are proposed: PEX pipe will need further development, or installations revert to copper pipe. Also network operators must be convinced of its durability, which has taken time in domestic plumbing. 3. <u>Route pipework underfloor to improve aesthetic and speed, with reduced material cost.</u> For the householder the visual impact of larger (insulated) DHN pipes may cause objections to installation as a whole. Refining a process which makes use of floor voids will minimise the intrusion on the living space. More difficult access to floor voids will be offset by reduced material costs. This solution will only apply to 2+ storey terraced properties with an accessible first floor void. 4. <u>Refinement – a further 15% reduction in labour time and 15% in cost of new materials.</u> <u>For labour:</u> Once a robust and reliable process is implemented, refinement activity can take place to ensure installation is optimised. This should enable a further 15% reduction in labour content, potentially enabled by simple tooling and jigs for pipe installation. <u>For materials:</u> Insulated trunking is estimated to cost £10/m (3 x the cost of current equivalent uninsulated products). Once the product has been developed and scaled there should be an opportunity to save 15% or more. For PEX pipe the costs used in solutions are based on current	

[7] An industrialised process is a systematically developed approach to improve capability and achieve repeatable results without waste, error or delay.

	retail pricing of premium products (for longevity & reliability). However, there are products available, which may perform sufficiently well, that are less than half the price. Therefore a 15% reduction in pipe cost may be conservative. How the solutions apply to different sections of the network: 1. Eliminate excessive material – can apply to all typologies, but with less significant impact on short pipe run properties (semis / detached where external pipe routes are preferred and flats). 2. Single day programme – a single installer is expected to be able to complete the short run pipework in a 10 hr day or less (Typologies B,D,E). A crew of 2 installing in a 10 hr day is envisaged as achievable[8] for all but the most complex long run properties. 3. Long Run pipework routed in underfloor voids – is the preferred option for Typology C. For these terraces there may be a proportion with solid floors or inaccessible floor voids (difficult floor coverings, ownership issues for houses converted into flats etc.). As a result it is assumed that 50% of Typology C properties will be suitable for floor void solutions. 4. 15% reduction in Labour & Material All ideas suggested in this aspect of the solution are independent of typology. **More speculatively there are potential further Opportunities** • There are few tasks which require a Gas Certificate or Electrical competence. There should be potential to use semi-skilled operators for one of the crew of 2 (potentially saving 10% of labour) cost. If the process can be made highly robust, both operators can be semi-skilled with potential 20% labour cost saving. • There is great value from a maintenance and meter reading perspective to site the Heat meter & HIU where it can be accessed from outside the property, at least £100 per year [Islington]. If this can be incorporated in the refined design there is a £300k+ / year potential OPEX saving. (OPEX: 3,300 homes x £100 saving)	

[8] Total Flow have enabled clients across industries to reduce process manual work content by typically 30-50%. Construction processes have particularly high levels of 'non value adding' content [ETI SSH] and the industrialisation of process will deliver significant benefit.

	• To enable rapid and accurate joist cutting a drill which clamps on joists and puts holes at a common depth, without excessive force will speed up floor void installation and reduce the risk of kinked pipes and electrical cable damage. [National Grid Gas]	
How the solution was identified	Contributors to the solution development, beyond the Project Team were: • Daniel Young, Principal Engineer, AECOM • Huw Blackwell, Decentralised Energy Project Officer, Islington Council • Peter Rayson, formerly National Grid Gas Solutions were developed in discussions with these contacts, building on their experience of both installation and operation of a range of heating and gas systems. Analysis was focused on solutions to address current aspects which attract disproportionate time, cost or uncertainty and risk.	
Capital cost		
Change relative to baseline CAPEX	**Baseline Cost Analysis** Baseline costs for internal connection pipework differ between the four domestic Typologies based on the lengths of internal piping modelled. To avoid disruption to householders the revised baseline cost model assumes that, where possible, DHN pipes will run externally to the property (in gardens or under driveways). This revision to the initial baseline added some extra cost to the DHN compared to internal piping, but is expected to be a more attractive solution for householders with less disruption. Model assumptions follow: Typology B: Flats – Assuming short distance to internal connection from a local riser. £ 386 Typology C: Terraces – A long run of internal pipe from the front to back of the house £1,491 Typology D: Semi-detached – Pipes run externally to the HIU location (e.g. drive – kitchen these costs are now included in the civil engineering elements of the cost model) £ 405 Typology E: Detached - Pipes run externally to the HIU location as for Typology D £ 447 All of these costs are treated individually in the full model, but for the simplicity of presentation here the solution is shown as two costed approaches: Longer internals for Typology C @ £1,491 per dwelling. Short internals for the remainder with an average baseline cost of £410. There may be instances where, as a result of householder preference or property construction (e.g. obstacles underground) there is a reason to divert piping internally. If trials show that there are significant numbers of properties where internal pipe runs are preferred; this will add weight to the benefit of an improved approach to internal piping.	

Part of the internal connection is the HIU installation in each property and the baseline cost is £350 of labour and a notional £50 for plant hire. The two option costs are built up as follows:

	Short Internal	Long Internal
Connection Pipework Labour:	£ £335	£ 970
Connection Material: Pipework and fittings	£ 75	£ 521
Connection subtotal (as above)	**£ 410**	**£ 1,491**
Plant & tools	£ 50	£ 50
HIU Connection – labour	£ 350	£ 350
Total connection cost per domestic property	**£ 810**	**£ 1,891**
Total Baseline Labour	£ 685	£ 1,320

The labour total for the two options is equivalent to:

- **Short**: A team of 2 trade plumbers for a standard day (8-3:30 pm) = 15 hrs
- **Long:** A team of 3 trade plumbers for an extended day (8-6pm) = 30 hrs

This includes a 125% Contractors' mark-up to cover delays, overhead and team bonus.

Estimated material build-up:

- **Short**: 4m x 22mm pipe, insulation, fittings, clips, trunking, gas, solder, sundries = £75
- **Long:** 32m x 22mm pipe, insulation, fittings, clips, trunking, gas, solder, sundries = £521

Plant costs of £50 would cover the long-term hire of core drill and other specialist equipment.
With significant diversity in the property types, layouts, condition and access there will be a range of material and labour used per property. The objective is to keep installation to less than a day in all cases to minimise householder disruption.

Solution Cost Analysis

The following tables show the cost savings achieved with the solutions from each of the Solution

Options described above. The full implications are complex based on multiple typologies and mix assumptions and some of the diversity is held within the cost model. Savings presented adjacent to option descriptions are for short and long run typologies respectively.

Option Cost Summary

This table shows the split of costs for the short and long run typologies in the baseline cost model. Each of the options is summarised and presented in turn.

Baseline	Short runs:(Flats, Semis, Detached)				Long: Terrace			
Labour	hrs	/hr	Total	% of Solution	hrs	/hr	Total	% of Solution
Installer A	7.5	£20	£152	19%	9.8	£20	£196	10%
Installer B	7.5	£20	£152	19%	9.8	£20	£196	10%
Installer C		£20	£0		9.8	£20	£196	10%
Mark-up		125%	£381	47%		125%	£732	39%
		Total Labour	**£685**	85%			**£1,320**	70%
		Total Plant	£50	6%			£50	3%
Material	Qty.	/m	Total	% of Solution	Qty.	/m	Total	% of Solution
Pipe (22mm Copper)	5	£3.86	£19	2%	32	£3.86	£124	7%
Pipe Insulation	5	£1.91	£10	1%	32	£1.91	£60	3%
Fittings & clips	£4.10	£4.70	£ 9	1%	£41.30	£9.40	£50	3%
Trunking	2.5	£8.23	£21	3%	16	£8.23	£130	7%
Sundries			£ 4	0%			£70	4%
Mark-up		20%	£13	2%		20%	£87	5%
		Total Material	**£75**	9%			**£521**	28%
Baseline Total install cost:			**£810**	Per home			**£1,891**	Per home

This summary of the baseline costs demonstrates that labour cost (including overhead mark-up) is the dominant aspect of internal connections. With between 70% and 85% of total cost being proportional to time on site. However, reducing manual work content needs to align with a working day to deliver savings. For example reducing installation time from 7.5 hrs to 6 will have little impact on cost because the team will not be able to make use of the saved time and will still charge for a full day. As a result the labour programmes which form the following solution options have focused on achieving a full 7.5 hr day or extending up to 10hrs (which is the limit of both householder and team acceptance [ETI SSH], [AECOM]).

Material costs are more significant where longer pipe runs are required.

	Short	Long
Option 1: Optimise material usage per property by eliminating over-ordering. - Reduce material usage per property to 80% of baseline – 20% saving. - Change the approach of supplying full packs of pipe / fittings to site; eliminating excess material consumption. - Introduce pre-picked kits in 3 – 5 kit types to suit different property types. - Use a pull system for site material with managed safety stock to prevent delay in the case of over-usage. This option achieves reduced material consumption, but also greater visibility of process performance problems and opportunities by analysing feedback from sites when safety stock is needed.	£ 15	£100

Option 1	Short runs:(Flats, Semis, Detached)				Long: Terrace			
Labour	hrs	/hr	Total	% of Solution	hrs	/hr	Total	% of Solution
Installer A				19%				11%
Installer B	As Baseline			19%	As Baseline			11%
Installer C	No Change				No Change			11%
Mark-up				48%				41%
	Total Labour		**£685**	86%			**£1,320**	74%
	Total Plant		£50	6%			£50	3%
Material	Qty.	/m	Total	% of Solution	Qty.	/m	Total	% of Solution
Pipe (22mm Copper)	4	£3.86	£15	2%	25.6	£3.86	£99	6%
Pipe Insulation	4	£1.91	£ 8	1%	25.6	£1.91	£49	3%

Fittings & clips	£3.30	£4.70	£ 8	1%	£33.00	£9.40	£42	2%
Trunking	2	£8.23	£16	2%	12.8	£8.23	£105	6%
Sundries			£ 3	0%			£56	3%
Mark-up		20%	£10	1%		20%	£70	4%
		Total Material	**£60**	8%			**£421**	24%
		Option 1 Total install cost:	**£795**	Per home			**£1,791**	Per home
		Saving vs. Baseline:	2%				5%	

The 2%-5% saving vs. baseline internal connection cost, achieved with a 20% reduction in material usage, demonstrates the dominance of labour. Solutions focusing on reducing site work content will have a more significant impact.

Option 2: Installation process standardisation and change of materials:	Short	Long
- Simplify Installation to achieve: 7.5 Hrs for a crew of 1 – Short runs.	£233	
10hrs for a crew of 2 – Long runs		£ 415
Standard work process design to achieve a 33% reduction in work content.		
- Insulated trunking / coving for rapid installation & improved aesthetics.	£ 5	£ 31
- Change internal pipe specification from Copper to premium Cross-linked polyethylene (PEX) (this is part of the change to enable faster installation)	£ 4	£ 26

Option 2	Short runs:(Flats, Semis, Detached)				Long: Terrace			
Labour	Hrs	/hr	Total	% of Solution	hrs	/hr	Total	% of Solution
Installer A	10	£20	£200	36%	10	£20	£200	15%
Installer B					10	£20	£200	15%
Installer C								
Mark-up		125%	£252	45%		125%	£505	38%
		Total Labour	**£452**	82%			**£905**	69%
		Total Plant	£50	9%			£50	4%
Material	Qty.	/m	Total	% of Solution	Qty.	/m	Total	% of Solution
Pipe (22mm PEX)	4	£3	£12	2%	25.6	£3.00	£77	6%
Pipe Insulation								

Fittings & clips	£3.30	£4.70	£ 8	1%	£33.00	£9.40	£42	3%
Insulated Trunking	2	£10	£20	4%	12.8	£10.00	£128	10%
Sundries			£ 2	0%			£56	4%
Mark-up		20%	£ 8	2%		20%	£61	5%
		Total Material	**£51**	9%			**£364**	28%
Option 2 Total install cost:			**£553**	Per home			**£1,319**	Per home
Saving vs. Baseline:			32%				30%	

This is the **Central** case for Internal Connection improvement. The step-change in labour content per installation is achieved with a rigorous approach to process design and team organisation. Similar results (up to 50% reduction in labour content) have been achieved in site processes for retrofit [ETI SSH] and water pipe installation [Anglian Water].

The diversity of properties (design and size) will be the key challenge to resolve with this solution.

Option 3: Installation in the floor void: Hidden pipework for improved aesthetics and also cheaper to insulate.(applies only to Long runs only).	Short	Long
- Simplify Installation process as described above, including tools for lifting floorboards gaining access to first floor void and reliably reinstating carpets.	N/A	£ 415
- Reduced material cost from eliminating the need for trunking and fewer fittings under floorboards with flexible pipe, post insulated.		£ 139
Option 3 is an alternative to Option 2: Savings are vs. Option 1 Labour and material, rather than cumulative to Option 2.		

Option 3	Short runs:(Flats, Semis, Detached)				Long: Terrace			
Labour	hrs	/hr	Total	% of Solution	hrs	/hr	Total	% of Solution
Installer A	Option 3 does not apply to Short runs: No Change from option 2			37%	10	£20	£200	16%
Installer B					10	£20	£200	16%
Installer C								
Mark-up				46%		125%	£505	41%
	Total Labour		**£466**	83%			**£905**	73%
	Total Plant		£50	8%			£50	4%
Material	Qty.	/m	Total	% of Solution	Qty.	/m	Total	% of Solution
Pipe (22mm PEX)	Option 3 does not apply to Short runs: No Change from option 2			2%	25.6	£3.00	£77	6%
Pipe Insulation					21.6	£1.91	£41	3%
Fittings & clips				1%	£17.00	£4.70	£21	2%
Insulated Trunking				4%	4	£10.00	£40	3%
Sundries				0%			£56	5%
Mark-up				2%		20%	£47	4%
	Total Material		**£51**	9%			**£282**	23%
Option 3 Total install cost:			**£553**	Per home			**£1,237**	Per home
Saving vs. Baseline:			32%				35%	

Option 3 is an alternative solution for long run properties, having no impact on short run installations. The cost difference of the two solutions is £82 (6%) all arising from material changes.

Expectations are that 50% of installations will be surface mounted pipework (Option 2) and 50% in the floor void (Option 3). Therefore, for simplicity and clarity of presentation: Option 4 savings are developed from an average of Options 2 and 3.

	Short	Long
Option 4: Further savings with fully industrialised process (estimated).		
- 15% additional labour saving (reducing from a 10hr – 8.5hr day). Achieved through process optimisation once tested at scale.	£ 67	£ 135
- 15% (cautious) cost reduction in new pipe and trunking materials with maturity and scale. Cost reductions achieved from material / product innovations once solutions are proven.	£ 9	£ 30
- 30% Reduction in plant cost - for a core drill and occasional generator.	£ 15	£ 15

Option 4	Short runs:(Flats, Semis, Detached)				Long: Terrace			
Labour	hrs	/hr	Total	% of Solution	hrs	/hr	Total	% of Solution
Installer A	8.5	£20	£170	37%	8.5	£20	£170	16%
Installer B					8.5	£20	£170	16%
Installer C								
Mark-up		125%	£215	46%		125%	£430	39%
		Total Labour	**£385**	83%			**£770**	70%
		Total Plant	£35	8%			£35	3%
Material	Qty.	/m	Total	% of Solution	Qty.	/m	Total	% of Solution
Pipe (22mm PEX)	4	£2.55	£10	2%			£65	6%
Pipe Insulation							£21	2%
Fittings & clips	£3.30	£4.70	£ 8	2%			£32	3%
Insulated Trunking	2	£8.50	£17	4%			£72	7%
Sundries			£ 2	0%			£56	5%
Mark-up		20%	£ 6	2%		20%	£49	4%

Total Material	**£42**	9%		**£293**	27%
Option 4 Total install cost:	**£**	Per home		**£**	Per home
Saving vs. Baseline:	43%			42%	

Option 4 is the **Optimistic case** in the summary tables which follow. The savings are anticipated after previous solutions have been verified and further improvements made after multiple iterations.

Options Impact Summary vs. Baseline		Short	Long
Option 1 Impact: As a % of Internal Connections Baseline		£ 15 2%	£ 100 5%
Option 2 Impact: As a % of Internal Connections Baseline	**Central Solution**	£ 257 32%	£ 572 30%
Option 3 Impact: As a % of Internal Connections Baseline		N/A	£ 654 35%
Option 4 Impact: As a % of Internal Connections Baseline	**Optimistic solution**	£ 348 43%	£ 793 42%

Pessimistic Solution:

For a more cautious analysis; the final summary table below assesses the impact of only achieving half of the savings in the Central solution.

As documented in the solution description above, these savings are based on insight extrapolated from Local Authority heating replacement programme rather than a DHN. As such the evidence base for the savings is limited and the potential should be seen as indicative rather than proven.

Central Case

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£987	£51	4.9%
C	£1,706	£1,601	£105	6.1%
D	£3,871	£3,786	£85	2.2%
E	£4,113	£4,023	£90	2.2%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£44,358	£831	1.8%
Total system Capex	£62,602	£61,771	£831	1.4%
Dense village Capex, no prelims	£3,641	£3,494	£147	4.0%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£183,259	£831	0.5%

Optimistic Case

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£969	£69	6.6%
C	£1,706	£1,560	£145	8.5%
D	£3,871	£3,756	£115	3.0%
E	£4,113	£3,991	£122	3.0%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£44,056	£1,133	2.5%
Total system Capex	£62,602	£61,469	£1,133	1.8%
Dense village Capex, no prelims	£3,641	£3,438	£203	5.6%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£182,957	£1,133	0.6%

Pessimistic Case

Typology	Network Costs		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£1,014	£24	2.3%
C	£1,706	£1,655	£51	3.0%
D	£3,871	£3,831	£40	1.0%
E	£4,113	£4,071	£43	1.0%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£44,795	£395	0.9%
Total system Capex	£62,602	£62,208	£395	0.6%
Dense village Capex, no prelims	£3,641	£3,570	£71	2.0%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£183,695	£395	0.2%

Certainty of outcomes

Certainty of outcomes	With a refined and optimised installation process there will be greater confidence in completing home installations to the required quality, in the target time of a single day. Having a cost effective internal solution will offer an alternative to external trenches where there are obstacles and high value	+1

	surfaces (e.g. block paving): This improves the certainty of delivery to a known cost and programme.	
Operational cost		**Operational cost**
Change relative to baseline OPEX	Marginal improvement in maintenance cost for speed of replacing piping and HIUs as required. Not sufficient to include in the cost model. (The full benefits are included in Solution 12)	
Lifecycle costs		
Change relative to baseline lifecycle costs	No significant impact on lifecycle costs.	
System performance		
Impact on DHN performance	No significant impact on DHN performance	0
Future flexibility	No significant impact on DHN flexibility	0
Attractiveness to Users & Investors		
Attractiveness to Users and Investors	From a user / householder perspective, there will be less disruption from internal works with less labour on site. However, there will still be work carried out for one full day so the improvement is not major. Householders may want a catalogue of coving/skirting options not just a choice of one. From DH Network Investors' perspectives the solution provides a more compelling case for the Local Authority and increases the chance of a proposed DHN progressing.	+1
Reduced Complexity		
Complexity	A slight impact in the complexity of ordering / supplying materials, using estimated Bills of Quantities per dwelling rather than over-ordering to ensure sufficiency. Not significant enough to score negatively.	0
Health, Safety and Environmental Impacts		
HSE	Minimal impact on HSE	0
Opportunity to scale		

Scope of opportunity	With the revised baseline taking the option of externalising pipework (in driveways / paths rather than through the house) the scope pipe runs internally are reduced, reducing the impact of this solution. Should internal piping costs (& disruption) vs. external pipework prove attractive, Options 1-4 can apply to domestic typologies as follows. • Options 1 & 2 are applicable to any housing typology and provide the most significant benefits in Typology C – terraces and where an internal route is selected for semi- and detached properties. • Option 3 is limited to properties with floor voids, but the estimate still covers 68% of the DHN stock overall. • Option 4 is a further development of the process and material ideas in Options 2 & 3 and is applicable to all domestic typologies.	+1
Increased Revenue		
Potential for synergies	The solution has potential to realise synergies with: • More extensive property retrofit: Energy efficiency retrofit and routine landlord or owner-occupier refurbishment programmes. • Roll-out of smart meters – although this programme is well underway and the overlap is likely to be limited. Alignment with these initiatives may prove difficult and neither has been included in the cost analysis.	+1
UK plc external Stakeholder Value		
Value for the UK	Potential to scale manufacturing and installation Possible opportunity for export	0
Technical feasibility		
Technical feasibility	The solution Options' benefit comes in the main from process optimisation and so technically there is minimal risk. New insulating trunking products are an adaptation of existing solutions. No need for new standards is anticipated.	-1
Effort to Implement Solution		
Effort	**Option 1: Minimal Solution** Very little effort required across all categories	0
	Pilot Study: Investment capital and research required to test **Central and Mixed Solutions**: • <=£500k for a pilot study of solutions, linked to DHN or other heating renewal programme (0) • Technology Readiness Level (commercial equivalent): TRL 8-7 (Solution Development) (+1) • Anticipated timescale to the point where the solution is delivering value: 18mths-3yrs (+1) • Likelihood of success – Probable (+1)	+1

	Option 2: Central Solutions Investment capital and research required: • £500k – £2M to develop low cost insulated pipe solutions and enabling tools (+1) • Technology Readiness Level (commercial equivalent): TRL 6-5 (Solution Demonstration) (+2) • Anticipated timescale to the point where the solution is delivering value: 3-5 yrs (+2) • Likelihood of success – Likely (+2)	+2
	Option 4: Optimistic Solution Investment capital and research required: • £2M - £5M to invest in the industrialisation of installation processes and improved capability. (+2) • Technology Readiness Level (commercial equivalent): TRL 4-3 (Prove feasibility) (+3) • Anticipated timescale to the point where the solution is delivering value: 3-5 yrs (+2) • Likelihood of success – Possible (+3)	+3
Other		
Any additional equipment required	All solutions are applications of existing technology and processes.	
Barriers	Potential for market push-back (technical specifiers) against simplified controls vs. current solutions.	

Solution name:	**Recycling Excavated Material for Backfill**	Evaluation Rating
Name of evaluator(s):	David Ross, St John Ager, Eoin Harris, Mary Kucharska, Paul Edwards, Lucy Pemble	
Solution ID:	14	
General		
Description of solution	The common approach currently for highways trench reinstatement associated with district heating is that the excavated material is removed from site by a 'muck-away' firm (the material typically being classified as 'inert' and recycled for other uses rather than sent to landfill). Newly quarried Type 1 aggregate is then purchased for use as backfill. Type 1 aggregate is traditionally made from primary crushed rock to provide a sub-base for engineering work. This is termed GSB1 in the Specification for the Reinstatement of Openings in Highways (DfT, 2010), and is also open to the use of crushed recycled aggregate sources e.g. crushed concrete or crushed demolition materials. Discussions have been held with contractors around why the backfill material is not recycled to reduce both material and haulage costs. • A key issue is lack of space to store any excavated material. Particularly in urban environments, there is limited space either next to the dig or in the site-compound. Furthermore, DH schemes currently are relatively small in scale and this limits potential efficiencies from excavated material from one part of the civils work being used for backfill elsewhere on the project. • The second issue is that not all excavated material is suitable without treatment for directly reusing as backfill e.g. if there is insufficient or excess moisture then adequate compaction may not be achieved, resulting in subsequent medium to long term settlement of the reinstatement. Whilst the excavated material could be treated (by the contractor, say), both the contractor and network developer appear to prefer to de-risk the approach by purchasing new backfill material. • There is also the need for some processing of the backfill to avoid, for example, any sharp objects damaging the DH or other utilities pipes. • There is also a historic perception amongst contractors and local authorities that reused and recycled fill is more prone to structural failure of the road/pavement after reinstatement, and this has been a barrier to their use. The Waste Resources Action Plan (WRAP) conducted extensive research in this area and	

produced guidance such as the Aggregates Quality Protocol, which, if followed, reduce the likelihood of road/pavement failure when using these materials.

Several possible solutions were evaluated below around reducing the cost of backfill. The following dimensions have been used to calculate the amount of backfill material needed:

- A trench length of 45km.
- A trench depth of 1800mm
- It is assumed that only 1000mm of the trench depth is currently replaced with the Type 1 aggregate. The remaining depth includes 300mm at the top for reinstatement of the road surface etc and 500mm at the bottom for granular material / pipe bedding to surround the pipe – hence, for example, the sand surround to the district heating pipework remains intact and is not impacted by the solutions here.

<u>Option 1: Re-use of Excavated Material</u>

This option is to re-use the excavated material as backfill where possible. For larger works, that are being considered as part of this project, careful management could allow excavated material from one part of the site to be used for backfill on another part of the site.

Through discussion, this option was not viewed as being attractive in comparison with the other options being considered here. In particular there are significant technical risks associated with the identification of materials suitable for re-use as backfill and the mitigation of the risk of future settlement of reinstatement associated with the use of unsuitable materials. Further consideration includes the logistics of not knowing how much material is suitable for re-use prior to excavations being started.

It is noted that this option would need a working area in the proximity of the utility works to enable segregation/sorting of excavated materials, including ensuring no damage to any other utilities present in the ground, as well as storage of materials to avoid them becoming unsuitable (e.g. covered to avoid them getting wet in the rain).

<u>Option 2: Use of Recycled Aggregate</u>

An alternative option is to use recycled aggregate compliant with the same standard as the primary aggregate i.e. GSB1 in the SROH (Dft, 2010). This could be used to replace primary aggregate for the full 1000mm depth. In this option there is no need to store on-site – the recycled aggregate can be organised to be brought to site as needed.

	The retail price of 1 tonne of recycled aggregate is approximately £13.50. (Telephone Conversation with Days Aggregates). This is a worst case cost based on a postcode that is not located close to a supply depot. The retail price of 1 tonne of virgin type 1 limestone aggregate is approximately £22.50 (telephone conversation with Days Aggregates). This is again a worst case cost based on a postcode that is not located close to a supply depot. Hence, there is potentially £9 saving per tonne. As an approximation, a conversion factor of 2.4 m^3 as equivalent to 1 tonne has been used. This potentially results in a maximum cost saving of £20 per m^3. As noted above, this is a maximum cost saving and will be reduced depend on geography. A more reasonable estimate of £15 per m^3 has been used in the model. Potential barriers associated with this approach is the acceptance of some local authority highway engineers for the use of recycled aggregates in GSB1 (note: this should not be a barrier since it should comply with the same specification), and also identifying suitable sources of quality controlled recycled aggregates which are complaint with the WRAP Protocol for Recycled Aggregates. <u>Option 3: Use of Hydraulically Bound Materials (Off-Site hub recycling)</u> A third option considered was to use Hydraulically Bound Materials (HBM). These are a mixture of excavated materials (aggregate and soil), water and hydraulic binder. Possible binders include cement, fly-ash, ground and/or granulated slag, lime, pozzolan and various other combinations. Binders can be generic or proprietary. The roadway / site may be constrained in that future works may also require the use of the same type of binder if the excavated area is re-opened in the future. In this option, the material from the excavated trench is taken off site and mixed with the additive at a batching plant. The arisings from the trench excavations need to be tested to ensure suitability for use within the HBM mixture. The material is then returned to site when required and used to backfill the trench. Costs of HBM were received from three companies (Brett Aggregates, Days Group, SMR). These varied from £15 per tonne to £27.50 per tonne. The product cost per tonne is more expensive than the recycled aggregate alternative; however, the cost benefit includes not having to dispose of all of the excavated material as some can be reused as part of the HBM. When this is taken into account the holistic costs are generally similar cost or a small net cost saving versus GSB1. Hence, it is expected that similar cost savings could be achieved to Option 2.	

	Waste management regulations may also apply to materials that are moved off site and the use of the CL:AIRE code of practice (COP) may be required. The use of the CL:AIRE COP will require the one-off establishment of a Materials Management Plan (MMP) and subsequent monitoring. Approximately £15,000 should be allocated for the initial establishment of the MMP, submission to the Environment Agency and monthly monitoring. <u>Option 4: Use of Hydraulically Bound Materials (On-Site)</u> As an alternative, the HBM approach can be applied on-site. A mobile plant is kept on-site and re-uses material from the excavated trench. Two companies were approached that offer this service - Keanes and Conroys Group (see http://www.conroysgroup.com/Mobile_Recycling_Unit.html and http://www.keanes.co.uk/civil-engineering/trenchmod/). The contractor would excavate the material and the HBM Supplier would do the processing of the material. The HBM supplier would do all of the testing of the material on site to ensure it is suitable for the process and for the end use. Conroy provided a range of costs from a small project (£24-£25 per tonne), to a very large scale project (may go down to about £16 per tonne of final material). Keanes was unable to provide costs in the timeframe required. It is noted that this is not significantly different to the HBM costs above. However, it does provide greater flexibility if there is not a fixed batching facility relatively close by to offer the services in Option 3. Conroys Group also suggested that they would need a compound to install the mobile plant and to store the material for mixing with the additive. They suggested that at maximum it would be about 40m by 40m. In discussing with AECOM colleagues, it should be possible to reduce this size through efficient working practices and/or it may be possible to use a smaller mobile plant through management of the recycle process (lower output rate). Note that additionally, space would be needed to store any excavated material and final product. In practice, the storage requirements may not be feasible on some developments and potentially very costly on others – further work could be undertaken to evaluate this. In addition a standard Environmental Permit (£3,000 to include Environment Agency fees and application costs) for Mobile Plant is likely be required. In determining the costs, it is important to consider the savings from reduced haulage and disposal costs of the excavated materials. These costs vary by location and the type of material. • As a reasonable approximation, it is assumed that 85% of the material would be classified as inert.	

	Based on feedback from one contractor (CPC Civils), the costs vary from around £22.50 per tonne in London to around half of that in the rest of the country. Assuming a conversion of 2.4 tonnes per m^3, this results in £54 per m^3. • As a reasonable approximation, it is assumed that 15% of the material would be classified as non-hazardous. Based on discussion with an AECOM expert, the cost varies depending on the type of non-hazardous material, but a reasonable value is £100 per tonne or £250 per m^3. • Hence, the average cost is around £80 per m^3. Note that this includes any costs for testing to determine the classification of the waste. Furthermore, as noted in Option 2, the retail price of 1 tonne of virgin type 1 limestone aggregate is approximately £54 per m^3. Hence, the saving of primary Tier 1 aggregate (GSB1) due to the use of HBM for 1 m depth is: • £48 per m^3 additional cost for HBM (based on £20 per tonne and a conversion factor of 2.4 m^3 as equivalent to 1 tonne) • £54 per m^3 cost savings from not using Tier 1 aggregate • £40 per m^3 cost savings associated with reduced haulage and disposal of excavated material (assuming that HBM comprises 50% of excavated material). • This gives a total of £46 per m^3 (i.e. £94 - £48). In practice, the cost savings are likely to be significantly lower than this: • The cost of materials varies with location and the values quoted here are towards the highest. • There will be transport costs within the site. With up to 2 additional people per day, with £200 additional equipment cost, this effectively results in the equivalent to £10 per m^3. • This solution is particularly dependant on space being available for plant on-site. Based on discussion with a contractor, this is expected to be £500 to £1000 per week outside London (London's prices are very dependent on location and availability). Over a 3.5 year construction period, this would equate to approximately £6 per m^3. Hence, the cost savings of this option are expected to be similar to those of Options 2 and 3. <u>Option 5: Use of Foamed Concrete</u>	

	For completeness it is worth including here the use of foamed concrete. This was identified early as an amber solution but has been summarised here for completeness as relates to the other solutions evaluated. The typical process for backfill is for GSB1 or HBMs to be installed in a series of compacted layers, typically around 150 to 200 mm thickness. This can be relatively time consuming on site and if not done correctly can result in the potential for future settlement of the reinstatement. An alternative considered here was to use foamed concrete, which is a flowable material which then sets into a solid. Whilst the cost of the concrete is several times greater than for aggregate, it has the particular advantage in that it is much quicker to backfill - the pipe is covered first with an aggregate material and the fill is then poured in and self-compacts – resulting in an overall cost saving (based on the view of PT Contractors). There is a key general concern around its feasibility in practice in terms of future access. Depending on the quality control of the process, and the tendency for greater strength to avoid any road settlement issues, the foamed concrete can be relatively hard. If submerged pipework needs to be subsequently maintained, for example, a mechanical digger is needed to excavate the fill. This can create problems in digging around utility pipes which is currently typically done by hand or by vacuum excavator to minimise the risk of damaging the pipework. This becomes a particular problem with district heating as there will commonly be other utilities at places in the trench and utility suppliers are not expected to welcome a solid material encompassing their pipework and consequent risks during maintenance. Another contractor (Trent Energy) highlighted the need for Local Authority approval for using foam concrete. Furthermore, from a further contractor’s point of view (CPC Civils), the time for excavation is significantly greater than the time for backfill – hence currently reducing the backfill costs has limited benefit. The reason that this is particularly noted here is that if the excavation was to significantly speed up (e.g. based on other solutions proposed in this ETI project), the time associated with backfilling may become a significantly greater part of the project programme and could increase the attractiveness of this solution. An indicative cost estimate has been included here. This is based on the backfill of a 50m trench. • Labour: – Based on a discussion with CPC Civils, as a rule-of-thumb, 20m of trench can be backfilled in a day at a cost of £1000 (4 people x £200, plus £200 for plant). Given that the trench width being considered in this model is relatively narrow for district heating, it is estimated that the 50m trench	

	can be completed in 2 days for a cost of £2000. This is the baseline cost. – Furthermore, based on a discussion with CPC Civils, it is estimated that if foamed concrete is used, it can be completed in less than one day with 2 people (i.e. at a labour cost of around £400). – Hence, there is a labour saving of £1600. • Materials: – As above, the cost of using Tier 1 aggregates is £54 per m^3. By comparison, the cost of using foamed concrete is £85 per m^3 (based on discussion with CEMEX). Hence this results in an increased cost of £31 per m^3. – Assuming both options are applied to backfill dimensions of 1m (height) x 0.5m (width), the additional material costs are around £800. • Overall: – This results in a £800 cost saving for the 50m trench or £16 per metre of trench. – It is noted that this is similar to the cost savings of the other options above.	
How the solution was identified	This solution originated from Stage 1 and was identified again at the civil engineering ECCR workshop. It has been evaluated further through: • Internal discussions within AECOM • Discussions with contractors offering this service (details provided in the description above) • Discussions with three contractors (details provided in the description above)	

Capital cost

Change relative to baseline CAPEX

The cost savings for Options 2 to 4 are shown below. This allows for the different widths of trench throughout the network.

Typology	NETWORK COSTS		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,927	£27	1.4%
B	£1,038	£1,028	£10	1.0%
C	£1,706	£1,681	£25	1.4%
D	£3,871	£3,838	£33	0.8%
E	£4,113	£4,077	£36	0.9%
Primary Network	£6,476	£6,436	£39	0.6%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£44,850	£340	0.8%
Total system Capex	£62,602	£62,262	£340	0.5%
Dense village Capex, no prelims	£3,641	£3,600	£41	1.1%
OPEX	£3,320	£3,320	£0	0.0%
TOTEX non-discounted	£184,090	£183,751	£340	0.2%

Sensitivity

This analysis has been based on quoted costs from contractors and a number of alternative options have been presented which provides a level of redundancy for this solution. Hence it is estimated that the potential of this solution as a whole is from 0% to 1.5%.

Certainty of outcomes		
Certainty of outcomes	No significant change	0
Operational cost		
Change relative to baseline OPEX	No significant change in operational costs	
Lifecycle costs		
Change relative to baseline lifecycle costs	No significant change in lifecycle costs other than the CAPEX costs reported above	
System performance		
Impact on DHN performance	No significant change	0
Future flexibility	No significant change	0
Attractive to Users & Investors		
Attractiveness to Users and Investors	Some Local Authorities perceive alternative backfill options as being inferior and increase the risk of settlement issues. Foamed concrete would not be attractive to some investors, as well as other utilities, due to the potential risks associated with future access to pipes.	-1
Reduced Complexity		
Complexity	Some additional minor complexity to organise compared to the current simpler system which has only a contract to remove and a contract to provide backfill to a defined quality with no risks.	-1
Health, Safety and Environmental Impacts		
HSE	No significant change. Whilst the solutions do tend to result in the reuse or recycling of the excavated material, in the baseline (current scenario), the material taken away by the 'muckaway' organisation is typically recycled rather than sent to landfill. However, for two of the options (Options 1 and 4), there is re-use of the extracted material on-site and less traffic and pollution. Options 1 to 4 have less impact on new aggregate extraction so less damage to environment.	1

Opportunity to scale		
Scope of opportunity	This approach can be applied to all Typologies.	2
Increased Revenue		
Potential for synergies	No significant additional opportunities here for synergies.	0
UK plc external Stakeholder Value		
Value for the UK	For two of the options (Options 1 and 4), there is re-use of the extracted material on-site and less traffic and pollution. Options 1 to 4 have less impact on new aggregate extraction so less damage to environment.	1
Technical feasibility		
Technical feasibility	Options 2 to 4 are available today and used by other utilities.	2
Effort to Implement Solution		
Effort	• Investment capital and research required: <=£500k as in general the solutions presented here are available today. (0) • Level of technological innovation, technology readiness level: TRL 9 (0) • Anticipated timescale to the point where the solution is delivering value: < 18 months to develop as solution is available today (0) • Likelihood of success: Certain (0) The issues to wider deployment are more around changing the client's and industry's perception of the approach rather than any technology challenge. Hence, whilst value is likely to be delivered in the short-term, it may take further time for wider acceptance. If foamed concrete is of value, it would likely need wide acceptance by utilities and Local Authorities for its wide-scale use. This includes confidence in the strength of the material and avoidance of significant access issues.	0
Other		
Any additional equipment required	None	

Barriers	Local Environment Agencies can have differing interpretation of what material can be recycled. Furthermore, some Local Authorities have a perception that recycled backfill is an inferior product – this tends then to orientate around arguments of the interpretation of the Specification for Reinstatement of Openings in Highways (SROH) and if trials are required to prove if a recycled materials works (or not). A barrier to this is likely to be available storage space close to the site. Most DHNs will use a staging post to manage pipework delivery before it is laid out for installation –this may be able to be expanded to include the staging and treatment of backfill material. Materials moved from one site to another e.g. from the point of excavation to a central point before redeployment are likely to be classed as 'waste' under waste management licencing regulations. However, in recognition of this potential legal barrier, the construction industry and the Environment Agency have developed the CL:AIRE Code of Practice, which adhered to closely, can mean that the material is not classed as waste and can be used beneficially. Early consultation with the local Environment Agency about the project and its aims can remove this barrier to the reuse and the trench arisings.	

Solution name:	**Shared HIUs (Heat Interface Units)**	Evaluation Rating
Name of evaluator(s):	Paul Woods, Andrew Cripps, Lucy Pemble, David Ross	
Solution ID:	15	
General		
Description of solution	The baseline design assumes that an indirect HIU with instantaneous hot water production is installed in each dwelling i.e. using two plate heat exchangers one for space heating and one for hot water heating. This is the most common system being installed in the UK at present (mainly for the new build market). In tall blocks of flats a substation is also used at ground floor level to avoid creating additional static pressure on the network. There are a number of ways in which this baseline solution can be challenged from a system design architecture view. The optimal proposed solution is likely to depend on the particular circumstances of the scheme and the typology, as is considered below. • Typology B – blocks of flats – HIU can be shared between all flats on a floor by floor basis or between all flats in the block (i.e. a '4-pipe' system) • Typology C – terraces – HIU shared between a group of terraces – e.g. 25 with an HIU located at the end of the terrace • Typology D – semis – HIU shared between a pair of semis • Typology E – detached – sharing is not considered feasible as the cost of additional buried pipework would more than offset the available savings [It is noted that the model is based on an 8-storey block. Normally blocks are more than 6 storeys as if lifts are required then it will only be economic to build at least 6 storeys. Although some existing tower blocks are 20 storeys, most are lower, so 8 storeys is assumed just to be typical. This assumption makes limited difference in the comparative analysis as the solution is mainly balancing additional pipework per floor	

	against number of HIUs per floor]. An indirect, instantaneous hot water HIU is assumed in all cases A separate solution form (Solution 10) has been developed for the use of direct connection and conversion of existing hot water cylinders. <u>Typology B – blocks of flats</u> *Option a) Use one HIU per floor* In this option an HIU is installed to supply 8 flats on the floor. The HIU needs to have larger heat exchangers say 30kW heat and 70kW hot water heating [The diversity factor is about 0.25 for 8 dwellings (see ADE/CIBSE Heat Network Code of Practice for the UK). Taking 35kW hot water peak x 0.25 x 8 = 70kW]. This unit will still be made in a similar manner to the dwelling HIU. Costs are estimated at £3000 for this unit (AMARC Fondo Combi range). Additional costs are incurred for the additional pipes for the hot water flow and return laterals (£914 per dwelling). At each dwelling there would be two meters; a heat meter (£260 each including labour, source: manufacturer data) for the space heating and a volume flow meter (£126 each including labour, source: manufacturer data) for the hot water with an automatic meter reading system to collect the energy data. There would also be a differential pressure control valve or pressure independent control valve (£401.80 including labour, source: SPONS 2017) to balance the maximum flow into each flat. However the major saving is then the omission of a HIU in each flat. *Option b) Use 4-pipe system in blocks of flats – single substation per block with space and hot water heating heat exchangers* This option does not require an HIU in the flat as hot water is generated from a central heat exchanger at the block substation and the space heating is directly connected to the radiator circuit. As for option a) each flat would have a differential pressure control valve or pressure independent control valve to balance the system. A heat meter and a separate volume meter would be required for the hot water together with an automatic meter reading system for two meters per dwelling. Additional costs would be incurred for the 4-pipe distribution around the block which would also have higher heat losses than the 2-pipe system as there is twice the length of pipe work. However, these losses would be useful gains to the building in winter. In addition, the space heating circuit can be weather compensated as it does not need to operate at >60C at all times to generate hot water. In summer the space heating circuit would effectively be shut down and heat	

	losses from the hot water system would be lower than for the 2-pipe system as the temperatures used will be slightly lower. The flow temperature would be controlled in relation to the instantaneous external air temperature however if the temperature is above a set point, probably 15°C-18°C, the space heating circuit would be turned off to save pumping energy, although circulation for a short time every few days would be needed to prevent build-up of air and ensure water treatment can be maintained. The block substation will be more complex with the hot water heat exchanger added together with a hot water circulation pump (cost estimated at £6000 additional to the sub-station cost). Return temperatures onto the network could be lower as the substation can be optimised further including two stage heating of the hot water using the space heating return to pre-heat the cold feed to the hot water heat exchanger. The 4-pipe system is the most common arrangement in Sweden but is less popular in Denmark. In the UK it is found in older social housing estates where it is an advantage in managing energy use in the absence of individual meters. It is also the typical solution for hotels, student accommodation etc. In summary the changes are: **Omit:** • indirect HIUs in each property **Add:** For Option a): • HIU for the floor • Hot water flow and return distribution from HIU on the floor to each dwelling (on floor or for the block) • Differential Pressure Control Value (DPCV) or Pressure Independent Control Value (PICV) for space heating in each dwelling • Volume meter for hot water in each dwelling For Option b): • Hot water heat exchanger and circulating pump for substation • Hot water flow and return distribution from substation at ground floor to each dwelling • DPCV or PICV for space heating in each dwelling • Volume meter for hot water in each dwelling Both of these options were costed and the results are given below. Option b) was found to provide the higher saving so this is taken forward into the summary table.	

Option A – Costings

Cost Savings (per dwelling)	
Indirect HIUs for each dwelling	£1,918
Cost Additions (per dwelling)	
HIU per floor	£2,400 (cost per floor) = £300 (cost per dwelling)
Extra Pipes	£914
DPCV	£126
Volume flow meter	£401.80
Fittings	£69
Drilling through wall	£51
Total Additional Cost (per dwelling)	**-£56**

Option B – Costings

Cost Savings (per dwelling)	
Indirect HIUs for each dwelling	£1,918
Cost Additions (per dwelling)	
Extra cost at substation (hot water heat exchanger and circulating pump)	£6,000 (cost per block) = £94 (cost per dwelling)
Extra Pipes	£1,004
DPCV	£126
Volume flow meter	£401.80
Fittings	£114

Drilling through wall	£51
Total Additional Cost (per dwelling)	**-£127**

It is noted that it may be possible to reduce the costs of fitting the pipes. In practice, the cost of 4 pipes should not simply be twice the cost of two pipes – there should be some labour savings e.g. planning the route of the pipework and it may be possible to simply fit four pipes within the same bracket. The Stage 1 work showed that labour costs are around 40% of the cost of supply and fitting of pipes. For the purpose of a sensitivity analysis, it is assumed that the labour costs are reduced by 25%. Then the total cost of extra pipes would reduce by 10%. Based on the above example, this would achieve an extra £100 cost saving per dwelling.

More importantly, the cost savings are very dependent on the price of the HIU. A relatively small 10% reduction in the price of the HIU would effectively eliminate any saving here and effectively this solution would move to a category 'red'. HIU prices have been falling over recent years. Furthermore other solutions focus on delivering a lower price HIU e.g. through the use of direct HIUs or value engineering of HIUs.

Typology C – Terraces

This is similar to the Typology B option b) solution of the 4-pipe system for a block of flats but is used for a terrace of 25 houses. However, further cost additions result in the baseline system being more economical than applying the innovative solution.

Initially, cost calculations were undertaken with excavation to bury the additional pipework between the HIU and each home. This made the approach too expensive.

Alternative options to reduce these costs include using the loft space or mounting the pipes externally on the wall (see Solutions 3 and 4, also noting particularly potential User Acceptance issues). However, the £127 cost saving for Typology B is eliminated for the following reasons.

- A full substation cost is required as for the block of flats. However, in addition, this must be able to be placed outside and so will need weather protection. The size of the unit is approximately 2m x 1m in plan and 2m high.
- There are extra costs associated with these alternative options. Having to mount the pipes along the

	external wall, for example, would similar to Typology B require doubling the length of pipe to run along the walls of each terrace of houses. However, in comparison to the solution for Typology B, there would particularly need to be additional costs for boxing-in the pipe that runs along the external wall. Again, there could be a reduction in the cost of fitting the pipes. However, fundamentally, the solution is very dependent on the price of the HIU which may be reasonably be expected to fall over time and eliminate any cost saving identified from this solution. <u>Typology D – Semi-detached</u> In this option a single HIU is shared between two semis. The cost of the HIU would be similar to that for an individual dwelling. The HIU would be located within one of the semis (or outside) and a space heating and hot water supply taken to the adjacent semi. This would require additional pipework and circulating pumps, and a heat meter and volume hot water meter would be required in the semi supplied from the HIU in the adjacent property. Again the baseline system was calculated as being more economical than applying the innovative solution. • The cost saving from having a single HIU shared is less in comparison with Typology B (only £1200 i.e. around £600 less) • There is the additional cost from trenching between the two neighbouring houses	
How the solution was identified	The cost model showed that HIUs were a significant cost element. It is known that there are differing views in the industry about the use and type of HIUs. HIUs were therefore seen as a separate challenge area. However, the fundamental way in which HIUs are used and the various types available can also be considered as part of the system design architecture challenge area. The issues of HIU design and system architecture were discussed at a number of workshops with industry representatives. The subject was also discussed with COWI in Denmark.	

Capital cost		
Change relative to baseline CAPEX	Costs of the DH **Network** The use of shared HIUs will reduce the cost of the HIUs as follows:	

Typology	NETWORK COSTS		Saving due to innovation	
	Baseline cost	Innovation cost		
	(£k)	(£k)	(£k)	(%)
A	£1,953	£1,953	£0	0.0%
B	£1,038	£1,007	£31	3.0%
C	£1,706	£1,706	£0	0.0%
D	£3,871	£3,871	£0	0.0%
E	£4,113	£4,113	£0	0.0%
Primary Network	£6,476	£6,476	£0	0.0%
Prelims	£3,748	£3,748	£0	0.0%
Total DHN Capex	£45,190	£45,127	£62	0.1%
Total system Capex	£62,602	£62,540	£62	0.1%
Dense village Capex, no prelims	£3,641	£4,184	£0	0.0%
OPEX	£3,320	£3,350	-£30	-0.9%
TOTEX non-discounted	£184,090	£182,100	£1,990	1.1%

Certainty of outcomes		
Certainty of outcomes	There is less certainty around these solutions as they all require an increase in space provision either within the block of flats at floor level, at ground floor level or for terraces some additional land is required.	-1

Operational cost		
Change relative to baseline OPEX	Costs of the DH **Network** The OPEX costs have not been presented in the table as this is an amber solution. Some supporting information is included here. Although the installed pipe length is higher for the shared HIUs which would increase heat losses, this is offset by the ability to reduce the temperatures in the space heating circuit and turn this off in summer. On balance, the heat losses are expected to be similar to the two-pipe system so no associated OPEX change. The overall operational costs are expected to improve marginally for any of these options as a result of lower maintenance costs as HIUs are shared between users and will be more accessible in typologies B and C. Savings of around £50 per dwelling per annum could be achieved. Costs of the DH **System** No additional changes.	
Lifecycle costs		
Change relative to baseline lifecycle costs	Costs of the DH **Network** No additional changes.	
System performance		
Impact on DHN performance	As the HIU is shared between dwellings there are fewer components to maintain on a per dwelling basis and this would be expected to improve reliability of service. For typologies B and C the HIU would be located in a more accessible position so easier to maintain as no need to gain access to the dwelling. 4-pipe systems could result in lower return temperatures and so there would be lower primary network heat losses, depending on the design detail.	0
Future flexibility	Changes in demand of any one dwelling can be more easily accommodated with a shared HIU	1
Attractiveness to Users & Investors		
Attractiveness to Users and	The shared HIU will result in less equipment in each dwelling except for semi-detached where one of the semis will have a slightly larger HIU.	1

Investors		
Reduced Complexity		
Complexity	In general, the proposals reduce technical complexity. However, it is noted that with the 4-pipe system, the use of two meters one for space heating and one for hot water may be more complex for the resident. However, it also provides more information on energy use which could be seen as an advantage.	1
Health, Safety and Environmental Impacts		
HSE	No change identified.	0
Opportunity to scale		
Scope of opportunity	This could be applied to multiple housing in close proximity – hence its application in Typologies B, C and D.	1
Increased Revenue		
Potential for synergies	Not applicable	0
UK plc external Stakeholder Value		
Value for the UK	No significant impacts on policy, jobs or exports.	0
Technical feasibility		
Technical feasibility	The solutions are all technically viable and the 4-pipe system is commonly used in Sweden for blocks of flats. However these typically do not have individual dwelling level heat meters.. There is no impact on standards.	2
Effort to Implement Solution		
Effort	• Investment capital and research required: <£500k (0). No significant effort required. The most useful approach would be through a UK demonstration scheme with suitable monitoring and metering. Training of designers to ensure they choose the most appropriate design of HIU would be of value. Published reports on costs and benefits, in-use performance and user experience of different systems would also assist the designer in the selection. • Level of technological innovation (uncertainty): Technology readiness level (TRL 8-7) (+1). The solutions are all technically viable and have been demonstrated in a number of schemes. As noted above, it would	0

	be beneficial to have a demonstration scheme to trial solutions in the UK. • Anticipated timescale to the point where the solution is delivering value: <18 months (0) • Likelihood of success: Certain (0)	
Other		
Any additional equipment required	None	
Barriers	For Typology B there may be challenges in finding space on each floor for an HIU or space in risers for the 4-pipe solution. For the terraced houses there would be a need to find space for the shared HIU – this may need to be in someone's garden and they would need to be compensated for this loss of space (cost not included). For the shared HIU in semis again there would be an issue of how the customers are treated fairly and how access is managed in the event of a fault that affects one property but not the other.	

9 Appendix E: List of Solutions

The full list of solutions is shown overleaf.

Solution ID	Solution	Reason for red or amber rating	Green Solutions
Reducing flow rates & thus the size of pipes			
RF1	Better knowledge of diversity factors for domestic hot water	This is potentially important to avoid over design. It is effectively now included in the solution entitled Knowledge Management, Research and Training. See O13.	Solution 1: Knowledge Management, Research and Training
RF2	Assume continuous heating under peak design conditions (no margin for heat-up times)	This is potentially important to avoid overdesign. Continuous heating is covered alternatively in the Reducing Peak Demand and Peak Flow Rate solution.	Solution 2: Reducing Peak Demand and Peak Flow Rate
RF3	Hot water priority at a dwelling or network level	Included in Reducing Peak Demand and Peak Flow Rate solution	Solution 2: Reducing Peak Demand and Peak Flow Rate
RF4	Use of hot water storage to reduce peak demands (primary side or domestic hot water)	The low flow rate (green) solution proposes that continuous heating is used during periods of very cold weather which will avoid the high peaks in space heating demands that occur with intermittent heating especially in the early morning start up. Peak hot water demands which occur with instantaneous hot water production can best be managed by shutting off the space heating for the period when hot water demands occur - i.e. using the building itself as a store. This is likely to be a cheaper solution than including a new primary heat store which will also require significant space in the building. However, where hot water cylinders already exist, the time control of these can be managed using remote controllers so as to reduce coincident peaks on the network at minimal cost. So retention of existing hot water storage where it exists is a viable green solution. Heat storage also has a value in optimising the heat production plant but generally it is cheaper and more efficient to use central stores for this purpose although local storage will also have a role.	Solution 9: Direct HIU System & Existing DHW Storage
RF5	Use of thermal storage embedded in the network to reduce peaks	See RF4 above - there may be some benefit but it will difficult to find suitable locations for heat stores within the network and land values may be too high. There may be some buildings, perhaps hotels and student accommodation blocks where local storage would be of value and also provide some additional resilience. Thermal stores are more efficient and cheaper the larger they are and so locating these at the Energy Centre is more beneficial.	
RF6	More accurate assessment of design demands using advanced surveying or heat	Included in Reducing Peak Demand and Peak Flow Rate solution	Solution 2: Reducing Peak Demand and Peak Flow Rate

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	load tests		
RF7	Design for higher pressure drops at peak times than normally used – potential for using distributed pumps to limit maximum pressures	Distributed pumps would reduce peak pressures on larger networks - this will help achieve direct connection and enable more optimal pipe sizing - but it may be difficult to find suitable locations for the pumps and will need some form of enclosure and power supply, also land may need to be purchased/rented - so extra costs for these pumps may offset any benefits. Could be an opex benefit as well as pumps will be more closely matched to required pressures - but opex for pumping is small anyway. Most continental schemes use centralised pumping except on large networks. Classed as an amber option as it has a small benefit and may be only important for larger networks.	
RF8	Use of additives to reduce friction and hence allow smaller pipes for same pressure drop	This area has been researched for several decades without a solution emerging that has a major impact. Most likely impact would be lower opex from lower pumping energy rather than a capex improvement. Pumping energy is already quite a small cost and the savings will be offset by the cost of the additives.	
RF9	Use gas or electric (incl heat pump) heating at times of peak demand (hybrid system)	Although of benefit in reducing the capacity of the network and hence its capex cost, there will be additional capex and opex costs for the peak heating systems in the building which will be more expensive than if this capacity is installed centrally. One of the attractions of DH is the benefit of not having to maintain boilers and the avoidance of the costs of annual gas safety checks, especially in social housing. There may be a benefit in retaining gas boilers in large buildings especially where a high degree of resilience is needed (e.g. a hospital) as this would potentially reduce the network size and avoid the need to build new boiler capacity centrally. If say the network capacity was reduced by 30% with peak gas boilers supplying 30% of peak demand in the coldest period the network capex would be reduced by about £1.12m (by extrapolation from low flow rate solution). It can be assumed that the local gas boiler will be the same capex as a centralised boiler (reasonable for mass production of hybrid HIUs) but the opex could be £100 per dwelling p.a. more because of the more complex equipment and the need for gas safety checks. For the 3,312 dwellings in the notional scheme this would be £331,200 p.a. which would outweigh the capex reduction after less than 4 years. Direct electric heating could also be considered but this would have higher energy costs than gas and require an upgrade of local electricity networks. If a heat pump was used for peak duty this would have less impact on the electricity grid but would have a high capital cost of say £4000 per dwelling, much higher than the predicted network capex saving (£339 per dwelling).	
Reducing return temperatures to very low levels – including to obtain step change in cost of return pipe			
RT1	Reduction in return temperatures is key to lower flow rates and hence smaller,	Reducing Peak Demand and Peak Flow Rate solution includes reduction in return temperature as part of increasing delta T	Solution 2: Reducing Peak Demand and Peak Flow Rate

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	cheaper pipes. The 4th generation research is proposing return temperatures of 20C to 30C.		
RT2	A large delta T e.g. 60C is possible instead of 30C assumed in baseline	Included in Reducing Peak Demand and Peak Flow Rate solution	Solution 2: Reducing Peak Demand and Peak Flow Rate
RT3	Exploit oversized radiators to maximum	Included in Reducing Peak Demand and Peak Flow Rate solution	Solution 2: Reducing Peak Demand and Peak Flow Rate
RT4	Use return temperature limiter valve on radiators or HIU	Included in Reducing Peak Demand and Peak Flow Rate solution	Solution 2: Reducing Peak Demand and Peak Flow Rate
RT5	Controls to limit the keep warm condition to avoid higher return temps when not in use	Included in Reducing Peak Demand and Peak Flow Rate solution	Solution 2: Reducing Peak Demand and Peak Flow Rate
RT6	Retrofit existing hot water cylinders with external plate heat exchanger	Retention of existing hot water cylinders is assumed as part of the HIU solutions. Retrofitting with external plate heat exchanger would increase capex but lead to lower return temperatures and a small reduction in peak flow rate and hence smaller pipes. On balance this option would result in an increase in capex although opex benefits could be more significant as lower return temperatures will result.	
RT7	Use of direct connection to avoid temperature drop across heat exchanger	Included in Direct HIU System & Existing DHW Storage	Solution 9: Direct HIU System & Existing DHW Storage
RT8	Use indirect connection but use 95C flow temperature at peak	Raising temperature to 95C would increase delta T and so lead to smaller pipes with a small capex reduction of about 0.3% for the network. However there would be increasing safety concerns with using 95C within dwellings and if this resulted in the need for more boxing in of pipework or an externally located HIU then this would offset the benefit. A higher temperature	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	with external HIU for safety reasons	would be less compatible with future heat sources such as heat pumps. So 90C is probably a better upper limit.	
RT9	Use mixing HIU with 95C flow but reduce down to 80C for radiator circuit	As for RT8 above the higher flow temperature would lead to lower network costs by c0.3%. Compared to a direct connection a mixing circuit requires a pump and control valve which would offset the benefit of avoiding a heat exchanger.	
RT10	Very low return temperatures <30C could mean insulation is omitted or reduced on the return pipe	It would be reasonable to reduce return temperatures to 45C by using the existing radiators, maximising the temperature difference with high quality pre-settable thermostatic radiator valves and limiting the heat output to match an accurate estimate of the steady state demand (see low flow rate solution). Further reductions in return temperatures would be possible but only by replacing radiators with larger radiators and operating with lower flow temperatures e.g. a 60/30 circuit. In some cases it may be possible to replace radiators with double panels where single panels are currently used which would reduce the need for changes to pipework. This solution would be less attractive to residents due to the disruption involved and potentially having bulkier radiators. If temperatures as low as 30C are achieved then the return pipe could be uninsulated which would be significantly cheaper in material costs and installation costs as the jointing would be simpler. However although the trench width would be slightly reduced the civils costs will not be significantly less and it is the civils costs that are the largest component. Hence the savings in using smaller pipes (with no or minimal insulation on the return pipe) would be offset by the investment in new radiators leading to only a small benefit if any. The benefit of lower return temperatures in reducing heat losses would be seen if the return pipe was insulated but heat losses would be slightly higher if the pipe was uninsulated. This remains an amber as there could be specific situations where new radiators are required anyway as a result of a large-scale renewal programme in which case the marginal cost of larger radiators would be relatively small and there could be schemes where a very low return temperature would be of benefit in maximising the output of a heat source e.g. industrial waste heat at low temperature.	
Radical route selection to reduce cost of civils			
RR1	DH Wall (external on wall above doorways – with or without external insulation)	Included in DH Wall	Solution 3: The District Heating Wall
RR2	Gas main route (gas becomes redundant)	Adopting the gas mains route is captured in Use of Trenchless Technologies. It is not proposed to reuse the gas pipe itself as this would only be viable for very low return temperatures as no insulation and in many cases condition of gas main will be uncertain. Also diameters may be OK in places but no guarantee that the supply point will be from the same	Solution 5: Trenchless Solutions

Solution ID	Solution	Reason for red or amber rating	Green Solutions
		direction etc. Also it only solves the return route problem and you still need to excavate for the supply pipe (or twin pipe if preferred).	
RR3	Front gardens or rear gardens (possibly using micro tunnelling)	These routes offer shorter branches and potentially less civils costs as the pipes can be shallower. However in many cases excavating trenches through gardens and driveways will result in significant disruption and the need for time-consuming reinstatement of surfaces, planting etc. Will be higher cost than DH Wall or loft space routes. Could be considered as a variant on trenchless technology solution as branches would be shorter than a street main. However, it will result in an additional route i.e. for this solution, one route down each side of the street.	
RR4	Eaves level (probably rear elevation)	Not evaluated in detail in this project. Potential cost savings and characteristics sufficiently evaluated in alternative radical route options - external wall RR1 and loft space RR5.	
RR5	Loft space (including pipe bridge between roof of semis)	Included in Loft Space / Cellar	Solution 4: Loft Space / Cellar Route
RR6	Kerb route to avoid services	Some particular challenges identified in early evaluation of this solution in ‘existing urban highway’ situations. 1. There are many types of kerbs, standard half batters, large half batters, square edged on large and small, 45 degree splayed face, trief kerbs for use when containment is required, cassel kerbs for use at bus stops, block paving kerbs in many different colours, dropped kerbs at crossings etc. Each is also available in concrete or granite conservation finish. Additionally there are several types of combined drainage kerbs eg beany blocks. All would need to be replicated to serve the same function and visual appearance to keep the highway and planning authorities satisfied (e.g. some local authorities require that kerbs of public roads are solid granite). Replicating some of the kerbs profiles (eg trief / cassal) will be problematic as they are subject to manufacturer's copyright. And the investment needed will significant. 2. Highway authorities can be ‘conservative’, have restricted maintenance budgets and don’t like change or taking on unnecessary risks. Highways England and Local Authority Highway departments may not wish to change the existing practices. 3. Where drainage kerbs already exist this will prevent installation of DH kerbs unless the drainage system is replaced. 4. Kerbs provide essential structural support to the edge of the carriageway and are given a	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
		very hard time due to large vehicles hitting them. In reality they are often damaged and need to be replaced or reset (most roads are scheduled for major refurbishment after only 25 years). Repairs will be more difficult to do if they contain within their structure third party cables or DH pipes that cannot easily be severed. This may be overcome by having modular units with top and bottom sections but such kerbs may not be of sufficient robustness. Where existing drainage kerbs are provided in modular form they are backed up with a very thick concrete haunching. 5. Kerbs are often cut into, or sections of kerbing temporarily removed. For example when retro installing traffic light signal loops or cutting service trenches cross across the kerbline. This may prove impractical or difficult for DH kerbs. 6. Having the services so shallow and accessible may well result in regular damage and maintenance costs. 7. The strength of the kerb is made up of both the kerb unit and concrete bed and backing because each kerb unit is not actually fixed to the adjacent kerb units. Any replacement kerb units that contain DH pipes or other services would still need the concrete bed and backing. If the New DH kerbs are larger, then the whole assembly will eat into the service zones already in use. This will be challenged by the other statutory utilities. 8. Assuming the kerbs are hollow then the DH pipes or other services may be pulled through. Kerbs are not always laid in straight lines. This approach may prove difficult unless the DH pipes are small enough and flexible enough to pass round bends. 9. How to provide access pits for joints on the kerbline will also need resolved. Such pits will necessarily need to be much larger than the kerb and may encroach further into both carriageway and footway. Similarly how individual service connections to houses is made is unclear 10. Ownership: kerbs are owned and maintained by the highway authority - the DH kerbs might need to be maintained on behalf of the highway authority by the DH company. If so then the DH company may need to provide substantial ongoing rapid response repair capabilities. An alternative may be pay up front charges to the Highway Authority, but this won't assist the Highway Authority in dealing with damaged DH pipework when rapid repairs are necessary. 11. Placing other media such as tele coms cables in the new kerbs might work where there are a few small cables but again there is the problem of how large insulated cable joints will fit or	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
		be accessed within the limited space available. 12. Road gully precast chambers and brickwork supporting the grating usually project under the kerb.	
RR7	Take pipe out of road and into verges - soft dig	This is a sensible idea. However, there are typically constraints in verges, for example from other services also taking the easiest route, driveways crossing verges or the presence of trees. It should be adopted where possible but difficult to cost the savings as it is very site specific. Worth noting that the use of verges may mean that lower heat density areas are not necessarily more expensive to supply with DH than more dense areas - important when considering the overall extent of DH in a given town or city. As an estimate of the maximum potential, for typologies D and E the single mains has been replaced by two mains per street (one on each side of the road located in soft dig verges) and shorter branches to each home. This results in approximately a 5% CAPEX saving for both typologies.	
RR8	Use routes from redundant pipework where possible e.g. gas pipes.	With respect to water pipes, this solution has been captured in New Network Revenues – Shared Civil Engineering Costs. With respect to reuse of gas pipework whilst this may be possible in some situations, the condition, diameter and pressure rating of the gas pipework may not be suitable and it would be uninsulated so only suitable for the return and a very low return temperature (see RT10). Utilising the route of the gas main by installing directly above and/or below it using trenchless technology or by bursting the pipe to install a DH pipe in its place are both opportunities included in the trenchless technology solutions. If the gas main itself is to be taken out of service then there will be costs associated with provision of temporary heating whilst the work to changeover the system is done and any gas cookers would need to be replaced with electric. So this solution would have a regulatory impact requiring 100% connection to DH.	Solution 8: Shared Civil Engineering Costs (New Network Revenues)
RR9	Single pipe system for a street	This is theoretically possible but ideally would be implemented for a new build system as there is a need to size radiators differently down the street. The cost of installing new larger radiators towards the end of the street would offset the saving from avoiding the second pipe. But it is a promising idea and could be taken forward for some applications where there is perhaps a general refurbishment project. Would also require advanced controls to manage the flow rates whilst maintaining low return temperatures (e.g. as proposed by Coheat).	
Improved design process and better standards for design based on operational data (overlaps with ideas from component design)			
ID1	Involvement of contractors earlier	Captured in Improved Front End Design and Planning	Solution 6: Improved Front End Design and Planning

Solution ID	Solution	Reason for red or amber rating	Green Solutions
ID2	Better survey information on existing services before tendering starts	Captured in Improved Front End Design and Planning	Solution 6: Improved Front End Design and Planning
ID3	Data from operating schemes to inform design especially for assumptions on diversity of demand / greater share of information across schemes and scheme operators	This is effectively now included in the solution titled knowledge management, research and training. See O13.	Solution 1: Knowledge Management, Research and Training
ID4	Rapid assessment of heat demands and temperature selection for installed radiators	Included in Reducing Peak Demand and Peak Flow Rate solution	Solution 2: Reducing Peak Demand and Peak Flow Rate
ID5	Use of 3-D design for buried pipework	Captured in Improved Front End Design and Planning	Solution 6: Improved Front End Design and Planning
ID6	Data from surveys will be shared by all utilities in the future	Captured in Improved Front End Design and Planning	Solution 6: Improved Front End Design and Planning
ID7	Better survey equipment and software to convert to 3-D CAD model	Captured in Improved Front End Design and Planning	Solution 6: Improved Front End Design and Planning
ID8	Get consents earlier e.g. traffic management, SHE planning.	Captured in Improved Front End Design and Planning	Solution 6: Improved Front End Design and Planning

Solution ID	Solution	Reason for red or amber rating	Green Solutions
Civils			
C1	Re-use of excavated material off-site	This amber solution has been presented in more detail in the Solution Form - Reducing the cost of backfill	
C2	Processing of excavated material on site to re-use	This amber solution has been presented in more detail in the Solution Form - Reducing the cost of backfill	
C3	Sharing of excavated material and backfill with other construction sites in the local area e.g. take to a central location or swapping service.	Assuming a significantly large construction of DH in the UK, it is assumed that there can be appropriate management of excavated material and need for backfill on a single construction works. Hence, there is no significant advantage of a 'mud bank' for sharing of excavated material. See also the amber Solution Form - Reducing the cost of backfill	
C4	Micro-tunnelling	Captured in Trenchless solutions	Solution 5: Trenchless Solutions
C5	Shallow burial of DH pipe. Conventional design requires DH pipes to be buried at a minimum depth of c600mm to avoid excessive force from traffic. In practice, this typically means installing at greater depth to avoid existing services. These costs could potentially be reduced if the pipes could be buried within the thickness of the road sub-base i.e. in the range	An initial estimate of the potential savings with this approach has been made with the following assumptions: - the shallow burial depth means less material to excavate and backfill and no shoring is needed - a rapid production rate is achieved as there is a services free route - however the pipe itself will be three times as expensive because of the need for greater structural strength The initial cost analysis using these assumptions and the cost model results in a DHN capex saving of 10%. Preliminary review of options available in the market has identified a twin wall corrugated stainless steel pipe as available by Brugg System (the Flexwell FHK range) is closely aligned to the solution proposed at a cost of about 3 times the conventional pipe systems. For this solution to be viable there would need to be extensive testing to ensure that the long-term performance of road surface is not compromised and no additional costs result in road maintenance so that agreement can be reached with the Highways Authorities. Also agreement will be needed with the other utilities as DH installations less than 1.2 meters cover are not in accordance with the current recommendations of the NJUG, and other statutory utilities are likely to object to assets being buried beneath DH pipework.	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	200mm-400mm cover. For structural support, the pipe could be located in a concrete duct or trough with a lid, or alternatively the pipes themselves could be designed to withstand traffic loading.	When buried shallower than around 0.7m cover it is likely the pipework (or any concrete surround) will form hard spots below the flexible road pavement and may cause deformation, wheel tracking or reflective cracking in the bituminous materials above. Most road carriageways are designed for a 25 year design life. At the end of the design life the road pavement is either fully replaced or partially replaced to a depth approximating to 0.7m. If DH pipes (including any surround) are laid shallow this will impact on the Highway Authorities capability of carrying out routine maintenance works without the need to specially protect or replace DH pipes at the same time. Although a significant cost saving is predicted there are significant challenges in achieving a viable technical solution so classed as amber.	
C6	Tunnelling 3-D printer. Combines developments in 3D printing with tunnelling solutions to deliver an entire pipe solution without ever having to break the road surface. The printer delivers the pipe, insulation, connections and valves.	Trenchless technologies together with pre-insulated pipe (see C4) looks more promising. The tunnelling aspect of this idea will be taken forward in C4 and the balance in cost between a factory made pipe delivered in a coil and a 3-D printer on site with a range of materials delivered to site is expected of more marginal benefit.	
C7	More construction above ground	This solution is addressed via both Radical Routes (e.g. RR1) as well as plastic piping in terms of jointing above ground and dropping into trench (e.g. PC1)	
C8	24-hour working (subject to noise impacts but would lower plant cost offset higher labour cost)	This potentially could reduce plant hire and prelims costs if the works could be completed quicker. Also easier traffic management issues when working outside normal hours. However, there would be increased labour costs from working unsociable hours as well as potential problems from noise when in residential areas. It may be better to focus on improving productivity during normal hours than simply extending the hours of work. Initial estimates based on 24 hour working and a programme of one-third of baseline would result in a savings in prelims of c5% of capex. However labour costs would increase perhaps by 50% which would increase costs by c10%. So no net benefit in capex. However in some technologies where	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
		there is a higher plant cost (e.g. trenchless technology) some extended working could be beneficial so this solution is retained as an amber.	
C9	Machine to dig, lay pipe, process material, reinstate	This may be worth investigating if no underground obstacles. However, the challenge is seen as particularly difficult given that there is commonly many underground services along the route and care is needed to excavate and lay pipe route around them. The cost saving would be small as it is the overall low rate of progress which leads to high costs rather than the machines being used. Having a combined machine would not overcome the difficulties of working at depth and avoiding existing services. To some extent this solution is covered by others related to reducing costs of backfill and the use of trenchless technology.	
C10	Excavation machine with intelligence to know what is below ground e.g. sensor in the bucket. Avoids hitting pipe and needing spotter.	It is unclear whether there is any significant benefit from this approach. Likely to still require a spotter - cannot guarantee 100% identification. Better approach is to know what is below ground before digging - see ID2.	
C11	In some cases, the excavation depth may be deeper than actually required so as to accomodomate potential future connections. Look to be more pragmatic now e.g. different zones of different depth.	Whenever there is uncertainty about future connections there tends to be overdesign and overprovision. This is best resolved by regulations which require all buildings in a given area to connect to DH so that this overprovision is avoided.	
C12	Can vacuum excavators remove earth quicker and/or quieter (e.g. can be limitations of use due to residents etc)	The typical expected suction excavator spoil extraction rates roughly, in cubic metres per hour, range from 10 m3/hr for sandy soil to 1.7m3/hr heavy soil with buried cables and pipes. It is particularly beneficial in comparison with manual hand digging e.g. 0.25m3/hr for heavy soil with buried cables and pipes excavated by hand. The efficiency of vacuum excavator drops when more services or heavy or more cohesive solid are encountered. This is partly due to the need that materials may need to be loosened with hand or hydraulic tools prior to removal by suction. Hence, increasing the suction rate in these situations may not necessarily significantly increase work rate. Furthermore, it may cause other difficulties in operation, risk damaging third party assets and could increase noise levels.	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
		Quieter vacuum extractors are appearing on the market-place to address needs. These, for example, use engineering controls to limit noise exposure such as improved design of the vacuum pump (blower) and lower amounts of engine power needed to run the blowers. e.g. (i) http://www.cpwrconstructionsolutions.org/heavy_equipment/solution/834/quieter-vacuum-extraction-trucks.html, (ii) http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0ahUKEwjl0JfSu9zPAhVsKMAKHeqABesQFgguMAM&url=http%3A%2F%2Fwww2.vermeer.com%2Fvermeer%2Fdocuments%2F1%2F531%2FVacuum%2520Full%2520Line%2520Final.pdf&usg=AFQjCNE4w7MO8I8BE97TSSPF3G-DPPP3MQ&sig2=vo1h2dAc7v_AHjBOLXupnw&bvm=bv.135974163,d.ZGg Best to focus efforts more on other solutions which more clearly increase production rate.	
C13	Better identification of redundant pipe that contractor can remove, say, rather than going around. Need better information upfront that the pipe is redundant.	Addressed in design process (e.g. ID2)	Solution 6: Improved Front-End Design and Planning
C14	Currently need to reinstate as found. This can add significant cost in some cases (eg If specialised surface) and may not really be necessary. Challenge specification and design intelligently.	Although in most cases reinstatement will be required for strength purposes when under roads there may be some areas where a lesser specification is acceptable however this is likely to be in a small minority of cases and will be site specific	
C15	Look to eliminate shoring by minimising depth and	Captured in other solution ideas e.g. C5, PC1	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	need for access.		
C16	Only shore at points where someone needs to enter trench.	Captured in other solution ideas e.g. PC1	
C17	Reverse vacuum excavator to supply sand around pipe.	Likely expensive to do as needs to be dry to reverse pump whereas sand purchased today and dropped in is not dry. Furthermore, unclear significant cost saving from doing so.	
C18	Use of foam concrete to reduce backfill cost	This amber solution has been presented in more detail in the Solution Form - Reducing the cost of backfill	
C19	Eliminate flushing e.g. prefabricated clean pipes, use roll of clean pipe, pipe with shield at end which disolves when water passes through first time, pigging (or something to clean pipe in sections), something akin to chimney sweep, change filters more often initially - reduce CAPEX but increase OPEX. Overall flushing is relatively small cost component.	The cost for flushing is relatively low although it can be a complex task. Considered important for long term operational effectiveness so reluctance to downgrade the procedures and standards.	
C20	Reduce cost of flushing by using rig which on site filters mains water etc to produce right quality of water.	The cost for flushing is relatively low although it can be a complex task. Considered important for long term operational effectiveness so reluctance to downgrade the procedures and standards.	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
C21	Retain water used in flush test for use in DH system for heating	The cost for flushing is relatively low although it can be a complex task. Considered important for long term operational effectiveness so reluctance to downgrade the procedures and standards.	
C22	Develop standards for flushing. However, considered little CAPEX saving.	The cost for flushing is relatively low although it can be a complex task. Considered important for long term operational effectiveness so reluctance to downgrade the procedures and standards.	
C23	Need to create a consistent standard for water quality into DH system as different schemes request different standards, some of which appear to be over cautious approach	Water treatment is not a large capital cost c1.2%. Furthermore, only a small reduction would be associated with standardised water quality in terms of reduction in capital costs associated with water treatment plant or cost associated with initial fill process. There would be concern from operators on long-term risks of internal corrosion from relaxing requirements. A 20% saving would be 0.24% of capex	
HIUs and internal connections			
IC1	Domestic hot water (DHW) production (linked closely to HIU design)	Included in Direct HIU System & Existing DHW Storage	Solution 9: Direct HIU System & Existing DHW Storage
IC2	Direct connection – with devices for leak detection and shut-off	Included in Direct HIU System & Existing DHW Storage	Solution 9: Direct HIU System & Existing DHW Storage
IC3	New manufacturing techniques with volume production	Included in HIU Optimisation solutions	Solution 10: HIU Optimisation (1) Design for Manufacture and Assembly (DfMA) Solution 11: HIU Optimisation (2) Further Simplification &

Solution ID	Solution	Reason for red or amber rating	Green Solutions
			Value Engineering at Scale Solution 12: HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage
IC4	External HIU box to reduce installation costs and disruption	This could be a useful option however the cost of a robust waterproof box, typically glass fibre and lockable for external use will be more than the cost of a pressed steel cover to the internal HIU. But there would be some opex benefit as critical equipment, strainer, heat meter etc would be more accessible to the DH operator. Other components such as the hot water heat exchanger may have to be located internally to avoid excessive pipe runs for hot water and hence delays in receiving hot water at the tap. this will be dependent on the layout though and an external HIU located just below the location of a combi boiler on a kitchen wall, reusing the hole in the wall left when the boiler flue is removed would be a possible solution that would be attractive to the resident (i.e. releases space in the kitchen) whilst better for the DH operator. Overall this is an opex benefit and a improved customer offer rather than a capex benefit.	
IC5	Return temperature control – correct HX sizing, RTL valve plus sophisticated ‘keep warm’ controls	Included in HIU Optimisation solutions	Solution 10: HIU Optimisation (1) Design for Manufacture and Assembly (DfMA) Solution 11: HIU Optimisation (2) Further Simplification & Value Engineering at Scale Solution 12: HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage

Solution ID	Solution	Reason for red or amber rating	Green Solutions
IC6	Standardised designs	Included in HIU Optimisation solutions	Solution 10: HIU Optimisation (1) Design for Manufacture and Assembly (DfMA) Solution 11: HIU Optimisation (2) Further Simplification & Value Engineering at Scale Solution 12: HIU Optimisation (3) Value Engineered Direct HIU & Existing DHW Storage
IC7	Combining components – e.g. Orchometer combines pressure separation, volume flow metering and flow limiting through one positive displacement pump	This remains an option to be explored further within the HIU solution - not enough information to take forward as a single solution but it is worth including in HIU solutions as one of a number of ideas to combine components	
IC8	Separate the HIU into two parts – only the hot water part is internal to the house, other parts – controls, metering are in external meter box	As above the external meter box will add to the cost and the main advantage is probably lower opex	
IC9	Improved	This is important and is now included within the knowledge management, research and training	Solution 1:

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	commissioning processes to ensure return temperatures are achieved and reduce number of call-backs (lower opex)	solution	Knowledge Management, Research and Training
IC10	4 pipe solution	Little or no cost saving. Detail included in the Sharing HIU solution form provided with the main report.	
IC11	Omit individual heat meters	Cost of meters is falling - saving may be only £100 per dwelling. Conflicts with current Regulations. May also be less attractive to customers who are suspicious of fixed charges. Likely to lead to higher energy use and so may increase CO2 emissions. However some have argued that it is the operational cost saving of not metering heat that is important - cost is c£100 p.a. which is not justified on the basis of potential lower energy use as with DH the production cost of heat is usually low. Future systems could look to provide a heat service - i.e. ensuring internal temperatures meet user requirements for a fixed charge and then control the system to minimise energy use. This is already the case with commercial buildings on continental schemes. Heat meters are useful for monitoring the system and spotting abnormal flows or temperatures which could indicate faulty equipment. Left as red as only a small capex benefit.	
IC12	Reduce cost of heat metering e.g. Volume metering or exergy metering vs heat metering	Cost of metering is falling and accurate volume metering would not offer much of a saving. Exergy metering would involve a temperature measurement as well as flow temperature cannot be constant at all propertiues through the year. Exergy appraoch would encourage customers to reduce return temperatures so would have a small opex benefit but unlikely to have a significant capex saving	
IC13	Put risers outside of apartment buildings. Locate HIU close to risers	Any layout that reduces costs by minimising cost of pipe distribution including costs of branches to HIUs will be of value but is site specific and in this case related to only one typology. External pipework likely to involve scaffolding which would add to cost compared to internal route - but worth considering if combined with other works e.g. window replacement, external insulation/cladding etc. Locating the HIU close to risers is good to minimise branch pipework but not good if it just means more cost on the dwelling side of the HIU for longer secondary pipework.	
IC14	Have a central system where installers can phone up re. specific HIU units. Corgi has this	Covered by the knowledge management solution	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	for gas boilers.Potential to reduce cost of installation.		
IC15	Streamline the installation process and reduce material use	Included in Internal Connections – Pipework & Connections Within the Property	Solution 13: Internal Connections – Pipework & Connections within the Property
Pipes and Connections			
PC1	Higher temperature plastic pipe solutions e.g. kevlar reinforced pipe that maintains flexibility even at larger diameters up to 150mm and can be delivered on a roll	This was initially a 'green' solution and the project team sourced a suitable product. However, there was little or no benefit of implementing the solution. All of the smaller pipes in the baseline model are already plastic. It is not cost-effective for the larger pipes (200mm and above) to be in plastic because there is no gain from the benefit of flexibility. In the baseline model there are only relatively short lengths of pipe that are in the range 80mm to 150mm inclusive. Hence, this solution was down-graded to 'amber'. However, it is important to recognise this innovation and, indeed, if the network model had been different with more intermediate pipe diameters employed in the network, then this solution could potentially have delivered a cost saving, from the flexibility of the pipe and the avoidance of expansion loops. Currently the cost of the pipe is significantly higher than that of conventional steel pipe and the net capex benefit is therefore not as great as first anticipated. Another product also offering flexibility is the flexible stainless steel pipe Flexwell from Brugg System. This would have similar costs and benefits to the high temperature plastics but again suits best a particular part of the market in terms of diameters and applicability.	
PC2	Glass-reinforced epoxy (GRE) pipe	This is a valuable addition to the options available but although there may be a small cost advantage with larger diameters the main selling point is high long-term reliability due to the use of a non-corrosive material	
PC3	Composite pipes	Effectively addressed in high temperature plastics solution (PC1) which is also a composite.	
PC4	Greater use of twin pipes (lower civils and opex)	Small pipe sizes in baseline model are already assumed to be twin pipe plastic and twin pipes not curently available at larger sizes. Also twin pipe is not so flexible in navigating obstructions as individual flow and return pipes as it needs to be installed at a constant horizontal plane.	
PC5	Pre-fabrication of plastic pipework off-site. This could include manufacturing a length of pipework	The benefit here is essentially to make the joints in a factory rather than on site which normally will result in a lower cost. However this solution is applicable to streets with many branch connections where we are assuming plastic pipes and mechanical couplings which are in any case relatively quick to install. The disadvantages of off-site production of joints are: the need for surveys in advance and the risk that the pre-fabricated position may not suit the site once the trench is dug and existing services uncovered leading to rework. The assembly with	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	with tees for house connections attached. Then delivered to site on a long roll.	branches would be bulkier and so more difficult to transport. The benefit is realised when a long length of pipe can be placed in a trench. If there are service crossings then the pipe would have to be cut and remade and if this is the case the conventional approach will be cheaper as it is more flexible and less risk of waste materials. Overall this solution is only tackling a small part of the cost involved (making branch connections) so will not have a significant impact.	
PC6	Use of mechanical couplings – e.g. Victaulic – avoids welding on site – already available for small diameter plastic pipe	Limited benefit as saves cost for connecting steel pipe only and potential long-term risk as less secure than welding	
PC7	Asymmetric pipes – flow pipe small to limit heat loss, return pipe larger to compensate for high pressure drop in flow, also different insulation thicknesses	In principle this could result in a lower opex but unlikely to have a significant capex benefit and means a more complex design and installation. Some people have advised that additional insulation on the flow is worthwhile but this would be a capex increase over baseline.	
PC8	UK stockist of pipes. Reduce waiting time e.g. identify need during excavation. Also reduce compound size and allow just in time delivery. Can also provide welded junctions rather than waiting for special solution.	Valid approach and appears to be starting e.g. CPV have large stock held in the UK (Hampshire) of steel and polymer pipework in variety of insulation specs. Will benefit from increase volume and standardisation of pipes. Little benefit project team can make at present.	
PC9	Elimate/replace expansion loops.	Previously used bellows but any failure is expensive to resolve. Preheat system to avoid expansion joints - done before welding. Pre-heating requires trench to be open over a long length which is not practical in urban areas.	
PC10	Use more flexible	Addressed substantially in PC1, Brugg system is flexible stainless steel pipe	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	steel pipe or high temperature plastic pipe		
PC11	Plastic pipe that comes flat and only inflates when in place and filled with water. Enables longer roll and easier lay	Not considered a significant advantage and CAPEX saving compared to standard plastic pipe solution which can come in a long roll.	
PC12	Reduce number of welds if know location of obstacles. For example use longer length of pipe if no obstacles (16m) or design route around obstacles.	Captured in Improved Front End Design and Planning	Solution 6: Improved Front-End Design and Planning
New Network Income			
NN1	Civil Engineering Cost Sharing	Covered in New Network Revenues – Shared Civil Engineering Costs	Solution 8: Shared Civil Engineering Costs - New Network Revenues
NN2	Duct provision for other utilities: Sale or lease	See solution form - Shared Civil Engineering Costs - New Network Revenues	
NN3	Local Authority - Resurfacing alignment	See solution form - Shared Civil Engineering Costs - New Network Revenues	
NN4	New combined business model	Covered in New Network Revenues – Shared Civil Engineering Costs	Solution 8: Shared Civil Engineering Costs - New Network Revenues
Other			
O1	Use of road transport using PCMs for more distant low cost heat	Some research papers have shown this to be more cost effective than pipelines but only for niche markets e.g. a zero cost waste heat source >50km from the heat customer	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	sources		
O2	alternatives to water as heat transport medium	No examples have been seen in the literature except for micro capsules for district cooling where delta T is small. Issues of environmental impact also need to be considered and water is cheap and non toxic	
O3	use of the heat network to transport low grade heat to act as a heat source for use with heat pumps located at the buildings or a street level.	This is a very different system architecture where low temperature water is tranposrted to buildings and heat pumps used at the buildings to raise the temperature to a useful level. The benefit is that the heat losses in the network are low and insulation levels can be reduced and omitted on the return pipe. However the delta T will be small c20C compared to the 30C to 45C being considered for the conventional approach so the pipes will be larger. The main cost of civil engineering trenching will therefore be higher. This may not be an issue for smaller schemes including those supplying only a small group of houses but would be an issue for larger schemes. The cost of heat pumps in each building will be higher than for a central heat pump system especially if there is a need to also include some gas use for peak duty (hybrid system). This type of system is of value where heat can be rejected into the network e.g. from commercial buildings but this is not a significant factor except in particular circumstances (e.g. a group of houses next to a supermarket) and not applicable for general heat network applications in areas dominated by residential heating. Report by Element Energy for DECC shows that centralised heat pump with DH has a lower lifetime cost than distributed heat pumps. Localised heat pumps at each building may need the electricity grid to be upgraded as well which would add to capex. Heat pumps at a street level so that the local heat network is at useful temperature but the main distribution pipework is at low temperature is another option. In this case the cost of the main upstream distribution pipework would be higher than for the basecase (as smaller delta T and larger pipes, although return could be uninsulated) but lower opex as lower heat losses. The local downstream heat network costs would be unchanged and this is where the bulk of the cost is seen anyway. Locating a large number of heat pumps at a street or neighbourhood level would be difficult and potentially costly to find the land, build an enclosure and obtain power supplies. Preliminary analysis indicates a higher network cost by 1%-2% partially offset by lower heat losses at 0.85% when capitalised. So no overall net benefit and the cost of the street level heat pumps would be higher than if these were installed centrally. Further comments below respond to additional question sposed by ETI in relation to this solution. Pipe sizing matters more for the larger distribution pipes and less for the local branch pipes. A street level heat pump would mean that the upstream pipes would see a smaller delta T and so need to be larger. These upstream pipes are larger diameter and their costs are more influenced by pipe size and so this solution would add to capex. Halving of flow rate led to a 3% reduction. This solution would increase the flow rate byc50% so an increased capex of 1% to 2% would be expected. The additional cost is offset slightly by the fact that	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
		some of the final heat energy is derived from electricity used in the heat pump so the upstream pipes will be carrying less heat than in the baseline. But a large number of small heat pumps will be more expensive than a single large one at the location of the waste heat source and there will be issues of siting these (planning, power supplies, noise etc). there may be a cost for upgrading the local electricity supply which will not have been sized for meeting heat demand in the area (albeit via a heat pump). In terms of use of waste heat, including from power stations, the base case would not prevent this as a heat pump could be placed at the power station (but a better solution is to extract steam from the turbine). The main benefit of distributing low grade heat is lower heat losses and in the case of a heat pump at street or neighbourhood level the heat losses upstream would be much less as the network would operate at 10C-30C depending on the heat source available. The smaller temperature difference between the DH water and ambient is offset by the need for larger pipes. From the breakdown of pipe sizes we can say that if the heat loss is 10% in total, the heat loss attributed to upstream pipes is 3%. This would be significantly reduced to around 0.5%. The cost of producing heat for DH is generally low however (especially if waste heat) so the benefit of this lower heat loss is correspondingly small, we estimate a lifecycle benefit of c0.85% of capex. Hence taking all of the above into account we estimate this option to have higher capex that is not offset sufficiently by lower heat losses. It would be best used for a system where there are multiple waste heat sources distributed throughout an area and is seen as having potential only in a niche market.	
O5	Make the most efficient use of resources on-site e.g. greater standardisation on site to reduce time from repeat work, multiple excavations in parallel where possible to minimise most time critical element, keep digging - time critical element, standardised and quick approach when things not as planned e.g. get pre-approval	Captured in Improved front end design and planning	Solution 6: Improved Front-End Design and Planning

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	for common issues to reduce time wasted		
O6	Greater standardisation of components e.g. standard bends, fittings. Reduce cost of components and time for familiarity. Also standardise any pipe joint system used in future - mix and match manufacturers components..	With respect to the pre-insulated pipe systems this has been standardised over the last 25 years or so starting with EN253 and there are now a number of associated standards for joints, valves and fittings. These have largely created standard dimensions for both carrier pipe and the outer casing with different outer casings being used to provide for variation in insulation thicknesses. It is already possible to connect pipes from two different manufacturers using a joint system manufactured by a third. This does allow some more competition in the industry but this is a fairly small commercial benefit and has largely been achieved already. With respect to other parts of the system there is greater scope for more commonality of individual components within HIUs and types of connection although these are largely of standard design as well. For example the dimensions of a heat meter to be inserted into an HIU are standardised so that a meter can be easily changed or added later. This is captured in HIU Optimisation solution. Similarly, there is greater scope for standardisation with respect to internal connections and this is separately covered in the Internal Connections solution.	
O7	Continuous operation - slowly roll along doing all processes as you go. Allow all staff to be continually involved and reduces traffic management issues.Likely depends on use of coiled pipe to be rolled out as go along. Need to address potential service obstacles and relatively slow speed of excavation vs other activities.	Effectively captured in O5 i.e. more efficient use of resources on-site.	Solution 6: Improved Front-End Design and Planning
O8	Planning portal with details of all	Effectively links to NN1	Solution 8: Shared Civil Engineering

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	highways work planned. Contractor can see intended works, co-ordinate and save costs.		Costs - New Network Revenues
O9	DH installation has authority to divert other utilities if this is cheaper than routeing around obstacle - this is the position in Denmark. DH company could contract with the utility to move services on their behalf or the utility company would be required to do the diversions directly and be refunded costs. But overall could be a saving compared to routing large diameter DH pipes around existing services	Issue here is around the utilities acceptance of this process even if their costs were covered. There would be a need for regulatory intervention to require other utilities to respond quickly to requests to divert or temporarily relocate existing services at reasonable cost. Or to permit DH company to do so themselves subject to satisfactory standards of work.	
O10	Contractual arrangements to reduce component of risk in contractor fee.	Commonly the contractor allows for uncertainty as part of their fee. Alternative contractual approaches could be explored to reduce/eliminate risk as part of the contractor's fee that is beneficial to both client and contractor. However, it has previously been agreed that this project focus primarily on technical rather than contractual solutions. In addition, the work in ID2 etc is focussed on better design up-front which should significantly reduce risk and thus the additional fee the contractor should need to include.	
O11	Framework contracts to reduce the cost of tendering.	Framework contracts are in place with contractors. However, from initial discussions, they appear to focus on pre-qualifying. Given the non-standard nature of each job, it appears that there are no fixed prices. In the short-term it is difficult to see this changing, what the project team can add here and ETI previous feedback that the project should focus on technical rather	

Solution ID	Solution	Reason for red or amber rating	Green Solutions
		than contractual solutions. It is noted that there are typically framework contracts with parts suppliers e.g. agreed prices for pipes.	
O12	Create governance body for all projects to ensure that the schemes deliver intended outcomes. Governance body would include residents/users, ESCO, contractor etc.	Likely more of OPEX benefit - albeit some learning for future schemes. Some duplication of outcomes with Knowledge Management, Research and Training (see O13 below).	
O13	Many commentators have noted that we are not very proficient at DH in UK and so some savings would result from better training, knowledge sharing, targeted research and more guidance or regulations. This would particularly address: - Over sizing - Over engineering - Poor commissioning • A national skills academy is proposed to co-ordinate activities including: research, publications, training and auditing of schemes • Greater	Captured in Knowledge Management, Research and Training.	Solution 1: Knowledge Management, Research and Training

Solution ID	Solution	Reason for red or amber rating	Green Solutions
	standardisation is also desirable and some people suggested the Building Regulations should be used to raise standards or a similar system to the MCS.		
O14	More general public education to minimise impact from general public when undertaking scheme. Note if public are keen to get the works done rather than fighting it - should speed up works and reduce barrier.	Valid idea and will certainly be needed if there is a greater degree of regulation which compels people to connect. Difficult to evaluate in terms of capex saving or cost of implementation.	

10 Appendix F: Testing Preliminary Findings with the Stakeholder Community

A summary of the feedback from the stakeholder event are included overleaf.

Title: Testing of Preliminary Findings with Stakeholder Community

Location: AECOM, Aldgate

Date: 9th March 2017

Introduction

A one day stakeholder workshop was held at the end of Stage 2 to gauge the initial level of acceptance to the preliminary findings. The attendee list is included in Annex 1.

Presentations were made on each of the 13 Green solutions with significant time allowed for stakeholder discussion. The presenters requested feedback on:

- any additional benefits/opportunities not identified?
- any additional challenges/obstacles not identified?
- what could be done to enhance the likelihood of the solutions being deployed?

Attendees were also issued with a questionnaire for completion at the end of each solution with the following questions.

Q1: The solution is likely to be deployed (strongly agree, agree, unsure, disagree, strongly disagree)?
Q2: Please explain the reason for you rating
Q3: What could be done to enhance the prospect of this solution being deployed?
Q4: Would you like to be involved in the route mapping process for this solution and, if so, how can you help?

A description of the full set of solutions (Green, Amber and Red) was placed on the wall for attendees to review during breaks. At the end of the workshop, attendees were given the opportunity to comment on whether any of the Amber and Red solutions were more promising than initially validated and whether there were other significant potential ideas that were omitted from the list.

These summary notes present the feedback from each solution in turn. It includes both the feedback from the meeting itself and the questionnaires. It also includes comments from the project team on whether any additional work is necessary.

The figure below shows that there was good support for all solutions although the two radical route solutions (Nos. 3 and 4) were less well supported. This was due to concerns over customer acceptance rather than the technical proposals and so the route map for these solutions includes measures to address customer acceptance.

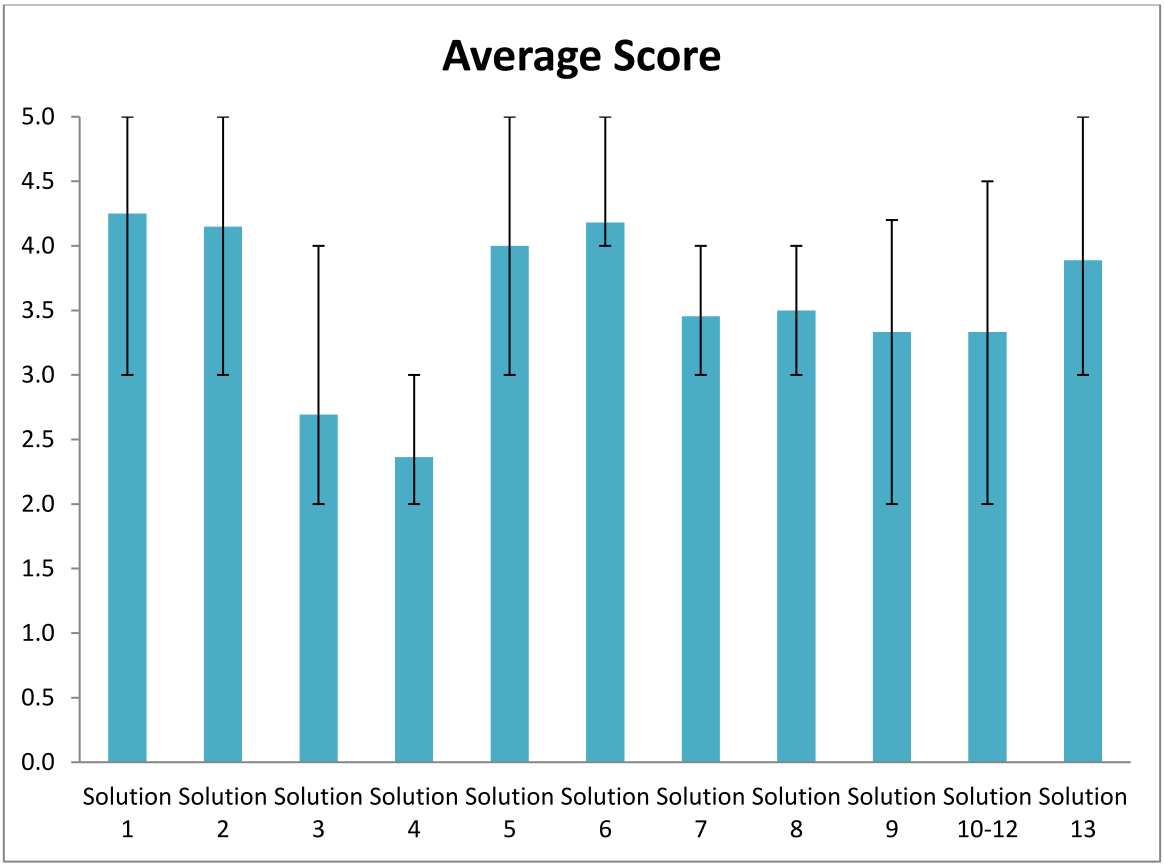


Figure 10: Feedback from delegates at the stakeholder event to the statement ‘this solution is likely to be deployed following further development work’ (score 5 = strongly agree, score 1 = strongly disagree, bars show 10^{th} and 90^{th} percentiles)

Solution 1: Knowledge Management, Research and Training

Feedback from the workshop

- There appeared to be general consensus that this is an essential solution, particularly as an enabler of all the other solutions. The focus of the discussion was on how to implement it.
- National body
    - There were suggestions to learn from other similar ventures e.g. how was BSRIA set-up? BSRIA is industry funded and has a testing facility. It has authority too.
    - Several attendees proposed that rather than setting up a new national body, an existing institution could take the lead e.g. CIBSE, BSRIA. A challenge noted by others is that the skill-sets needed for district heating are more diverse than existing institutions e.g. CIBSE and BSRIA are focussed around building services whereas a key part of district heating is civil engineering.
    - The national body will need one, or possibly several, determined leaders to make it work; personality is key. It will require a significant amount of effort including co-ordinating together the various parties necessary to make progress.
- Guidance
    - It was noted that the Code of Practice was very complex to write and co-ordinate input as many disciplines are involved in district heating.

  - Could existing guides e.g. Code of Practice and BRE, GLA, LBI technical guides be drawn together?
  - It was noted that Code of Practice check lists are in development.
  - It is important that things are published quickly so they are not out-of-date. Wikis etc. are faster to publish than books which can take a long time to prepare. Therefore websites and other alternative formats should be considered, rather than books.
  - Some basic points could be closed out now, rather than getting distracted by writing up a complete guide, focus on the essentials that can be published and standardised quickly. We need a short guide; quicker to produce and more likely to be used/read/referred to. This should be visual to help impart information easily.
  - The IET wiring regulations could provide a useful model.
  - It was noted that the DHC discussion group are planning to write a DH manual. They are currently considering the audience and how to get it to them. BSRIA is also in the process of drafting guidance. Islington would like to get their guidance into any revision of the Code of Practice.
  - Part L compliance guide is not widely known and only a small part relates to DHN. Do we need more regulations?
  - In Scandinavia design standards are produced by Industry bodies rather than public bodies.
  - The Danish Technical Guide is being translated into English for BEIS. The Danish approach (technical solution) may not be cheap solution, and although it works well it is not necessarily suitable for the UK. Once the translation is available it should be reviewed for suitability in the UK context.
- Industry practice
  - There was a suggestion that we could learn from Scandinavia. For example, they have some fixed requirements for district heating such as radiator temperatures. In Sweden new radiators have not been allowed to run over 55°C since the mid-80s. This helps achieve greater standardisation and quality. Note that this specific requirement would have a big impact. This approach has been adopted for a scheme in Birmingham.
  - Several suggested that there should be standardised solutions that the industry agrees work and that the industry can be trained to meet. Perhaps the Code of Practice includes these as an Appendix. There would need to be justification to implement an alternative solution. There are risks with simplifying to this level, but it might work.
- Data
  - There is a lack of real data on the performance of district heating schemes to better understand what works and what does not work. This is a starting point to help identify improvement and then assess their benefit.
  - It will need organisations to work more closely together (often a number of separate organisations are involved in the design, construction and operation of a scheme) to collect, share and interpret such information.
- Academic institutions
  - There is no academic centre focussed on district heating. Hence it was suggested that there is limited academic research in this field. It was also suggested that EPSRC does not fund more practical research and can be too ‘ivory tower’.
  - Others suggested that there is some academic research in DH ongoing but it is not collated together. Someone needs to bring together research findings and present in a simple to understand common format (rather than having to read a PhD thesis).
- Training

- There was a shortage of engineers, installers, operators and tradesmen with the right skills.
- It was noted that training is a high priority at BEIS. The DH industry should take advantage of this.
- It was noted that it takes time to recruit and train people. It may take 3-5 years for any training programme to have a significant impact on new recruits.
- There was the suggestion that those involved in the DH industry need qualifications which they can also be proud of.

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. The feedback was overall very positive.

	Response Frequency
Strongly Agree	9
Agree	8
Unsure	2
Disagree	1
Strongly Disagree	0

Additional points not covered in the above discussion are included below.

- Overall, it was a good solution but there is the need for leadership and resources. It was suggested that it would need support from central Government. ADE and UKDEA need to work together in any solution. Other housebuilder organisations should be involved e.g. the G15 housing associations and the National Housing Federation (NHF).
- It was highlighted that it was important to action this urgently as poor schemes damage the reputation of the DH industry. Risk that progress will be slow due to complexity and number of stakeholders.
- It was suggested that a single training school has benefit and it should have strong links to academic and industrial research. It was suggested that University of Manchester may be interested in being the Centre of Excellence.
- There is the need to set minimum compliance standards to give consistency across industry. It would also be beneficial to have standardised solutions.
- It was important to mandate qualifications i.e. model on NICEIC. There is the potential for a degree in district heating. It was also recommended to review the MCS installer approval process and the voucher system.
- It was suggested that a good place to start was an update of CP1 and TM46. Another recommendation was to build on training modules that are already available across the industry and add the DH specifics. It was highlighted that training designers is easier than training the installers due to wide range of skills needed and different pipe systems in the market. It was important that guidance should include management and operation of schemes.

There were offers of support for the Stage 3 route mapping exercise.

- Ramboll would like to be involved
- Graham Wenden of BEIS would like to attend future meetings (subject to time pressures)
- Huw Blackwell of LBI would like to be involved as he has written guidance
- Kaz Hayat of Trent Energy would like to be involved to bring lessons learned and good practice as examples that bring cost benefits

- Natalie Miles of BEIS suggest liaison with BEIS DH team and to learn from other Government initiatives in FE/Apprenticeships
- Oliver Martin-Du Pan of EOn would like to be involved
- Paul Kay of Vital would like to be involved but has limited time
- Phil Jones (chair of CIBSE CHP/DH group) would like to be involved
- Steve Richmond of Rehau would like to be involved as has experience of running training programmes
- Susan May of Clarion Housing Group can provide contacts in other housing provider
- Tim Rook of BESA would like to be involved – leadership question, publications, training and can host meetings if required

Project team proposals for any additional work

The points noted above will be considered further during Stage 3. The plans for the route map do not need amending and no additional work is planned.

Conclusions

There was strong support for the solution and the discussion highlighted the large number of different stakeholders involved. The initial activity on the route map would be to carry out further research into the current state of play and to then define more clearly the way forward. The proposal to create a new body was not well supported; however, after further research this may still be the best option. But there was definitely agreement around the need for a lead organisation and greater co-ordination of the work.

Solution 2: Reduced Peak Demand and Peak Flow Rate

Feedback from the workshop

- Greater reductions in flow may be able to be achieved. There is commonly excessive safety margin in the designed flow rates to ensure sufficient heat delivered to the occupant in practice. Greater standardisation in design would help support reducing this safety margin. Furthermore, it would benefit from better quality in implementing and commissioning as a safety margin is in part to allow for systems not being set up correctly.
- Important to increase team work across the supply chain to ensure a safe design but without excessive margins. Risk of litigation creates barriers.
- It was noted that this solution focussed on the domestic typologies. Whilst complex, there was potential additional saving for Typology A (commercial/institutional buildings).
- Given that combi boilers are widely used and accepted, it was questioned why space heating and DHW demands are added together for HIU sizing.
- Thames Water only guarantees 9l/min (no one gets over 12l/min).
- Most houses just use 36kW combi; at the moment one size does fit (almost) all. It was questioned whether this approach be replicated for HIUs. Temperature differential and therefore plate heat exchanger size is critical.
- For single houses supply pipe sizing should be based on DHW but at the main-pipe level we need to consider diversity.
- There is very little data for commercial buildings but not much for residential either.
- There was discussion around the heat flow needed – on average 3-4kW may be needed per property but this may increase to 10kW for initial start-up when cold; this can over-burden the system so may need to limit through valve control. There may be benefits of continuous running of the system to minimise peak load. There was a discussion around the use of predictive control systems which had been tested on SBRI projects and remove control from the resident and thus help minimise peak flow and avoid user disruption. Furthermore, it was suggested that some digital controls on HIUs reduce the level of commissioning necessary i.e. automatically help optimise the performance.
- There are predictive controls that have been developed for underfloor heating. Similar controls have been developed for DH. Smart phone controls also offer this. Weather compensation is a key (and well established) part of this strategy, also linked to weather forecasts. There was the suggestion that weather compensation would remove the need for re-balancing of the radiators and the inclusion of TRVs - it was said that this is the approach taken when installing new combi boilers.
- Commissioning is a tricky issue at the edge of the design envelope. Commissioning becomes absolutely critical and so training and on-site quality control are also critical. Remote controls can help with this as commissioning errors can be solved remotely or commissioning can be designed out. This requires the use of electronics.
- It was noted that smart controls on HIUs provide useful data on the quality of the system. They help demonstrate where the performance of a system is poor and useful for commissioning. There is generally a lack of data to show the performance of the system [See Solution 1 feedback as well].
- Design out commissioning – include control valve to limit flow. The Guru System includes automated control of flows etc. There was the suggestion to engage with Chris Parsloe on software for variable flow systems.
- It is important to consider all issues holistically when designing the heating system e.g. thermal mass, ventilation, cooling etc.
- Recent reviews (e.g. Bonfield review) have highlighted the need to ramp up the level of expertise of those involved in the construction industry (training being critical), particularly those new to the industry. Need to focus on outcomes and not simply the individual components / processes. More certified installers who are proud of their

qualification. Need to consider soft landings type approach – greater focus on competency, procurement, aftercare (for fine tuning and seasonal adjustment).
- Need to allow for future proofing of system when designing – impact of climate change/occupancy patterns etc

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. The feedback was overall positive.

	Response Frequency
Strongly Agree	6
Agree	11
Unsure	3
Disagree	0
Strongly Disagree	0

Additional points not covered in the above discussion are included below.

- Smart controls have more potential than presented in the solution.
- Data gathering from existing schemes is key to avoid oversizing – especially with new build.
- Reducing a pipe size can have knock-on benefits in making it easier to navigate obstructions and other services.
- Need to ensure installers are trained not just designers.
- Need to update TM46 as the benchmarks are too conservative in some cases. This includes the need for better benchmarks and knowledge of diversity factors.
- Benefit may be larger than indicated as pipe sizing itself needs looking at.
- Need to be clear about liabilities especially in new build.
- Some good examples are already out there – needs better dissemination.
- OPEX saving of this solution is more significant than CAPEX saving.
- If the design ends up being undersized it is difficult to recover the position.
- More affordable heat leads to lower turnover of rental properties so additional savings.
- Changing climate and lifestyle changes will impact on energy demand profiles in the future
- The nature of the construction industry is often adversarial and this leads to adoption of ‘safe design’ to avoid any potential for claims
- Half-hourly pricing of energy may assist in changing demand profiles

There were offers of support for the Stage 3 route mapping exercise.

- Ramboll would like to be involved
- Graham Wenden of BEIS would like to be a corresponding member
- WSP would like to be involved as worked on a SBRI funded project on reducing peak demands
- Huw Blackwell of LB Islington would like to be involved and can provide some data
- Natalie Miles of BEIS would like to be involved
- Oliver Martin-Du Pan of EOn would like to be involved
- Paul Kay of Vital would like to be involved but has limited time
- Steve Richmond of Rehau would like to be involved and can offer cost analysis to show benefit

- Stuart Grant of Passiv Systems would like to be involved as they are already doing trials in this area of smart controls
- Tim Rook would like to be involved – already working on new form of contracts

Proposals for any additional work

The points noted above will be considered further during Stage 3. The plans for the route map do not need amending and no additional work is planned.

Conclusions

The solution was well supported and the comments made reinforce the approach that will be taken in the route map. The route map should, however, emphasise more the potential OPEX benefits of the solution and consider the potential for smart controls to support this solution. These aspects can be incorporated within the current workplan for the route map.

Solution 3: District Heating Wall

Feedback from the workshop

- This solution has been undertaken before e.g. Vital Energi has undertaken it in Glasgow. It was applied in social housing which had DH previously and not popular with all. Another scheme had the DH pipes running below balconies as less visual impact and this had been successful.
- Concerns raised included loss of property value, legal complications in implementation and the potential to be more susceptible to vandalism. Need to carefully consider design e.g. getting around rainwater down pipes
- There was the suggestion to incorporate with the guttering i.e. a one piece solution. Need care to secure the system as would be significantly heavier than currently and may be greater risk of corrosion.
- It was suggested that there should be consumer survey – what do residents say about the solution and what could improve likelihood of it being deployed?
- Need to take care of expansion if a fully bonded solution. It was suggested that even for plastic pipes there could be some expansion provision needed.
- There was the suggestion that if the solution was not standardised (i.e. needed to be tailored to the particular housing), it would increase cost. However, it was noted that if significant number of similar local houses, there should be significant volume to manage cost.
- It was noted that water companies may be supportive and help share cost if installed in conjunction with purpose made soakaways. Water companies may contribute to solutions that remove rainwater from combined foul drainage and surface water systems due to overloading of existing sewers and treatment works
- It was noted that combining with solid wall insulation has merit.
- It was suggested that this solution is set-up to fail. If reliant on all occupants agreeing to scheme, there would always be someone who would say no to including on their property. Whereas for conventional trenching you would just miss out a house.

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. There was a mixed response to this solution with particular concerns around gaining sufficient buy-in from residents.

	Response Frequency
Strongly Agree	0
Agree	3
Unsure	4
Disagree	5
Strongly Disagree	1

Additional points not covered in the above discussion are included below.

- It would require too much regulatory and policy intervention to make this viable.
- Customer acceptance is already a challenge for DH and this solution will be a hard sell. Combining with external wall insulation is a better prospect. There is potential for certain properties in single ownership i.e. social housing.

There were offers of support for the Stage 3 route mapping exercise.

- Kaz Hayat of Trent Energy would like to be involved to bring experience from new build sector where this solution could be used
- HNDU team at BEIS could ask Local Authorities if there is interest in this solution

Proposals for any additional work

The points noted above will be considered further during Stage 3. The plans for the route map do not need amending. Sensitivity analysis will be undertaken to determine impact or one or more houses refusing consent for installation.

Conclusions

There was a mixed response from the stakeholders to this proposal. The main concerns were around objections from householders which depends very much on the low carbon heating options that will be available in the future and the potential level of regulation in this area. The route map will need to consider the impact on householders, especially any negative impact on property prices. This could involve carrying out specific market research to establish reaction which could then lead to changes to the physical design or new proposals for regulations. It is not proposed that the Stage 3 route map work considers in detail regulatory change although this may be an important parallel stream of work for this solution to be taken forward.

Solution 4: Loft space / cellar route

Feedback from the workshop

- One attendee thought more likely to be accepted than Solution 3 as less visually intrusive externally.
- There was a question around what happens if it leaks – how many homes would it affect. Both an actual and perceived concern.
- There was concern about impacts upon selling a house. The legal representative may raise concerns if someone else's pipe is going through your property (albeit it was questioned as to whether it is any different to other utilities).
- It was discussed for Solution 3 and 4 the potential necessity for legislation. However, would Government legislate for something that residents saw as intrusive? There is other external furniture on homes like aerials and satellite dishes but these are the residents' choice and not forced upon them.
- One of the attendees recently visited Denmark and discussed the DH industry. There was a view that Denmark was able to legislate for district heating back in the 1970s when there was the oil crisis. It would be unlikely that similar legislation could be implemented in Denmark today. However, another noted the Scottish Government consultation which included identifying zones for district heating.
- It was noted the difference between LAs installing in social housing and requirements put upon private housing.
- It was noted that where this solution had been successful, it was where there was easy access. For example, it was implemented in a terraced street where the social housing tenants had no access to the loft space which had no party walls in between the properties i.e. a straight run. Also easier where there was existing rights for DH network for the properties.
- There was the suggestion that instead of a pipe bridge, the pipe could go down, across and up again. However, this would increase pipe length.
- Easier to apply on new-build where the lofts are empty and do not need to build around loft conversions.
- It was noted that this solution could be applied to some detached homes as in practice they can be quite close together.

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. There was a mixed response to this solution with particular concerns around achieving sufficient buy-in from residents.

	Response Frequency
Strongly Agree	0
Agree	1
Unsure	3
Disagree	6
Strongly Disagree	1

Additional points not covered in the above discussion are included below.

- It would require too much regulatory and policy intervention to make this solution viable.
- There is potential for this solution but only in social housing under common ownership.

- Future access issues would be of concern.
- Householders are unlikely to accept solution and the impact of leaks is severe.
- There is potential application in new build.
- Loft conversions and use of loft for storage would be an issue.
- Could combine with improving roof insulation as part of a package of work.
- Need market research with owners to see what they think of solution.
- The heat losses are likely to vary more over the year – is this important?

There were offers of support for the Stage 3 route mapping exercise.

- Kaz Hayat of Trent Energy would like to be involved to bring experience from new build sector where this solution could be used
- Steve Richmond of Rehau would like to be involved and can suggest pipe design options that would be suitable

Proposals for any additional work

The points noted above will be considered further during Stage 3. The plans for the route map do not need amending. Sensitivity analysis will be undertaken to determine impact or one or more houses refusing consent for installation. The variability of heat losses over the year was considered but is judged to be insignificant in terms of peak load. Heat losses would be higher in winter and lower in summer but on average losses over the year would be similar or less than the base case.

Conclusions

Similar to Solution 3 there was a mixed response from the stakeholders to this proposal. The main concerns were around objections from householders which depends very much on the low carbon heating options that will be available in the future and the potential level of regulation in this area. There were additional negative views expressed on the impact of leaks and difficulties of access. The route map will need to consider the impact on householders, especially any negative impact on property prices. This could involve carrying out specific market research to establish reaction which could then lead to changes to the physical design or new proposals for regulations. It is not proposed that the Stage 3 route map work considers in detail regulatory change although this may be an important parallel stream of work for this solution to be taken forward.

Solution 5: Trenchless Solutions

Feedback from the workshop

- Trenchless has been carried out in Germany for plastic DH pipes using the following methods: Pulling in (using a special 'sock'), Ploughing in and Horizontal Directional Drilling (HDD). See pages 55-57 of the following link - they have pictures of these technologies being used on DH pipes. https://www.rehau.com/download/1347030/pre-insulated-technical-manual.pdf. It is cost-effective to do so.
- Open cut is the traditional approach taken in the UK and hence automatically the approach taken.
- It was suggested that 80% of the work on the gas network is trenchless and 40-50% for water. Note that this is for replacement of existing pipework rather than introducing new pipes.
- Difficulty in applying in the centre of London as too much uncertainty of what is below ground – too much liability of hitting something. Unlikely to be cost-effective in rural areas as can simply plough fields to achieve open-cut more cost-effectively. Sweet spot for trenchless is in between the two.
- Need a collaborative approach across the industry – determining objectively what is the best technique for different locations – open-cut or trenchless.
- Better to use coiled plastic pipe than rigid steel pipe. More effective in streets.
- One representative openly welcomed working with the trenchless industry to better understand the potential and cost.
- There was a discussion around warranty. It may be necessary to provide warranty of work for 50 years or more. Hence, it is important that what goes below ground is reliable and will last for a long time. In particular the joints were seen as the greatest risk and may be difficult to establish quality when in a tunnel. However, with long runs of plastic, there may not need to be any joints, apart from branches to homes.
- Towing socks or cable socks are used for pulling cables and pipe found in the HDD industry. This is particularly used for new-build development.
- There was a discussion around the importance of planning where HIUs are located and minimising lengths of internal connections [More for Solution 13].
- It would be useful to go on a gas network site visit to better understand the utilisation in practice of the keyhole technology (and thus cost assumptions).

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. The feedback was overall positive.

	Response Frequency
Strongly Agree	3
Agree	5
Unsure	3
Disagree	0
Strongly Disagree	0

Additional points not covered in the above discussion are included below.

- Technology needs to be proven for DHN and adapted / refined from Europe and gas/water.
- Need collaborative exemplar projects for DHN specifically.
- There needs to be shared costs and learning post-project.
- Mixed views on applicability: from limited areas to 80% of the network. More evidence is needed.
- Multiple options proven to reduce costs at limited scale.
- Need to address: risk, robustness, warranty and CAPEX barriers.
- The savings in semi-rural areas may not be sufficient to achieve DH viability. House connections first step – urban mains possibly later.

There were offers of support for the Stage 3 route mapping exercise.

- Engie would like to be involved
- Trakto Technik would like to be involved
- Trent Energy would like to be involved and has some past experience
- BEIS (G Wenden) limited experience
- Rehau – Can share videos / costs from Germany for HDD, ploughing, pulling
- Paul Kay of Vital suggested that others in organisation may be interested to critique and test approach

Proposals for any additional work

The points noted above will be considered further during Stage 3. There is considerable enthusiasm for a pilot project to demonstrate trenchless capability. There is potential for the project team to work directly with the Heat Network team at BEIS to accelerate a specific project call. However, a demonstration project is expected to achieve a more valuable result if linked with other route maps.

Conclusions

There is a consensus that Trenchless solutions have significant potential but need to be further proven in the DHN environment. Collaboration between DHN developers, designers, contractors and equipment manufacturers is seen as crucial to enable optimum results. Key points to clarify are the potential scope and limitations for trenchless solutions. The technology is ready to test, and refine as necessary on near-term projects.

Solution 6: Improved Front End Design and Planning

Feedback from the workshop

- Comment made that seeking to agree a lower fixed price with a contractor was not the best way forward. A target price contract with a pain/gain sharing mechanism would be better. This drives a collaborative approach to seeking lower costs and is common practice in the water industry. This then enables you to manage the risks better as the work is carried out rather than trying to drive out risk by more front end design.
- Have you varied the costs between the typologies in terms of rate of progress? i.e. less saving in suburban areas as less density of service. Answer given was yes there are separate rates for both pipe sizes and areas of work.
- Need for greater cost certainty recognised, and therefore an early collaborative approach was seen as key.
- There needs to be a more collaborative approach earlier on. In particular, optimising the pipe route and reducing costs should be civils led – they have the best skills and experience as they will be delivering the network in practice.
- There was discussion around statutory rights as to where you can position the DH pipe underground. This can limit where DH pipe can be located. It was noted that other utilities have greater rights than DH installations. This potentially should be reviewed.
- Need more detailed design for more specialist activities such as rail and canal crossings.
- There was discussion around making the best use of data on underground obstacles. Should be much better sharing of data on other utilities. It was noted that utility data is available from Groundwise etc. It could be that, for example, legislation is introduced for a more comprehensive data set to be held by the LA. This could be the latest information from utility providers – if not fully accurate it is a good start. It could include third-party GPRS survey data, including 3D data and drawings.
- Too much work done at 2-D level thinking about hydraulics and 3-D underground mapping is then carried out too late.
- It was noted that there may often be limited co-ordination between those doing the pipe design work and involved in procurement, and the civil engineers installing the scheme. A lot of time can be undertaken in 2D/3D drawings, designing routes and procuring specialist pipes which are not practical to implement by the civils contractor. In a similar vein, twin-pipe is often procured as it has a lower capital cost but due to limitations in bending it puts constraints on the route to keep the pipe at the same level throughout and results in significantly greater labour costs on-site.
- However, it was noted that in principle 3D design and pre-fabricated specialist pipework can result in faster installation and greater quality.
- Need to consider ground material itself when selecting route as ground contamination can be expensive to dispose of.
- There is no requirement for underground mapping in HNDU ITTs. There is an expectation that underground mapping occurs much later in the process. Perhaps HNDU feasibility process should be extended to include mapping as this significantly impacts on route and viability. Failing that, mapping could be included in the pre-tender route proving stage.
- It is necessary to quantify the potential saving from this solution in order to encourage the change of practice proposed. This can be done by a detailed assessment of the time and costs spent on each task on a few typical projects.

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. The feedback was overall positive.

	Response Frequency
Strongly Agree	4
Agree	6
Unsure	0
Disagree	1
Strongly Disagree	0

Additional points not covered in the above discussion are included below.

- Several respondents highlighted that they foresaw this solution as being relatively straightforward to implement.
- Several respondents highlighted the need for greater collaboration between the various parties to implement this solution. Ideally, to motivate involvement, this would include details of savings realised from actual schemes which adopted this approach.
- Several respondents commented on the need for a more comprehensive underground map which, potentially, could be collated by the Local Authority. Need to be clear how the map is financed.

There were offers of support for the Stage 3 route mapping exercise.

- Andy Simms (Engie) would be interested in further involvement
- Dominic Bowers (WSP) would be interested in further involvement
- Kaz Hayat (Trent Energy) would be interested in further involvement
- Paul Kay (Vital Energi) suggested that one of their DH managers may be interested in further involvement
- Phil Jones (independent) suggested that he may be interested in further involvement

Proposals for any additional work

The points noted above will be considered further during Stage 3. No additional activities proposed from those planned.

Conclusions

In general, this solution had positive feedback. It suggests that in developing the route map it should consider further two questions: (i) how to motivate the DH company to invest early in upfront design and planning, and (ii) some further consideration of the most appropriate contractual arrangement that will encourage the contractor to deliver at lowest fee.

Solution 7: Pipe Crossings

Feedback from the workshop

- It would be useful to have a standardised design(s) for crossings. Furthermore if the designs are approved by Network Rail etc there should be fewer restrictions in using existing infrastructure. Standardised designs could be nationally agreed by the industry through ADE/UKDEA.
- Also helpful to have a standardised agreement between Network Rail, say, and the DH developer.
- DH has less of a risk profile compared to, say, gas. Need to educate others such as Network Rail that DH is safer and hopefully achieve greater acceptance. Perhaps onerous commercial terms arise due to prior experience with other utilities.
- There was the suggestion that pipes could simply be placed at the bottom of the canal rather than below or above it. Needs to be strong enough such that it is not damaged during dredging. This was also highlighted during the final wrap-up session when another attendee suggested that Canals and Rivers Trust do not like this approach – they do not wish to implement anything that increases the risk of issues. It was looked at in Birmingham but concluded not possible.
- Greater problems in practice if looking to install with existing structures (bridges) than including on new ones. To minimise actual/perceived risk, there may be a requirement for construction of a separate structure rather than connecting to an existing structure.
- Thrust bore may be more cost-effective than tunnelling.
- In the cost model, is the crossing duplicated to allow for service break? Answer was no only a single crossing was assumed.
- It was noted that Brugg have a flexible steel product which would allow pipe to be removed and replaced in a tunnel with limited access.
- It was suggested that schemes should avoid crossing railways where possible – lots of complications in doing so and presently crossings often render schemes unviable.

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. The feedback was mixed with the majority being unsure and the remaining being positive.

	Response Frequency
Strongly Agree	1
Agree	3
Unsure	7
Disagree	0
Strongly Disagree	0

Additional points not covered in the above discussion are included below.

- It would require regulatory change to make this underwriting process happen.
- Standardised solutions agreed with Network Rail and Canal and Rivers Trust would be of benefit.
- The solution likely to be resisted by Network Rail and Highways Agency

Proposals for any additional work

The points noted above will be captured in the report. However, this solution is not being route mapped in Stage 3.

Conclusions

The stakeholders agreed that this was an important area and that developing standardised designs that can be pre-agreed with both the DH industry and organisations such as Network Rail would reduce the time for negotiation. Reviewing the legal terms on a national basis would also assist the adoption of the lowest cost solution.

Solution 8: New Network Revenues

Feedback from the workshop

- Attendees were aware that utilities had been installed in the same trench for: Kings Cross, Centre Parcs, Spire defence contract (Ownership of pipe was a challenge; MOD ended up buying the land to resolve this). More common when implementing new developments.
- No evidence provided or suggested where the cost / benefit / complexity has been fully evaluated other than for new-build or major regeneration.
- Needs to co-ordinate with where and when existing networks are being replaced. Furthermore, coordinating Utility companies is challenging.
- May be a challenge to fit multiple pipes into a single trench.
- MOD implemented a scheme with multiple services – a key problem was integrating it to the existing services at either end.
- Replacement of whole lengths of pipes rather than patch repairs is of marginal benefit to water companies but DHN may tip the balance. It was noted that when renewing the water network, they are able to reduce network length (by up to 30% accounting for changes in housing) and reduced leaks but even so find it difficult to make viable on its own.
- Should not be a problem with heat transfer from DH pipes to water or cables if properly designed – more a perceived risk.
- There was the suggestion to talk to water companies about spare capacity of their drainage and sewage.
- It was also noted that the project team could review a MUSCO application in Elephant and Castle for a ducted system to include all utilities (contact suggested was Brian Dunlop). However, it was noted that this multi-utility ducted system was not taken up for the Elephant and Castle scheme as this joint approach had no interest from the industry.

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. Feedback highlighted the attractiveness of the solution but balanced by the expectation of significant commercial and legal challenges.

	Response Frequency
Strongly Agree	1
Agree	5
Unsure	8
Disagree	0
Strongly Disagree	0

Additional points not covered in the above discussion are included below.

- Consensus that the potential needs evaluation on an individual basis, and testing for wider applicability over a significant period 5ys+. Regeneration projects may be an interim step.
- Collaborative demonstration is the key to overcome perception of complexity.
- Multi-party Legal / contractual arrangements are key. DHN may need statutory status first.
- Lack of incentive / regulation for utilities to collaborate (Metropolitan utilities may be more supportive). May require market restructuring, regulation or incentives / penalties.

- Highly dependent on unique local circumstances: is it replicable? Exercise to map network upgrade plans of major utilities vs. DHN plans.
- A link with a LA energy infrastructure masterplan as in Denmark.
- If proven the potential benefits go beyond DH and should be shared. Potential to be the standard for new development.
- Needs a business case focus and a standard commercial approach as an enabler.

There were offers of support for the Stage 3 route mapping exercise.

- Engie would like to be involved
- Trent Energy – would like to be involved and brings in experience of DH and alongside other utilities
- London Borough of Islington – would like to be involved and brings in experience of major route excavation for DHN installation

Proposals for any additional work

The points noted above will be considered further during Stage 3. Stage 3 plans for a business case review of the potential opportunities for shared civils with Bristol Water. In addition ETI have identified a consortium of Northumbrian Water / Northern Gas Grid / Northern Power Grid that is looking at similar options. There may be value and interest for a parallel workstream or combined work, which may require additional resource. A shared civils project could be linked with Trenchless technology as suggested by two workshop participants.

Conclusions

The feedback from stakeholders reinforced the attractiveness of the idea of shared civils, but also the expectation that there are significant commercial and legal challenges. There was also agreement that participants were unaware of any public evidence base which summarises the value of, or obstacles to, shared civils works. This reinforces the need for further research and supports the proposal for a trial project.

Solution 9: Direct HIU and existing DHW storage

Feedback from the workshop

- Introducing storage can increase peaks because reheat takes a long time so the diversity drops; higher peaks result and return temps also rise as the tank warms up.
- Hot water storage is not permitted on Danish heat networks.
- Cylinders can allow network to turn off a branch to reduce heat loss but this requires smart control.
- May want to control timing of tank heat up to avoid peaks.
- Proliferation of power showers causes problems with pumps drawing large volumes.
- Storage can help to reduce pipe sizes.
- HIU turn down is an issue; if the HIU is sized to deal with a power shower it then cannot turn down enough to deal with low hot water requirements. This conundrum can lead to the need for 2 HIUs, 1 HIU for the shower and one for everything else. Off peak operation is key in DHN design.
- If cylinders are retained, occupants will be reassured by knowing they have immersion heater to fall back on.
- Scaling happens over 55°C and fast shut off of primary flow is critical.
- It was questioned why HIUs are being pushed to higher temps (e.g. 60°C) than combis. Combis supply at 43°C. This may be because boilers are installed by plumbers and DHNs are professionally designed.
- Cylinders may need to be replaced anyway so might as well use instantaneous.
- Customers will expect HIUs to be fixed really quickly so cannot pass risk onto residents simply by asking them to retain existing equipment.
- Replacing cylinder with more compact HIU may be a major selling point
- Ultimately it may be customer preference that determines whether this solution is needed as customers may be willing to pay more to have cylinder removed.

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. The feedback was mixed as some stakeholders were convinced that instantaneous heat exchangers were more efficient as return temperatures would be lower. Others recognised that in some situations cylinders offered advantages in reducing heat losses from long branches. The mixed response probably reflects the fact that this is not a solution appropriate for every situation.

	Response Frequency
Strongly Agree	1
Agree	3
Unsure	3
Disagree	2
Strongly Disagree	0

Additional points not covered in the above discussion are included below.

- More research is needed in this complex area.
- Needs a building survey to determine the most appropriate option in each case.
- One delegate supported retaining cylinders but saw technical issues with direct connection.
- The view that the solution is neutral to heat losses if cylinder retained was questioned – it was proposed that heat losses are likely to rise.

- There is an issue of the condition and long term integrity of the reuse of an existing cylinder.
- The cost of maintenance of the more complex HIU (indirect/instantaneous) may outweigh the benefits of greater network efficiency.
- An alternative option could be to replace existing cylinders with new cylinders.
- An option proposed for further consideration was connecting DH only to space heating and use electricity for water heating (has been proposed on some continental schemes).

There were offers of support for the Stage 3 route mapping exercise.

- Ramboll would like to be involved including getting input from the Danish colleagues
- Oliver Martin-Du Pan of EOn would like to be involved
- Pete Mills of Bosch would like to be involved – brings manufacturer's experience
- Susan May of Clarion Housing Group could contact residents to establish views on cylinders vs instantaneous hot water

Proposals for any additional work

The points noted above will be considered further during Stage 3. The plans for the route map do not need amending and no additional work is planned. However the definition of the solution may be amended to reflect the emphasis on providing greater customer choice.

Conclusions

The discussion focused on the pros and cons of cylinders and recognised that customer choice could be the overriding factor rather than simply the lowest cost solution. For example, the value to customers of retaining electricity back-up by keeping a cylinder and the reduced disruption compared to the benefit of releasing space from taking out a cylinder were likely to be resolved on a case by case basis. The route map will need to include the development of a range of designs that will provide greatest customer benefit. This process for developing standard designs will need to be informed by market research to understand better the range of views that customers and landlords may have. The solution as proposed may not suit all customers but will enable a wider range of designs to be offered to the market.

Solution 10-12: HIU Optimisation

Feedback from the workshop

- It was highlighted that there is a lot of variation in HIU design between networks. However, it was noted that the 40 market players in HIUs are drawing closer together in some aspects of design.
- Bespoke systems can also make training harder and limits the amount of training that takes place.
- It was asked whether the contractors' margins are to cover bespoke HIU solutions?
- Bypass and preheat can mean that a 70/40 system really works at 75/70.
- If ΔT is not achieved, then pumps try to deal with this by ramping up.
- Regarding the cost reduction graph, most manufacturers in the room felt they were already some way along the path and not at the start of it (generally less than the £1,500 evolved baseline, typically around £1,000 per HIU for more standard products.
- HIUs can be bought for less than £800 but some felt these may ruin the network.
- It was asked which functions are lost as a result of price drops?
- Differential pressure capacity of valves is key and puts the cost up.
- It may be better to pay more to design out the commissioning engineer because they cost money to appoint and make mistakes which cost even more.
- HIU manufacturers compete on reliability and service rather than design.
- There is value in making units last longer than the typical combi boiler (10-15yrs). HAs want 30-60yrs with no moving parts.
- Manufacturers say electronics improve reliability because this avoids scaling and has other benefits.
- HAs are concerned that electronics, heat and water don't mix well and so might combine to result in early failure; mechanical parts may last longer.
- Software control is clever but needs some sort of human monitoring. This cost needs to be included and quantified.
- Architectural design does not currently typically allow for external mounting of HIUs.
- External mounted units may have copper stolen, so should design not to use copper.
- Direct connection raises issues of ownership and responsibility. In Denmark 80% of HIUs are direct, whereas in the UK this may be more like 20%.
- If direct connection is used then there is a risk that domestic customers can replace radiators with ones which cannot deal with pressure.
- Low temperatures should be specified for direct HIUs for reasons of safety.
- Heat meter costs are high. It was questioned whether the accuracy of the MID2 (Measurement Instrument Directive Class 2) standard is needed which is common in Europe. Heat billing regulations require MID2, but there is a consultation coming soon on this.
- HAs propose that meter accuracy is not important but it is important to discourage excessive energy use. Furthermore, customer attitudes may be affected if they know the heat meter is not accurate. It was asked how accurate do meters need to be for regulatory purposes?

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. The feedback was mixed. The response from manufacturers was that a focus on cost risks a 'race to the bottom' on performance and margin. This risks undermining the investment in high quality capacity and inferior products being specified. A performance based specification and more certain future demand would reduce this risk and this will be explored in the route-map.

	Response Frequency
Strongly Agree	1
Agree	2
Unsure	1
Disagree	2
Strongly Disagree	0

Additional points not covered in the above discussion are included below.

- Volume & standardisation are crucial. Mass production offers the opportunity of reduced CAPEX, but not all are convinced it can maintain / improve performance & reliability.
- Corollaries with other industries are cited by some.
- Needs closer engagement of manufacturers, designers and clients.
- There is a desire for ultra-reliability from social landlords – it is worth paying extra for.
- Need CAPEX / OPEX / TOTEX balance to avoid short-termism.
- Spend on controls / heat meter could enable higher OPEX Savings.
- There is a vested interest of manufacturers in the current high cost.
- Need an industry aligned to system level outcomes – grow the market not fight for share for a niche product.
- Two separate aspects of OPEX: System performance (ΔT) and repair cost; Reducing both should be the goal.

There were offers of support for the Stage 3 route mapping exercise.

- London Borough Islington - Clear operator requirements and direct experience for such systems.
- Ormandy – HIU and piping manufacturer.

Proposals for any additional work

The points noted above will be considered further during Stage 3. 2nd strand of route-map to plot ultra-reliable, zero maintenance solution as well as lowest CAPEX.

Conclusions

The discussion became slightly partisan between groups that either envisaged reduced cost equating to poorer performance and others that considered that scale and an industrial approach could deliver both savings and improved performance. A crucial insight arising from the session was that, in the domestic rental sector, reliability and low maintenance (fit and forget) solutions are very important. This gives extra weight to reliability in Stage 3.

Solution 13: Internal Connections – Pipework and Connections within the Property

Feedback from the workshop

- Plastic pipes must have a diffusion barrier and need to be specified as such. There have been cases where oxygen in the water has caused all steel elements (including pipes) to rust and all pipes needed to be replaced – very expensive. Take care using cheap unbranded pipes.
- It was questioned whether the focus of the study should be more on reducing whole life cost/maximising value rather than to reduce CAPEX. However, it was noted that CAPEX is more important as a determinant of whether the scheme gets built. It was also noted that the project does look at both CAPEX and whole life costs.
- Whole life cost studies should be undertaken to demonstrate if plastic is actually cheaper overall. It was suggested that plastic pipes may be more easily damaged etc. However, it was also suggested that plastic pipes have less pressure drop and less thermal mass; these both result in OPEX savings.
- It was asked how is value measured? It is often measured on the basis that all customers have heat but ignores efficiency.
- Installation of plastic pipes is key to avoid system leaks, especially for joints.
- Debris in pipe is the most common issue for call back. This is partly caused by poor flushing and not checking the filters.
- HIUs exist which can be fitted by one person which reduces cost.
- It can be problematic to meet COSHH regulations around the solvents used for plastic pipe joints. Hence, solvents are being avoided by many. Some housing associations are reverting to soldered copper.
- Some new flats are now bunding electric risers to reduce the impact of leaks; if pipes burst water can run down cables and damage expensive switch gear.
- Form of contracts and sub contracts is important.
- It was asked at which point is coving the cheapest option? It was presumed to be a function of the number of bends. There was a request for someone to produce a decision tree/table to provide guidance on this.
- Consumers may want a catalogue of coving/skirting options not just a choice of one.

Feedback from the questionnaire

Attendees were asked whether the solution is likely to be deployed. The feedback was overall positive.

	Response Frequency
Strongly Agree	2
Agree	4
Unsure	3
Disagree	0
Strongly Disagree	0

Additional points not covered in the above discussion are included below.

- Important to undertake a pilot to confirm user reaction to the approach.
- Pre-manufactured assemblies (radiator & HIU brackets) & lighter HIUs would enable rapid install.
- This solution would be supported by better collaboration between designers, developers and manufacturers.

- It would be worth considering external HIUs.
- Better control of sub-contract labour is needed.
- Improved solutions may be needed for Pressure Relief Valve waste for HIUs.
- Concerns of costs restoring the property (+externals) to an acceptable condition for residents. Challenge of liability when something goes wrong. Trials are required.
- Need to account for heat loss and pumping costs associated with bends, choice of material etc.
- Challenges of customer communications (beyond scope) and logistics.
- Lone working is not advisable.

There were offers of support for the Stage 3 route mapping exercise.

- London Borough of Islington – limited experience: in flats only
- Ormandy – HIU and piping manufacturer
- Ramboll – tbc less directly involved
- Clarion – Resident and aesthetic perspective
- BESA – contractor / installer feedback

Proposals for any additional work

The points noted above will be captured in the report. However, this solution is not being route mapped in Stage 3. There is a potential opportunity outside of this project to gather direct householder reaction from Clarion / LBI tenants for their requirements and preferences.

Conclusion

There is recognition that there is disproportionate labour required for installation within properties, with opportunities to improve performance. However, diversity of property and installation type are challenges to overcome. There was agreement that this area has had little attention and the work could be carried out more effectively at lower cost.

Other Comments

Feedback from the workshop

- Trent Energy representative noted that recycling excavated material can be cost effective. Directly below the layers of tarmac (typically around 300mm of make-up) on most roads lies usually Type 1 fill material which is usually excavated and removed to waste landfill sites. Then exactly the same material is imported when carrying out reinstatement. In principle this excavated material is usually tested for classification/contamination before it is mucked away as part of the site waste management procedures. If the material is free from contamination then this material could be re-used. The representative has come across occasions where if it can be demonstrated that the excavated material is suitable for re-use, and that it will not cause harm to human health, natural waters or the wider environment, then it can be re-used provided that the correct EA protocols are followed. This also reduces the number of lorry movements which is also an obvious issue with pollution and congestion etc. It was noted by another attendee that this can be a problem in some places where there is hazardous material (e.g. as can be in London). It was noted that with trenchless solutions there may need to be careful handling of fluids used in the process if they become contaminated.
- There was the suggestion that the velocity could be increased in the pipework, particularly in the branches. Current practice appears to be quite conservative compared to manufacturer's specifications. Only need peak capacity/pressure for a short time. Could possibly reduce pipes by a further size.
- It was noted that in Copenhagen, LAs need to produce a masterplan of energy and infrastructure needs every 3 years. It needs to be in sufficient detail to know where to put pipes etc. Could do something like this for the UK. Would need sufficient expertise in the LA to implement this. However, the upskilling would make the LA better at co-ordinating the implementation of multiple utilities.
- Given the Ordnance Survey maps, one attendee expressed surprise that there was not something similar for the below ground services. Needs to be a below ground map. Perhaps OS should have that role, if provided with suitable information.
- It was highlighted that in the drive to reduce CAPEX it does not result in an increase in OPEX.
- In implementing solutions, it is important for achieve long reliability and avoiding continually digging up the road. For other utilities, it is assumed 100 years for steel pipe and 50 years for plastic pipe.
- Frequency of HIU/meter testing and lifetime of components needs looking at – Heat Trust work could help?
- Attendees noted that they would like to receive the following.
    - Presentation
    - The cost model
    - The outputs from the work

Comments from handout

- Ramboll fed back that for France regarding utility surveys, the Local Authority and consultant/ESCO have access to a common platform to request utility maps/survey. Each utility has the obligation to answer and send the utilities maps within a period and is very useful to help DHN design. Then when the DHN is built, there is an obligation for the LA/ESCO to indicate the route on a public platform.
- Ormandy fed back that there is a need to establish what the requirement is for the longevity of the system.

- Greater Manchester Combined Authorities said that further to CAPEX/OPEX/TOTEX, is there any reflection on how the proposed solutions impact on the quality of the project outcomes i.e. final heat price, carbon emissions etc. There is no point in reducing CAPEX if the scheme’s performance is poor. Note: This was captured in the criteria used to evaluate the solutions.
- Clarion Housing Group – Suggested that Solution 3 should be ‘red’ as installing pipework externally on semi-detached/terraced homes will result in aesthetic/planning/visual quality implications. Note: the related route map includes some work on planning aspects to confirms solution will be acceptable before proceeding to demonstration projects

Annex 1: Attendees

Name	Organisation
Grahame Wenden	BEIS
Natalie Miles	BEIS
Tim Rook	BESA
Pete Mills	Bosch
Phil Jones	CIBSE
Susan May	Clarion Housing Group
Oliver Martin-Du Pan	E.ON
Andrew Simms	Engie
Alex Hobley	GLA
Alex Trebowicz	Greater Manchester Combined Authority
Ashley Bateson	Hoare Lea
Huw Blackwell	Islington Council
David Port	Options
Murdo MacDonald	Ormandy
Stuart Grant	PassivSystems
Alexia Gonin	Ramboll
Steve Richmond	Rehau
Matthew Izzard	Tracto Technik
Kaz Hayat	Trent Energy
Paul Kay	Vital Energi
Dominic Bowers	WSP Parsons Brinckerhoff
Nick Eraut	ETI
Alex Buckman	ETI
David Ross	AECOM
Ewan Jones	AECOM
Ben Stroud	AECOM
Paul Woods	AECOM
Tim Hall	Total Flow