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Low Carbon Heat - Innovation Needs Assessment

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Executive Summary

This report presents the findings of research conducted by the Building Research Establishment Limited (BRE) on behalf of Scottish Enterprise to identify the innovation needs of low carbon heat technologies. The study provides an innovation evidence base to help Scottish Enterprise understand innovation needs when developing potential new schemes to support businesses to capitalise on low carbon heat opportunities relevant in the Scottish context i.e. considering the role they could play in helping meet Scotland's net zero targets, as well as creating value to consumers through cost reductions and creating new business opportunities.

The study consisted of desk-based research coupled with one-to-one interviews with external stakeholders. This combined approach enabled the identification and assessment of potential technical, financial, and societal barriers as well as gaps, and weaknesses, in low carbon heat innovation. These needs have been analysed and reported to help Scottish Enterprise consider the merits of developing relative support measures where deemed appropriate.

The resulting key innovations needs have been summarised in a matrix to provide a simplified comparative analysis of each innovation need (per technology group) with commentary and relative assessment of the potential cost and performance improvement potential, as well as the applicability potential of each innovation need in respect of domestic and non-domestic building stocks, and to heat and energy networks.

Key findings

This study has identified that for heat pumps there is opportunity to improve the user experience (e.g. by incorporating smart monitoring and control systems), to improve efficiency (e.g. via better design and/or improved operation and maintenance) and to reduce environmental impact (e.g. by developing refrigerants with low global warming potential). The development of smart monitoring systems for improved energy management, diagnostics and user engagement is another key innovation need identified in this study. For ground source heat pumps the study identified potential to further improve installation and drilling processes (e.g. communal installations) to help reduce cost.

The study identified a wide range of opportunities to overcome the barriers associated with the high cost of district heating networks (DHNs). Improved design, deployment of low temperature systems, new installation and piping techniques and approaches, improved heat interface unit solutions, increased use of waste heat and renewable sources, deployment of demand side management and forecasting solutions, and development of knowledge exchange platforms were all identified as areas where technical innovation could contribute to the development of more efficient district heat networks. The research also identified that there is potential to develop innovative thermal storage systems (sensible, latent and thermochemical), implementing new approaches and using new phase changing materials (PCM) to help increase efficiency and reduce cost.

The research also highlighted that waste heat (e.g. from industrial processes or commercial buildings) could be utilised in a wide range of buildings if suitable heat recovery and transmission processes can be developed and deployed cost effectively. There are potential opportunities to capitalise upon waste heat from a range of sources e.g. power stations, old mine water, waste treatment plants, distilleries, and buildings with high cooling demand such as supermarkets and data centres. There is also potential to develop new tools and mapping approaches which could help to more accurately measure and identify

the waste heat coming from industrial facilities and large buildings and enable the effective matching of supply with demand.

A key finding from stakeholder interviews was a consistent view, across all the interviewees, that greater growth in the roll- out of low carbon heating solutions could be achieved through various educational, market, fiscal and policy-based mechanisms as opposed to technical innovation alone; with many stakeholders commenting that technical improvements would typically only lead to incremental improvements by comparison.

Air source heat pump related innovation opportunities were focused on by the majority of interviewees as they viewed this technology as having the biggest potential for mass roll- out. Smart heating controls and thermal energy storage were also discussed by a significant number of interviewees. Smart heating controls and energy storage technologies were generally viewed as providing essential support to the roll out of low carbon heating technologies in terms of smarter, flexible management of large numbers of low carbon heating installations. This was especially focused on by interviewees when considered against predicted step rises in grid electricity demand at peak times due to higher penetrations of electric heating. Interviewees also stressed the importance of innovation within the installation processes for low carbon heat technologies, including innovation to improve installation techniques, skills, education and data collection.

Conclusions

This study has identified the key innovation needs that can be considered by Scottish Enterprise when developing innovation calls. This study shows that there is a need to develop user-centred, smart and integrated solutions in order to maximise the benefits of existing low carbon heating technologies. In addition to the technological innovation needs identified, the study suggests that the implementation of effective user and public engagement approaches, along with an integrated approach to energy efficiency, are essential to delivering innovation in low carbon heat.

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Acronyms Glossary

ADE	Association for decentralised Energy
ANN	Artificial Neural Network
ASHP	Air Source Heat Pump
BEIS	Department for Business, Energy & Industrial Strategy
BRE	Building Research Establishment Limited
COP	Coefficient of Performance
DHN	District Heat Network
DSRM	Demand Side Response and Management
EfW	Energy from Waste
EHPA	European Heat Pump Association
EPSRC	Engineering and Physical Sciences Research Council
EV	Electric Vehicle
FASHION	Flexible Air Source Heat pump for Domestic Heating Decarbonisation (research project)
GDP	Gross Domestic Product
GLA	Greater London Authority
GSHP	Ground Source Heat Pump
GWP	Global Warming Potential
HP	Heat Pump
HVAC	Heating Ventilation and Cooling
IEA	International Energy Agency
IoT	Internet of Things
IRENA	International Renewable Energy Agency
LHEES	Local Heat and Energy Efficiency Strategies
NINES	Northern Isles New Energy Solutions (research project)
O&M	Operation and Maintenance
OFWF	Oil Forced Water Feed Transformer
PCM	Phase Change Materials
PV	Photovoltaic
PVT	Photovoltaic Thermal
RES	Renewable Energy Systems
STES	Sensible Thermal Energy Storage
TES	Thermal Energy Storage
WSHP	Water Source Heat Pump

Introduction

The Scottish Government has a legal requirement to achieve net-zero emissions by 2045, with an interim target of reducing emissions by 75% by 2030. At a sector level, the recent Climate Change Plan update requires a 68% reduction in emissions from Scotland's building stock by 2030, aiming to reduce demand for heat in buildings, increase energy efficiency and installations of low carbon heating systems to address climate and fuel poverty.. The Heat in Buildings Strategy published by the Scottish Government indicates that there is a need to rapidly scale up deployment of zero emissions heating systems so that by 2030 over 1 million homes and the equivalent of 50,000 non-domestic buildings are converted to zero emissions heat (Scottish Government, 2021).

To support the decarbonisation of heat agenda, Scottish Enterprise have commissioned research on low carbon heat related innovation opportunities, needs and potential barriers, considering the unique circumstances and challenges of Scotland's housing stock, fabric and energy use. This research aims to build an innovation evidence base to help Scottish Enterprise support Scottish businesses to overcome innovation challenges relating to developing low carbon heat solutions, considering the role they play in helping meet Scotland's net zero targets, as well as creating value to consumers through cost reductions and new business opportunities.

This research covers the low carbon technologies specified by Scottish Enterprise. For the purposes of this project, "low carbon heat" for residential, commercial, retail and public sector buildings incorporates:

- Heat pumps
- Smart controls and sensors/digital technologies suitable for buildings and wider energy systems;
- District heat networks
- Thermal energy storage
- Waste heat recovery
- Direct electricity (direct space heating technologies)

The following areas were out of scope for this study;

- Hydrogen
- Industrial process heat
- Energy efficiency that is not deployed alongside low carbon heat solutions
- Biofuels, biomethane, etc.

Methodology

The project consisted of desk-based research and one-to-one interviews with external stakeholders to gather data and support the validation of findings. This combined approach has enabled data gathering and the identification of potential technical, financial and societal barriers, plus gaps and weaknesses in low carbon heat innovation. The stakeholder interviews were used to identify additional data, discuss innovation needs and support the validation of the study findings. The innovation needs were analysed and reported to help Scottish Enterprise consider the merits of developing specialist support measures where appropriate. An outline of the approach is presented in Figure 1 below.

Literature review

- Conduct background research to identify and collect information about low carbon heat technologies
- Develop and maintain a spreadsheet to collate and analyse key information and findings from reviewed sources

Stakeholder engagement

- Conduct semi-structured interviews with key stakeholders to gather views on low carbon heat technologies, innovation needs, barriers and opportunities

Analysis of innovation needs

- Review the research and interview findings and identify the key innovation themes
- Re-group the findings based on the key themes and identify the key innovation needs
- Review and complete a comparative analysis of key innovation needs identified in the research and via stakeholder engagement

Figure 1 Project approach

Literature Review

In this phase, we identified and reviewed published studies, reports and literature to identify the key barriers, opportunities for the low carbon heat technologies defined in the project scope. The research investigated and collected data on innovation needs of individual low carbon heat solutions and identified the key factors impacting the scalability potential of each innovation need, such as: likely capital and O&M cost improvement potential. The research also considered the limitations / applicability of the innovation to the building stock in Scotland. The research included the review of publications such as the Low Carbon Innovation Coordination Group's Technical Innovation Needs Assessment (TINA) Heat Summary Report, ClimateXChange's recent studies on heat pumps and Scottish Energy Efficiency Programme research, and BEIS research on energy innovation needs. The full list of reviewed publications and projects can be found in the References section.

Stakeholder Engagement

In this stage, we engaged with key stakeholders to obtain additional insight on needs, barriers and challenges of low carbon heat technologies and the potential innovation opportunities, considering the key findings from initial research. At the beginning of this stage, we identified a set of stakeholders and arranged interviews with them to discuss the key issues around low carbon heat needs and barriers to support the project.

30 organisations were contacted, and 25 semi-structured interviews were progressed. One manufacturer interviewee and one large scale utility interviewee could only provide written answers to selected questions. The spread of the 27 respondents by sector / organisation group was as follows:

- 10 interviewees from manufacturers and industrial organisations
- 7 interviewees from industry/professional bodies
- 5 interviewees from large scale utility providers
- 3 interviewees from research/academic institutions
- 1 interviewee from a UK Government department
- 1 interviewee from a Certification Body

The interviews drew upon the stakeholder's expertise to examine a range of issues including:

- Technical barriers, opportunities and innovation needs of low carbon heat technologies
- Potential cost and performance impact of innovative low carbon heat solutions
- Wider market barriers and opportunities for the adoption and development of low carbon heat solutions in Scotland

Analysis of Innovation Needs

Following the review of findings from the desk-based research and stakeholder interviews, the key innovation-need areas/themes were identified (e.g. some general themes included: improved product design and configuration; development of new installation and commissioning approaches and methods; smart controls and monitoring systems; improved recyclability and lower carbon footprint; user awareness and demonstration of performance and implementing a whole-building approach, etc.).

As part of the analysis the innovation needs were summarised in a matrix (per technology) to enable a comparative analysis of each innovation need (per technology group) along with supporting commentary.

A relative assessment of the innovation needs was then undertaken, as outlined below, to understand the relative potential impact of the innovation needs.

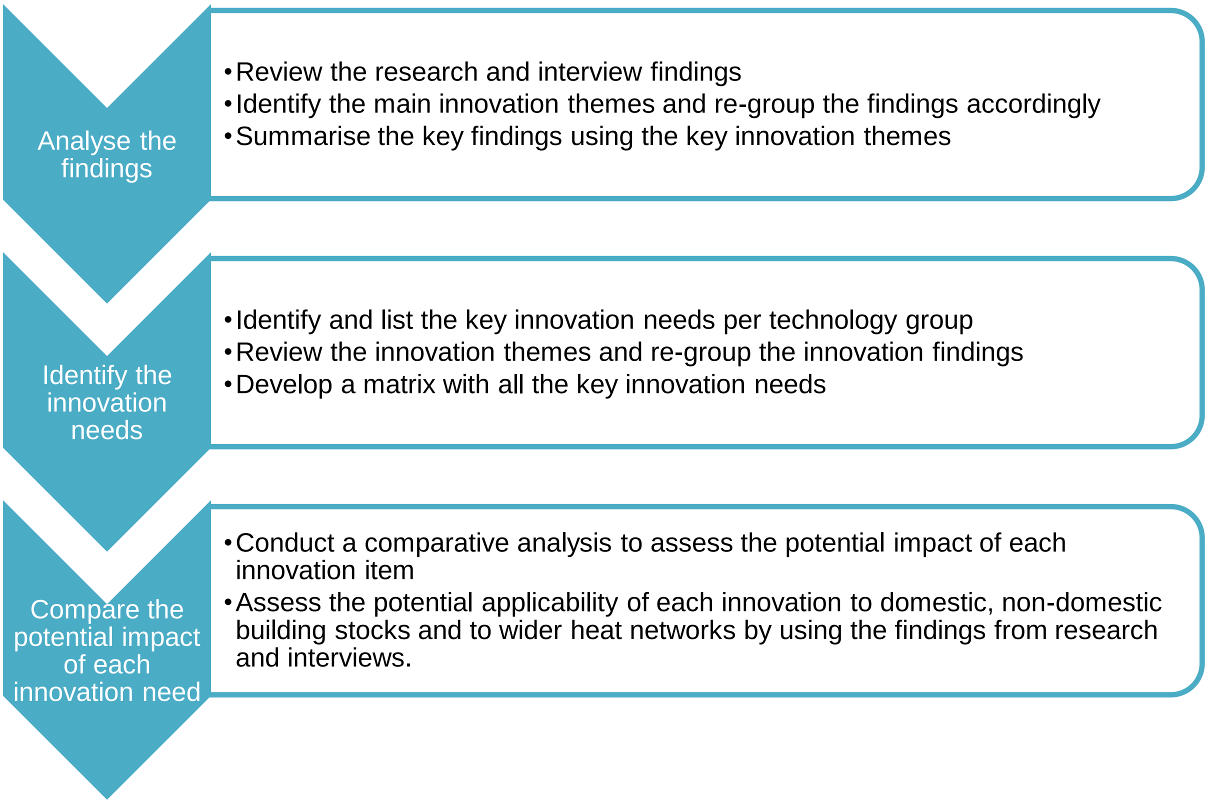

Figure 2 Outline of the analysis process

In the ‘impact’ assessment, the following measures were considered when estimating the potential impact of different innovation needs:

- **Capital cost improvement potential of each innovation need** i.e. what is the level of capital cost reduction potential that could be achieved via each innovation need, in comparison to state-of-the art technologies?
- **Performance improvement potential of each innovation need** i.e. what is the level of performance improvement potential that could be achieved via each innovation need, in comparison to state-of-the art technologies?
- **Applicability potential** i.e. how applicable is the innovation to the domestic building stock, non-domestic building stock and to heat and energy networks in Scotland?

The following scoring mechanism was applied to the assessment:

Potential Impact Level	Definition
N/A	Not applicable / no impact
Low	Low level of potential for improvement
Medium	Medium level of potential for improvement
High	High level of potential for improvement

Limitations

The following limitations were identified in this research:

- **Commercial sensitivity of information** – Due to confidentiality of commercially sensitive information, interviewees were not able to provide detailed technical information on certain innovative solutions or market opportunities.
- **Lack of quantitative modelling to verify potential impact** – Due to the time and resource constraints, this project did not include any quantitative (economic) modelling to estimate the potential impact of each innovation need. Only a simplified desk-based comparative review was undertaken, using the findings from the research and stakeholder interviews. Further research would be required to robustly quantify the potential economic impact of each innovation need.
- **Lack of evidence and information on specific technologies** – There was lack of information available on innovation needs of water source heat pumps and waste heat recovery opportunities. Further research would be required to investigate these areas.

Literature Review Findings

The key findings from the literature review are grouped below by technology and by common innovation themes.

Heat Pumps

Improved product design and configuration

Several research studies and publications suggest that there is potential to improve the coefficient of performance (COP) of heat pumps. The International Energy Agency (IEA) indicates that the typical seasonal performance factor of heat pumps has increased steadily since 2010 to nearly 4.0 today for most space heating applications, with the transition from non-inverter to inverter technologies playing an important role in improving efficiency. They highlight that inverter technologies avoid much of the energy loss that results from the stops and starts of non-inverter technologies, while also reducing the temperature lift for the compressor (IEA, 2020).

A 2019 Scottish Government report highlights that there is a need to improve coefficient of performance via appropriate design and sizing of heat pump systems (Scottish Government, 2019).

Similarly, the Energy Innovation Needs Assessment commissioned by BEIS emphasises that there is a need to:

- improve system designs (including gas sorption, new compressors, and expanders) which can reduce capital costs
- improve performance and improve product designs: including modularisation of heat pumps (e.g. “plug ‘n’ play”) and improved ancillary services (e.g. plumbing heat emitters), which make installation easier and improve customer and installer confidence
- develop products designed with improved opportunities to integrate with other technologies (e.g. heat storage, solar PV) (Vivid Economics, 2019)

A study conducted by BEIS in 2020 also highlights that there is a need for greater modularity, enhancing circularity of systems (along with greater standardization of components) in heat pump systems. BEIS also highlights that since monobloc heat pumps dominate the UK market (with a 69% of total UK market share in 2019), it could be beneficial to focus on optimising their efficiency, size and appearance (BEIS, 2020).

Refrigerants with low Global Warming Potential (GWP)

Many publications suggest that there is a need for developing low GWP refrigerants suitable for heat pumps. In the Energy Innovation Needs Assessment (Vivid Economics), it is identified that the innovation, research and development around refrigerants could present a valuable opportunity for the UK, as opposed to manufacture itself. Due to changes in EU F-gas regulations, there has been a move away from synthetic refrigerants with high global warming potential (GWP) to natural refrigerants such as carbon dioxide and propane. However, these refrigerants require higher pressures to work, which can lead to higher manufacturing costs. Currently in the UK, deployment of propane-based heat pumps in all buildings is constrained by legislation restricting the amount of compressed propane that is permitted inside buildings (Vivid Economics, 2019). According to the consultancy company WSP, single-split heat pumps typically use a hydrofluorocarbon (HFC) refrigerant (such as R410A) and contain a charge of between 1-5kg; while larger multi-split systems may have a charge up to 50kg (typically for systems over 250kW). The most common fluids used in heat pumps are HFCs which have a global warming potential (GWP) over 1,000 times that of CO_2 (R410A has a GWP which is 2,088 times that of CO_2). WSP highlight that the long-term trend in Europe is a move away from high GWP refrigerants. They also highlight that high GWP refrigerants are being limited on the market through increased regulation and there has been an increase in their cost. Although there are alternative solutions already available on the market, they need careful design and operation consideration before installation (WSP, 2018). Similarly, the International Energy Agency also highlight that there a is a need to transition to the use of refrigerants with very low or zero global warming potential (IEA, 2020).

Defrost solutions

A 2019 report which summarises the key findings from an analysis of responses to the *Energy Efficient Scotland call for evidence: the future of low carbon heat for off gas buildings* highlight that there is a need to develop frost-free air source heat pumps (Scottish Government, 2019). A recent research study (Flexible Air Source Heat pump for domestic heating decarbonisation, FASHION) led by the University of Glasgow and funded by EPSRC, has been investigating the use of alternative frost protection methods for heat pumps. On their project website, they indicate that heating capacity and coefficient of performance of heat pumps drop dramatically, when the ambient air temperature falls. They indicate that this can cause frost to build up at the surface of the outdoor unit heat exchanger when the air temperature drops to around 6^{o}C. To avoid this, they suggest that the outdoor units have to be regularly defrosted and this is something that is typically controlled automatically by a heat pump. The FASHION project aims to develop a novel flexible, multi-mode air source heat pump (ASHP) which could offer energy-free defrosting and is capable of continuous heating during frosting, thus eliminating the backup heater that is typically required by current ASHPs (Engineering and Physical Sciences Research Council, 2021).

Smart controls and monitoring systems

According to the Heat Pump Manufacturing Supply Chain Research published by BEIS, there is a growing demand for the deployment of smart control systems (particularly where hybrid systems are employed, for example in a combined boiler and heat pump system). It is indicated that heating systems are also becoming more connected, allowing installed systems to vary their output in response to occupancy and usage patterns, weather forecasting, grid carbon intensity, time-of-use tariffs, connected devices, and other factors. According to BEIS, smart controls are widely used as part of hybrid heat pumps and they represent one of the key areas of potential innovation, and the UK is at the forefront of developments in energy technology markets (BEIS, 2020). A technology innovation needs assessment conducted by Carbon Trust indicates there is a need for research and development into “smart control systems” for heat pumps that can: generate high quality data on performance, account for customer preference, optimise heat pump performance, and/or increase ease of use for building residents (Carbon Trust, 2016).

Many different studies highlight the need for developing smart controls to manage heat demand and maximise the overall efficiency of heat pumps. For example, in a recent report, the Scottish Government highlight that there is a need for wider adoption of smart controls and the use of remote monitoring to minimise maintenance costs, particularly in areas with a limited installer base (Scottish Government, 2019). Similarly, BEIS’s 2019 Energy Innovation Needs Assessment demonstrates that there is a need for the development of smart control systems that provide demand-side response and management (DSRM), allow for efficient switching for hybrid systems, to improve monitoring of heat pump performance, and reduce the perceived complexity around heat pumps among domestic end-users (Vivid Economics, 2019). The Heat Pump Manufacturing Supply Chain Research Project research report published by BEIS also recognises smart monitoring as one of the key opportunity areas for heat pumps (BEIS, 2020).

The Heat Pump Manufacturing Supply Chain Research study also found out that a number of interviewees considered hybrid heat pumps (i.e. a heat pump and a boiler combined in one single unit) and bivalent systems (i.e. a separate heat pump and boiler installed in parallel with an overarching control system) as a 'bridging technology' that could allow the benefits of heat pumps to be achieved sooner, especially in retrofit programmes (BEIS, 2020).

The Heat Pump Association recognises that Internet of Things (IoT) solutions, providing the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction, could enable the delivery of new services such as offering enhanced system monitoring, prognostics and ensuring system efficiency is maintained (Heat Pump Association, 2019).

The European Heat Pump Association also highlights that the increase of intelligent and responsive systems and approaches (IoT) has enabled more flexible and intelligent maintenance operations that can detect indicators of failure, providing the foundations for predictive maintenance solutions. In a recent report, they indicate that there is an opportunity to further investigate the use of remote monitoring and diagnostics for the implementation of predictive maintenance as part of innovation and demonstration, developing tools for extending the life of the HVAC systems and optimising the energy consumption (EHPA, 2021).

The Energy Innovation Needs Assessment highlights that domestic users often have difficulty understanding the instructions for operating and using the complex controls of their heat pump which impacts on performance and efficiency. They suggest that an improved interface could provide users with simpler controls and enable users to receive clear real-time feedback on their consumption patterns. They indicate that for commercial users, smart controls can enable the benefit of providing dynamic alerts for irregular energy consumption, predictive maintenance, tariff avoidance, and other options for more efficient use, allowing for the reduced operating costs through real-time monitoring and optimisation as well as reduced costs from breakdowns (Vivid Economics, 2019).

Additional research has highlighted innovation projects that trial different types of smart control systems. For example, the FREEDOM project developed and tested smart control technology for hybrid heat pumps. As part of this project, 75 hybrid heat pumps (incorporating thermal storage) were installed in dwellings and controlled using a predictive demand control technology to deliver set thermal comfort levels for occupants (i.e. via a heat-as-a-service provision) whilst also enabling the aggregated system to exploit demand flexibility to create new value propositions and manage peak load. The final project report indicates that their field data has shown that hybrid heating systems could provide fully flexible demand that was able to respond dynamically to network, price, carbon signals and constraints. The study showed that with good design and control, demand was proved to be fully flexible and able to respond to a broad range of energy system conditions. Also, demand could be accurately predicted and capacity constraints can be imposed at both home and aggregated levels and centrally managed. The project team suggested that "*A new energy market design is required across multiple timescales, ranging from capacity markets with a horizon of multiple years to balancing markets operating very close to real-time, in order to recognise the full system value of smart hybrid heating".* (FREEDOM Project, 2018)

Research carried out by the Climate Change Committee indicates that there are uncertainties over how hybrid technologies perform in-situ. They indicate that trials undertaken by the Energy Systems Catapult have shown that performance can be highly variable and dependent on household heating behaviours (Climate Change Committee, 2020). The European Heat Pump Association also highlights that there is a need to implement and showcase pilot sites in diverse geographical (e.g. diverse RES resources, urban/rural, etc.), climatic, economic (e.g. difference in GDP per capita adjusted for purchasing parity) and sectoral (e.g. agricultural, renovations, EVs, etc.) circumstances, proving their versatility.

Whole-building approach

The International Energy Agency highlights that beyond further improvements in the vapour-compression cycle (e.g. through next-generation components), increasing the heat pump seasonal performance factor to 4.5-5.5 by 2030 would require system-oriented solutions (to optimise whole-building energy use) (IEA, 2020). The study carried out by BEIS also highlight that there is a need for accompanying energy efficiency improvement requirements in the retrofit market (BEIS, 2020).

A key difference between heat pumps and traditional forms of heating is that they operate most efficiently at lower flow temperatures. A study carried out in London indicated that optimising performance in London buildings will often require upgrading the heat emitters (i.e. radiators) and reducing heat loss through the thermal fabric of the building. Therefore, in their study they emphasized that heat pumps require a greater focus on the holistic energy performance of the building, and that best practice design involves minimising heat losses as well as optimising supply (Carbon Trust; GLA, 2020).

Similarly, a study carried out by Energy Technology Institute and Energy System Catapult indicates that electric heat pumps can provide good comfort in existing residential building if designed and operated effectively in combination with targeted building fabric upgrades (Energy Technologies Institute, 2018). Furthermore, the Scottish Government in a 2019 report also emphasize that there is a need to use innovative systems to improve the efficiency of existing wet heating systems and to investigate the use of high temperature heat pumps able to work with existing wet space heating systems (Scottish Government, 2019).

User awareness and demonstration of performance

A BEIS report highlights that there is uncertain demand for heat pumps mainly due to low customer awareness and acceptance, demonstrating the need to improve customer awareness and deliver incentives to switch to heat pumps. They note that consumers are either not aware heat pumps exist as an alternative for heating and cooling or have insufficient incentives to switch to heat pumps as costs are currently not competitive against existing fossil fuel-based heating (BEIS, 2020).

A study was undertaken by the Carbon Trust for the Department of Energy and Climate Change (DECC) to inform their evidence base on domestic high temperature heat pump[1]. The report indicated that as high temperature heat pumps can provide the high temperature space heating outputs, and supply domestic hot water, they could help overcome the consumer inertia which favours gas boilers. However, they also note that there are additional barriers related to high temperature heat pumps compared to standard heat pumps, such as high upfront cost, and lower awareness and greater space requirements and there is a lack of trial information, so the cost benefits and performance are unproven (Carbon Trust, BEIS, 2016).

Improved recyclability and lower carbon footprint

The Heat Pump Manufacturing Supply Chain Research Project research report recognises enhanced circularity of heat pump systems (requiring greater standardization of components, smart monitoring, developed logistics/reverse logistics) as one of key innovation opportunities (BEIS, 2020). Although there is currently limited research on the circularity of heat pumps, the European Heat Pump Association (EHPA) outlines three key principles for circularity: (1) Prioritise renewable inputs, (2) Maximise product use, (3) Recover by-products and waste. In a circular economy resources are kept in use alleviating costs associated with extraction, transport and disposal, associated with linear design. Once their lifetime is over, materials are recovered, recycled and reused. EHPA indicates that there is a need to showcase HPs ability to recover and re-use waste heat for heating and cooling and to deliver innovation in developing modular heat pump designs with easily replicable and upgradable modules/sub-systems,

[1] high temperature heat pumps are considered to be products capable of producing an output temperature of at least 65°C

allowing for easy re-use and servicing. EHPA adds that there are opportunities to deliver innovation in the development of tools and strategies for the proper recycling and disposal of HP units and other HVAC systems beyond refrigerants (EHPA, 2021).

Improved installation and commissioning approaches and methods

An Energy Innovation Needs Assessment study indicated that technical solutions to make drilling easier are considered the most important innovation for reducing costs and addressing other barriers to the deployment of GSHPs that include a vertical ground loop. The report states that incorporating ground-loops directly into foundations for new builds is another key opportunity that requires consideration (Vivid Economics, 2019). For instance, the GEOTECH project (EC-funded R&D) investigated a different drilling concept that is based on dry auger methods that requires less capital-intensive equipment, enhances safety and avoids the environmental risks, complexity and costs of dealing with water supplies and contaminated waste. In their project brief, they highlight that drilling operations often require significant quantities of drinking quality water and dispose of dirty water and mud. By developing a different drilling concept, they aim to overcome these challenges (European Commission, 2015).

District Heat Networks

BEIS's Clean Growth Strategy indicated that in 2018 around 91% of heat networks are powered by gas. However, they envisage that more low-carbon fuel sources, like heat pumps and waste heat recovery, will be developed in the future and are seeking to encourage this through the design of the Heat Networks Investment Project and the future market framework for heat networks (BEIS, 2018). The Technology Innovation Needs Assessment carried out in 2016 highlights that innovation in installation, design, and the heat interface unit offer the bulk of the potential for district heat networks. The report indicates that innovation (learning-by-R&D) and process improvements (learning-by-doing) have the potential to drive down deployment costs by up to 16% by 2050 (Carbon Trust, BEIS, 2016).

Improved product design and configuration

Many different studies highlight the need to develop new approaches and design solutions to improve the overall efficiency of district heating systems. The Energy Innovation Needs Assessment conducted by Vivid Economics in 2019 highlights that there is a need to design low-temperature heat networks that allow the wider integration of energy sources (such as waste heat and large-scale heat pumps), as well as thermal storage, and to adopt low-temperature tertiary systems to facilitate the adoption of low temperature heat networks, combined with research on operating these effectively (e.g. meeting domestic hot water demand at the lowest temperature possible without the risk of introducing Legionella).

The Energy Technologies Institute emphasizes that there is a need to improve front end design, to develop tools to help increase accuracy of heat demand estimates and maximise difference between temperatures entering and leaving the buildings, to replace indirect with direct heat interface units and make use of existing hot water tanks. They also emphasise that there is a need to innovate to reduce the cost of heat interface units for retrofit schemes (Energy Technologies Institute, 2018).

Similarly, a study conducted by Element Energy in 2015 on behalf of Committee on Climate Change also indicates that there is potential for improved cost and performance of district heating infrastructure in UK networks by reducing oversizing, reducing network flow and return temperatures, and/or reducing network thermal losses (Element Energy, 2015).

<u>Adoption of waste heat and renewable sources in DHN</u>

The Technology Innovation Needs Assessment carried out in 2016 also indicate that waste heat recovery, and the integration of heat pumps and novel renewable sources can offer further system cost reduction opportunities (Carbon Trust, 2016). A 2019 research study emphasizes that district heating can only be deployed successfully when the consumer prices are competitive with alternative heating costs. To achieve this, they suggest that DHN operators can lower distribution costs with the use of co-generation, waste incineration, waste industrial heat, geothermal, biomass or a mix of options. Additionally, by deploying demand side management systems and closely matching supply and demand, the efficiency of the network can be increased, leading to lower operating temperatures and lower distribution and transmission costs. An academic study suggests that Artificial Neural Network (ANN) models, a method of short-term thermal load prediction, could be potentially used to adjust temperature and flow in a distribution system to match a known thermal demand. However, for ANN forecasting to be successfully deployed, a large amount of data would be required, which can be challenging for heat network operators. The research suggests that it is essential to improve the efficiency, and therefore lower the cost of district heating networks in the United Kingdom. This can range from simplistic tank storage to more complex phase change materials and load prediction (Michael-Allan Millar, 2019).

Smart controls and monitoring systems

According to the Technology Innovation Needs Assessment carried out in 2016, there are opportunities for technology innovation through R&D impact with the shift to 3rd and 4th generation heat networks, implementing a systems perspective to technology adoption, and smart and intra-system communication technologies and strategies. It is indicated that design, controls, interface and streamlined installation could provide the greatest cost reduction opportunities for district heat (Carbon Trust, 2016). In the Energy Innovation Needs Assessment, Vivid Economics identified that there is a need for design optimisation through extensive data collection and dissemination exercises on priority issues. For example, more granular heat demand profiling across the UK can enable design efficiencies relating to both network size and location. The study also mentioned that there is a need for innovations that can improve the metering interface and allow heat customers to monitor and engage with their energy consumption in ways that increase efficiency and save costs (Vivid Economics, 2019).

The Energy Institute also draws attention to the need for improving user experience and knowledge sharing in the industry. In a recent publication, they indicate that there is a need to establish a district heating knowledge centre to share learnings and increase the impact of all other innovations (Energy Technologies Institute, 2018)

Development of new installation and commissioning methods and technologies

The Association for Decentralised Energy (ADE) indicates that for new buildings, if opportunities can be identified early enough, the capital costs of installing the heat network pipes in the ground can be reduced by sharing the civil engineering costs with other infrastructure. If new homes can achieve high efficiency standards, they can connect to fourth generation heat networks that operate at lower temperatures and can use low grade waste heat sources (The Association for Decentralised Energy (ADE), 2018).

A study conducted by Energy Technologies Institute outlines the key opportunities and barriers for district heat networks in the UK. The report highlights that district heating has the potential to play a much larger role in the UK energy system, whilst high capital costs is the most significant barrier preventing the wider deployment of networks. To reduce the capital cost of heat networks, the study emphasizes the need to develop design solutions that could reduce the costs of civil engineering, such as, by running heat distribution pipes along the buildings themselves (i.e. above ground), or by developing trenchless technologies that allow for drilling of heat distribution pipe tunnels underneath the surface, and therefore, removing the need for expensive trenching. These key products require development to make them more cost effective, and to deliver solutions that could enable the sharing of civil engineering costs between utilities working in the same region (Energy Technologies Institute, 2018).

Improved business models

The heat networks policy paper published by BEIS indicates that there is a need to see innovation in financing, with debt and equity instruments available from a diverse range of investors. BEIS anticipates more debt instruments from banks, and equity instruments from domestic and international infrastructure investors and pension funds, as well as ongoing investment from project sponsors and energy services companies. They note that they are also interested in the role that lease financing and crowdfunding might play in the district heat sector. A BEIS policy paper highlights that to increase investment opportunities for district heat projects and to lower the cost of capital, the risk profile of heat networks and the level of return should be reduced by implementing a series of policy change (BEIS, 2018).

Thermal Energy Storage

Improved materials, product design and configuration

Use of Phase Changing Materials (PCMs) in thermal energy storage

Several publications and studies identify the need to develop new thermal energy storage solutions using PCMs. For instance, an Energy Innovation Assessment indicates that PCM based energy storage solutions are between 5 to 10 years away from mass commercialisation in the UK. They recognise that there is a need to develop thermal time shifting and intraday storage solutions using PCMs and also to develop new chemicals, materials, and designs for high energy density PCMs in district heating to reduce space and save on installation and O&M costs (compared to alternative water tank options). The study also indicates that the use of PCM-based solutions could be explored to develop cold storage to address infrequent hot weather events through re-usable technologies (Vivid Economics, 2019).

The Innovation Outlook report published by the International Renewable Energy Agency (IRENA) suggests that in the short term (5 years), there will be opportunities for the development and trial of PCM thermal batteries combined with energy management systems, and to demonstrate how such batteries can use off-peak power to decarbonise heat and save consumers money. They indicate that in the medium term (5-10 years), there will be opportunities for the development in materials to improve thermal properties and corrosion resistance in Tank Thermal Energy Storage and solid-state thermal energy storage (TES) technologies that could improve efficiency. They also note that enhanced innovations in integration and control systems can improve cost-effectiveness (IRENA, 2020).

Another study recognises that there is an opportunity to use heat pumps with heat storage products using phase-change materials in order to reduce the footprint of thermal storage technologies in homes (DELTA Energy and Environment, 2019). On the other hand, a research study commissioned by ClimateXChange highlights that the price of some energy storage technologies is too high to support effective business models for deployment. It is noted that increasing cyclability (which measures how often a material can charge/discharge energy) is an important issue to address, especially for PCMs which undergo structural changes as they absorb or release heat. (Radcliffe & Li, 2015).

An Energy Systems Catapult study reviewed a range of existing and innovative TES technologies and investigated policy and regulatory barriers to TES alongside district heat networks. One of the key findings of their study is that centrally located TES can provide value to DHNs by helping to reduce the size / capacity of heat generators, potentially overcoming key barriers. For a centrally based store within a high temperature heat network, sensible heat thermal energy storage (STES[2]) was considered to be a cost-effective solution. However, the report stated that *"at small capacities, the cost difference between STES and latent heat thermal energy storage was small and if space is a premium and/or land value is high, then the higher energy density of phase change material-based storage technologies could make them cost-competitive and/or preferable to STES".* The report suggests to conduct more research on improved cross-vector integration of heat and power systems and to exploit the link between district heating and the grid offered by certain large-scale technologies e.g. cogeneration of electricity and heat, power- to- heat production (Energy Systems Catapult, 2020).

<u>Thermochemical storage solutions</u>

BEIS's 2016 Technology Innovation Needs Assessment report highlighted that for latent and thermo-chemical heat storage, and also inter-seasonal heat storage, there is significant potential for innovation, as innovation in heat extraction technologies and installation processes have the potential to reduce costs (Carbon Trust, 2016). The 2019 Energy Innovation Assessment indicated that tank storage is not likely to see significant cost changes as this is a relatively mature and well-established technology. The study indicates that thermochemical storage (and PCM based storage), is between 5 to 10 years away from mass commercialisation in the UK. They indicate that there is a need to develop thermochemical heat storage solutions, where reversible chemical reactions are used to store large quantities of heat in a compact volume for medium and long-term/seasonal storage (Vivid Economics, 2019). The same study also emphasizes that for thermochemical heat storage to become economically feasible, several innovations are needed. The study indicates that the reactor design needs to reach high output temperatures for a sufficiently long time period, and there is a need to improve materials so that higher storage density can be achieved at a lower price. The study highlights that the humidification process of thermochemical heat storage also requires improvements to achieve greater system efficiency (Vivid Economics, 2019).

An Innovation Outlook report published by the International Renewable Energy Agency (IRENA) outlines the key innovation potential of thermal energy solutions in buildings (IRENA, 2020) in the long term (>10 years), and that R&D activities focusing on realising material and system improvements in thermochemical TES technologies could see them move into demonstration. The following figures show the current stage of thermal storage technologies and the potential efficiency and cost improvement that could be expected by 2030 (IRENA, 2021).

[2] In Energy Systems Catapult's study, sensible thermal energy storage covers the following technologies: electric storage heaters, tank thermal energy storage, pit thermal energy storage, aquifer thermal energy storage, borehole thermal storage, high temperature sensible thermal storage.

Figure 3 Thermal energy storage 'district heating and cooling' applications status and outlook (Source IRENA 2021)

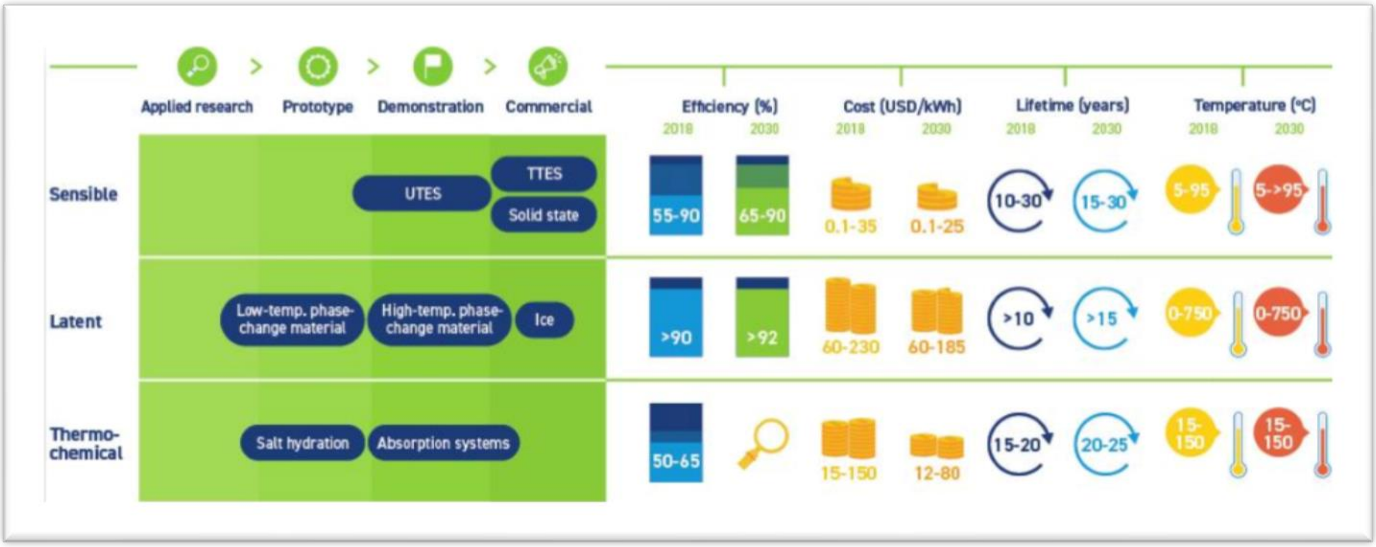

Figure 4 Thermal energy storage 'buildings' applications status and outlook (Source IRENA 2021)

<u>Electric heaters and thermal storage</u>

According to a consultation paper published by the Scottish Government, electricity is the primary heating fuel of 12% of Scottish households and in 2017, 52% of those using electric heating systems (and 40% of those using oil) were in fuel poverty, compared to 19% of households connected to the gas network. Direct or resistive heaters, electric panel heaters and infrared heaters can all be used to provide space heating but these solutions typically use relatively high cost on-peak electricity and thus can be expensive to run if they are the only heat source in a property (Scottish Government, 2019). In the same study, it is indicated that storage heaters can act to partly decouple energy demand from energy supply and provide an opportunity to manage utilisation of energy as part of a 'smart' electricity system, acting as a means of lessening demand at peak times (Scottish Government, 2019). For instance, the NINES research pilot project (led by Scottish and Southern Energy Networks) designed, developed and tested the performance of a domestic demand side management system in the form of energy storage heaters and immersion water cylinders in circa 734 homes in Shetland. The trial project also included the installation and testing of a 4MW electrical boiler for non-domestic demand side management system which was linked to a thermal storage system (Scottish & Southern Energy Networks, 2021).

Waste Heat

The study found that there is currently only limited information available on specific innovation needs of waste heat recovery processes and solutions. However, there are a number of research studies and publications that show that there is opportunity to capture and utilise waste heat occurring at industrial processes, commercial buildings, waste treatment plants, etc. For instance, recent BRE's research for ClimateXChange on waste heat opportunities identified a waste heat potential of circa 1,677 GWh across some 932 sites in Scotland. This study concluded that the largest waste heat potential was estimated to be in the distillery and waste-water treatment sectors (among the studied sectors). Bakeries and paper and pulp are the other sectors with high waste heat potential due to their relatively large energy consumption (Sinclair & Unkaya, 2020). A 2015 study highlights that industrial processes often result in significant amounts of waste heat:

- A number of energy-intensive industries provide potential for recoverable heat: refineries, iron & steel, ceramics, glass, cement, chemicals, food & drink, paper & pulp.
- Research exploring the largest UK sites in the EU ETS identified the recoverable potential as around 30 TWh/year (resource based on analysis of the top 72 sites)
- Some of this could be available at low cost. For example, around 4TWh/year of recovered heat can be made available for DH at less than £30/MWh, then a further 24 TWh/yr would be available at around £90 /MWh.

Similarly, a study conducted by AECOM demonstrates that around 2.5 megawatts per kilometre square (MW/km2) could be obtained on average using open-loop ground source heat systems in the mined areas of Scotland which is estimated to equate to circa 12 GW of capacity. AECOM consider this to be an approximate estimate of the maximum potentially accessible resource, i.e. how much heat energy could theoretically be extracted from all the mined areas of the Midland Valley of Scotland, bearing in mind the geological constraints on how much water can in practice be abstracted. The study indicates that mine waters could theoretically provide the equivalent of approximately one third of Scotland's heat demand. However, the actual contribution is likely to be significantly less for three main reasons (AECOM, 2013):

- Heat cannot be transported efficiently over large distances, so would only be used above or close to suitable mine workings (although many towns and villages in Scotland's Midland Valley lie directly above mine workings, reflecting their historic roots)
- A proportion of mine workings will not be suited to heat extraction
- Heat delivered by GSHP is most effectively used in new-build properties; existing building stock would likely require extensive upgrading to benefit from mine water heat

Related to this, BEIS highlight in their recent report that the Coal Authority is exploring using heat pumps for domestic heating using disused mine shafts in the UK and the report highlights a project that aims to build a new 1,500 home garden village at Seaham, County Durham directly adjacent to a disused mine, where heat derived from this mine is expected to provide heat to the entire village (BEIS, 2020)

Studies have also suggested that electricity substations could also be potential sources of waste heat, as significant amount of heat is rejected to the environment. A study carried out by Imperial College London and Sohn Associates highlight that the amount of waste heat that can be captured from electricity substations varies depending on the cooling system type and Oil Forced Water Forced (OFWF) transformers typically offer the greatest opportunity for heat recovery (Imperial College London and Sohn Associates (2014).

Interview Findings

Twenty seven respondents across the different low carbon heat sector groups commented that greater growth in the role out of low carbon heating solutions could be achieved through various educational, fiscal, and policy-based mechanisms compared to innovation alone (with many commenting that costs reductions from technical improvements alone would be incremental by comparison). As one academic interviewee summarised in their interview:

> *"You cannot solve this problem with just technology alone. You need a holistic approach looking at financial and social aspects as well. For example, a serious educational campaign is needed to train the work force for installing and maintaining heat pump technologies."*

The majority of interviewees across all sectors also suggested there was a need for;

- Support in scaling up of Scottish based supply chains and manufacturing of low carbon heating installations in order to create market scale impacts on costs and benefit jobs and skills creation in Scotland.
- The low carbon heating tech roll out to be preceded by building fabric upgrades wherever possible in order to reduce peaks in heating demand and reduce the size of low carbon heating installations required and maximise the efficiency of low carbon heating systems.

Air Source Heat Pumps

Seventeen of the interviewees chose to focus on Air Source Heat Pump (ASHP) based innovation needs, as they thought that ASHPs would make up the majority of low carbon heating installations going forward due to the ease of installation and lower costs by comparison to other low carbon heating technologies.

Innovation needs

Improved design and configuration

Interviewees suggested that there are innovation opportunities to develop smarter, easier to install, and more modular heat pumps that could be a better fit for the thermal performance of Scottish building stock, and a better match with existing heat distribution systems.

- Nine interviewees said that larger scale local manufacture of ASHPs was required to help bring down their costs via economics of scale. Many of these interviewees called for innovations to adapt ASHPs to better fit Scottish building stock (buildings with low air tightness and high temperature heat distribution systems). Two interviewees said that there was a need to design ASHPs that would work better under Scottish climatic conditions (greater humidity compared to continental Europe), and would work better in conjunction with higher temperature heating distribution systems used in Scottish homes.

- Eight interviewees said that heat pump costs could be reduced, and the ease of their installation could be improved with increased offsite manufacture of modular systems, with greater use of modular designs that are smaller, smarter, and with a greater emphasis on adaptable plug and play systems that can better match up with existing heat distribution systems.

- Three interviewees across the academic, government and supplier / service provider sectors raised concerns over the issue of managing electricity grid demand with the increased use of ASHPs and other electrified heating options.

- Three interviewees across the academic, government and supplier/manufacturer sectors said that the continuing removal of hot water cylinders with the roll out of combi boilers (that provide instantaneous hot water on demand) could be a problem as ASHPs can work better with thermal storage. A need for innovation that consider the re-purposing of existing hot water cylinders along with heat pumps was emphasized.

Improved Coefficient of Performance (COP)

Interviewees thought that ASHPs are a mature technology and very likely that only incremental cost reductions can be achieved through purely technological innovation of the ASHPs alone. They proposed that ASHPs should be smarter with automated control systems that are linked with local waste heat sources and onsite renewable energy generation.

- The majority of interviewees from industry bodies and academic sectors said that because ASHPs are now a mature technology with large numbers installed globally each year, it was very likely that only smaller incremental improvements in their overall costs through technological innovation alone could be achieved. It was mentioned that, in particular, improved condensers and micro-exchangers could potentially lead to 1-2% cost decreases over 5-10 year timescales.

- Eight of the interviewees commented that the COP of ASHPs could be improved with smarter, automated operational systems incorporated into them. These systems could have sensors to evaluate outside temperatures to understand the best times of day to harvest heat, along with indoor sensors to understand the best times of day to heat a building based on user occupancy and internal air temperatures – however this would require system to have thermal storage to enable operation in this way. This would allow ASHPs to run automatically without the need for extensive user input, reducing the risk for poor system control. Interviewees also pointed to grid balancing benefits of innovation in this area.

- Five industry bodies and one academic interviewee commented that there is a need to implement a more integral and innovative approach to heat pump design and installation. It was mentioned that building upgrades (retrofit of existing building fabric) to improve heat pump efficiency would require time and financial support.

- Two interviewees suggested that the increased use of instantaneous waste-water or sewage pipe heat recovery in buildings with heat storage could be linked to ASHPs to improve their efficiency. On a similar note, two other interviewees suggested combining ASHP systems with photovoltaic thermal panels (PVT) to increase system efficiency (PVT generates electricity for the ASHP, while the ASHP in turn provides cooling to the PVT panels increasing its efficiency).

Refrigerants with low GWP

Interviewees commented that the use of alternative low GWP and natural refrigerants in ASHPs should be increased, however the refrigerant leakage was not seen as a major problem for domestic applications.

- Eleven of the interviewees mentioned that there was a shift in ASHP development to favour using alternative refrigerants. These refrigerants included hydrocarbon-based types (R32, R135, R290) that could run at higher temperatures. Most of these interviewees pointed out that fire safety and toxicity issues would need to be overcome before these can be regularly used in ASHPs.

- Five interviewees commented that there was growing interest in the use of natural refrigerants such as ammonia and carbon dioxide with lower Global Warming Potential (GWP) compared to synthetic refrigerants. One academic also noted there was research into the use of smaller qualities of refrigerant in ASHP systems to reduce the environmental impact of system leaks. However, it was mentioned that the overall cost reduction on systems was likely to be marginal.

- Four supplier / manufacturer interviewees commented that refrigerant leakage was not seen as a big issue in domestic systems and that was more important concern for larger commercial systems as they use larger quantities of refrigerant.
- Two interviewees noted that factory sealed mono-block type ASHP systems could have less leakage risk compared to split systems, where the leakage risk could be more challenging to manage.

Defrost solutions

Interviewees suggested that innovations to reduce frost built up on external parts of an ASHP would help to reduce the energy requirement for defrosting and lead to more efficient ASHPs.

- Two interviewees mentioned that smart coatings on ASHP coils could be used to prevent frost build up on them.
- One academic interviewee mentioned that up to 10-15% of the total annual energy use of a ASHP could be consumed on defrosting the devices. Therefore, innovations around improving defrost cycles could potentially increase operational efficiency.

Improved recyclability and lower carbon footprint

Increased local manufacture of ASHPs in Scotland was suggested by interviewees as a way of reducing their embodied carbon.

- Four interviewees called for an increase in local manufacture of components in Scotland as there was a reliance on international supply chains. This could in turn reduce the emissions associated with supply chain (i.e. manufacturing, transport, etc). One industry body interviewee commented that recent logistics / supply chain and raw material supply issues might lead to an increase in the cost of parts for ASHPs within the next ten years and innovation would be required to combat these rising costs.
- Three interviewees mentioned that there would be a future need to consider better recycling facilities for ASHPs.
- One supplier / manufacturer suggested that there could be potential innovations to improve the lifecycle of heat pumps (i.e. the use of better weather-proof materials for those parts of the system that need to be outside).

Development of new installation and commissioning methods and approaches

Interviewees suggested that innovation was needed to make ASHPs more like plug and play modules that are simpler to install. Suggested innovations around the roll out of ASHPs included smarter home surveys before installations, large scale ASHP installations in focused residential areas, and more innovative ways of training/upskilling existing gas installers.

- The majority of interviewees suggested there was potential for innovation in the ASHP installation process to make it simpler, perhaps by creating plug and play modules, because with the large number of installers requiring rapid re-skilling in low carbon heating system installation.
- Four interviewees said that larger scale coordinated roll-outs of modular ASHP installations (e.g. for groups of similar architype homes in focused local areas) could lead to cost reductions for the labour installing them. Some interviewees commented that up to two thirds of the cost of a ASHP

was due to the installation time, therefore with a large-scale role out in a focused area the associated installation costs would be reduced.

- Two interviewees stated that innovation would be required to make the design and installation process easier for ASHP systems, making it more straightforward for installers to know what system to install in each situation and reducing the designing/sizing effort required. In this way, the installed efficiency of systems could be maximised.
- Two supplier manufacturer interviewees and one industry body interviewee said there was an opportunity to make pre-installation home surveys easier, with the use of newer technologies such as room scanning and remote surveys of homes. Similarly, one industry body interviewee suggested that residents should be able to scan their homes and survey them so that installers could remotely survey a home ahead of an ASHP installation and reduce the number of times a visit is required (especially for rural areas).
- One supplier / manufacturer interviewee and an industry body interviewee both discussed the challenges and opportunities to upskill huge numbers of gas boiler engineers and move them away from fossil fuel based heating systems to heat pumps. Interviewees also mentioned that most small and medium enterprises (installers) would find it too expensive and impactful to have their gas boiler installers retrained and potentially away from their fee-earning role during that time. They therefore, suggested that training provided should be innovative and more flexible.

User awareness and demonstration of performance

Interviewees believed that the majority of consumers are not aware of ASHP systems and their potential benefits. They suggested that innovation is needed to better monitor ASHPs remotely, and support consumers in a smarter way to use ASHPs in the most efficient way.

- Most interviewees commented that consumers were not aware of ASHP technology and its potential benefits. Many suggested that an educational campaign would be required to address this and increase public awareness.
- Five interviewees said that there was a need to develop and adopt better monitoring systems and user training for households to understand heat pump systems. This could in turn improve user experience and system performance. Suggestions included:
    - Developing easy user guides to explain how ASHPs work;
    - Adoption of automatic systems to avoid too much system interruption by householders, and;
    - regular checks by installers to guide consumers to make better use of their systems
- Most interviewees noted that noise was not generally a problem with current heat pump designs, but some interviewees noted that if homes were better insulated, they would require smaller size heat pumps which are potentially less noisy.
- One supplier / manufacturer stated that innovation was needed to connect better datasets of existing building stock with installers as this data was highly important to determine which buildings would be suitable for different types of heat pump solutions.

Improved business models

The ‘heat as a service’ model was a popular business model that interviewees suggested could help increase ASHP installation numbers, as in their opinion this could create demand for ASHPs that function better for longer. They also commented that support funding could be helpful to establish better business models.

- Seven interviewees commented that 'heat-as-a-service' business models (where a company owns, installs, operates, and maintains heat pumps whilst providing an agreed level of heating service to a customer) typically leads to better quality design and installations (as the heat-as-a-service provider can directly benefit from improved performance). Some commented that it can also create demand for the development of ASHPs that require less maintenance, and some also suggested that as long as such companies could provide a good service for households, residents tended to be less likely to change control settings in an unhelpful manner. Contrasting views were however also expressed by a couple of interviewees suggesting that a downside to third party asset ownership is that it would make it harder for people to quickly change energy supplier, potentially leading them to become trapped with potentially higher energy prices.
- A number of interviewees said that new business model approaches would require innovation support funding to help test and build them in order to support the growth of the ASHP market.
- A number of interviewees commented that in the social housing sector, arrangements could be made for third party ownership of ASHP assets with a performance guarantee, involving financial lenders (pension funds for long term investment) which would help to unlock funds with the certainty of customer payments over the long term.
- Other business model ideas included;
    - Loans for households to help pay off the high upfront capital cost and pay off over time with low interest (NB: this is already in place via Scottish Government's 'Home Energy Scotland Loan' scheme)
    - A heat pump rental scheme, similar to the schemes for renting out roof space for PV installations.
    - Heat pumps becoming part of the mortgage on a new home, ensuring long term low interest loans.

Ground Source Heat Pumps

Only one of the interviewees (a supplier / manufacturer) chose to discuss GSHP based innovation needs, although four other interviewees mentioned aspects of GSHP's while discussing ASHPs. The majority of interviewees pointed out that the high capital costs, potential disruption from ground works and significant efforts required for design and installation of GSHP systems were the key barriers to their installation.

Improved design and configuration

Interviewees suggested innovation was needed to develop more communal GSHP systems which could help reduce costs per GSHP installation and develop better inter-seasonal storage capabilities for GSHPs.

- The supplier / manufacturer interviewee discussed opportunities around installing community based GSHP systems (the potential for opportunities in this application area was also supported by other interviewees). which could provide a heat pump based heat network that households could 'plug into' for low carbon heat. Overall, this would require less civil engineering works, fewer boreholes, and give residents the choice of being able to connect to a low carbon heat network.
- Multiple interviewees commented that GSHP's could offer the following benefits compared to ASHPs including;

- They generally, maintain a high COP due to more stable temperature conditions underground.
- They have the potential to provide longer term seasonal storage of heat, if GSHP's are run in reverse to pump heat underground in the summer recharging ground heat reservoirs for use in the winter months. But interviewees suggested that more research was required to develop this area.

Improved business models

- A supplier / manufacturer interviewee said that for two properties on a street, it would be cheaper to drill one 200m deep borehole, compared to the cost for two separate 100m deep boreholes, and that this could potentially reduce installation costs by 25%. If systems were installed on a street-by-street basis this would also create economies of scale and cost savings.
- The supplier / manufacturer interviewee also discussed the potential opportunity for a split ownership model for a communal ground source loop array where homeowners would then be able to get an installer to simply plug into the established ground loop infrastructure hopefully at a cheaper cost.

Other

- One industry body interviewee commented that innovation would be needed to create better data around the sources of heat and green spaces for the scaling up of communal GSHP installations.

Water Source Heat Pumps

None of the interviewees from across all the sectors chose to focus on water source heat pump (WSHP) based innovation needs, although three of the interviewees touched upon the aspects of WSHPs while discussing ASHPs. One supplier / manufacturer called for greater use of WSHPs in larger urban areas with canals / rivers and a dense population creating higher heating demand. One certification body interviewee suggested that there could be significant opportunities for using WSHPs in Scotland due to the number of lakes, rivers, canals, and old mine water locations across Scotland. However, no specific innovation needs were identified.

Smart Controls

Five of the interviewees offered insight around smart heating controls innovation needs, although many of the other interviewees talked about the aspects of smart heating controls while discussing other areas of focus.

Innovation needs

The majority of interviewees suggested that innovation would be needed to overcome the lack of an open data protocol, which meant different technologies could not communicate with each other. Many interviewees also suggested that there was a strong case for innovation to increase the installation of smart heating controls as part of building retrofits, with low carbon heating technologies. Interviews also suggested that innovation could lead to greater data collection and allow for better customer engagement and aggregated systems in 'virtual power plant' systems to help with grid balancing.

Improved product design and configuration

All the interviewees had positive attitudes regarding potential for increasing the inclusion of smart heating controls with low carbon heating systems, with comments including that they could:

- Be relatively cost effective and easy to install compared to the other low carbon heating systems

- Allow for the development of demand side services with financial incentives for homeowners to use energy at non-peak times
- Enable real time monitoring for pre-emptive maintenance of low carbon heating systems
- Work alongside hybrid systems, buffer storage, electric vehicles & community waste heat sources for even greater flexibility in the generation and consumption of low carbon heat and
- Help to engage customers on when the best time is to use energy and help to educate consumers on how to get the best value from time of use tariffs through smarter controls.

- Some interviewees discussed the innovation opportunities for smart heating controls to collect more data to better match different low carbon heating systems with typologies of properties and consumers over time. However, it was stressed by some of the interviewees that this would have to be done in a way that protected consumer data properly.
- Many interviewees across the sectors said that the trend for removal of hot water cylinders / storage due to increased use of combi boilers (which provide instantaneous hot water) could be a problem as hot water storage could support flexible smart heat pump systems by providing potentially for demand side response and / or enabling use during cheaper electricity tariff periods.
- Some interviewees commented that larger scale smart heating control installations could create the right conditions for the creation of virtual power plants connecting the generation capacity of multiple buildings in an area to provide grid balancing services and generate financial benefits for consumers.
- Two interviewees highlighted that hydrogen fuel-based heating systems could be used alongside heat pumps as a backup or in buildings where fabric upgrades would be harder to achieve.
- Two interviewees commented that smart controls could allow customers to gain financial rewards from consuming and generating energy at the right times in order to maximise revenues and minimise the consumer costs of electrified low carbon heat.
- Two interviewees said that smart controls could be built into heating products directly.

User awareness and demonstration of performance

The general opinion among interviewees was that there is broad consumer acceptance of smart heating controls, but they suggested that innovation was required to make such controls more user friendly for less technologically savvy consumers and to allow for greater user engagement to improve experiences.

- In general, interviewees indicated there was broad acceptance and engagement with smart heating controls from consumers, however some interviewees suggested that there would likely be more resistance to them from certain users (e.g. older consumers who may be less tech savvy) who might find them too complex. Therefore, innovation efforts around developing user-friendly equipment and improving handover processes after installation to explain systems to users would be needed.
- Interviewees mentioned that there is a general misunderstanding among consumers over what smart heating controls are, as consumers consider their smart meters to be smart heating controls, whereas smart heating controls can help manage heating systems with minimal human interventions, can help make best use of flexible tariffs, etc.
- A utility interviewee discussed that there was a need for smart heating controls to allow for greater customer engagement and the setup of thresholds for personalisation of heating preferences, which would balance customer comfort requirements against automatically

generating heat at times of cheaper energy rates. Interviewees thought that the best times for automated ASHP operation might seem strange to homeowners and therefore efforts would be required to ensure there is enough education/guidance to allow consumers to understand the benefits of automation including more efficient operation and access to cheaper energy tariffs.

- One interviewee suggested there could be innovation potential for creating more smart heating control system applications with voice controls, predictive performance monitoring, and systems that provide relevant suggestions to consumers with tips on how to reduce usage and costs.

Improved business models

Interviewees were generally of the opinion that innovation was required in smart heating controls to maximise the benefits of using cheap tariffs (e.g. time of use tariffs) and to help open up the heat as a service model with monitoring data being key for the third party owners to manage their low carbon heating systems. A utility interviewee also suggested that innovation in smart heating controls could open new opportunities for closer engagement with consumers and tailored energy supply packages.

- Many of the interviewees suggested that the heat as service model is opened up by better use of smart heating controls and data monitoring. Some interviewees discussed the creation of energy communities that could provide resilience to the energy network. However, one interviewee pointed out that the heat as a service model might not work well on a house-by-house basis as all properties are different and have different user times. Therefore, the concept might work better in larger blocks of flats with more consistent energy demand profiles.
- Some interviewees spoke of the need for innovation to allow for smart heating controls to provide closer engagement between suppliers and customers.
- Interviewees also highlighted that smart heating controls could allow them to provide tiered energy supply packages to consumers for increased cooperation with suppliers (through behavioural changes and using less energy during peak periods) with opportunities for reducing running costs for consumers.

District Heat Networks

Three interviewees focussed on DHN based innovation needs, although two other interviewees also discussed aspects of innovation in DHNs while discussing other areas of focus. The majority of interviewees who discussed DHNs all said that current DHN technologies are mature and has been deployed at scale in many other parts of the world.

Innovation needs

Interviewees suggested that innovation was required for DHN technology to allow for better integration of existing DHN networks, the establishment of more microscale DHNs at new build sites, greater use of waste heat sources, more standardisation of DHN parts, and for lower temperature DHNs to be able to supply heating to older thermally poor buildings.

Improved design and configuration

- Multiple interviewees across different sectors commented that innovation to reduce DHN costs will largely depend upon the establishment of better supply chains, as long-term confidence in DHN implementation needs to be increased. Interviewees added that there needs to be a visible pipeline in DHN projects, which would lead to increased investment in the manufacturer of DHN parts in Scotland, with more localised production and less reliance on imports. An interviewee added that there are lessons to learn from how the UK offshore wind industry has created a local manufacturing base in the UK.

- Multiple interviewees said there were opportunities for:
    - Better cooperation between established DHN's and their neighbours
    - Better integration of networks / shared energy networks to provide cooling demands as well (5G networks), that also create greater efficiencies for the network, and
    - The roll out of micro DHN at new build sites, as these are much cheaper to install compared to retrofitting them at existing sites
- One interviewee commented that there were opportunities for smaller scale, lower temp heat pump based DHNs in blocks of flats. These networks could benefit from a lower temperature (below 65ºC) distribution system which in their view was an optimum temperature between keeping the costs of the systems as low as possible while allowing the best integration of heat pumps into the network system.
- Another interviewee discussed opportunities in Scotland for lower temperature networks to make best use of waste heat recovery for DHN's from sources such as old mine water, large data centres, etc. They also discussed the better integration of smart controls into networks which would lead to a step change in the ability to control networks, but more work would be required to reduce the costs of these systems. They also called for better education for consumers to show them how low temperature DHN's would work in practice and for better mapping of waste heat sources.
- Another interviewee commented that in order to increase DHN efficiencies lower return flow temperatures could be created by using thermal storage to locally store heat at times of higher return flow temperatures, and this could also be used as a form of demand side response to shift demand to time periods with cheaper energy rates.
- One interviewee suggested that the biggest barrier to the deployment of low temperature DHN's is the requirement for 80ºC / 90ºC heating for older thermally poor buildings in urban areas, which are often difficult / expensive to retrofit. They also commented that it would be challenging to retrofit existing DHNs to become lower temperature networks. This was seen as an area for further research and development.
- An interviewee commented that there needs to be more standardisation of parts that go into heat networks (pipework, compressors & heat interface units) and the roll out of better training and skills for people in the DHN design and installation.

User awareness and demonstration of performance

Interviewees suggested that innovation would be needed in communicating the facts around DHN to consumers.

- Interviewees generally commented that DHN's were not as well known in the UK compared to Europe.
- An interviewee called for better education of consumers on the facts around DHNs. They added that it takes a long time to move customer perceptions away from their heating system status quo.
- Another interviewee said that consumers are generally accepting of DHN's, but the cost of heat is their biggest concern as they want prices to be fair. They added that for social tenants' system reliability is their biggest concern. Lastly, they felt that there was not enough information provided by LA's on how to connect into existing DHN's. Consumer protection controls will also need to be addressed to help provide consumer confidence.

Improved business models

Interviewees suggested that innovation in DHN business models was required to support longer term ownership of DHNs, allow for costs to be spread over longer periods and better standardisation of contractual arrangements.

- All interviewees who commented called for more open funding models for DHN's, with more delivery by the market in order to reduce construction costs.

- Interviewees suggested that entities could be responsible for networks for a longer period of time to ensure interest in keeping the systems working well over a longer period, reducing the risk for unexpected repairs and disruption.

- Interviewees discussed different innovative ways of supporting a greater roll out of DHN at new build developments including:
    - Innovations in business models for shared ground loop based projects, including how these are treated by regulations, as they believe there are 'grey areas' around this
    - More financial support for house builders in a similar model to how gas networks provide a rebate to house builders who connect into their networks, and
    - Spreading the cost of DHN installations at new build sites over a longer period to leverage financial models of fixed charging/heat as a service to consumers

Other

- An industry body interviewee commented that Local Heat and Energy Efficiency Strategies (LHEES) would be required to be set up along with better heat network zoning, and better mapping of anchor loads in order to allow for increase scalability of DHN's.

Thermal Energy Storage

One supplier / manufacturer commented on thermal energy storage based innovation needs, although three other interviewees discussed aspects of thermal energy storage while discussing other areas of focus.

Innovation needs

Interviewees suggested that innovations in thermal energy storage are needed to decrease the costs of newer phase change material (PCM) systems, allow for deeper integration of thermal energy storage systems, low carbon heating technologies, PV, PV Thermal Hybrid Solar Collectors (PVT) and smart heating controls.

Improved materials, product design and configuration

- All the interviewees who responded commented that thermal energy storage represents a good opportunity to use millions of existing hot water cylinders with smart controls to help provide grid balancing services, using them alongside electric car battery storage for example. Innovation is however required to match smart controls to existing hot water cylinder systems.

- All the interviewees who discussed thermal energy storage commented that increased local manufacture of these devices would lead to economies of scale, as thermal energy storage is still a small-scale industry, in need of better integrated supply chains and better material sourcing.
- Most of the interviewees called for innovation to allow for deeper integration of thermal energy storage systems with demand side response and home energy management systems in order to monetise the grid network benefits of home energy storage for the benefit of the end user. If the storage as a grid service aspect could be fully or partially monetised, then it could make thermal storage much more financially viable for consumers.
- Four interviewees including three supplier / manufacturers and one academic called for innovations around the use of water based thermal storage. They suggested better integration of this type of thermal storage with smart heating controls. One supplier / manufacturer interviewee suggesting that millions of thermal stores with immersion heaters could be linked up to provide large scale aggregated storage for the electricity grid.
- Two interviewees discussed the use of existing building fabric as a thermal storage medium such as block walls or floor slabs. This solution would use less material and have a lower carbon footprint.
- One supplier / manufacturer interviewee commented that the use of energy storage for demand side response is a complex area and would require more research and development. They also discussed the need for innovation in standards around smart energy appliances that would manage heating systems (such as PAS1878) and energy storage.
- A supplier / manufacturer interviewee commented that increasing the energy density of PCMs could drastically reduce costs by halving the cost per kWh stored with every doubling of energy density storage capacity, however this would come at some cost in terms of performance of the device. They also discussed that the scaling up of individual thermal energy storage systems could reduce costs up to a certain point. The controls for these systems will always be the same size, and at some point, you would have to scale up the heater in the product as well, however, the increasing costs for the heater scale slower than the growing benefit of increased energy stored in a larger PCM thermal energy storage device.
- One supplier / manufacturer interviewee commented that PCM based thermal storage technologies were not well known by the public outside an early adopter group. Many interviewees commented that there is a lack of skills and knowledge in the design and sizing of more recently developed thermal energy storage systems due to the rise of combi-boiler installations and removal of existing hot water cylinders. Therefore, innovative & larger scale training initiatives would be required for upskilling of installers.
- One interviewee said that there is a need for innovation in inter-seasonal storage of low-grade heat in the ground via the use of GSHPs.
- One interviewee also discussed a lack of energy tariffs that reward flexibility in energy use which would encourage the installation of more energy storage systems. In their opinion, the thermal energy storage market was not well regulated.
- One interviewee called for better innovation to better integrate thermal energy storage with low carbon heat sources. They commented that storage technologies should be combined with ASHPs, GSHPs and solar generation to provide an integrated, flexible low carbon heating solution.

Improved business models

- Many of the interviewees suggested that there was potential for innovative development of different energy tariffs that could encourage more thermal energy storage installations e.g. by creating a monetised value to end users for providing a demand side response with their storage devices.

Waste Heat

None of the interviewees chose to focus on waste heat source-based innovation needs, although four interviewees discussed some aspects of waste heat source while discussing other areas of focus.

Innovation needs

The general opinion of interviewees was that innovations could be needed to map and capture data on waste heat sources to make greater use of waste heat sources in local heating networks.

Improved design and configuration

- All interviewees who discussed this topic area suggested that multiple waste heat sources had the potential to be exploited such as old mines infrastructure, data centres other sources of waste heat that could be fed into lower temperature DHN's. Research should also be stepped up on opportunities to support the linking up between networks of heat and waste heat / coolth demand.
- One interviewee commented that areas with a high density of heat demand close to waste heat sources would be key for the development of waste heat sources and called for better data and mapping of these areas.
- One interviewee discussed the potential for using water cooling instead of air-cooled condensers at Energy from Waste (EfW) plants in order to create large inter-seasonal stores of heat. They suggested this should be investigated, especially if these are used with lower temperature heat networks including heat pumps.
- One interviewee called for the development of more LHEES, with better incentives and/or regulations to increase the use of waste heat sources. They also added that there were instances of waste heat sources close to areas of demand that were more costly to develop because they were located within a different LAs area leading to increased administration costs.
- Two interviewees commented that a significant barrier to the use of waste heat was matching up the timescales for how long a waste heat source will be active for against the lifespan of the heat network it could help supply. It was mentioned that in many cases these did not match up well enough and/or this would present commercial challenges / risk which often prevents investment.

Direct Electric Heating

None of the interviewees choose to focus on direct electric heating-based innovation needs, although seven interviewees chose to discuss limited aspects of direct electric heating while discussing other areas of focus. Interviewees generally discussed the widely held view by most consumers that direct electric heating is typically an expensive way to heat a home compared to other types of heating, and that it would be challenging to address and/or overcome this barrier without high levels of energy efficiency and/or use of renewable energy.

Innovation needs

Interviewees proposed that innovations in direct electric heating could include, further development of infrared heating systems to lower the surface temperature of some systems, innovations to combine direct electric heating with thermal energy storage and smart heating controls to allow flexible demand side response services.

- Two interviewees discussed developments in infrared heating, and one of them discussed developments in infrared wallpaper, which it was claimed could operate at 40ºC and keep occupants comfortable by heating people and objects in a room and not the air. They also discussed similar infrared heaters using a resistive load, but the interviewee commented that some of those ran at quite hot temperatures up to 60ºC which would create a safety issue and be too hot to touch, therefore innovation could be needed to create infrared heaters with lower surface temperatures.
- All of the interviewees discussed the combined use of direct electric heating systems with smart heating controls and energy storage technologies to create a flexible demand side response system in consumers' homes as this would be a big opportunity for creating grid service markets and new revenue streams for consumers.

Other General Interview Findings

Other interviewee comments on innovation in low carbon heating in Scotland included:

- Careful grid balancing would be required to ensure the successful roll out of electric heating without causing significant transmission and distribution grid problems.
- Careful planning of supply chains would be required to help overcome potential material and product shortages.
- There is not enough consumer knowledge of low carbon heating systems and a large-scale educational campaign would be needed to:
    - Explain why these systems are needed,
    - Show how these systems should be installed correctly,
    - Demonstrate how these systems should be used compared to gas boilers / fossil fuel heated systems,
    - Change the negative attitudes towards these technologies created by bad news stories of poor installations in previous years, and;
    - Engage consumers by showing the benefits of these systems.
- When changing from gas boilers to heat pumps, a large scale upskilling of gas boiler installer workforce will be required. It was mentioned that for a number of years there has been a decrease in skills around design of heating and thermal storage installations due to:
    - The relative ease of design / sizing requirements for gas boiler installations, and,
    - The rising numbers of combi boiler installations which have led to the removal of many existing hot water tank storage tanks.
- There is potentially a need for a Scottish heat pump knowledge network to enable new entrants into the market collaborate with each other and with more established companies.
- Building Energy Performance Certificates could be re-designed to allow for data to be collected and linked to Local Authority records, which could allow industry to better understand energy efficiency data across areas and regions and allow for better focus in funding development of energy efficiency retrofits and low carbon heating installations.

Policy Considerations

- Interviewees called for a clear and long-term policy certainty concerning for the transition to low carbon heating from the UK and Scottish Governments. It should be noted that these interviews were conducted before the recent release of the Scottish Government's final draft 'Heat in Buildings Strategy[3]' on October 7th, 2021 and the UK Government's Heat and Building Strategy.
- Some interviewees called for a better version of Renewable Heat Incentive, as previous schemes have not encouraged enough uptake. One utility provider said that technology prices tended to become pegged to the support given by the scheme so this would need to be carefully considered when implementing any new support scheme.
- Five interviewees commented that the imbalance of taxes on electricity compared to gas is a huge barrier on the path to increasing the roll out of electrified heat.
- Two interviewees called for greater standardisation of DHN contractual arrangements, support services, legal elements, and better regulation of DHN technical standards.
- A large scale utility interviewee called for DHN's to become regulated utilities, so that they would be able to work with other utilities when they conduct civil engineering works in an area. With better planning and coordination of works, DHN installations costs could be reduced.
- One manufacturer called for a joined-up innovation strategy of market support with simplified approaches and government policy guidance to foster innovation.
- One manufacturer / supplier commented that lower tax rates for retrofit activities versus new build activities could be considered to enable more retrofits and building fabric improvements.

[3] Heat in Buildings Strategy - achieving net zero emissions in Scotland's buildings - gov.scot (www.gov.scot)

Analysis of Innovation Needs

This section summarises the key innovation needs identified within the study. The assessment criteria are included in the Methodology section (see page 7), and it should be noted that this subjective assessment is based on the findings from literature review and stakeholder interviews and is not based on quantitative modelling of the potential impact.

Heat pumps

Theme	Heat pumps key innovation needs	Capital cost improvement potential	Operational performance improvement potential	Applicability potential to domestic building stock in Scotland	Applicability potential to non-domestic building stock in Scotland
Improved product design and configuration	Improved system designs for better performance (e.g. development of design tools and solutions to support better design)	Med	Med	High	High
Improved product design and configuration	Development of modular heat pump solutions for better operation and management (e.g. plug and play solutions, easily replicable and upgradable modules/sub-systems, allowing for easy re-use and servicing, development of spare parts or modules that can be compatible with different types of units)	Med	Med	High	High
Improved product design and configuration	Adoption of integrated solutions using waste heat and/or renewable sources (e.g. use of waste heat released from neighbouring buildings for space heating or hot water)	Low	High	Med	High
Improved product design and configuration	Development of improved design and installation approaches to communal heat pump systems (e.g. centralised system design for better efficiency, reduced maintenance)	Med	Med	High	High
Improved product design and configuration	Improved performance of heat pump components (e.g. improved vapour-compression cycle components for higher efficiency heat pumps)	Low	Med	High	High

Theme	Heat pumps key innovation needs	Capital cost improvement potential	Operational performance improvement potential	Applicability potential to domestic building stock in Scotland	Applicability potential to non-domestic building stock in Scotland
Improved product design and configuration	Development of new pipe materials and design approaches for better conductivity and efficiency of ground source heat pumps	Low	Med	Low	Med
Refrigerants with low GWP	Development and adoption of refrigerants with lower GWP	Low	Med	Med	High
Defrost solutions	Development of new defrosting, or frost-free, heat pump solutions	Low	Med	High	High
Development of new installation and commissioning approaches and methods	Development of new or more effective drilling concepts for ground source heat pump installations	High	Low	Low	Med
Development of new installation and commissioning approaches and methods	Development of solutions to deliver training for installers to improve installation, commissioning and O&M processes	High	Med	High	High
Development of new installation and commissioning approaches and methods	Improved heat pump installation and commissioning processes to reduce time and cost (e.g. development of new surveying tools, commissioning processes)	High	Low	High	High
Smart controls and monitoring systems	Design and integration of smart control and monitoring systems for improved efficiency, use and/or preventative maintenance (e.g. development of remote diagnostics for the implementation of predictive maintenance solutions, prognostics etc).	Low	High	High	High

Theme	Heat pumps key innovation needs	Capital cost improvement potential	Operational performance improvement potential	Applicability potential to domestic building stock in Scotland	Applicability potential to non-domestic building stock in Scotland
Smart controls and monitoring systems	Improved compatibility / interoperability approaches and standardisation to enable different devices / system to work efficiently	Low	Med	Med	High
Smart controls and monitoring	Better understanding / assessment of user needs and development of user-centred digital solutions (e.g. improved user interface design, delivering real-time feedback to users for better operation and management)	Low	Med	High	High
Improved recyclability and lower carbon-footprint	Development of improved end-of-life solutions and approaches (e.g., development of tools and strategies for the recycling and disposal of HP units and refrigerants)	Low	Low	High	High
User awareness and demonstration of performance	Collection of performance data and exchange of lessons learned to improve consumer awareness. Development of new tools and approaches to address and quickly adapt to user needs and consumption patterns	Low	Med	High	High
User awareness and demonstration of performance	Design of innovative measures and solutions to increase awareness and knowledge on heat pump solutions in the industry (e.g. demonstration of successful projects and case studies using innovative communications methods and mediums)	Low	Low	High	High
User awareness of demonstration of performance	Improved testing, commissioning and in-use monitoring of hybrid heat pumps systems and creation of greater understanding of operational performance in different geographical, climatic and economic regions.	Low	High	Med	High
Whole-building approach	Accompanying energy efficiency improvements to maximise system efficiency (e.g. implementing a whole-building approach)	N/A	High	High	High

District Heating

Theme	District heating key innovation needs	Capital cost improvement potential	Performance improvement potential	Applicability potential to domestic building stock in Scotland	Applicability potential to non-domestic building stock in Scotland
Improved design and configuration	Development of design approaches to facilitate the adoption of low temperature heat networks (e.g. use of heat pumps and ambient loop systems)	Med	Med	High	High
Development of new installation and commissioning solutions	Development of pipe system and network piping solutions and techniques that could reduce the cost of civil engineering (e.g. development of trenchless technologies that require minimal excavation)	High	Med	High	High
Development of new installation and commissioning solutions	Development of improved solutions and approaches to enable collaboration in civil engineering between utilities working in the same region for better planning to reduce costs of installation	High	Low	High	High
Development of new installation and commissioning solutions	Development of solutions to reduce the cost of heat interface units for retrofit schemes (e.g. improved components and controls)	Med	Low	High	Med
Smart controls and monitoring systems	Development of distributed storage systems for improved flexibility and efficiency in networks (e.g. developing solutions to re-purpose and/or maximise the use of existing hot water tanks)	Med	Med	High	High
Smart controls and monitoring systems	Development of demand forecasting and management systems to maximise efficiency and reduce heat losses and increase accuracy of heat demand estimates (e.g. development of new tools and approaches to increase accuracy of heat demand estimates and maximise difference between temperatures entering and leaving the buildings)	Low	High	High	High

Theme	District heating key innovation needs	Capital cost improvement potential	Performance improvement potential	Applicability potential to domestic building stock in Scotland	Applicability potential to non-domestic building stock in Scotland
Smart controls and monitoring systems	Improved integration of heat and power systems and better use of the link between district heating and the grid	Med	Med	High	High
Smart controls and monitoring systems	Development of more accurate and live energy demand datasets or digital tools to support better planning (e.g. development of open-source datasets)	Low	Med	High	High
Improved business models	Development of new business models for improved operation and maintenance, and reduced system disruption	Low	Med	High	High
Greater use of waste heat sources	Improved design solutions integrating waste heat (e.g. heat released from mine water, cooling systems or industrial processes) and renewable sources (e.g. solar PV)	Med	High	High	High
Greater use of waste heat sources	Development of digital tools, mapping techniques, etc. to gather key operational and energy data from industrial facilities to initiate the use of available waste heat at nearby sites	Low	Med	High	High
User awareness and demonstration of performance	Development of knowledge sharing, data exchange platforms to maximise impact and share learnings	Low	Low	High	High

Thermal Energy Storage

Theme	Thermal energy storage key innovation needs	Capital cost improvement potential	Performance improvement potential	Applicability potential to domestic building stock in Scotland	Applicability potential to non-domestic building stock in Scotland	Applicability potential to heat network and/or wider energy systems in Scotland
Improved design and configuration	Development of solutions to maximise the use of existing hot water cylinders along with heat pumps and smart monitoring systems	Med	Med	High	Med	Low
Improved materials, product design and configuration	Development and adoption of PCM-based thermal storage technologies (low temperature) using new chemicals, materials and configurations for time shifting and intraday storage	High	Med	High	High	Low
Improved materials, product design and configuration	Development of new configurations and materials for high temperature PCMs, suitable for district heating applications	Med	Med	Low	Low	High
Improved materials, product design and configuration	Development in materials to improve thermal properties and corrosion resistance in Tank Thermal Energy Storage and solid-state TES technologies	Low	Med	Med	High	High
Improved materials, product design and configuration	Development and adoption of new inter-seasonal thermal storage technologies and solutions (e.g. improved design and installation for better efficiency, use of alternative heat sources and sinks in the built environment)	Med	Med	Low	Med	High
Improved materials, product design and configuration	Development and adoption of thermo-chemical storage technologies for waste heat and solar energy (e.g. improved reactor design to reach high temperature, improved humidification process for better efficiency)	High	Med	Low	Med	High
Improved materials, product design and configuration	Development of cold storage technologies / solutions to overcome challenges for overheating due to climate change (e.g. sub-zero PCM)	Med	Med	Med	High	Low
Smart controls and monitoring systems	Development and adoption of smart energy management systems along with thermal storage (e.g. demand site management systems)	Low	Med	Med	Med	High

Summary of Innovation Needs per Stakeholder Group

The innovation needs identified during the above assessment have been grouped below for different stakeholder groups:

Heat pump manufacturers

- Development of solutions to maximise the efficiency and the whole life performance of components, whilst reducing the whole life carbon footprint
- Development of modular heat pump solutions for better operation and management (e.g. plug and play solutions, easily replicable and upgradable modules / sub-systems)
- Development and adoption of refrigerants with low GWP
- Development and adoption of energy efficient defrosting solutions

Heat pump installers

- Development of solutions to improve the heat pump installation and commissioning processes to reduce time and cost (e.g. developing surveying tools)
- Development of solutions to deliver training for installers to improve installation, commissioning and O&M processes (in collaboration with manufacturers and professional bodies)
- Development and adoption of new drilling concepts for ground source heat pump installations to reduce cost

Designers

- Improved system designs for better performance (e.g. development of design tools and solutions for better design), implementing a user-centred approach
- Improved whole-building design methods to maximise the efficiency of systems and buildings
- Maximised use of integrated solutions, using waste heat and renewable energy solutions in combination with heat pumps
- Development of new approaches to enable data collection and to quickly adapt to user needs and consumption patterns
- Development of design approaches to facilitate the adoption of low temperature heat networks (e.g. 4th generation, 5th generation heat networks)
- Development of solutions to reduce the cost of heat interface units for retrofit schemes (when connecting to district heating)
- Development of distributed storage solutions for improved flexibility and efficiency in networks
- Development of innovative solutions to maximise the use of existing hot water cylinders along with heat pumps and smart monitoring systems
- Development of new approaches to enable exchange of information/ lessons learned

Data / IoT / Controls and Instrumentation

- Development of solutions to improve compatibility between control devices and heating systems at building and central levels
- Development of demand management systems to predict and manage consumption at building and central levels
- Development of solutions for predictive maintenance and efficient operations of low carbon heat technologies
- Development of control and management systems with improved user interface design (better matching the needs of users)
- Development of digital tools and maps to gather key operational and energy data from industrial facilities to initiate the use of available waste heat at nearby sites

Thermal energy storage manufacturers / technology providers

- Development of solutions to enable the use of existing hot water cylinders along with heat pumps and smart monitoring systems
- Development and adoption of PCM-based thermal storage technologies (low temperature) using new chemicals, materials and configurations for time shifting and intraday storage
- Development of new configurations and materials for high temperature PCMs, suitable for district heating applications
- Development of new inter-seasonal and thermochemical thermal storage solutions with better efficiency
- Development of cold storage technologies/solutions to overcome challenges for overheating due to climate change (e.g. sub-zero PCM)

Utilities / DHN operators

- Development of pipe system and horizontal drilling / piping solutions which could reduce the cost of civil engineering (e.g. development of trenchless technologies) in district heating applications
- Development of accurate and live energy demand datasets or digital tools for better planning and development of demand forecasting and management systems to maximise efficiency and reduce heat losses and increase accuracy of heat demand estimates
- Development of solutions and approaches to enable collaboration in civil engineering between utilities working in the same region for better planning to reduce costs of installation
- Development of knowledge share, data exchange platforms to maximise impact and share learnings
- In collaboration with data specialists, development of digital tools and maps to gather key operational and energy data from industrial facilities to initiate the use of available waste heat at nearby sites

Conclusions

This project presents an evidence base to help Scottish Enterprise understand innovation needs when developing potential support schemes to enable businesses to capitalise on the opportunities relating to the low carbon heat solutions relevant in the Scottish context i.e. considering the role they could play in helping meet Scotland's net zero targets, as well as creating value to consumers through cost reductions and creating new business opportunities

By conducting a desk-based research and multiple one-to-one interviews with external stakeholders, the study has identified potential technical, financial, and societal barriers, gaps and weaknesses in low carbon heat innovation. These have been analysed and reported in order to help Scottish Enterprise consider the merits of developing relative support measures where appropriate.

This study has identified that for heat pumps there is opportunity to improve the user experience (e.g. by incorporating smart monitoring and control systems), to improve efficiency (e.g. via better design and/or improved operation and maintenance) and to reduce the overall environmental impact (e.g. by developing refrigerants with low global warming potential). The development of smart monitoring systems for improved energy management, diagnostics and user engagement is another key innovation need identified in this study. For ground source heat pumps the study identified potential to further improve installation and drilling processes (e.g. communal installations) to help reduce cost.

There are a wide range of opportunities to overcome the barriers associated with the high cost of district heating networks (DHNs). Improved design, deployment of low temperature systems, new installation and piping techniques and approaches, improved heat interface unit solutions, increased use of waste heat and renewable sources, deployment of demand side management and forecasting solutions, and development of knowledge exchange platforms were all identified as areas where technical innovation could contribute to the development of more efficient district heat network systems. This research also identifies that there is potential to develop innovative thermal storage systems (sensible, latent and thermochemical), implementing new approaches and using new phase changing materials (PCM) to help increase efficiency and reduce cost.

The research also highlights that waste heat (e.g. from industrial processes or commercial buildings) can be utilised in a wide range of buildings if suitable heat recovery and transmission processes can be developed and deployed cost effectively. There are potential opportunities to capitalise upon waste heat from a range of sources e.g. power stations, old mine water, waste treatment plants, distilleries, and buildings with high cooling demand such as supermarkets and data centres. There is also potential to develop new tools and mapping approaches which could help to more accurately identify, map and estimate waste heat coming from industrial facilities and large buildings and enable the effective matching of supply with demand.

The following table provides an overview of the key innovation areas identified in this study:

Technology	Summary of the key innovation areas identified in this study
Heat pumps	The study identified a need to develop smart and modular heat pump solutions which could meet the needs of different user groups, and opportunities to develop innovative installation and commissioning solutions to reduce the installation cost and time. The study also identified an increasing need to develop and use refrigerants with low global warming potential and to improve the overall recyclability and carbon footprint of heat pumps. The study identified that the development of demand side management systems (to predict and manage consumption) is another key innovation need, as is the need to develop digital control and monitoring solutions which could improve the user experience and maximise the efficiency of heat pumps (e.g. predictive maintenance and efficient operations of low carbon heat).

District heat networks	Improved design and deployment of low temperature district heat systems, new installation approaches to reduce the civil engineering costs, and increased use of waste heat and renewable sources have all been identified as areas of potential innovation opportunity. Furthermore, the deployment of demand side management and forecasting solutions, and the development of knowledge exchange platforms, were also identified.
Thermal energy storage	The study identified opportunities to develop new materials and configurations for both sensible and latent heat storage solutions (e.g. for solid state storage, low temperature and high temperature PCM, sub-zero PCM) and also, opportunities to develop new materials and approaches for inter-seasonal storage systems (e.g. absorption systems and salt hydration). There is also a need to explore new ways of using existing hot water cylinders along with heat pumps and smart monitoring systems.
Waste heat	The study identified a need to develop innovative tools and mapping techniques which could help enable more accurate measurement and identification of potential waste heat sources (e.g. those from industrial facilities and large buildings). There is also a need to further explore the feasibility of using different waste sources in buildings and district heat networks (i.e. waste heat from waste water treatment plants, mine water, distilleries and buildings such as data centres, and supermarkets etc.).

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Appendix

Interview Questions

Technology Group	Questions
General	What are the key technology related issues, challenges, barriers that exist for Low carbon heating technologies deployed in homes and commercial settings in Scotland?
	What are the key innovation opportunities currently existing for Low carbon heating technologies deployed in homes and commercial settings in Scotland?
	Would you have any recommendations for how best to support technical and business model innovation in the low carbon heating sector in Scotland?
	How would you rate different low carbon heating solutions in terms of their scalability, overall carbon reduction impact / potential for innovation?
	Any other useful research or papers that we can refer to that are related to this technology innovation research?
	Are there opportunities for new business models which could support the transition to low carbon heating?
Heat Pumps	What are the technology related key issues, challenges, barriers, that are currently existing for heat pumps deployed in homes and commercial settings in Scotland?
	What are the key opportunities currently existing for innovation in heat pumps deployed in homes and commercial settings in Scotland?
	Do you have any experience with the use of alternative refrigerants with low GWP? How do you think refrigerant leakage can be minimised?
	Are there any other opportunities to improve efficiency (increased COP) of heat pumps?
	What do you think users/consumers opinions are of HP installations?
	Can user experience with HP's be improved, and if so how?
	Would you know if there are any innovations in heat pump technology that could reduce the space requirements, noise, and generally make them a better fit for Scotland's building stock?
	Do you think there are any opportunities for reducing the carbon footprint of heat pumps? Are there any opportunities for innovative O&M and end of life services?
	Which low carbon heating technologies can HP's best compliment when used together?
	Are there opportunities for new business models which could support the transition to low carbon heating?
	What innovations could lead increased scalability heat pump installations over the next 10 years?
	What steps can be taken to reduce heat pump costs? (purchasing, installing, operational)
	Where do you think the most impactful opportunities lie for cost reduction in HP tech? Is there % cost reduction breakdown of the different innovations that could be made?

Technology Group	Questions
District Heating	What are the key technology related issues, challenges, barriers affecting deployment of district heating systems?
	What are the key opportunities for innovation in DH systems?
	Can heat pumps and/or energy storage be used to improve the efficiency of DH systems?
	What are the Challenges for low temperature heat networks?
	What are the opportunities for low temperature heat networks?
	What do you think users/consumers opinions are of DH systems? How do you think recent market uptake of this solution has progressed?
	What can be done better to improve user experience of DH systems?
	What steps can be taken to reduce DH costs? (purchasing, installing, operational)
	Where do you think the most impactful opportunities lie for cost reduction in DH tech? Is there % cost reduction breakdown of the different innovations that could be made?
	What innovations could lead increased scalability of DH installations over the next 10 years?
Waste Heat	What are the key issues, challenges, barriers currently existing for waste heat recovery?
	What are the key opportunities for innovation in waste heat?
	Which low carbon heating technologies can waste heat best compliment when used together?
	What do you think users/consumers opinions are of waste heat source systems? How do you think recent market uptake of this solution has progressed?
	What can be done better to improve user experience of waste heat source systems?
	Are there opportunities for new business models combined with waste heat and could support the transition to low carbon heating?
	What steps can be taken to reduce waste heat source system costs? (purchasing, installing, operational)
	Where do you think the most impactful opportunities lie for cost reduction in waste heat source tech? Is there % cost reduction breakdown of the different innovations that could be made?
	What innovations could lead increased scalability of WHS installations over the next 10 years?

Technology Group	Questions
Electric heating	What are the key issues, challenges, barriers currently existing for electric heating systems?
	What are the key opportunities for innovation in electric heating systems?
	What do you think users/consumers opinions are of energy storage systems?
	What can be done better to improve user experience of energy storage systems?
	Which low carbon heating technologies can electric heating best compliment when used together?
	Are there opportunities for new business models combined with electric heating to support the transition to low carbon heating?
	What steps can be taken to reduce electric heating costs? (purchasing, installing, operational)
	Where do you think the most impactful opportunities lie for cost reduction in electric heating tech? Is there % cost reduction breakdown of the different innovations that could be made?
	What innovations could lead increased scalability of electric heating installations over the next 10 years?
Energy storage	What are the key issues, challenges, barriers currently existing for energy storage systems?
	What are the key opportunities for innovation in energy storage systems?
	What scale of energy storage would be best for low carbon heating transition in Scotland going forward, dwelling scale, community scale, larger scale?
	Which low carbon heating technologies can energy storage best compliment when used together?
	What do you think users/consumers opinions are of energy storage systems?
	What can be done better to improve user experience of energy storage systems?
	What steps can be taken to reduce energy storage costs? (purchasing, installing, operational)
	Where do you think the most impactful opportunities lie for cost reduction in energy storage tech? Is there % cost reduction breakdown of the different innovations that could be made?
	What innovations could lead increased scalability of energy storage installations over the next 10 years?

Technology Group	Questions
Smart Controls	What are the key issues, challenges, barriers, currently existing for smart control systems?
	What are the key opportunities for innovation in smart control systems?
	Which low carbon heating technologies can smart controls best compliment when used together?
	What do you think users/consumers opinions are of smart control systems?
	What can be done better to improve user experience of smart control systems?
	Are there opportunities for new business models combined with smart controls to support the transition to low carbon heating?
	What steps can be taken to reduce smart control system costs? (purchasing, installing, operational)
	Where do you think the most impactful opportunities lie for cost reduction in smart control tech? Is there % cost reduction breakdown of the different innovations that could be made?
	What innovations could lead increased scalability of smart control installations over the next 10 years?
Hybrid heat pump	What are the key issues, challenges, barriers that are currently existing for hybrid heat pump systems?
	What are the key opportunities for innovation in hybrid heat pump systems?
	What steps can be taken to lower hybrid heat pump installation and operation costs?
	What do you think users/consumers opinions are of hybrid heat pump systems?
	What can be done better to improve user experience of hybrid heat pump systems?
	Which low carbon heating technologies can hybrid heat pumps best compliment when used together?
	Are there opportunities for new business models combined with hybrid heat pumps to support the transition to low carbon heating?
	What steps can be taken to reduce Hybrid heat pump costs? (purchasing, installing, operational)
	Where do you think the most impactful opportunities lie for cost reduction in hybrid heat pump tech? Is there % cost reduction breakdown of the different innovations that could be made?
	What innovations could lead increased scalability of hybrid heat pump installations over the next 10 years?