Energy Innovation Needs Assessment

Sub-theme report: Heating & cooling

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The views expressed in this report are the authors' and do not necessarily reflect those of the Department for Business, Energy and Industrial Strategy.

Acronyms and abbreviations

Table 1. **Key acronyms and abbreviations**

Acronym/abbreviation	Definition
4GDH	Fourth Generation District Heating
ASHP	Air-Source Heat Pump
ADE	Association for Decentralised Energy
BEIS	Department for Business, Energy & Industrial Strategy
CAPEX	Capital Expenditure
CCC	Committee on Climate Change
CHP	Combined Heat and Power
CoP	Coefficient of Performance
DHW	Domestic Hot Water
DSRM	Demand side response and management
EfW	Energy from Waste
EINA	Energy Innovation Needs Assessment
EMS	Energy Management System
EPCm	Engineering, Procurement and Construction Management (services)
ESC	Energy Systems Catapult
ESME	Energy System Modelling Environment
EVI	Enhanced Vapour Injection
GSHP	Ground-Source Heat Pump
GVA	Gross Value Added
GWP	Global Warming Potential
HIU	Heat Interface Units
HNIP	Heat Networks Investment Project
HNDU	Heat Networks Delivery Unit
HP	Heat Pump
HTHP	High-Temperature Heat Pumps

HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
LCOE	Levelised Cost of Energy
O&M	Operations and Maintenance
OPEX	Operating Expenditure
PCM	Phase Change Material
PHES	Pumped Heat Energy Storage
RCA	Revealed Comparative Advantage
RD&D	Research, Development, and Demonstration
RHI	Renewable Heat Incentive
RoW	Rest of World
SDS	Sustainable Development Scenario
SEER	Seasonal Energy Efficiency Ratio
SH	Space Heating
TES	Thermal Energy Storage
THS	Thermochemical Heat Storage
TINA	Technology Innovation Needs Assessment
TRL	Technology Readiness Level

Glossary

Table 2. **Key terms used throughout this report**

Term	Definition
Learning by doing	Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards, which tend to increase in direct proportion to capacity increases.
Learning by research, development, and demonstration	Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D); increases with spend in RD&D and tends to precede growth in capacity.
Sub-theme	Groups of technology families which perform similar services which allow users to, at least partially, substitute between the technologies. For example, a variety of technology families (heat pumps, district heating, hydrogen heating) have overlapping abilities to provide low carbon thermal regulation services and can provide flexibility to the power system.
System value and Innovation value	Estimates of change in total system cost (measured in £ GBP, and reported in this document as cumulative to 2050, discounted at 3.5%) as a result of cost reduction and performance improvements in selected technologies. This is the key output of the EINAs and the parameter by which improvements in different technologies are compared. System benefits result from increasing deployment of a technology which helps the energy system deliver energy services more efficiently while meeting greenhouse gas targets. Energy system modelling is a vital tool in order to balance the variety of interactions determining the total system costs. Innovation value is the component of system value that results from research and development (rather than from ‘learning by doing’)
Technology family	The level at which technologies have sufficiently similar innovation characteristics. For example, heat pumps are a technology family, as air-source, ground-source and water-source heat pumps all involve similar technological components (compressors and refrigerants). Electric vehicles are also a technology family, given that the battery is a common component across plug-in hybrids and battery electric vehicles.
Gross Value Add	Gross Value Add (GVA) measures the generated value of an activity in an industry. It is equal to the difference between the value of the outputs and the cost of intermediate inputs.

Introduction

Box 1. **Background to the Energy Innovation Needs Assessment**

The Energy Innovation Needs Assessment (EINA) aims to identify the key innovation needs across the UK's energy system, to inform the prioritisation of public sector investment in low-carbon innovation. Using an analytical methodology developed by the Department for Business, Energy & Industrial Strategy (BEIS), the EINA takes a system-level approach, and values innovations in a technology in terms of the system-level benefits a technology innovation provides.[1]. This whole system modelling in line with BEIS's EINA methodology was delivered by the Energy Systems Catapult (ESC) using the Energy System Modelling Environment (ESME™) as the primary modelling tool.

To support the overall prioritisation of innovation activity, the EINA process analyses key technologies in more detail. These technologies are grouped together into sub-themes, according to the primary role they fulfil in the energy system. For key technologies within a sub-theme, innovations and business opportunities are identified. The main findings, at the technology level, are summarised in sub-theme reports. An overview report will combine the findings from each sub-theme to provide a broad system-level perspective and prioritisation.

This EINA analysis is based on a combination of desk research by a consortium of economic and engineering consultants, and stakeholder engagement**.** The prioritisation of innovation and business opportunities presented is informed by a workshop organised for each sub-theme, assembling key stakeholders from the academic community, industry, and government.

This report was commissioned prior to advice being received from the CCC on meeting a net zero target and reflects priorities to meet the previous 80% target in 2050. The newly legislated net zero target is not expected to change the set of innovation priorities, rather it will make them all more valuable overall. Further work is required to assess detailed implications.

The low-carbon heating and cooling sub-theme report

The heating and cooling sub-theme focus on five main categories: heat pumps, heat networks, heat storage, and cooling and hydrogen boilers. Innovation in these technology areas can play an important role in meeting the UK's future heat demand, whilst also facilitating renewable uptake and driving further efficiency gains. Other hydrogen end use appliances such as hydrogen cookers, hydrogen fires, hydrogen fuel

[1] The system-level value of a technology innovation is defined in the EINA methodology as the reduction in energy system transition cost that arises from the inclusion of an innovation compared to the energy system transition cost without that innovation.

cells and hydrogen gas meters may also have an important role to play, however only hydrogen boilers have been considered as part of this research. Industrial process heat is not within the scope of this report (see the Industrial EINA), nor biomass for heat (see Biomass EINA).

The report has four sections:

- **Low carbon heating and cooling and the energy system:** Describes the role of low carbon heating and cooling technologies in the energy system.
- **Innovation opportunities:** Provides lists of the key innovations available within low carbon heating and cooling technologies and their approximate impact on costs.
- **Business opportunities:** Summarises the export opportunities for low carbon heating and cooling technologies, the GVA and jobs supported by these opportunities, and how innovation helps the UK capture the opportunities.
- **Market barriers to innovation:** Highlights areas of innovation where market barriers are high and energy system cost reductions and business opportunities significant.

Key findings

Innovation areas in low carbon heating and cooling technologies

The main innovations for the heating and cooling sector are identified below. The list is not a substitute for a detailed cost-reduction study. Rather, it is a guide for policymakers and stakeholders on key areas to consider in the design of any future innovation programme.

The innovation priorities below select individual or groups of the top scoring innovations. Table 3 maps the top scoring innovations to individual technology components, and Tables 6, 8, 10, 12, and 14 set out the full list of innovations by technology and their scores.

Heat pumps

- New system designs (such as gas sorption, new compressors and expanders) to help reduce capital and operating costs and improved product designs (such as modularisation) to facilitate installation.
- The use of smart control systems to facilitate demand-side response and management (DSRM), the efficient use of hybrid heat pumps, improved performance monitoring, and greater integration with other low-carbon technologies (such as storage and solar photovoltaics).

Heat networks

- The development of low-temperature heat networks, including the use of compatible temperatures in tertiary heating systems, to allow the integration of various low-carbon heat sources into heat networks.
- Advances in heat network design optimisation to better serve customers through technical data gathering, research, and dissemination (e.g. on UK heat demand profiles, the benefits of thermal storage, market innovations, and regulatory innovations).

Heat storage

- Innovative materials such as phase change materials (PCMs) that are capable of time-shifting heating loads for intraday storage in new buildings and can be integrated with other thermal storage for refurbishments.
- Thermochemical heat storage for medium- and long-term inter-seasonal storage.

Hydrogen boilers

- Component improvements (such as burner technology, flame failure detection and leakage detection) allowing for the development and demonstration of packaged systems that can match the features of natural gas boilers.
- Innovations that avoid (or minimise) the need to replace gas pipework in houses (such as by providing affordable, low pressure hydrogen fittings that are applicable to domestic installations).

Cooling

- Smart control systems to provide better feedback to users on performance. This can enable improved monitoring to reduce breakdowns and maintenance, optimisation of equipment, and the use of advanced occupancy data (through new toolsets to model cooling demand).
- System integration with other technologies, including with heating systems, solar photovoltaics, and thermal storage.

Business opportunities for the UK

Innovation provides a business opportunity to grow low-carbon heating and cooling exports, contributing almost £900 million GVA and 7,000 jobs per annum by 2050. In the business opportunities section below, GVA and jobs results are set out by component (Table 15).

- Heat pumps offer the greatest export opportunity, contributing £500 million GVA per annum. This sizeable opportunity is driven by the large market size for heat pumps, particularly in North-western Europe. This market is most similar to that of the UK and hence likely to import from the UK. Although the UK's industry will need to grow from a low base, it is plausible for the UK to capture nearly 10% of this market.
- The UK's ability to compete in the heat pump market is relatively uncertain given the limited existing base. Large-scale domestic deployment could drive the development of a competitive UK supply chain.
- Other export opportunities unlocked are focussed in the commercial Heat, Ventilation and Air Conditioning (HVAC) sector, hydrogen boilers, and heat network engineering, procurement, and construction management services (EPCm). These are, however, all significantly smaller. This is primarily because the expected (traded) market in Europe is an order of magnitude smaller than that for heat pumps.
- Domestic business opportunities could support £3.9 billion GVA per annum and 43,000 jobs by 2050. This would be significantly larger than export opportunities, primarily because of the business associated with installing and maintaining new heating and cooling technologies. However, as discussed in more detail in the

domestic analysis, the GVA and jobs associated with these opportunities are unlikely to be additional, largely replacing current activity associated with traditional heating and cooling technologies.

Market barriers to innovation in the UK

Opportunities for HMG support exist when market barriers are significant and cannot be overcome by the private sector or international partners. In the market barriers section below, the barriers are set out by component, where possible (Table 16). The main market barriers identified by industry are:

For heat pumps, the main barriers to innovation are high upfront cost of installation and a need for market creation.

- One of the main reasons for uncertain demand for heat pumps is low customer awareness and acceptance. 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.
- Heat pumps require high upfront investments, which can be unaffordable for consumers. In the absence of tax incentives and effective financing schemes, these costs can be prohibitive.
- Replacement is often required only when the existing heating system needs substantial repair. In these situations, consumers prefer a quick fix instead of thinking comprehensively about the options available.

For district heating systems, coordination and strategic alignment between planning regulations and climate policy would offer opportunities for deployment at scale.

- Unestablished policy framework and regulatory barriers prevent reaching critical mass for deployment.
- Grid access and capacity present barriers to deployment at scale, as the grid is not ready for whole neighbourhoods to be converted to electricity. This reduces incentives to innovate as future revenues and costs are uncertain until grid capacity is known.
- High upfront capital costs associated with the construction of plants, heat networks, and connections, compared with low capex for gas heating, disincentivise investment and financial products are insufficient to overcome this.

For storage, the main barriers are high capital costs for medium- to long-term heat storage.

- High capital costs for medium to long term heat storage and the lack of a clear revenue stream limit incentives for investment.

For hydrogen boilers, the main barriers are around the high upfront and running costs due to lower technological maturity and hydrogen being more expensive than natural gas.

- Hydrogen boiler deployment is limited by the lack of a well-established hydrogen supply chain.
- Installation costs and disruption associated with the refurbishment of pipework can also inhibit large scale roll out.

Key findings by component

Government support is justified when system benefits and business opportunities are high, and Government is needed to overcome barriers.

Table 3. **Cost and performance in low carbon heating and cooling technologies (see key to colouring below)**

Overall statistics for low carbon heating and cooling: System value = £12.9 billion (range: 7.2-19.1 billion), 2050 export opportunity (GVA) = £0.9 billion, 2050 potential direct jobs supported by exports = 6,800				
Component	**Example innovation**	**Business opportunities**	**Market barriers**	**Strategic assessment**
Heat pumps – O&M	Smart control systems for heat pumps.	NA (not traded)	Moderate	Innovations in smart control systems can reduce operating costs through improved performance and greater integration with the energy system (such as heat storage). By allowing integration with other technologies, smart controls can also reduce heat pump deployment barriers. Without government intervention, heat pump innovations in this area will likely occur at a lower speed.
Heat pumps – System	New heat pump systems.	Medium-low	Moderate	Designing new heat pumps systems with new components and technologies (e.g. gas sorption and new compressors) can lower the capital and operating costs of heat pumps. Without government intervention, innovation in heat pump systems will occur at a lower scale and speed. Innovation in heat pumps could unlock the greatest heating and cooling export opportunity for the UK, given high levels of expected deployment in the UK's major export markets.
Heat networks – Design	Design of low-temperature heat networks.	Low (EPCm services)	Severe	Low-temperature heat networks can allow for the distribution of cheaper and lower-carbon heat by facilitating the integration of a wide variety of heat sources. Without government intervention, innovations in the design of low-temperature heat networks will be significantly constrained. EPCm services associated with heat networks present a small global opportunity for UK exporters.
	Technical data gathering exercise		Severe	For optimum design of heat networks, vast amounts of data (such as heat demand profiles across the UK) needs to be gathered and disseminated.

Overall statistics for low carbon heating and cooling: System value = £12.9 billion (range: 7.2-19.1 billion), 2050 export opportunity (GVA) = £0.9 billion, 2050 potential direct jobs supported by exports = 6,800				
Component	**Example innovation**	**Business opportunities**	**Market barriers**	**Strategic assessment**
	for design optimisation.			Without government support in this data gathering exercise, heat networks will be unable to optimise their designs accordingly.
Heat storage – Heat store	Thermochemical heat storage for inter-seasonal storage.	NA	Moderate	Thermochemical materials are expected to be a key long-term innovation to facilitate inter-seasonal heat storage. Without government intervention, innovation will occur at a lower scale and the technology will reach commercialisation later.
	PCM for diurnal storage.		Moderate	Phase change materials (PCMs) can be used in new buildings, as well as in retrofits, to reduce the size or increase the capacity for intraday heat storage. Without government intervention, innovations in heat storage using PCMs will occur at a slower pace.
Hydrogen boilers – Ancillary works	Hydrogen boilers that can be integrated into homes with minimum disruption.	Low	Moderate	Integrating boilers into dwellings with no, or minimum, refurbishment to the existing gas pipework would reduce installation costs, as well as deployment barriers to hydrogen boilers. Government intervention will be essential to speed up innovations in this area to allow for the large-scale deployment of hydrogen boilers. Innovation could allow UK businesses to leverage existing gas boiler expertise for global export.
Cooling – O&M	Cooling systems integrated with smart control systems.	Low (assessed HVAC systems exports)	N/A	Cooling systems, especially in commercial settings, can see reductions to costs and deployment barriers by using smart controls to optimise performance. Without government intervention, the adoption of smart controls in cooling systems will occur at a lower speed. The UK could build on existing HVAC system exports but can only reach a limited export market.

Source: *Vivid Economics, Carbon Trust*

Note: *The main innovations per component are the innovations that score the highest in the innovation inventory. This table only includes technology-specific market barriers. Cross-cutting barriers are included in the market barriers section below. Market barriers for cooling are not discussed in this report. We only include export markets in this assessment because it is more directly linked to additional benefits to the UK economy. However an assessment of the domestic market is included in the report below.*

Table 4. **Key to colouring in the key findings by component**

Business opportunities	Market barriers
High: more than £1 billion annual GVA from exports by 2050	**Critical:** Without Government intervention, innovation, investment and deployment will not occur in the UK.
Medium-High: £600-£1,000 million annual GVA from exports by 2050	**Severe:** Without Government intervention, innovation, investment and deployment are significantly constrained and will only occur in certain market segments / have to be adjusted for the UK market.
Medium-Low: £200-£600 million annual GVA from exports by 2050	**Moderate**: Without Government intervention, innovation, investment and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
Low: £0-200 million annual GVA from exports by 2050	**Low:** Without Government intervention, innovation, investment and deployment will continue at the same levels, driven by a well-functioning industry and international partners.

Source: Vivid Economics, Carbon Trust

Box 2. **Industry workshop**

A full-day workshop was held on 6th February 2019 with key delegates from the heat pump, heat network, and heat storage sectors, academic communities, and trade associations. Key aspects of the EINA analysis were subjected to scrutiny, including innovation opportunity assessment, and business and policy opportunities assessment. New views and evidence were suggested; these have been incorporated into an update of the assessments.

The views of the attendees were included in the innovation's assessment. In addition, several contextual issues were raised at the workshop:

- Current heat pump technologies are well established, with the challenges for increased penetration being, in part, dependent upon innovations that can lower the cost of manufacturing heat pumps.
- The cost assumptions used in the energy modelling for heat pumps do not differentiate between domestic and commercial use and as a result affect the reliability of assessing an innovation's cost-reduction potential.
- In addition to technological innovations, heat networks require strong support in business model and regulatory innovations to reduce their barriers to deployment.
- Cooling is an area that has been largely overlooked in the UK and requires specialised studies to identify opportunities.

Low carbon heating and cooling and the whole energy system

Current situation

Heat is the largest energy consuming sector in the UK today (accounting for 44% of final energy consumption in 2017), ahead of transport and electric power. Greenhouse gas (GHG) emissions from heat are also the single largest contributor to UK emissions, mostly from space heating (and cooling) and industrial processes[2]. Therefore, low-carbon heating technologies will play a very important role in meeting the UK's target to reduce emissions by at least 80% by 2050 (compared to 1990 levels), as set out in the Climate Change Act 2008.

Heat pumps

Overall, there are around 180,000 heat pumps installed in the UK[3], or less than 1% of the UK's heating systems. In comparison, there are 26 million gas boilers installed, representing 85% of the UK's heating systems[4].

Air-source heat pumps (ASHPs) are by far the most popular type of heat pump, representing over 80% of the 17,000 installed heat pumps in 2017. The rest of which were ground-source heat pumps (GSHPs)[5]. However, the total number of heat pump installations in 2017 was just 1% of the number of new gas boiler installations, which stood at 1.7 million in 2016.

Heat pumps are the most popular domestic renewable heating technology in the UK. Over 45,600 heat pumps were installed from 2014 to 2018 under the domestic Renewable Heat Incentive (RHI) scheme (compared to 12,700 biomass systems and 8,900 solar thermal systems). However, commercial installations are lagging, with under 1,500 heat pumps installed through the non-domestic RHI since 2011 (while close to 17,000 biomass boilers were funded in the same time)[6]. Even though RHI-installed heat pumps represent only a portion of all installed heat pumps, their uptake under the scheme is illustrative of overall market demand.

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[2] BEIS (2018). Clean Growth – Transforming Heating. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766109/decarbonising-heating.pdf

[3] European Copper Institute (2018). Heat pumps: integrating technologies to decarbonise heating and cooling. Available at: http://www.buildup.eu/sites/default/files/content/ehpa-white-paper-111018.pdf

[4] BSRIA (2017). Global boiler market heats up as the UK is no longer the largest market. Available at: https://www.bsria.co.uk/news/article/global-boiler-market-heats-up-as-the-uk-is-no-longer-the-largest-market/

[5] European Copper Institute (2018). Heat pumps: integrating technologies to decarbonise heating and cooling. Available at: http://www.buildup.eu/sites/default/files/content/ehpa-white-paper-111018.pdf

[6] RHI deployment statistics, December 2018. Available at: https://www.gov.uk/government/collections/renewable-heat-incentive-statistics

Hydrogen boilers

Currently, hydrogen boilers are a commercially immature technology still in development. While most of the components can be adapted from existing technologies (e.g. burners from natural gas boilers and flame failure detection systems from industry), these have not yet been put into a packaged system that is suitable for large-scale adoption[7].

Heat networks

There are around 14,000 heat networks in the UK providing heating and/or cooling to over 75,500 buildings. Of these heat networks, around 12,000 are communal heat networks (serving only one building) and 2,000 are district heat networks (serving multiple buildings)[8]. The total heat network infrastructure is estimated to be around 1,800km long (compared to the 282,000km of gas pipework)[9].

Currently, district heat networks supply around 2% of total UK heat demand, serving approximately 480,000 customers. Heat networks generate 17.7 TWh of heating and hot water, and 1.9 TWh of cooling[10]. A vast majority of the final customers (92%) are residential, reflecting the higher proportion of communal heat networks which are generally connected to apartment blocks.

The current energy mix of heat networks (when looking at both communal and district) is dominated by natural gas (56%), efficient gas Combined Heat and Power (CHP) (32%), and biomass (10%). Networks in planning or under construction are expected to have a larger share of large-scale heat pumps and energy-from-waste (EfW) in the mix. Once heat networks are constructed, they are flexible and can be switched over to low-carbon sources with minimal disruption to consumers, even if they were initially supplied by fossil fuels.

Heat storage

Water-based tank storage is already a mature market in the UK. There are around 11 million hot-water cylinders and thermal stores installed in homes and approximately 400,000 are sold per year. Larger water-tank systems (greater than 500 litres) sell units in the low thousands each year for large residential or commercial applications. There are tens of systems in the district heating

[7] E4Tech pilot study for the heating and cooling EINA

[8] BEIS (2018). Energy Trends: March 2018, special feature article - Experimental statistics on heat networks. Available at: https://www.gov.uk/government/publications/energy-trends-march-2018-special-feature-article-experimental-statistics-on-heat-networks

[9] ADE (2018). Market Report: Heat Networks in the UK. Available at: https://www.theade.co.uk/assets/docs/resources/Heat%20Networks%20in%20the%20UK_v5%20web%20single%20pages.pdf

[10] BEIS (2018). Energy Trends: March 2018, special feature article - Experimental statistics on heat networks. Available at: https://www.gov.uk/government/publications/energy-trends-march-2018-special-feature-article-experimental-statistics-on-heat-networks

segment, where tanks are usually of between low hundreds to thousands of cubic metres in size[11].

Other heat storage systems have seen much more modest uptake, with numbers ranging from a few single projects to low tens of installations for different underground thermal storage technologies (e.g. pit-thermal, borehole-thermal, and aquifer-thermal energy storage). These projects are limited due to their more niche applications, limited discussion in academic literature, and, most importantly, high upfront costs.

The UK is home to a breadth of R&D into large-scale electrical and thermal energy storage. Researchers at Newcastle University recently developed the world's first grid-scale pumped heat energy storage (PHES) system. It has a maximum power output of 150kW and a storage capacity of 600kWh. Using a reversible heat pump/engine, it can dispatch both heat for buildings and/or electricity by reversing the process[12].

Cooling

The UK's cooling demand is relatively low, currently standing at ~1% of the heat demand. Less than 10% of the buildings in the UK meet their cooling needs today. However, all buildings in the UK are likely to provide some level of heating[13].

Cooling demand in the UK is skewed towards the commercial sector. Estimates suggest that around 0.5% of UK homes have air conditioning[14], while 30% of retailers and 65% of offices have air conditioning[15].

Future deployment scenarios

Various scenarios suggest that heat pumps will play an important role in decarbonising the UK's heating system:

- The National Grid's 'Community Renewables' scenario of decarbonisation estimates that 12 million residential heat pumps will be installed by 2041, up from 136,000 in 2020. In this scenario, heat pumps are installed in

[11] BEIS (2016). Evidence gathering: Thermal Energy Storage Technologies. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545249/DELTA_EE_DECC_TES_Final__1_.pdf
[12] ETI (2019). New energy storage technology places the UK at the forefront of an emerging global market. Available at: https://www.eti.co.uk/news/new-energy-storage-technology-places-the-uk-at-the-forefront-of-an-emerging-global-market
[13] Connolly et al. (2015). Heat Roadmap Europe: UK country report. Available at: https://heatroadmap.eu/wp-content/uploads/2018/11/STRATEGO-WP2-Country-Report-United-Kingdom.pdf
[14] National Grid (2015) quoting a Mintel report (2008). UK Energy Strategy: Electricity Demand. Available at: http://fes.nationalgrid.com/media/1155/electricity-demand-slides.pdf
[15] BRE (2016). Study on Energy Use by Air conditioning. Available at: https://www.bre.co.uk/filelibrary/pdf/projects/aircon-energy-use/StudyOnEnergyUseByAirConditioningFinalReport.pdf

almost 60% of households by 2050 – ASHPs being the most popular, followed by hybrid heat pumps (running on electricity and gas) and GSHPs. This scenario is based on a decentralised energy landscape[16].

- The EINA 'Baseline' and 'High Innovation' scenarios both estimate that ASHP capacity could reach 49GW by 2050, which represents a 37-fold increase from the 1.3GW installed in 2020.
- In the Committee on Climate Change's (CCC) 'Central Scenario' for cost-effective decarbonisation, a combination of heat pumps and heat networks provide heat for around 13% of homes and over 50% of businesses by 2050[17].

Hydrogen boiler capacity could exceed heat pump capacity by 2050:

- In the EINA 'High Innovation' Scenario, hydrogen boilers see an installed capacity of 57GW in 2040, up from nearly zero in 2030. Deployment is then expected to double by 2050, reaching 127GW of installed capacity[18]. Hydrogen boilers are expected to see a rapid uptake once they become commercialised around 2035.
- In the CCC's 'Full Hybrid' scenario, the heating demand in buildings is primarily met by hydrogen boilers in 2050, with an expected consumption of 470 TWh. This assumes gas networks are repurposed to hydrogen. There are several technical and commercial challenges that would need to be overcome in order to produce the volume of hydrogen needed for this[19].
- The CCC's 'Hybrid Hydrogen' scenario also assumes that gas networks are repurposed for hydrogen. However, hydrogen consumption is limited to playing a back-up role during peak demand for hybrid heat pumps. This would result in a 75% reduction in hydrogen use for buildings compared to the 'Full Hybrid' scenario.

Heat networks will continue expanding to deliver low-carbon heat to buildings, though there are differing views as to how much they will grow:

- The National Grid's 'Two Degrees' scenario of decarbonisation estimates that 2 million homes will be connected to heat networks by 2035 and over 3 million by 2050, accounting for 10% of all homes by 2050. This scenario is based on decarbonisation through larger and more centralised technologies[20].

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[16] National Grid (2018). Future Energy Scenarios. Available at: http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

[17] Committee on Climate Change (CCC) (2015). The Fifth Carbon Budget. Available at: https://www.theccc.org.uk/wp-content/uploads/2015/11/Committee-on-Climate-Change-Fifth-Carbon-Budget-Report.pdf

[18] Energy Systems Catapult (2018). Estimates based on the ESME whole-systems modelling tool following BEIS' EINA methodology.

[19] CCC (2018). Hydrogen in a low carbon economy. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf

[20] National Grid (2018). Future Energy Scenarios. Available at: http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

- KPMG's 'Diversified Energy Mix' scenario for decarbonisation estimates that 25% of the UK's heat demand will be met through heat networks by 2050. This scenario envisages a mix of technologies based on the best available solutions depending on the area in the country.[21].
- The Association for Decentralised Energy (ADE) estimates that 14-20% of the UK's heat demand could be cost-effectively met by heat networks by 2030 and 43% by 2050.[22].
- The Clean Growth Strategy (CGS) set out an indicative pathway to 2050 for heat networks to provide 17% of heat demand in homes and up to 24% of heat demand in commercial and public-sector buildings[23]. This is in line with the Committee on Climate Change's estimate that heat networks will be limited to around 20% of total building heat demand due to their need for high-density demand for them to be economic[24].

Hot-water tank storage will continue to be the most popular thermal energy storage (TES) system in the coming decades:

- Domestic tank storage will almost double from an estimated capacity of 161GWh in 2020 to over 294GWh in 2050.
- Large-scale tank storage (e.g. for district heating) is expected to increase 100-fold from a capacity of 4.73GWh in 2020 to over 471GWh by 2050.[25].
- The discrepancy in growth estimates stems from the fact that domestic hot-water tanks are already a relatively popular technology, but there are currently very few industrial-scale tank stores in the UK. As heat networks expand throughout the UK, so will large-scale tank storage.

Air conditioners are expected to become more widespread in the UK due to rising temperatures:

- The Met Office estimates that by 2070, summer temperatures could be up to 5.4°C warmer, and winter temperatures could be up to 4.2°C warmer. Both drive up cooling demand.[26].

[21] KPMG (2016). 2050 Energy Scenarios. Available at: https://www.energynetworks.org/assets/files/gas/futures/KPMG%20Future%20of%20Gas%20Main%20report%20plus%20appendices%20FINAL.pdf

[22] ADE (2018). Market Report: Heat Networks in the UK. Available at: https://www.theade.co.uk/assets/docs/resources/Heat%20Networks%20in%20the%20UK_v5%20web%20single%20pages.pdf

[23] HM Government/BEIS (2017). The Clean Growth Strategy: Leading the way to a low carbon future. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

[24] Committee on Climate Change (2016). Next Steps for UK Heat Policy. Available at: https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/

[25] Energy Systems Catapult (2018). Estimates based on the ESME whole-systems modelling tool following BEIS' EINA methodology

[26] BEIS (2018). Clean Growth – Transforming Heating. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766109/decarbonising-heating.pdf

- Four times more dwellings are expected to have air conditioning in 2050 than in 2020. This would be the equivalent to adding air conditioning in an additional 2.8 million dwellings.[27].
- As the expected increase in cooling demand will be met by electric cooling systems, decarbonising the grid will also decarbonise cooling. Projections by BEIS estimate that most of the UK's electricity supply will be low-carbon (renewables or nuclear) by 2035.[28].

Sub-theme system integration: Benefits, challenges and enablers

The integration of heat pumps, heat networks, heat storage, hybrid boilers, and cooling systems can offer many benefits to the energy system. These include providing efficient and low carbon electric heating and cooling, shifting heat and electricity loads, and facilitating the use of a wider range of heat sources (such as waste heat).

Heat pumps can be a very efficient means of electrifying heat:

- Given their high efficiency in upgrading ambient heat using electricity, and the expectation that the power sector will largely decarbonise between now and 2030, heat pumps are an important element of any attempt to decarbonise heating.[29].
- Heat pumps should be installed to the highest standards (e.g. the Microgeneration Certification Scheme guidelines) for optimum performance. Poor design and commissioning can undo the cost and carbon savings of switching to heat pumps and generate consumer mistrust.[30].
- Reversible air-to-air heat pumps (often categorised as part of the air conditioning market) are also able to provide cooling, hence integrated systems can meet temperature demands across seasons.[31].

Heat networks can maximise system efficiency and provide flexibility by distributing a variety of different heat sources to centres of demand based on local circumstances:

[27] Energy Systems Catapult (2018). Input assumption into the ESME whole-systems modelling tool following BEIS' EINA methodology.
[28] BEIS (2018). Updated energy and emissions projections 2017. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671187/Updated_energy_and_emissions_projections_2017.pdf
[29] Delta Energy & Environment (2018). Heat Pumps in Smart Grids. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/680512/heat-pumps-smart-grids-roadmap.pdf
[30] Energy Saving Trust (2013). The heat is on heat pump field trials phase 2. Available at: https://www.energysavingtrust.org.uk/sites/default/files/reports/TheHeatisOnweb%281%29.pdf
[31] Delta Energy & Environment (2017). The Contribution of Reversible Air-to-Air Heat Pumps to the UK's Obligation under the Renewable Energy Directive. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/680534/renewable-energy-reversible-air-to-air-heat-pumps.pdf

- Various low-carbon sources of heat can be integrated into heat networks (e.g. large-scale heat pumps, industrial waste heat, and energy-from-waste). The design of low-temperature heat networks further facilitates the broader integration of sources.
- Changing the heat source of a network that distributes energy to various buildings at once is more feasible and efficient than retrofitting individual dwellings with low-carbon heating.

The large-scale deployment of hydrogen boilers could encourage the development and growth of a national hydrogen supply chain, as well as of supporting technologies:

- Demand for hydrogen boilers, and therefore demand for hydrogen, will have a knock-on effect on other sectors. This includes power generation, where hydrogen can replace natural gas as the primary backup fuel complementing renewables and nuclear. It also includes transport, especially for heavy-duty vehicles, where the use of hydrogen fuel cells is expected to increase[32].
- The supply of hydrogen will likely rely on production methods other than just electrolysis, such as gas reforming or coal gasification. These methods need carbon capture and storage (CCS) to provide decarbonised hydrogen[33]. Therefore, the hydrogen supply chain will likely be developed in tandem with CCS technologies, which can also be used in the industrial sector. For further discussion on hydrogen across different sectors, see EINA sub-theme reports on hydrogen, road transport, industry, and CCUS.

Heat pumps can be integrated with other technologies, such as smart controls and storage, to balance the energy system:

- Recently published research suggests that the UK's heat demand is less "peaky" than previously believed. Peak national heat demand on a cold day is 170GW (rather than 277GW as previously estimated), which makes the electrification of heating more feasible[34].
- Peak heat demand can be met through smart control systems that enable heat pumps to 'pre-heat' a building to smooth out intra-day electricity demand variations.
- On the coldest days where heat demand is the highest, hybrid systems (using gas or low-carbon hydrogen) can switch to boilers to complement the heat pump[35].

[32] Committee on Climate Change (2018). Hydrogen in a low carbon economy. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf
[33] ERP (2016). Potential Role of Hydrogen in the UK Energy System. Available at: http://erpuk.org/wp-content/uploads/2016/10/ERP-Hydrogen-report-Oct-2016.pdf
[34] Watson et al. (2019). Decarbonising domestic heating: What is the peak GB demand? Available at: https://www.sciencedirect.com/science/article/pii/S0301421518307249
[35] CCC (2018). Hydrogen in a low carbon economy. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf

- Thermal energy storage (TES) can also help improve system performance by smoothing supply and demand, as well as improving the reliability of the heating source.[36].

[36] BEIS (2016). Evidence Gathering: Thermal Energy Storage (TES) Technologies. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545249/DELTA_EE_DECC_TES_Final__1_.pdf

Box 3. **System modelling: Low carbon heating and cooling in the UK energy system**

Following the BEIS EINA methodology, whole energy system modelling was conducted using the ESME^{TM} Version 4.4 to estimate where innovation investments could provide most value to support UK energy system development.

ESME is a peer-reviewed whole energy system model (covering the electricity, heat and transport sectors, and energy infrastructure) that derives cost-optimal energy system pathways to 2050 meeting user-defined constraints, e.g. 80% greenhouse gas (GHG) emissions reduction.[37]. The model can choose from a database of over 400 technologies which are each characterised in cost, performance and other terms (e.g. maximum build rates) out to 2050. The ESME assumption set has been developed over a period of over 10 years and is published.[38]. ESME is intended for use as a strategic planning tool and has enough spatial and temporal resolution for system engineering design.

Like any whole system model, ESME is not a complete characterisation of the real world, but it is able to provide guidance on the overall value of different technologies, and the relative value of innovation in those technologies.

The EINA Methodology prescribes the approach to be taken to assess the system-level value of technology innovation. This involves creating a baseline energy system transition without innovation (from which a baseline energy system transition cost is derived), and on a technology-by-technology basis assessing the energy system transition cost impact of “innovating” that technology. Innovation in a technology is modelled as an agreed improvement in cost and performance out to 2050.

For the EINA analysis, the technology cost and performance assumptions were derived from the standard ESME dataset[37] as follows[6]:

- In the baseline energy system transition, the cost and performance of all technologies is assumed to be frozen at their 2020 levels from 2020 out to 2050.
- The “innovated” technology cost and performance for all technologies are assumed to follow the standard ESME dataset improvement trajectories out to 2050 (these are considered techno-optimistic).

Whole system analysis using the BEIS EINA Methodology described above shows that there is significant value to the UK in continued (and accelerated) innovation in heating and cooling technologies:

- **Innovations in low-density heat networks have the potential to nearly double deployment rates as opposed to the baseline**

scenario. The EINA 'high innovation' scenario estimates a 25% drop in costs per dwelling for heat networks of all density areas. This would result in a 90%, 50%, and 13% increase in the number of dwellings connected to heat networks in low-, medium-, and high-density areas respectively. Low-density heat networks have the highest potential for increased deployment through innovation. This is because the cost per dwelling is over twice as much as in high-density areas.

- **Support for GSHPs could result in over a 10-fold increase in GSHP capacity deployment.** The EINA 'high innovation' scenario estimates that GSHPs could have an installed capacity of 3.4GW by 2050, as opposed to the 305MW expected under the 'baseline scenario'. The same scenario also estimates that GSHPs could see a cost reduction of 17% between 2020 and 2050. ASHPs would see the same cost reduction, but it would not affect its deployment rates as the optimisation in the 'baseline scenario' builds out ASHPs at (or very close to) their maximum required amount. However, due to the inhibitive cost and spatial requirements of GSHPs, better performance can have a larger impact on its uptake.
- **Hybrid heat pumps (running on gas and electricity) are expected to comprise 20-40% of the 9 million heat pumps installed by 2050**. They are expected to see cost reductions of around 17%, in line with cost reductions of other heat pumps. With a typical heat output of around 8kW, 80% of space heating is met via the heat pump, the remainder through the gas boiler, during peaks.
- **Hydrogen boilers are expected to see a 15% cost reduction from 2020 to 2050 in a High Innovation scenario.** Hydrogen boilers are expected to become commercialised around 2035. This would result in an installed capacity of 57GW in 2040, from nearly zero in 2030. Deployment rates would then double up to 2050, resulting in 127GW of installed capacity.
- **Large-scale hot-water tank storage is expected to increase 100-fold** from a capacity of 4.73GhW in 2020 to over 471GWh by 2050. This increase would be to provide storage capabilities to the heat networks connecting to millions of new customers.
- **Domestic air conditioning could see costs fall 25% in a 'high innovation' scenario.** This would mean air conditioning costs reducing from £250/kW in 2020 to £188/kW in 2050 as demand for them quadruples.

Whole system analysis using the BEIS EINA Methodology described above shows that there is significant value to the UK in continued (and accelerated) innovation in hydrogen. The value to the energy system of innovation in upstream hydrogen technologies is £12.9 billion cumulative to 2050 (discounted at 3.5%). The value to the system arises due to changing of the fuel to low carbon, rather than the changing of the boilers to become hydrogen compliant. Further work is required to determine how the estimated value of innovations in heating and cooling may change according to different system scenarios.

Box 4. **Learning by doing and learning by research**

The total system value follows from two types of technology learning:

- **Learning by doing:** Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors such as the impact of standards which tend to increase in direct proportion to capacity increases.
- **Learning by research:** Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D). It increases with spend in RD&D and tends to precede growth in capacity.

The EINAs are primarily interested in learning by RD&D, as this is the value that the HMG can unlock as a result of innovation policy. Emerging technologies will require a greater degree of learning by RD&D than mature technologies. Academic work suggests that for emerging technologies around two-thirds of the learning is due to RD&D, and for mature technologies around one-third is due to RD&D.[39].

By applying these ratios to the system value of technologies in the EINA 'High Innovation' scenario, the estimated values to the whole energy system by 2050 attributable to RD&D is £4.3 billion (of the £12.9 billion of total system value).

For the above technologies, the ratio applied to its system value was one-third. They can all be considered mature technologies. The exception are hydrogen boilers, for which two-thirds was applied. They are an emerging technology.

Note, this is an illustrative estimate, with the following caveats:

- The learning-type splits are intended to apply to cost reductions. However, in this study, we apply them to the system value. As system value is not linearly related to cost reduction, this method is imperfect.
- In practice, learning by RD&D and learning by doing are not completely separable. It is important to deploy in order to crowd-in investment to more RD&D, and RD&D is important to unlock deployment.

[39] Jamasb, Tooraj (2007). "Technical Change Theory and Learning Curves", The Energy Journal 28(3).

Innovation opportunities within low carbon heating and cooling

Introduction

Box 5. **Objective of the innovation opportunity analysis**

The primary objective is to identify the most promising innovation opportunities within low carbon heating and cooling technologies and highlight how these innovations may be realised and contribute to achieving the system benefit potential described above.

The innovations included in this section of the report are those that require government support to become commercialised, rather than innovations that are more likely to be delivered by industry. A longlist of innovation needs was compiled, dividing them into those two categories. The list was circulated to the attendees before the workshop. During the workshop it was confirmed that the innovation needs were correctly divided.

This section provides:

- A breakdown of the costs within low carbon heating and cooling across key technologies and activities.
- A list of identified innovation opportunities, and an assessment of their importance to reducing costs and deployment barriers.
- Deep dives into the most significant technology innovations.

Innovations in low carbon heating and cooling offer many benefits that can support cost savings and decarbonisation within the UK energy system. Heat pumps can deliver heat with low or zero emissions and can accommodate a range of renewable electricity generation sources. Widespread deployment of hydrogen boilers would support the development of a low-carbon hydrogen supply chain, which can benefit other sectors like transport and power. Heat networks and storage can relieve the pressures of a highly variable heat demand that fluctuates over the course of a day and between seasons. Heating, ventilation, and air conditioning (HVAC) units can cost-effectively meet both heating and cooling demands.

Despite many of the core technologies being well-established, their market uptake and penetration remains relatively limited in the UK. Without additional investment in key heating and cooling innovation areas, the UK will likely continue its reliance on other countries to develop new technologies.

The following sections of the report will highlight the key innovations needed in heating and cooling technologies. The technologies are presented separately in order to reflect their different cost structures and innovation needs.

Heat pumps

Cost breakdown[40]

Heat pumps are a mature technology and are manufactured at considerable scale, with over 4 million units sold globally in 2017.[41]. The total costs of heat pumps will vary by type and size, however overall there are still opportunities for cost reductions. For example, ASHPs could see cost reductions of around 20% in the UK if they reach "mass market adoption".[42]. Up to 50% of these cost reductions could be derived from non-equipment costs (e.g. efficient supply chain and better-trained installers). Up to 10% of the cost reductions could come from reducing unit costs through economies of scale and newer components.

The operating costs (made up of O&M and fuel costs) of heat pumps account for the largest cost component across varieties (as shown in Table 5). Operating costs account for a combined 77% of the lifetime cost for a commercial HVAC system, down to 56% for a domestic hybrid heat pump. Fuel costs account for the highest portion of the lifetime costs for all heat pumps except GSHPs.

In general, the combined cost of the main unit and ancillary parts are higher than the installation costs across all types of heat pump. However, the capital costs of individual components vary across models. Installation costs vary between 11-17% for all heat pumps except commercial, advanced HVAC systems, where installation makes up only 3% of the costs (see Table 5).

The key identified cost components for heat pumps are:

- Main unit: the compressor, condenser, evaporator, and refrigerant.
- Ancillary parts: valves, switches, thermostats, and other connected devices.
- Installation: the cost of labour to install a heat pump.
- O&M: operations and maintenance costs, accounting for check-ups and breakdowns.
- Electricity (and gas for hybrids): the cost of the fuel to run the heat pump.

[40] Table 5 provides a more detailed breakdown of costs, assumptions, and sources.
[41] IEA (2019). Renewables 2018. Available at: https://www.iea.org/renewables2018/heat/
[42] Delta Energy & Environment (2016). Potential cost-reductions for air-source heat pumps. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/498962/150113_Delta-ee_Final_ASHP_report_DECC.pdf

Table 5. **Levelised cost of heat pumps over a lifetime of 20 years**

Component	Domestic heat pumps		Commercial heat pumps	
	9kW Air-source heat pump	5kW Hybrid heat pump	100kW Ground-source heat pump	267kW Advanced HVAC system
Main unit	12%	21%	7%	7%
Boiler Unit	-	5%	-	-
Ancillary parts	10%	2%	9%	13%
Installation	15%	17%	11%	3%
Ground loop and installation	-	-	14%	-
O&M	16%	20%	30%	8%
Electricity (and gas for hybrid)	48%	36%	28%	69%
Total levelised cost of heat	**£0.135/kwh**	**£0.081/kwh**	**£0.145/kwh**	**£0.069/kwh**

Notes: *Seasonal coefficient of performance (CoP) average of 2.5 for domestic HPs and commercial HVAC; seasonal CoP average of 4 for commercial GSHP.*
Noise (dB): 40~50 for domestic HPs, 50~60 for commercial HPs.
Hybrid heat pump heat demand met by 80% electric heat pump, 20% gas boiler.
Advanced HVAC system provides electric heating and cooling (electric chiller-based), uses dry heating and cooling system (air ducts), HFO and HC as refrigerant, not using free cooling.
*Package sizes (m): 1.7*0.6*0.7 (ASHP), 1x0.45x0.4 (hybrid HP), 1.2*0.8*0.9 (GSHP).*

Source: ***For domestic heat pumps:*** *Capex, O&M, annual capacity factor, lifetime, and CoP from Sweett Group evidence collection via UKTM data. Cost breakdown from Delta-EE (2013). 2013 retail electricity price for residential buildings taken from BEIS 2017 Updated Energy & Emissions Projections.*
For commercial heat pumps: *O&M, annual capacity factor, lifetime, and CoP from UKTM data. Capex and cost breakdown from Buys et al., Investigation into capital costs of HVAC systems (2004). Capex inflated to 2013 price and converted to GBP. 2013 Services electricity price taken from BEIS 2017 Updated Energy & Emissions Projections. The HVAC equipment for cooling and heating is one and the same, the CAPEX and O&M should be treated carefully to avoid double counting. General technology constraints from Frontier Economics, Pathways to high penetration of heat pumps (2013). Expert interview; and E4tech & Vivid Economics analysis.*

Inventory of innovation opportunities

There is potential for technical innovation in heat pumps to both reduce costs and accelerate market deployment of the technology through overcoming existing barriers.

The opportunities expected to contribute most to reducing costs are:

- New system designs (including gas sorption, new compressors and expanders) which can reduce capital costs and improve performance.
- Products designed with improved opportunities to integrate with other technologies (e.g. heat storage, solar PV).
- Smart controls that provide demand-side response and management (DSRM), allow for efficient switching for hybrid systems, improve monitoring of heat pump performance, and reduce the perceived complexity around heat pumps among domestic end-users.

Innovation opportunities with the greatest potential to tackle barriers to deployment include:

- Improved 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.
- Further development of high-temperature heat pumps (HTHPs) which can integrate into existing wet heating systems and deliver low-cost domestic hot water.

For opportunities related to GSHPs, technical solutions to make drilling easier are considered the most important innovation for reducing costs and addressing other barriers to the deployment of GSHPs. Building ground-loops directly into foundations for new builds is another key opportunity that requires consideration.

For hybrid heat pumps the key innovation is in smart control systems that allow hybrids to efficiently switch between the electric heat pump and gas boiler. These smart controls should go beyond the conventional control systems based on external temperature. By load shifting to gas when the electricity system is reaching peak demand, hybrid heat pumps can provide comfort and cost reductions.[43]. However, it is important to optimise use across the gas and electricity components. Some studies show that the boiler component of the hybrid heat pump may meet up to 70% of the annual heat demand[44], reducing the potential of the hybrid system to cut emissions.

[43] Wales & West Utilities (2018). Freedom Project: Interim findings. Available at: https://www.wwutilities.co.uk/media/2715/freedom-project-short-paper-2018.pdf
[44] Element Energy (2017). Hybrid heat pumps. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf

It is also important to note that if hybrid systems see widespread domestic deployment, they may need to be replaced again in the future to completely decarbonise heating. In the short-term, installing hybrid heat pumps can lower the barrier to uptake, allow for the increased acceptance of heat pumps in general, and help grow the heat pump supply chain.

The table below highlights the specific innovation needs for heat pumps, their respective impact on reducing the costs and deployment barriers and the approximate timeframe for deployment. The workshop participants discussed the contents of the table and offered feedback. The updated table was afterwards circulated amongst workshop delegates with the opportunity to provide further comments. Prioritisation of cost reduction and barriers to deployment were elaborated by the Carbon Trust to reflect the importance of some innovations in the workshop interaction. The magnitude of the contribution to cost reduction and reducing deployment barriers are described in qualitative terms relative to other innovation opportunities:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

Table 6. **Innovation mapping for heat pumps**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Heat source	Gas sorption heat pumps with significant efficiency improvements over gas boilers. The innovation need is around design, for manufacturers to halve the cost per unit and further enhance reliability.	3	4	New (gas driven)	Gas boilers	2025-2030
System	Further development of high-temperature heat pumps (HTHPs), lowering their costs to deliver domestic hot water (at 60°C-80°C).	2	4	Electric heat pumps		2020-2025
	New heat pump products based on innovative new compressors and expanders currently in R&D phase (e.g. build on current research, which is already at TRLs 3-7 on new compressor designs).	4	2	Electric heat pumps	Gas boilers	2020-2025
	Products that also provide domestic cooling but can integrate to current wet heating systems.	2	3	Electric heat pumps	Gas boilers and cooling	2025
Installation	Improved product design (including ancillary services such as plumbing heat emitters) to facilitate installation cost reduction.	3	4	All heat pumps		2020
	Modularisation of systems (such as “plug ‘n’ play” and heat pumps with standardised backplates) to reduce installation costs and facilitate deployment.	3	3	All heat pumps		2020s
Integration	Products designed with improved opportunities to integrate with other technologies (e.g. heat storage, solar PV). Likely to rely on improved controls.	4	2	All heat pumps	Cooling family	2020-2025
O&M	Smart control system providing better integration of and efficient switching for hybrid systems. Demand-side response and management (DSRM). Feedback to user on performance and how to improve use. Improved monitoring to reduce costs from breakdowns and need for maintenance. Wider use of multi-zone controls.	3	3	All heat pumps	Cooling family	2020-2025

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Installation	Technical solutions to make drilling easier/more suited to multiple domestic sites, therefore lowering costs through mobility and flexibility.	3	3	Ground-source heat pumps only		2025
	Building ground loops into foundations for new build properties.	3	2	Ground-source heat pumps only	Gas boilers	2020-2025
	Technology to improve understanding of ground conditions pre-installation.	2	2	Ground-source heat pumps only	Gas boilers and domestic air conditioning	2025

Source: (1) LCICG, Technology Innovation Needs Assessment Heat Summary Report; (2) 2016, Delta-EE for DECC, Potential cost reductions for Air Source Heat Pumps, 2016; (3) IEA Energy Technology Perspective 2017; (4) Expert interview; and E4tech & Vivid Economics analysis.

Innovation opportunity deep dive: Advanced controls for heat pumps

Advanced and smart controls are considered an important innovation to improve heat pump operation and whole system performance, through demand side response and management (DSRM). This provides considerable reductions in cost and deployment barriers. The benefits of improved controls will vary between commercial and domestic users.

Domestic users often have difficulty understanding the instructions for operating and using the complex controls of their heat pump. This impacts on performance and efficiency. An improved interface could provide users with simpler controls, such as the ones they are accustomed to with boilers. Smart controls can also provide clear real-time feedback to users on their consumption patterns. Through DSRM, they can also take advantage of market mechanisms to reduce heating costs.

Smart control systems are also a key technology for allowing hybrid heat pumps to efficiently switch between the electric heat pump and gas boiler based on real-time conditions and price signals.[45]. Users can determine the comfort levels they want, enabling the smart control system to optimise how to achieve this. As the heat pump provides heat at a lower rate than the boiler, for it to contribute fully to comfort levels, the heat pump can commence operation earlier by pre-heating the home. When the heat pump is unable to provide all the space heating needed (e.g. on colder winter days), the boiler can switch on to provide boosts of heat to the system as a supplement.[46]. This switch could also be done as a response to price signals and grid constraints to further save on running costs.

For commercial users, smart controls can monitor heat pump performance in real-time. This has the benefit of providing dynamic alerts for irregular energy consumption, predictive maintenance, tariff avoidance, and other options for more efficient use. In this way, improved controls would reduce operating costs through real-time monitoring and optimisation as well as reduced costs from breakdowns. Improved controls are also essential for successful integration with other technologies, the benefits of which are explored below.

Innovation opportunity deep dive: Integration of high-temperature heat pumps (HTHPs) with other technologies

HTHPs are heat pumps that produce output temperatures above 65°C, which is enough for domestic hot water and space heating needs. Heat pump system

[45] Wales & West Utilities (2018). Freedom Project: Interim findings. Available at: https://www.wwutilities.co.uk/media/2715/freedom-project-short-paper-2018.pdf
[46] Committee on Climate Change (2018). Hydrogen in a low-carbon economy. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf

designs that allow high-output temperatures include heat pumps with cascade systems, enhanced vapour injection technology and gas-driven sorption products[47].

HTHPs have the added benefit of reducing a key deployment barrier by integrating into existing radiator systems as well as in homes with a high heat-loss rate. This avoids the need for disruptive and costly refurbishments to the building. This technology is currently most cost-effective for large or old properties, often off the gas grid (where the cost to connect to the gas grid makes these heat pumps more competitive).

Integrating HTHPs with smart controls and thermal energy storage (TES) could make running heat pumps just as, or more, cost-effective than gas boilers. In a recent field trial in a domestic UK setting, a HTHP integrated with water-tank TES replaced a gas boiler without any other modifications to the existing heating systems (such as radiators). At an average coefficient of performance (CoP) of 2.2, it was able to provide a flow temperature of 75°C. By using the stored heat, it could also provide thermal comfort during the highest calls for heat (in the mornings and evenings), albeit at a lower CoP. Such a system, running at an average CoP of 2.5, would be able to reduce emissions by 30%, compared to a conventional gas boiler, and at the same running costs[48].

Heat networks

Cost breakdown

Heat networks require significant upfront capital investment before low-cost heat can be generated and supplied to customers. A recent study for the Energy Technologies Institute[49] identifies the main capital costs for a baseline heat network. The model is designed based on current good practice, and with a network that connects to a range of domestic and non-domestic buildings with various dwelling densities. The largest capital costs identified came from the actual network infrastructure costs (72%), followed by the energy centre (28%), which acts as the central point of energy generation. Of the network's capital costs, the highest expenditure came from installation (26%), followed by design and the connection to the heat user (17% each), and piping (12%).

The operational costs of a heat network (such as maintaining pipes and generating the heat) can be far less than the capital costs, when compared on a net present value (NPV) basis. One of the main aims of a heat network is to

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[47] BEIS (2016). Low Carbon Heating Technologies: Domestic High Temperature Heat Pumps. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/565239/Domestic_High_Temperature_HPs-_FINAL2.pdf

[48] Shah et al. (2018). Analysis on field trial of high temperature heat pump integrated with thermal energy storage in domestic retrofit installation. Available at: https://www.sciencedirect.com/science/article/pii/S1359431118316521

[49] AECOM (2017). Reducing the capital cost of district heat network infrastructure. Available at: https://d2umxnkyjne36n.cloudfront.net/teaserImages/Reducing-the-capital-cost-of-district-heat-network-infrastructure.pdf?mtime=20171103092304

facilitate the use of low-cost heat. This is especially true in low-temperature heat networks, which are designed to facilitate the wider use of a variety of heat sources (such as industrial waste heat).

The cost of heating will vary depending on the heat source. Therefore, one must approach general cost assumptions with caution. Recent data[50] on heat from an EfW facility to a range of public and private sector buildings estimated that heat generation is 20% of the total costs. The overall cost breakdown from this project is in the table below.

The key cost components identified are:

- Installation: the civil engineering work of excavating and reinstating trenches.
- Design: the planning, design, and legal costs accrued before a contractor is appointed.
- Connection/Interface with heat user: the cost of Heat Interface Units (HIUs) and internal pipe connections from the building boundary to the HIU.
- Pipes: network transmission and distribution pipes, including all buried pipes, insulation, and joints.
- O&M: operation and maintenance include costs for pumping, maintenance of pipe connections and HIU, heat loss, and maintenance of the energy centre.
- Energy centre: the cost of building the central point of energy generation that supplies heat throughout the network.
- Heat generation: the cost of the heating fuel or the generation of heat in the energy centre. This cost will vary widely depending on the heat source used, which can include gas CHP, EfW facilities, or heat pumps.

[50] Heat Networks Delivery Unit (HNDU): 2018 Q2 Pipeline. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728865/HNDU_Pipeline_2018_Q2.pdf

Table 7. **Shares of heat network costs**

	Cost element	Costs of EfW-fed heat network
Component	Connection/interface with heat user	10%
	Network design, installation, & pipes	32%
	Energy centre	24%
	Operations & Maintenance	14%
	Heat generation costs	20%
General	**Total CAPEX**	**66%**
	Total OPEX	**34%**

Notes: *These are the estimated costs over 25 years at NPV discount rate of 3.5%. It is a £24 million large-scale network in the UK, supplying 34.5GWh of heat per year, with heat generated from an Energy-from-Waste facility.*

Source: *Heat Networks Delivery Unit (HNDU): 2018 Q2 Pipeline.*

Inventory of innovation opportunities

The primary innovations with the greatest potential to reduce heat network costs are:

- Designing 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. These alternative heat sources typically have lower emissions than gas-fired CHP and therefore support the transition to a low carbon heating system.
- 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.

There are also a handful of innovations that can contribute to reducing barriers to the deployment of heat networks, including:

- Adopting 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).
- 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.
- Research into regulatory innovations (e.g. simpler routing permissions) to optimise the regulatory framework and reduce deployment timescales.

The table below highlights the specific innovation needs for heat networks, their respective impacts on reducing the costs and deployment barriers and the approximate timeframe for deployment. The participants to the workshop discussed the contents of the table and offered feedback. The updated table was afterwards circulated amongst workshop delegates who were given the opportunity to provide further comments.

Prioritisation of cost reduction and barriers to deployment was elaborated by the Carbon Trust to reflect the importance of some innovations in the workshop interaction. The magnitude of the contribution to cost reduction and reducing deployment barriers are described in qualitative terms relative to other innovation opportunities:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

Table 8. **Innovation mapping for heat networks**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Design	Design of low-temperature heat networks, which facilitate integration of renewables, waste heat, thermal systems, cooling, large-scale heat pumps, storage, and novel component technologies.	4	5	Heat network	Large-scale heat pumps	2025
	Adopting low-temperature tertiary systems (e.g. underfloor heating) in new build/refurbishments to facilitate low-temperature network designs.	4	4	Heat network	-	2025
	Optimisation of design through extensive data collection and dissemination exercises, including heat demand profiles, waste heat availability, and greater emphasis on illustrating the benefits of heat storage.	5	3	Heat network	-	2025
Installation	Research into regulatory innovation (e.g. simpler routing permissions and reducing deployment timescales) that can optimise the regulatory framework for district heating.	4	5	Heat network	-	Early 2020s
Connection to heat user	Research and collection of data on the benefits of modifying tertiary heating systems to operate effectively at lower temperatures (while avoiding Legionella risks). This helps to achieve lower network return temperatures, allowing smaller pipes to be used (or more heat to be carried).	4	4	Heat network	-	2025
Interface with heat user	Innovation in metering/monitoring systems by improving accuracy, integrating wireless tech, and standardising heat exchangers at the interface.	3	3	Heat network	-	2025
	Customer monitoring and billing that incentivises engagement with energy consumption for energy efficiency and savings. Better customer service and interface to increase desirability and deployment.	3	4	Heat network	-	Early 2020s

Source: Carbon Trust research and interviews

Innovation opportunity deep dive: Designing low-temperature networks

Work is accelerating to commercialise so-called "4th generation" district heating (4GDH) .[51]. The International Energy Agency (IEA) promotes a long-term global vision to supply heat at on average 50°C, while obtaining a return temperature of 20°C. This is down from 3rd generation networks where the supply and return temperatures have been suggested to be 80°C and 40°C respectively. To be able to retain current radiator sizes, challenges for the design of lower temperature networks need to be overcome. Challenges include the elimination of temperature errors in distribution networks, customer substations and customer heating systems. In addition, challenges emerge when using longer thermal lengths in substation heat exchangers, to reduce temperature differences.

The main benefits of operating low-temperature networks are that they extend the scope of locally available sources of residual and renewable heat. This can allow the flexible operation of multiple heat sources, including integration of waste heat from industry or data centres, as well as the use of large-scale heat pumps. Low flow temperatures will also lead to less heat losses, thus increasing distribution efficiency. Demand for fossil fuels will reduce as a result of less heat loss from lower temperatures in the distribution networks. Additionally, reductions in running costs are expected from the increased efficiency of heat generation and the use of heat that would have otherwise been wasted.[52].

Innovation opportunity deep dive: Adopting low-temperature tertiary systems

Adopting low-temperature tertiary systems would enable the design of low-temperature networks. The design of low-temperature heat networks requires the development of tertiary heating systems, such as domestic hot water (DHW) and space heating (SH) (e.g. underfloor heating) systems, that are compatible with low-temperature requirements. These should use the limited available temperature difference between the supply and the return temperature. Lower temperature heating will result in lower network return temperatures, which are crucial to energy plant efficiency as they allow for minimising both pipe sizing and pumping energy.

During the workshop, experts emphasised the need to address how DHW loads can be met at the lowest temperature without introducing health risks, such as that of Legionella. The temperature required for DHW preparation is mainly driven by the prevention of legionella generation (50-60°C is internationally considered as usual). DHW production often implies higher supply and/or return temperatures than SH because of this risk.

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[51] IEA-DHC (2017). Transformation Roadmap from High to Low Temperature District Heating Systems. Available at: https://www.iea-dhc.org/fileadmin/documents/Annex_XI/IEA-DHC-Annex_XI_Transformation_Roadmap_Final_Report_April_30-2017.pdf
[52] Ibid.

Depending on national regulation, three strategies have been adopted to avoid legionella risk.[53]. (i) DHW production and storage at a temperature higher than 55°C to avoid the proliferation of Legionella. (ii) Temporary overheating (e.g. 1-2h everyday) of the storage tank at 60°C to 70°C, involving higher supply temperatures. (iii) Instantaneous DHW production at low temperatures without long-term storage. However, more research needs to be done to provide a lasting solution to this innovation barrier. The regulations adopted in the UK may act as a barrier to the use of low-temperature systems in the UK.

Innovation opportunity deep dive: Extensive data collection and dissemination for design optimisation

According to experts at the workshop, extensive data collection and dissemination for design optimisation has high potential to contribute to cost reductions and reduce deployment barriers of heat networks. It can act as a key enabler by disseminating information on knowledge-gaps and training the workforce.

While acknowledging the guidance provided in the ADE/CIBSE Code of Practice[54], there is a lack of centralised and coordinated empirical knowledge sharing on how to deliver low cost projects. There can be a reluctance to share knowledge among heat network developers as it may be perceived to be commercially sensitive, or that the process is too time-consuming, resulting in duplicative work. There was consensus that the entire industry would benefit from an extensive data collection and dissemination exercise on priority issues. Workshop experts agreed that regionally disaggregated heat demand profiles should be a key priority to allow for targeted network design optimisation.

Workshop experts also emphasised the importance of undertaking technical studies into regulatory innovation to facilitate heat network deployment. An example of an area to be explored for regulatory innovation is in routing permissions (e.g. for heat networks crossing railway tracks) as currently network developers have no special rights/support in their engagements with railway operators, making the design and installation process overly cumbersome. HMG has recently committed to looking at the statutory powers of heat networks.[55]

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[53] Dalla Rossa et al. (2014). Toward 4th Generation District Heating: Experience and Potential of Low-Temperature District Heating. Available at: https://www.iea-dhc.org/fileadmin/documents/Annex_X/IEA_Annex_X_Final_Report_2014_-_Toward_4th_Generation_District_Heating.pdf

[54] ADE & CIBSE (2015). Code of Practice for Heat Networks. Available at: https://www.theade.co.uk/resources/ade-cibse-code-of-practice-for-heat-networks

[55] BEIS (2018). Heat networks: ensuring sustained investment and protecting consumers. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774586/heat-networks-ensuring-sustained-investment-protecting-consumers.pdf

Heat storage

Cost breakdown

Cost of heat storage varies significantly depending on the type of technology used. There can be a wide range of capital costs depending on technology development level and how the heat is to be stored. Total costs can vary from less than £0.30/kWh for large inter-seasonal storage to above £400/kWh for small PCM stores.

Cost-reduction trajectories vary depending on deployment tests. Tank storage is unlikely to see significant cost changes as this is a relatively well-established technology. Other technologies, such as PCM and thermochemical storage, are between 5 to 10 years away from mass commercialisation in the UK. Therefore, it is difficult to accurately forecast cost trajectories, given that unforeseen step-change developments may occur and significantly reduce costs[56]. There is also limited data available on O&M costs.

Table 9. **Cost of thermal energy storage**

Category	Levelised cost of technology	Other performance factors affecting deployment
Tank	1-180 £/kWh	Technology is costlier at domestic scale.
Pit	0.30-0.80 £/kWh	Suitable only for heat network applications.
Borehole	As low as 0.30 £/kWh	Highly dependent on size and method.
Aquifer	600-1,000 £/kWh	Suitable for heat networks and larger commercial buildings.
PCM	250-400 £/kWh	Potentially as low as 50 £/kWh for large scale installation.
Thermochemical energy storage	-	Highly variable at current stage of development.

Note: Indicative values taken from a 2016 study.

Source: BEIS (2016). Evidence Gathering: Thermal Energy Storage (TES) Technologies.

[56] BEIS (2016). Evidence Gathering: Thermal Energy Storage (TES) Technologies. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545249/DELTA_EE_DECC_TES_Final__1_.pdf

Inventory of innovation opportunities

The primary innovations with the greatest potential to reduce cost and deployment barriers are:

- Thermal time shifting and intraday storage using PCMs (materials that undergo phase transitions during the absorption or emission of heat). PCMs can be used in new buildings, as well as in retrofits where they can be integrated with water tanks to reduce storage size or increase capacity.
- Thermochemical heat storage, where reversible chemical reactions are used to store large quantities of heat in a compact volume for medium and long-term/seasonal storage.
- Using alternative heat sources and sinks in the built environment (e.g. building fabrics and wastewater networks) to facilitate heat storage at the building and/or heat network scale.

Additionally, other innovations with the potential to reduce the costs of storage include:

- Cold storage for infrequent hot weather events through re-usable technologies (e.g. PCMs including ice).
- 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 table below highlights the specific innovation needs for heat storage, their respective impacts on reducing the costs and deployment barriers and the approximate timeframe for deployment. The workshop participants discussed the contents of the table and offered feedback. The updated table was afterwards circulated amongst workshop delegates, who were given the opportunity to provide further comments.

Prioritisation of cost reduction and barriers to deployment was elaborated by the Carbon Trust to reflect the importance of some innovations in the workshop interaction. The magnitude of the contribution to cost reduction and reducing deployment barriers are described in qualitative terms relative to other innovation opportunities:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

Table 10. **Innovation mapping heat storage**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Heat source & sink	New solar thermal collectors (e.g. using volume-based absorption).	3	4	Heat storage	Heat network	2025
	Building's fabric and property's road/tarmac as a heat source (e.g. coating technologies, smart windows).	4	4	Heat storage	Building fabric	2035
	Water/wastewater networks acting as the heat source and heat sink.	5	4	Heat storage	Heat network	2025
Heat store	Diurnal thermal energy batteries using buildings as heat store by incorporating phase change materials (PCMs).	2	3	Heat storage	Building fabric	2020
	Diurnal storage incorporating PCMs or other cost-effective technology into in-house water system (e.g. wastewater form showers).	4	4	Heat storage	-	2025
	Intraday storage through PCMs in new buildings and retrofits (integrated with water tank) to reduce storage size or increase its capacity	5	4	Heat storage	Heat network	2025

	(including extraction of heat).					
	Thermochemical heat storage (THS) for medium and long-term/seasonal storage.	5	4	Heat storage	Heat network	2035
	Cold storage for infrequent hot weather events through re-usable technologies (e.g. PCMs including ice).	5	3	Heat storage		2025
	Integration of buildings-scale seasonal storage e.g. underground thermal storage technologies (pit, borehole, and aquifer).	3	3	Heat networks	Grid-scale thermal storage	2025
	High energy density phase-change materials for district heating to reduce space and save on installation and O&M compared to water tanks.	5	3	Heat networks	Buildings, grid-scale thermal storage	2020

Source: Carbon Trust research and interviews

Innovation opportunity deep dive: Thermochemical heat storage as seasonal storage

Thermochemical heat storage (THS) for medium- and long-term/seasonal storage uses reversible chemical reactions to store thermal energy in the form of chemical compounds. This energy can be discharged at different temperatures, dependent on the properties of the thermochemical reaction. The benefits of using THS materials include (i) high energy density, (ii) low charging temperature, (iii) high thermal conductivity, and (iv) high sorbate uptake.[57]. The utilisation of solar energy in the summer period for charging THS systems would make seasonal storage possible. This would be ideal to supply buildings with cheap hot water and space heating in the winter months. However, the high regeneration temperature requirement of adsorbents is still the main obstacle to benefiting from solar systems. Research into hybrid processes, where solar collectors coupled with THS heat pumps are integrated and optimised, should be carried out together to improve the performance of THS.

Though many promising research studies are ongoing, THS technology is still not at a sufficiently developed stage for commercialisation. For THS to become economically feasible, several innovations are needed. The reactor design needs to reach high output temperatures for a sufficiently long time period. Materials must improve, to be used for higher storage density and at a lower price. The humidification process must also be improved for overall system efficiency.

Innovation opportunity deep dive: Phase-change materials as diurnal storage

Using phase-change materials (PCM) as diurnal storage offers opportunities for innovation. A PCM is a substance with a high heat of fusion that can store and release large amounts of energy through undergoing transitions between solid and liquid phases. Buildings can be used as a heat store using paraffin (a non-flammable PCM) in its building materials. This is already in the final stages of innovation but currently expensive, even though there have been small cost reductions.

Raising awareness, knowledge, and know-how within the house building sector on how to incorporate PCMs into building design will be key to supporting widespread deployment. As well as building materials, PCMs can be used to capture the large amounts of heat that is wasted in domestic greywater (e.g. after showering and washing), recycling the heat back to the household heating system. This has the added advantage that it can be easily implemented in refurbishments because it does not affect any other systems. PCMs can also be incorporated directly into water tanks and have the potential to be used in new or retrofit houses to decrease water tank size or increase the water tank's storage capacity.

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[57] Aydin et al. (2015). The latest advancements on thermochemical heat storage systems. Available at: https://www.sciencedirect.com/science/article/pii/S1364032114007308

Innovation opportunity deep dive: Cold storage through ice

Cold storage through ice is a form of latent heat storage, where energy is stored in a material that undergoes a phase change as it stores and releases energy (therefore ice behaves as a PCM). Ice has excellent material properties for cold storage, including a high heat of fusion, good heat capacity, and non-corrosive behaviour.[58]. As the solid form of water, ice is easily available and inexpensive. To store cold energy in ice, off-peak or renewable electricity can be used to freeze water using chillers or ice generators placed above ice tanks. For discharging, the cold energy can transfer via water or additional heat transfer fluid, such as glycol. Ice thermal energy storage systems have two typical configurations, namely as bulk ice storage and ice-on-coil storage.

Although more expensive than chilled water tanks, cold storage through ice offers a lower spatial footprint. Thermal storage using ice is available for buildings and district cooling schemes. In the US, an estimated 1 GW of ice storage has been deployed to reduce peak energy consumption in areas with high numbers of cooling-degree days. As domestic cooling demand is infrequent in the UK. More support for this technology is needed for it to be commercially available.

Hydrogen boilers

Cost breakdown

Hydrogen boilers are expected to have relatively low capital costs (comparable to gas boilers), however the higher cost of hydrogen as a fuel will drive up overall costs. In a like-for-like switch of natural gas heating to 100% hydrogen boilers, the higher cost of hydrogen fuel would account for 75% of the increased lifetime costs of a hydrogen boiler. The upfront costs of switching the pipework and appliances contribute 25% of this increase. The cost of hydrogen will be significantly higher than gas because the full hydrogen chain is still nascent, as well as due to conversion inefficiencies. For example, electrolysing low-carbon electricity, supplying it to the hydrogen grid, and then burning it in a boiler may yield a 38% loss of the supplied electricity through the conversion process.[59].

Estimates from the Committee on Climate Change (CCC) suggest that a national switchover to hydrogen use in buildings would cost around £2,000-4,000 per household. This includes pipework upgrades in the home and conversion of additional gas appliances but excludes the cost of transforming the gas networks. Costs could be reduced by around £1,500 per household if ‘hydrogen-ready’ natural gas boilers could be installed as part of regular boiler replacement cycle.[60].

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[58] IEA (2014). Technology Roadmap: Energy Storage. Available at: https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergystorage.pdf
[59] Committee on Climate Change (2018). Hydrogen in a low carbon economy. Available at: https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf
[60] Ibid.

The key cost components identified for hydrogen boilers are:

- Boiler unit: all parts of the boiler unit (e.g. the burner, heat exchanger, fan, valves etc.) that are used to generate heat from hydrogen.
- Installation: the cost of labour to install the hydrogen boiler.
- O&M: operations and maintenance costs (e.g. for check-ups and breakdowns).
- Hydrogen fuel: the cost of the hydrogen to run the boiler.

A 24kW hydrogen condensing boiler has been chosen to reflect hydrogen boiler costs as it is expected to be the most deployed technology in this technology family. This reflects modelling conducted in an earlier phase of the EINA project (the Stage 1 methodology development) in which this technology was the single most deployed type of hydrogen boiler.[61].

Table 11. **Cost and performance of hydrogen boiler (24kW condensing boiler)**

	Component	Levelised cost of heat	Other performance factors affecting deployment
Component-specific	Boiler unit	14%	Lifetime 20 years
	Installation	10%	Installation takes two days
	O&M	28%	
	Hydrogen fuel	53%	HHV efficiency 84%
	TOTAL	**£0.137/kWh**	
General	Speed of gas network transition to hydrogen	Speed of transition affects demand for hydrogen boilers and so manufacturing scale (number of units per year), which is the primary influence on unit cost.	
	Buildings that can use hydrogen boilers	Limited to buildings with wet heating systems, unlikely to be changed through innovation given the limitations in safety and space, and cost of changing from dry heating system.	
	Ancillary works	Existing natural gas pipework might need to be replaced/retrofitted/upgraded for hydrogen application. Cost depends on existing pipework type and can be up to £2,000/house for new pipework.	
	Hydrogen flame colour	Hydrogen burns with a pale blue flame that is not visible in daylight conditions which presents safety and maintenance concerns. Can be mitigated by colourisation.	
	Hydrogen odour	Hydrogen has no taste or odour which cannot be detected, causing safety concern. Can be mitigated by odorization.	

Sources: *Capex assumed to be 250% of gas boiler cost, from Kiwa Desk study on the development of a hydrogen-fired appliance supply chain (2016). O&M, annual capacity factor, lifetime, and efficiency from UKTM data. Cost breakdown from Frazer-Nash Appraisal of Domestic Hydrogen Appliances report (2018). Hydrogen price (£0.076/kWh) from Leeds City Gate H21 report. E4tech analysis and expert interview.*

[61] Based on E4Tech research using the UK TIMES model (UKTM) developed by researchers at UCL.

Inventory of innovation opportunities

Hydrogen boilers are a commercially immature technology still in development. While most of the components can be adapted from existing technologies (e.g. burner from natural gas boiler and flame failure detection from industry), these have not yet been put into a packaged system suitable for large-scale adoption. Most of these innovations fulfil essential safety requirements. These include flame failure detection, leak detection and colourisation. Others fulfil basic user needs, such as designing a domestic hydrogen burner. While some innovations, including heat exchangers for specific hydrogen appliances, are aimed at cost reduction.[62].

The low overall system technology readiness level, but high component technology readiness level, suggests that mass manufacture is required to drive costs down. A clear demand signal will enable boiler makers to manufacture at scale and lower costs through economies of scale. Furthermore, a sustainable supply of low-carbon hydrogen is essential to satisfy demand, however this is outside the scope of this sub-theme EINA.

The key innovations in hydrogen boilers that can reduce costs are:

- Scaling-up of hydrogen boiler manufacturing to coincide with deployment stages in a planned roll-out of the technology.
- Solutions that avoid (or minimise) the need to replace gas pipework in houses, such as by providing affordable, low pressure hydrogen fittings applicable to domestic installations.

Key innovations in hydrogen boilers that can reduce deployment barriers are:

- Development and demonstration of a packaged system that can match the features of natural gas boilers (e.g. appliance efficiency, lifetime, maintenance requirements, size and ease of use).
- Component improvements such as burner technology, flame failure detection and leakage detection.

Table 12 highlights the specific innovation needs for hydrogen boilers, their respective impacts on reducing the costs and deployment barriers and the approximate timeframe for deployment. The workshop participants discussed the contents of the table and offered feedback. The updated table was afterwards circulated amongst workshop delegates, who were given the opportunity to provide further comments.

[62] E4Tech (2018) EINA pilot report on heating & cooling

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- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

Table 12. **Innovation mapping for hydrogen boilers**

	Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Which technology will this innovation affect	Impact on other energy technology families	Feasible timeframe
Component specific	Boiler unit	Hydrogen burner technology suitable for domestic appliances.	3	5	Hydrogen boilers	Hybrid heat pumps, oven, hobs	2020
	Boiler unit	Fast-acting, low-cost and reliable flame failure sensor suitable for mass manufacture (UV and IR sensor in industrial process).	2	5	Hydrogen boilers	Hybrid heat pumps, oven, hobs	2020
	Boiler unit	Heat exchanger that can handle hydrogen's higher temperature output.	3	3	Hydrogen boilers	Hybrid heat pumps	2020
	Boiler unit	Leakage detection and prevention, investigation of leakage and material degradation with hydrogen at low pressures used in domestic properties.	3	5	Hydrogen boilers	Hybrid heat pumps, oven, hobs	2020
	Boiler unit	Hydrogen flame colourisation to make it visible - involves investigating effect of additives in hydrogen source and burner.	1	4	Hydrogen boilers	Hybrid heat pumps, oven, hobs	2020
	Boiler unit	Hydrogen odorization to make it human-detectable if there's a leakage and increase safety.	1	5	Hydrogen boilers	Hybrid heat pumps, oven, hobs	2020
	Boiler unit	Packaging of all above components designed for hydrogen combustion, to optimise operation and minimise package size.	3	5	Hydrogen boilers	Hybrid heat pumps	2020
	Ancillary works	Solution that avoids or minimises need to replace gas pipework in house.	4	5	Hydrogen boilers	Hybrid heat pumps, oven, hobs	2020
General	Speed of gas network transition to hydrogen	Staged deployment to allow manufacturing scale-up in tandem with roll-out planning, to enable manufacture at scale to bring down capital costs.	5	5	Hydrogen boilers	Hybrid heat pumps, oven, hobs	2020

Sources: (1) Frazer-Nash for BEIS (2018). Appraisal of Domestic Hydrogen Appliances. (2) Expert interview; and E4tech & Vivid Economics analysis

Innovation opportunity deep dive: hydrogen boiler component improvements

Hydrogen has a significantly higher flame speed, greater flammability range and is likely to burn at a higher temperature than natural gas. These characteristics present significant engineering challenges that particularly affect the burners in hydrogen boilers (as well as hydrogen hobs and ovens). Specifically, there are concerns with light-back (the spread of flames back through the burner), higher nitrogen oxide emissions and the potential explosion of unburned gas. To mitigate these effects, it may be necessary to remove the primary aeration, re-size the burner ports (holes) and remove internal cavities where combustible gas mixtures could form. It will also be necessary to select and test materials that are suitable for higher temperature combustion. There is currently no consensus on the best type of burner for hydrogen combustion and the innovation currently has a TRL of 2-4.[63].

Another key technical concern is the Flame Failure Device (FFD) which detects the presence of a flame and shuts off the gas supply if it is extinguished. Natural gas boilers use ionisation sensors to detect flames (through the resulting combustion gases) and these cannot be used with hydrogen. Alternatives, such as ultraviolet and infrared sensors, are available and used for industrial processes but these will need to be redeveloped to reduce their size and cost. As these require extensive reliability and lifetime testing, they have a TRL of 4-5. Additionally, hydrogen also burns with a pale blue flame difficult to see in daylight, presenting safety concerns.

Innovation opportunity deep dive: integrating hydrogen boilers with existing pipework

Installing hydrogen boilers requires reinforcing or checking the pipework to reduce the risk of leakage. Due to its small molecular size, hydrogen has a greater propensity to leak through small openings than natural gas. There is a particular concern with leakage through flanged joints and screwed connections, which may require welded joints to avoid. However, the appliances will need to be accessible for servicing and this will require further consideration by selecting appropriate quality of fittings for serviceable joints.

Hydrogen is also known to reduce the service life of metallic components such as pipework and valves. Embrittlement of metals is the most common form of damage; however, this often occurs at higher pressure (e.g. for vehicle refuelling or industrial metal welding). For domestic gas appliances working at low pressures (e.g. 20 mbar), embrittlement is unlikely to be a concern. Tests have shown that hydrogen blended with natural gas has minimal material degradation, however testing on the

[63] Frazer-Nash Consultancy (2018). Appraisal of Domestic Hydrogen Appliances. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/699685/Hydrogen_Appliances-For_Publication-14-02-2018-PDF.pdf

internal appliance pipework will be needed to ensure adequate reliability and lifetime for low pressure applications using 100% hydrogen.[64].

Cooling

Cost breakdown

Cooling units are a mature technology and have been manufactured at large scale (135 million units sold globally in 2016[65]). As a result, it is expected that there is relatively limited opportunity for further capital cost reductions. The cooling family in the scope of this EINA includes standalone air conditioning units which only provide cooling. It also considers reversible heat pumps, which can provide both cooling and heating. These are part of a heating, ventilation, and air conditioning (HVAC) unit. These reversible heat pumps are fundamentally the same technology as employed within the heat pump family. Even though cooling is most popular in commercial buildings, commercial users are typically more aware of air conditioning systems and may overlook HVAC units that have the benefit of providing integrated heating and cooling services. The legacy of poor and uncertain performance also affects confidence in HVAC technology, although this is not as significant an issue as for domestic heat pumps.

A commercial 267kW HVAC system (using electric chillers) has been chosen to reflect HVAC costs. This reflects modelling conducted in an earlier phase of the EINA project (the Stage 1 methodology development) in which this technology was the single most deployed technology in the cooling family.[66].

Table 13. **Levelised cost of commercial 267kW advanced HVAC system for cooling**

Component	Levelised cost for cooling	Levelised cost for heating	Other factors affecting performance
Main unit	13%	7%	Lifetime: 20 years
Ancillary parts	23%	13%	
Installation	5%	3%	May require decommissioning of existing wet heating system after converting to dry heating system (air ducts) which are also used for cooling.
O&M	15%	8%	
Electricity	45%	69%	CoP (seasonal average) of 3 for cooling, 2.5 for heating. Heat/cold loss in distribution.
TOTAL	**£0.089/kwh**	**£0.069/kwh**	

[64] Ibid.
[65] IEA (2018). The future of cooling. Available at: https://webstore.iea.org/download/direct/1036?fileName=The_Future_of_Cooling.pdf
[66] Based on E4Tech research using the UK TIMES model (UKTM) developed by researchers at UCL.

Notes: *Advanced HVAC system provides electric heating and cooling (electric chiller-based), dry heating and cooling system (air ducts), HFO and HC as refrigerant.*

Source: *O&M, annual capacity factor, lifetime, and CoP from UKTM data. Capex and cost breakdown from Buys et al. (2004), Investigation into capital costs of HVAC systems. Capex inflated to 2013 price and converted to GBP. 2013 Services electricity price taken from BEIS 2017 Updated Energy & Emissions Projections. The HVAC equipment for cooling and heating is one and the same, the CAPEX and O&M should be treated carefully to avoid double counting. General technology constraints from Frontier Economics (2013), Pathways to high penetration of heat pumps. Expert interview; and E4tech & Vivid Economics analysis.*

Inventory of innovation opportunities

This technology family is worth investigating separately given that cooling demand profiles and deployment patterns (skewed towards commercial buildings) are different from heating. However, technology development status, costs, innovation opportunities, barriers, and the interaction with the wider energy system will share similarities to heat pumps. Industrial, agricultural, or retail refrigeration were not in the scope of this report and could be considered in further iterations of this analysis.

The primary innovations with the greatest potential to reduce the costs of cooling are:

- Smart control systems providing better feedback to user on performance; improved monitoring to reduce breakdowns and maintenance; optimisation of equipment and energy source based on operating conditions; advanced occupancy data.
- New chillers based on innovative new compressors currently in R&D phase.
- Development of advanced toolsets to model cooling demand and identify the most effective system design to meet need (based on big data analysis).

Other innovations that can also contribute to reducing deployment barriers to cooling include:

- Alternative to vapour compression cycle refrigeration (e.g. magnetic refrigeration, evaporative cooling, membrane cooling, sorption cooling etc.).
- System integration with other technologies (such as heat source, solar PV, and thermal storage) to improve CoP.

Table 14 highlights the specific innovation needs for cooling, their respective impact on reducing the costs and deployment barriers and the approximate timeframe for deployment. The workshop attendees discussed the contents of the table and offered feedback. The updated table was afterwards circulated amongst workshop delegates, who were given the opportunity to provide further comments.

Table 14. **Innovation mapping for cooling**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Main Unit	System integration with other technologies to further improve CoP, including integration with heating systems, solar PV, and thermal storage.	3	3	Cooling family	Heat pump family	2025
	New chillers based on innovative new compressors currently in R&D phase (e.g. build on current research which is already at TRLs from 3-7 on new compressor designs).	4	2	Cooling family	Heat pump family	2025-2030
	Heat exchanger-related innovations such as compact size, improved materials and coatings, and new forming methods to provide new form factors.	3	3	Cooling family	Heat pump family	2025
System	Alternative to vapour compression cycle refrigeration (e.g. magnetic refrigeration, sorption cooling etc.).	2	4	Cooling family	Heat pump family	2030
Design	Development of more advanced toolsets to model cooling demand and identify most effective system design to meet need (based on big data analysis) and facilitated by smart controls.	4	3	Cooling family	Heat pump family	2030
Control	Linking cooling with the energy system. Smarter controls enhancing flexibility for grid services (e.g. demand-side management).	3	2	Cooling family	Heat pump family	2020-2025
O&M	Smart control system providing: Better feedback to user on performance; Improved monitoring to reduce breakdowns and maintenance; optimisation of equipment and energy source based on operating conditions.	4	3	All heat pumps	Heat pump family	2025
Storage	Use of phase change materials within, or integrated with, refrigeration systems to enhance cooling system flexibility (linked to smart controls).	3	3	Cooling family	Heat pump family	2030

Source: *(1) LCICG, Technology Innovation Needs Assessment Heat Summary Report; 2016, Delta-EE for DECC, Potential cost reductions for Air Source Heat Pumps, 2016; (2) IEA Energy Technology Perspective 2017; (3) US Department of Energy, Energy Savings Potential and Research, Development, & Demonstration Opportunities for Commercial Building Heating, Ventilation, and Air Conditioning Systems, 2011; (4) Navigant and Oak Ridge National Laboratory, The future of Air Conditioning for Buildings, 2016; (5) Expert interview; and E4tech & Vivid Economics analysis.*

Innovation opportunity deep dive: Advanced control systems

HVAC systems in commercial buildings already use a variety of monitoring data, traditionally relying on temperature and humidity sensors in a thermostat to determine whether the current status meets pre-set comfort settings. Small buildings will often have one thermostat for each HVAC system, whereas larger commercial buildings will have sensors across different zones to feed information into the central energy management system (EMS). The current generation of sensors can operate effectively but require costly wired connections and can often not account for the changing dynamics of the building in real time, such as occupancy.

Advanced controls from multifunction plug-and-play wireless sensors can enhance the capabilities of sensor networks for commercial HVAC applications. Beyond using improved sensors, these systems incorporate wireless communications, low-energy computing, energy harvesting technologies and advanced manufacturing processes. These features reduce installation cost and complexity, facilitate predictive maintenance, and allow for increased deployment across the commercial buildings space.[67].

These hardware and software advances can provide energy savings by improving the control of commercial buildings, through occupancy sensing, automatic setpoint scheduling, and other strategies. For example, sensors can determine the number of occupants within a room to adjust ventilation rates and allow the control system to relax the temperature setpoint once the occupants leave. Control system improvements can also provide new demand-side management opportunities. This is particularly true for larger loads, where the thermal mass of buildings can be utilised to allow HVAC systems to be turned down during periods of peak demand. While these features can be incorporated in larger buildings with EMS, small and older commercial buildings often cannot incorporate these strategies cost-effectively.

As well as being key to improving the operation of commercial HVAC systems, an expansion of sensor networks can enable several wider benefits in other areas. This includes energy-saving strategies around lighting controls, or non-energy benefits such as occupant mapping for building safety, security, and space utilisation.

Innovation opportunity deep dive: Magnetocaloric refrigeration

Magnetocaloric cooling systems provide an alternative to vapour compression cycle refrigeration. They use the unique properties of materials that undergo a reversible temperature change when exposed to a changing magnetic field. These paramagnetic materials increase temperature when magnetised and decrease temperature when demagnetised. By cyclically altering the magnetic state of the

[67] US Department of Energy (2017). Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems. Available at: https://www.energy.gov/sites/prod/files/2017/12/f46/bto-DOE-Comm-HVAC-Report-12-21-17.pdf

materials, the system functions like a conventional cooling cycle, absorbing heat from the space, then rejecting heat to a heat sink. This is an emerging technology area. If magnetocaloric cooling systems could be successfully developed, they could offer potential energy savings for space cooling and refrigeration applications. This would reduce the need for refrigerants with high global-warming potential (GWP)[68]. Magnetic cooling systems have the potential for wide-scale adoption as they could be used in all vapour-compression type air cooling systems for commercial buildings. The technology could also operate as a reversible heat pump, but limited information is available on space heating performance. The current barriers faced by the technology are in issues related to materials and system assembly.

Developing compact, high-capacity systems at reasonable cost is needed for magnetocaloric space cooling systems to be commercially viable. The near-term market introduction of magnetic cooling systems for small refrigeration applications is a promising sign that the technology may have wider potential. Nevertheless, additional R&D is necessary to improve on the temperature lift, cooling capacity, and efficiency of conventional air conditioning systems. Beyond cooling performance, magnetic cooling systems must meet the cost, size, weight, and reliability requirements of mature vapour-compression air conditioning products.

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[68] US Department of Energy (2017). Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems. Available at: https://www.energy.gov/sites/prod/files/2017/12/f46/bto-DOE-Comm-HVAC-Report-12-21-17.pdf

Business opportunities within low carbon heating and cooling

Introduction

Box 6. **Objective of the business opportunities analysis**

The primary objective is to provide a sense of the relative business opportunities against other energy technologies. To do so, the analysis uses a consistent methodology across technologies to quantify the 'opportunity'; in other words, what *could* be achieved by the UK. The analysis assumes high levels of innovation but remains agnostic about whether this is private or public. This distinction is made in the final section of the report. The two key outputs provided are:

- A quantitative estimate of the gross value added, and jobs supported associated with low-carbon heating and cooling technology, based on a consistent methodology across technologies analysed in the EINA. Note, the GVA and jobs supported are *not* necessarily additional, and may displace economic activity in other sectors depending on wider macroeconomic conditions.
- A qualitative assessment of the importance of innovation in ensuring UK competitiveness and realising the identified business opportunities. Note, the quantitative estimates for GVA and jobs supported cannot be fully attributed to innovation.

The following discussion details business opportunities arising both from exports and the domestic market. An overview of the business opportunities, and a comparison of the relative size of export and domestic opportunities, across all EINA sub-themes is provided in the overview report. More detail on the business opportunities methodology is provided in the Appendix.

Global heating and cooling markets are large and well established.
The global stock of installed heating systems exceeds 3 billion[69], while 1.6 billion air conditioning units were in place as of 2016.[70]. These stocks are forecast to reach over 6 billion and 5 billion units respectively by 2050, with most of the growth coming from the residential sector, particularly in emerging economies. Across regions,

[69] IEA (2017), "Energy Technology Perspectives"; https://www.iea.org/etp/
[70] IEA (2018), "The Future of Cooling"

heating solutions are diverse due to national characteristics such as climate and fossil fuel endowments. Similarly, cooling is concentrated in a few countries, with two-thirds of the current stock in China, the US, or Japan.[71]. Large multinational companies operate across the global supply chain, such as Johnson Controls and United Technologies in the US, Ingersoll-Rand and Electrolux in Europe, and Hitachi in Japan.

The heating and cooling industry is transitioning towards low carbon alternatives, with several countries targeting emission reductions from the sector. A large degree of the global transition will come from further improvements in efficiency. For example, the average seasonal energy efficiency ratio (SEER) of residential ACs reached 4.2 in 2016, 50% higher than in 1990.[72]. In addition, technology change will drive the transition. The IEA's 2-degree scenario has the global share of coal, oil, and non-condensing boilers fall from 50% of installed heating equipment today to 11% by 2050. Heat pump deployment reaches 15% by 2050, from 3% today.[73]. Heat networks supply 11% of global heat demand and offer a low carbon alternative to traditional heating methods when powered with renewable energy, though most systems today are fuelled by coal or gas.[74].

Box 7. **The UK's current low carbon heating and cooling industry**

- UK strengths include: Existing strength in the commercial HVAC industry; expertise in the refrigeration industry, which has some spill over with cooling technologies; a strong domestic gas boiler industry.
- Notable UK producers include: Mitsubishi, the UK's largest heat pump manufacturer, produces over 25,000 heat pumps annually in Scotland. Smart Renewable Heat & Star Renewable Energy in ASHPs. Kensa Heat Pumps claim to be the sole GSHP manufacturer in the UK. Domestic HVAC producers include Grayson and Airedale; and Green Cooling Ltd in energy-efficient refrigeration. Several international companies, including Glen Dimplex and Daikin, have a strong UK presence.
- Key competitors include Germany in HVACs and the wider heating and cooling sector. France, which is a dominant player in the European heat pump market. China, which manufactures over 4 million heat pumps a year. Japan and the US, which have mature heat pump and HVAC system supply chains in their local regions.

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[71] Ibid.
[72] IEA (2018), "The Future of Cooling"; the seasonal energy efficiency ratio (SEER) is a ratio for cooling equipment that measures energy used to cooling energy produced.
[73] IEA (2018), Energy Technology Perspectives"; https://www.iea.org/etp/
[74] REN21 (2018), "Renewables 2018 Global Status Report"; http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_final_.pdf

The business opportunities analysis focusses on HVAC systems (for commercial buildings), heat pumps, hydrogen boilers, and heat network services. These likely represent the greatest export opportunity for the UK given its areas of strength and the size of the export markets. The UK has developed commercial HVAC supply chains, with products exported globally, and has an established gas boiler industry. Conversely, domestic heat pump manufacturing is limited, but demand is expected to increase exponentially from current levels as a result of the expected transition from gas boilers to low-carbon heating technologies. Heat storage is relatively immature, and export opportunities are considered within heat pump deployment, as expert consultation has indicated that widespread heat storage is likely to be led by increasing heat pump installation. Heat network services are also considered, as expert consultation has indicated that export opportunities will arise from the services associated with heat networks. Across these technologies, outsourcing manufacturing techniques and the export of intellectual property has been identified as an opportunity. The size of this opportunity has not been quantified as the market cannot be determined from trade data or cost breakdowns. Therefore, this analysis focusses on domestic manufacturing opportunities.

Due to the nature of technological innovations expected in the domestic market, export opportunities are strongest in countries with similar heating demands. UK innovations are likely to focus on locally applicable technologies, meaning export opportunities are primarily located in countries with similar regulations, climate, and space needs. For this reason, countries in North-western Europe are the primary focus for export opportunities, with some exports to the rest of Europe, and minimal exports elsewhere.[75]. The countries identified as key export opportunities are outlined in Box 8.

The business opportunities analysis is set out as follows

- An overview of the global market, with a focus on markets for exports
- A discussion of the UK's competitive position, with a focus on exports
- A discussion of the business opportunities from exports
- A discussion of the UK business opportunities in the UK's domestic market, including a comparison of the relative importance of export and domestic opportunities

[75] This is reflected in the analysis by assuming that 100% of the NW Europe market is accessible by UK exports, whereas only 10% of RoW market is potentially accessed by UK exporters.

Box 8. **Focussed export opportunity countries**

Countries within Europe identified as having similar heating and cooling needs are:
Austria, Belgium, Denmark, France, Germany, Ireland, Italy, Netherlands, Poland, and Slovenia.

Market overview

The global heating and cooling systems industry (which includes commercial HVACs and heat pumps) was valued at £140 billion in 2018 and is expected to grow at an annual rate of 6.8% to 2023.[76]. Over 4 million heat pumps were sold in 2017, from 1.8 million in 2012 – year-on-year growth of 30%.[77]. Sales of air-conditioners for commercial buildings reached 40 million units in 2016, with the installed stock doubling since 1990.[78]. The Asia-Pacific market is currently the largest, with producers in Japan and China supplying much of the global heat pump and air conditioning markets.

Service exports associated with heat pumps and HVACs are limited, but there are opportunities to export heat network services. Export opportunities around installation and operation and maintenance services are limited as they tend to be performed locally. Services such as building design, retrofit planning, and execution are linked with increasing deployment of heating and cooling, and are considered in a separate EINA report on building fabric. Therefore, the services opportunities considered in this report focus on engineering, procurement, and construction management services associated with heat networks, as expert consultation has indicated these offer the greatest opportunities for UK businesses.

The global heat network services industry was valued at £21 billion in 2018[79]; most of this currently comes from combined heat and power (CHP) networks. However, renewable heat is forecast to grow quickly. Solar heat networks are recognised as a cost-effective way to decarbonise the heating sector and are seeing rapid growth. Over 1.74 million m^2 of solar thermal systems were connected to

[76] Markets and Markets (2018) https://www.marketsandmarkets.com/PressReleases/hvac-system.asp
[77] IEA: https://www.iea.org/renewables2018/heat/
[78] IEA (2018), "The Future of Cooling"
[79] Markets and Markets (2018): https://www.prnewswire.com/news-releases/district-heating-market-worth-203-0-billion-by-2023-exclusive-report-by-marketsandmarkets-tm--863761390.html;
assumed services at 16% of the total market based on the cost breakdown in AECOM (2017);
https://d2umxnkyjne36n.cloudfront.net/teaserImages/Reducing-the-capital-cost-of-district-heat-network-infrastructure.pdf?mtime=20171103092304.

district heating systems by 2017, up from under 600,000 m^2 in 2012.[80]. Europe holds a major share of the heat networks market in 2018, with over 90% of installed district heating capacity. China may see significant growth in future[81], providing an additional export opportunity. Major players in the market include Engie, Vattenfall, and Fortum in Europe, and NRG Energy and Shinryo outside of Europe.

Growth in (low carbon) heating and cooling demand is sensitive to changes in climate and policy action, particularly outside of Europe. Under a 2-degree scenario, European demand for low-carbon heat increases by 450% by 2050. In a business-as-usual scenario, demand for low-carbon heat increases by 250% of today's level. In a beyond-2-degrees scenario demand for low-carbon heat increases to 550% of today's level. Commercial HVAC deployment is less variable, with an increase of 45% over today's level in the 2-degree and business-as-usual scenarios. This is limited to a 4% increase in a beyond-2-degrees scenario. Much of the deployment in HVACs comes from replacement demand and more efficient coolers, which are less affected by changes in climate.

Figure 1 **The current and future low carbon heating and cooling market**

Current market for low-carbon heating and cooling

- *Production:* Global heating and cooling demand was over 19 TWh in 2014, of which 41% was generated using low-carbon fuels
- *Trade:* Limited UK production is focused in domestic deployment, with some global exports of commercial HVACs
- *Markets:* Heat pumps and networks are popular in the Asia-Pacific region and parts of Europe, while HVACs are deployed globally

Tradability of market

- *Goods:* Products are tailored to climate and building specifics, encouraging trade among similar countries
- *Services:* Installation and maintenance can largely be performed by local electricians due to a lack of specialised knowledge
- *Trends:* Mature markets imply technical innovation will be required to break into established international markets

Trends in deployment

- *Global:* Deployment of low-carbon heat is expected to grow to around 6x today's levels by 2050, while demand for cooling is expected to grow to 2x today's level
- *Growth pattern:* Growth in low-carbon heating and cooling will occur globally, with a larger share of growth in cooling coming from Europe
- *Uncertainty:* Deployment of low-carbon heating may be halved if a 2C degree scenario is exceeded, while cooling would increase to 4x today's level

Global and regional market size to 2050

- *Growth trend:* Near exponential growth forecast out to 2050 to meet SDS targets.
- *Key markets:* Europe will demand increasing levels of cooling, while the rest of the world has the greatest growth potential in low-carbon heat

Source: Vivid Economics

[80] REN21 (2018), "Renewables 2018 Global Status Report"; http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_final_.pdf
[81] There have been several recent feasibility studies for deployment of solar heat networks in China, connected to its large existing solar thermal capacity.

UK competitive position

The UK currently has a relatively small domestic heating and cooling industry and is reliant on imports of components and systems. Current annual heating and cooling exports are around £1.4 billion, primarily in refrigeration, while imports in the same sector are 40% larger, at £1.9 billion.[82]. The UK has a revealed comparative advantage (RCA) of 0.63. Any RCA under 1 suggests a comparative disadvantage. Thus, exports of heating and cooling equipment are not a relative strength of the UK.

The UK has a small share of global exports in the wider heating and cooling sector (2%), and similarly small shares in HVACs and heat pumps. This contrasts with leading competitors; France has a small share in the wider heating and cooling sector and in HVACs (2%) but has established a dominant position in the global heat pump market (30%). Meanwhile, Germany and China have leveraged their share of the global heating and cooling market (24% and 9% respectively) in order to break into the HVAC systems and heat pump markets. In addition, heat network deployment is limited in the UK, indicating exports of heat network services is not a UK strength. Domestic turnover in 2013 was £482.7 million in 2013[83], compared with key competitors at £5.9 billion (Germany) and £1.8 billion (France)**.**

The UK's gas boiler market is its greatest strength in the wider heating and cooling sector. This creates both opportunities and barriers to developing markets for new technologies. Globally, 12.7 million gas boilers were installed in 2016, with the UK deploying 1.7 million of those[84], primarily from replacement demand.[85]. By 2050, the UK will increasingly use heat pumps and hydrogen boilers to meet heating demand. The domestic market for low-carbon heating technologies could be of a similar size to that of boilers currently. This could spur a domestic industry capable of exporting. However, barriers to deployment of low-carbon heat exist, such as the dominance of gas boiler technology and the thermal inefficiency of the UK's old building stock. The potential interactions between the gas boiler market and markets for low-carbon heating and cooling are discussed further in the business opportunity deep dive (page 75).

The UK has a supply chain around commercial HVAC production, with expertise in refrigeration boosting competitiveness. Domestic manufacturers

[82] Based on UN COMTRADE data – 2015-2017 averages used.
[83] Euroheat (2016): http://www.euroheat.org/wp-content/uploads/2016/03/2015-Country-by-country-Statistics-Overview.pdf
[84] On a stock of over 26 million boilers.
[85] BSRIA (2017), https://www.bsria.co.uk/news/article/global-boiler-market-heats-up-as-the-uk-is-no-longer-the-largest-market/

export commercial HVAC systems globally, drawing on previous deployment of vehicle HVAC systems and industrial chilling systems, while service providers work with international manufacturers, providing services for local installations.[86]. In addition, expertise in the refrigeration sector has led to relatively high levels of reversible heat pump deployment to date.

Expertise in heat pumps focusses on the UK's space requirements and climate. Heat pump and HVAC design is, to a significant degree, driven by local regulation and building needs. To illustrate, the UK's best-selling heat pump[87] recently released an "ultra-quiet" model, enabling deployment in previously inaccessible residential buildings due to building regulations and noise concerns.

The UK could develop competitiveness in heat network services. The UK has some early experience in deployment of heat networks (see the current situation, on page 14). The Heat Networks Investment Project[88], a recent £320 million BEIS initiative, is expanding domestic deployment and providing opportunities for innovation and development of a supply chain. The UK has strengths in some heat network innovations, such as automatic monitoring, which, combined with wider strength in engineering services, it could leverage to export services globally to both new and existing markets. However, there is strong local competition from firms with a history of delivery in countries with established heat networks, such as Danfoss in Denmark and STEAG New Energies in Germany.

Given the UK's areas of expertise and specific needs, countries with a similar climate and building stock represent the greatest deployment opportunities. UK innovations are likely to target domestic requirements, meaning export opportunities will be focussed on countries with similar regulations, climate, and space needs. Local markets within Europe have been identified as like the UK's and offer the greatest export opportunities. These include the Netherlands, Germany, France, and other countries concentrated in North-western Europe. Other countries in Europe offer some export opportunities, given their proximity and similarities within regulation and trading regimes. Exports to areas such as the US and Asia-Pacific region suffer from sizeable transport and regulatory costs and are unlikely to offer an export opportunity for deployment of UK heating and cooling beyond niche products.

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[86] BDO (2016): https://www.bdo.co.uk/en-gb/insights/industries/manufacturing/heating-ventilation-and-air conditioning-2016
[87] DMS installations: https://www.dmsenergysolutions.co.uk/renewable/air-source-heat-pumps/mitsubishi-electric-ecodan-heat-pump/
[88] BEIS: https://www.gov.uk/government/publications/heat-networks-investment-project-hnip-scheme-overview

Figure 2 **The UK's competitive position in trade in low carbon heating and cooling goods**

Current UK competitiveness

- *Shares (wider sector, heat pumps, HVAC):*
  EU ~ 2.9%, 0.5%, 2.8%
  RoW ~ 1.4%, 0.6%, 1.2%
- *Strengths:* Some early innovation into heat pump technologies, established commercial HVAC sector, large domestic demand for heat
- *Weaknesses:* Limited share of heating and cooling exports, strong presence of international HVAC companies

Key EU competitor - France

- *Shares (wider sector, heat pumps, HVAC):*
  EU ~ 4.7%, 38.4%,4.4%
  RoW ~ 1.4%, 11.5%, 1.2%
- *Strengths*: Recognised as first mover in heat pumps with established export market share
- *Weaknesses:* Not a strong exporter of wider heating and cooling

2nd EU Competitor - Germany

- *Shares (wider sector, heat pumps, HVAC):*
  EU ~ *14.8%, 12.6%, 11.2%*
  RoW ~ *7%, 16.1%, 5.8%*
- *Strengths*: Largest EU exporter of heating and cooling
- *Weaknesses:*

Global competitor – China

- *Shares (wider sector, heat pumps, HVAC):*
  EU ~ *9.7%, 7.1%, 12.3%*
  RoW ~ *30.3%, 14.1%, 30.7%*
- *Strengths:* Large share of global heating and cooling exports, giving it a foothold into low-carbon technologies
- *Weaknesses:* Products less marketable in Europe given differences in climate

**of content by value*

Note: *Market shares are based on UN COMTRADE data.*
Source: *COMTRADE; Vivid Economics analysis*

Box 9. **Industry workshop feedback regarding business opportunities**

- Stakeholders identified areas of NW Europe as a key export market due to similarities in climate and the building stock and confirmed the limited opportunities beyond Europe due to transportation and regulation costs.
- Stakeholders believed barriers to domestic deployment of both heat pumps and cooling in buildings is hindering the opportunity to develop a supply chain in these industries.
- Stakeholders were mixed regarding the importance of innovation in unlocking export opportunities, with innovation believed important for newer technologies while existing ones were seen to have less opportunity.

Table 15. **Export market shares and innovation impact – low-carbon heating and cooling**

Technology	Tradeable market 2050 (£bn)	Current market share	2050 outlook *with* strong learning by research			
			Market share	Captured turnover (£m)	GVA (£m)	Rationale for the impact of innovation
Heat pump	**NW Europe: 11** RoW: 15	**NW Europe: 0.5%** RoW: 0.6%	**NW Europe: 9.6%** RoW: 2.9%	**NW Europe: 1,000** RoW: 420	**NW Europe: 360** RoW: 150	Importance of innovation in developing a domestic supply chain – through reaching a critical mass of domestic deployment, export opportunities will become increasingly accessible. Based on this we take a market share of 9.6% in NW Europe, a quarter of market leading France, as a plausible market share.
HVAC	**NW Europe: 2.3** RoW: 3.6	**NW Europe: 2.8%** RoW: 0.9%	**NW Europe: 4.5%** RoW: 3%	**NW Europe: 100** RoW: 110	**NW Europe: 40** RoW: 40	Existing strength in refrigeration is leveraged to a degree, but this is an established market. Therefore, we take a market share equal to half of Germany's current market share in commercial HVACs.
Heat networks (services)	**NW Europe: 0.6** RoW: 1.3	N/A	**NW Europe: 11.8%** RoW: 11.8%	**NW Europe: 70** RoW: 155	**NW Europe: 40** RoW: 80	Domestic deployment following innovations and government investment such as the Heat Networks Investment Programme develops a supply chain capable of exporting innovative network services to renewals in local markets and new markets in rest of world. The UK captures the same share of the heat network services market as it currently captures in oilfield services.
Hydrogen boilers	**NW Europe: 0.7** RoW: 4.2	N/A	**NW Europe: 11.2%** RoW: 9.7%	**NW Europe: 80** RoW: 400	**NW Europe: 30** RoW: 140	The UK deploys hydrogen boilers at scale domestically, developing an international supply chain that allows it to reach half of Germany's (the EU market leader) current market share in the wider boiler market.

Note: *RoW: Rest of world (outside NW Europe). Future market shares are not a forecast, but what UK business opportunities could be. The possible market share of the UK, and rationale for the impact of innovation, are based on stakeholder input gathered in a workshop. Table is based on IEA scenario from the 2017 Energy Technologies Perspective. The scenario used in this table is the 2-degrees scenario, which is the standard reference throughout the business opportunities section. Further information on the methodology behind this table can be found in Appendix 2.*

Source: *Vivid Economics*

UK business opportunities from export markets

Box 10. **Interpretation of business opportunity estimates**
The GVA and jobs estimates presented below are *not* forecasts, but instead represent estimates of the potential benefits of the UK capturing available business opportunities. The presented estimates represent an unbiased attempt to quantify opportunities and are based on credible deployment forecasts, data on current trade flows, and expert opinion, but are necessarily partly assumption-driven. The quantified estimates are intended as plausible, but optimistic. They assume global climate action towards a 2-degree world and reflect a UK market share in a scenario with significant UK innovation activity.[89] More information on the methodology, including a worked example, is provided in Appendix 2, and a high level uncertainty assessment across the EINA subthemes is provided in Appendix 3.

Growth of UK exports could add around £900 million GVA per annum and 7,000 jobs by 2050. The UK achieves annual exports of over 210,000 heat pumps and around 3,000 commercial HVAC systems by 2050. Growth in total demand is driven by IEA deployment forecasts for low-carbon heating and cooling, with heat pumps the largest tradeable market at £26 billion. Of this market, the UK captures £1.4 billion, increasing GVA by £500 million and providing 4,000 jobs. The increase in UK-captured turnover relies on the premise that the UK can increase its market share as a result of continued innovation to overcome remaining technological barriers. A breakdown of GVA, turnover, and market size by technology is shown in Table 15.

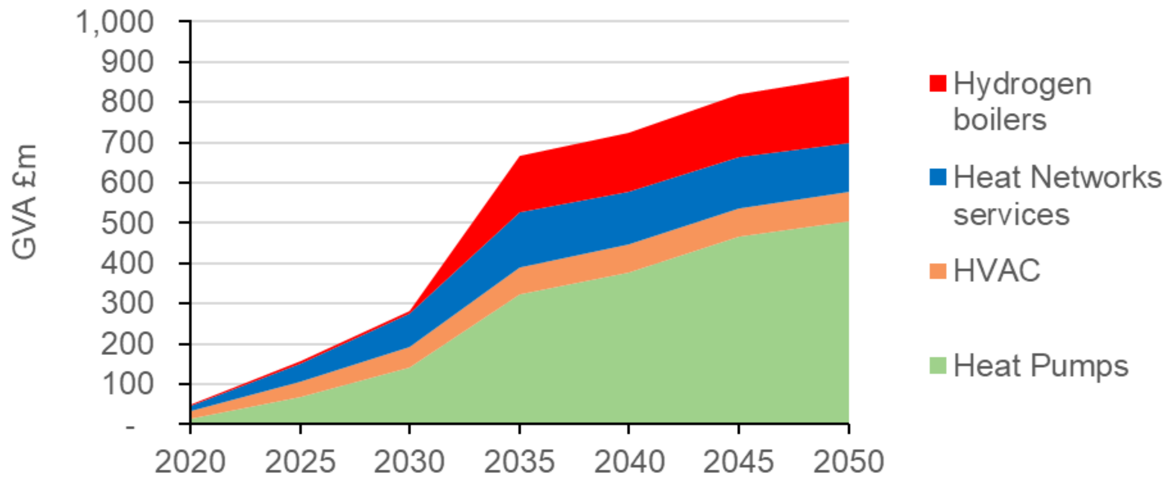
The NW European market is expected to be the prime export market for the UK, driving jobs figures. Exports to NW Europe support more than half of all jobs in the low-carbon heating and cooling industry. This is driven by the heat pump market, where 71% of exports are captured by North-western Europe given similarities in the heating markets. Around half of commercial HVACs produced are exported to NW Europe, while hydrogen boilers are exported globally due to a large market outside NW Europe.

Business opportunities are concentrated in the export of goods, but heat network services can contribute up to £120 million and 800 jobs per year by the mid-2030s. Services are exported globally, with less regulatory or transportation costs compared with goods exports. Despite this, NW Europe captures around a third of services exports, given similarities with the UK's heating system and the

[89] Note, other IEA climate scenarios were also used as a sensitivity. Where the level of global climate action has a meaningful impact on market size, this is highlighted in the market overview section. Full results are available in the supplied Excel calculator.

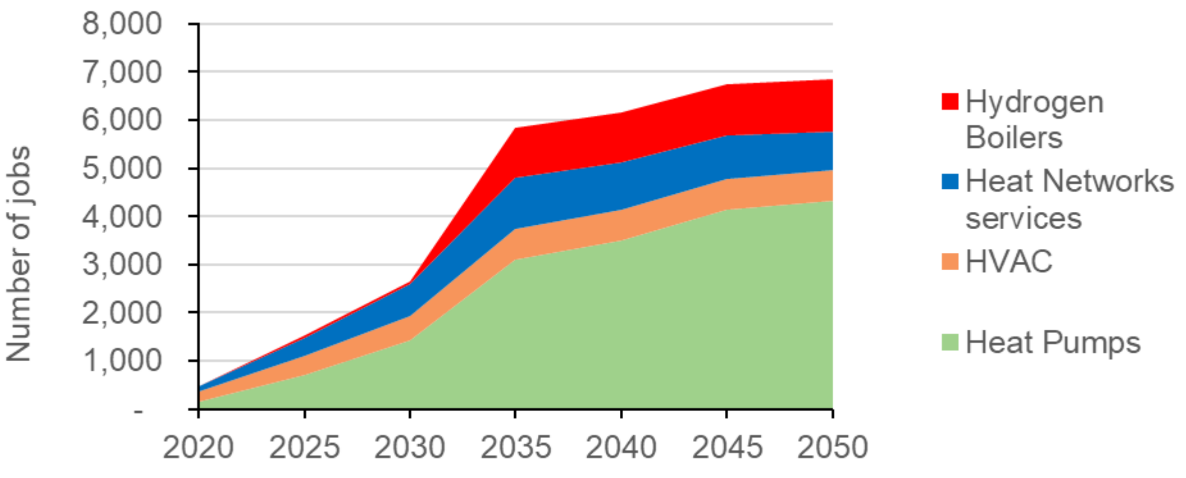
large renewal demand expected in the next 30 years from existing heat networks in Europe.

Figure 3 **GVA from export markets by component – low-carbon heating and cooling**



Source: *Vivid Economics*

Figure 4 **Jobs supported from export markets by component – low-carbon heating and cooling**



Source: *Vivid Economics*

UK business opportunities from domestic markets

Discussion

The transition to low-carbon heating presents domestic business opportunities in the period to 2050. Heat is the largest energy consuming sector in the UK today, accounting for 44% of final energy consumption in 2017.[90]. In turn, greenhouse gas (GHG) emissions from heat are the single largest contributor to UK emissions at 37%, primarily from space heating and industrial heat. In order to meet an 80% emissions reductions target, ESME modelling suggests deployment of around 6.5 million heat pumps and 6 million hydrogen boilers by 2050. Furthermore, ESME estimates 5.5 million houses will be connected to heat networks by 2050. Recent Committee on Climate Change (CCC) recommendations to achieve net-zero emissions suggest even greater deployment of low carbon heat.[91].

In addition to components considered in the export analysis, we value goods associated with heat networks and installation and operation and management (O&M) services. Business opportunities within the heating and cooling sub-theme are associated with 4 main components; heat pumps, commercial HVACs, heat networks, and hydrogen boilers. Heat storage is relatively immature, and so business opportunities are considered within heat pump deployment, as expert consultation has indicated that widespread heat storage is likely to be led by increasing heat pump installation. In the export analysis, goods opportunities were sized for heat pumps, HVACs and hydrogen boilers, while only EPCm services associated with heat networks were assessed as a substantial business opportunity. Goods associated with heat networks have been included in the domestic analysis, and include the energy centre, connections with users and the actual piping. In addition, installation and O&M of low-carbon heating goods has been sized, as this is expected to be mostly captured by domestic businesses and sole traders.

UK businesses can build on existing strengths in the gas boiler and refrigeration markets. Across the four technologies considered, the shares of the UK market captured by businesses are outlined in Table 16, and detailed below:

- **Heat pump** manufacturing is relatively immature in the UK. Domestic manufacturers currently capture only 15% of the UK heat pump market, with many imports from France and other European countries.[92]. Under a high innovation scenario, we expect UK businesses to be able to capture 37%[92] of the domestic market, in line with current expertise in the wider HVAC sector.

[90] BEIS (2018). Clean Growth – Transforming Heating: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766109/decarbonising-heating.pdf
[91] UK CCC (2019) Net-Zero Technical report: https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-Technical-report-CCC.pdf
[92] Current market shares of heat pumps, commercial HVACs and gas boilers come from PRODCOM data analysis.

- **Commercial HVACs** represent a relative strength within heating and cooling for UK businesses, with expertise built on the UK's refrigeration sector leading to a 37% share of the current market[92]. Given the relative maturity of this market and the limited scope for innovation identified in HVAC systems, this is expected to stay constant to 2050 under a high innovation scenario.
- **Heat networks** are currently immature in the UK, with some early deployment and pilot systems. Expert consultation has indicated that heat network goods will not be a UK strength, and highlighted the presence of established European competitors[93]. We therefore expect the UK will capture 15% of the goods market by 2050, the share it currently has in the heat pump market. Given the UK's relative strength in engineering services and in heat network innovations such as automatic monitoring, UK businesses are expected to capture a greater share of heat network EPCm services. This share reaches 77% by 2050 under high innovation, in line with UK businesses' current share of the domestic oilfield services sector, which the UK is currently highly competitive in[94].
- **Hydrogen boilers** are not yet commercially sold. This makes the UK's potential share of this market more uncertain. However, given the similarities with the existing UK gas boiler market, UK businesses are expected to achieve 56% of the domestic market for hydrogen boilers under high innovation, in line with the current share of the domestic gas boiler market[92].
- **Installation** and **O&M** of heating and cooling systems is expected to largely be captured domestically, as these tend to be performed by local installers. To be conservative, we estimate that the UK captures 95% of the domestic market.

Domestic business opportunities in low-carbon heating and cooling could support £3.9 billion of GVA and 43,000 jobs annually by 2050. This is significantly more than export opportunities, which are estimated at £900 million per annum and 7,000 jobs by 2050, as shown in Figure 5 and Figure 6 below. This is due to the inclusion of installation and O&M services, which were not captured in the export analysis, and higher market shares of the domestic market across all technologies compared with the export market. Services make up 78% of total GVA from low-carbon heating and cooling in 2050, with the remainder coming from goods. O&M is the single biggest contributor to GVA, at 43% by 2050, while installation contributes 30% (Figure 7 and Figure 8 below).

Opportunities within installation, O&M and EPCm services could support £3 billion GVA per annum and 36,000 jobs, though this includes some

[93] Business Sweden (2016) Opportunities in the UK heat networks market: http://heatnetworks.se/wp-content/uploads/2017/01/Opportunities-in-the-UK-heat-networks-market-and-options-for-entry.pdf
[94] The UK oilfield service sector market share is estimated based on EY (2017): https://www.ey.com/Publication/vwLUAssets/EY-review-of-the-UK-oilfield-services-industry-January-2017/$FILE/EY-Review-of-the-UK-oilfield-services-industry-January-2017.pdf, and Oil & Gas UK (2017): https://oilandgasuk.co.uk/wp-content/uploads/2017/09/Economic-Report-2017-Oil-Gas-UK.pdf

replacement of existing services. By 2050, 1.8 million houses will have a heat pump or hydrogen boiler installed or become connected to a heat network each year. The associated installation is expected to be partially offset by a reduction in gas boiler installations, though some initial installations will come from additional demand. In addition, jobs supported by O&M services are expected to displace existing boiler O&M services 1:1.

Goods support over £800 million GVA per annum and 7,000 jobs. Heat pumps present the largest opportunity, contributing 42% of goods GVA in 2050, followed by hydrogen boilers at 28%. Heat pumps and heat networks are expected to deploy in the medium term, with over 100,000 heat pump installations and a similar number of connections to heat networks each year contributing over £80 million to GVA by 2030. Hydrogen boilers only become commercial from 2035 but are expected to deploy rapidly over the 2035-2050 period. This growth pathway reflects ESME modelling assumptions on total system cost.

Domestic climate and policy action will influence the timeline of deployment and size of the market. ESME modelling is aligned with the UK achieving a total emissions reduction of 80% across the economy, which requires additional policy action. Limited or delayed climate action may reduce the total deployment of low-carbon heating and cooling by 2050, reducing the size of the UK market and the share captured by UK businesses. On the other hand, in order to meet a net-zero scenario, domestic deployment of heating and cooling equipment is expected to increase relative to ESME modelling results (given these are calibrated to an 80% target), which would mean the numbers presented here are an underestimate.

In addition, alternative deployment scenarios could alter the magnitude and distribution of business opportunities. In practice, it is possible that a dominant technology will emerge, which means low-carbon heating deployment may be concentrated more heavily in heat pumps, heat networks or hydrogen boilers than in these results. For example, the UK CCC's recent technical report suggests deployment of 17 million heat pumps by 2050 in their core scenario, which includes hybrid heat pumps and reduces emissions by 80% over 1990 levels. They also mention the possibility of a net-zero hydrogen boiler scenario, with up to 16 million hydrogen boilers deployed by 2050 in place of heat pumps. These forecasts would alter the estimates presented here fairly significantly. For example, GVA per unit for heat pumps and hydrogen boilers is around twice as high as for heat networks given their higher installation costs, implying a higher share of heat pump or hydrogen boiler deployment would boost GVA and jobs further.

Of the total business opportunities, domestic opportunities within low-carbon heating and cooling sustain 87% of jobs by 2050, with just 13% supported by exports. This is driven largely by the magnitude of the installation and O&M sectors in the domestic analysis, which sustain almost 34,000 of the 50,000 jobs associated with low-carbon heating and cooling in 2050. A large number of these jobs are expected to displace ongoing O&M and installation supported by the UK's existing gas boiler industry, which installed 1.7 million units in 2017.[95]. Opportunities associated with goods and EPCm services are more evenly allocated, with 9,000 jobs supported by domestic deployment and 7,000 jobs supported by exports.

[95] BSRIA (2017), https://www.bsria.co.uk/news/article/global-boiler-market-heats-up-as-the-uk-is-no-longer-the-largest-market/

Quantitative results

Table 16. **Domestic market shares and innovation impact – low-carbon heating and cooling**

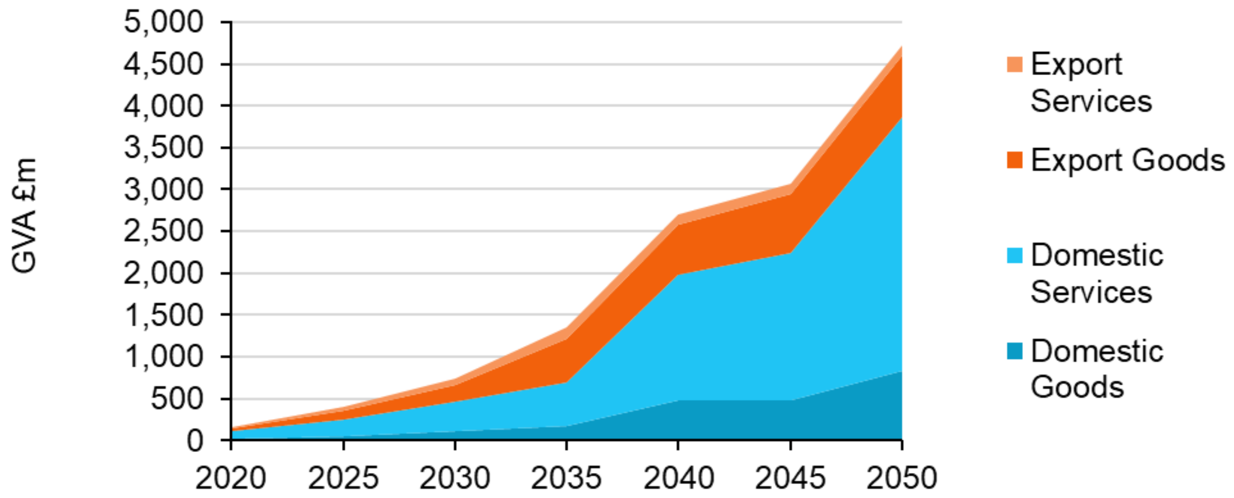
Technology	Domestic market 2050 (£m)	Current share of related UK market	2050 outlook with strong learning by research			
			Market share* (%)	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
Heat pump goods	2,800	15.4%	36.7%	1000	350	UK manufacturers could grow their current share of the UK market to almost 40% by the mid-2030s through innovation but face strong competition from exporters such as France.
Heat pump O&M	1,200	95%	95%	1,200	520	The UK market share remains at 95% by 2050 as this component is assumed to have low tradability.
Heat pump installation	1,800	95%	95%	1,800	780	The UK market share remains at 95% by 2050 as this component is assumed to have low tradability.
HVAC goods	200	36.7%	36.7%	70	30	The UK maintains its current share to 2050 under innovation, given that this is a relatively mature market.
HVAC O&M	50	95%	95%	45	20	The UK market share remains at 95% by 2050 as this component is assumed to have low tradability.
HVAC installation	25	95%	95%	20	10	The UK market share remains at 95% by 2050 as this component is assumed to have low tradability.
Heat networks (goods)	4,000	n/a	15.4%	620	220	UK businesses are not expected to be competitive in equipment for heat networks and face strong competition from countries with established heat network industries, leading to a 15% share after high innovation.

Technology	Domestic market 2050 (£m)	Current share of related UK market	2050 outlook with strong learning by research			
			Market share* (%)	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
Heat networks (EPCm services)	540	77% (Oilfield EPCm services)	77%	415	220	Domestic deployment following innovations and government investment such as the Heat Networks Investment Programme develops a domestic supply chain capable of capturing the same share of the heat network services market as it currently captures in oilfield services.
Heat network O&M	580	95%	95%	560	300	The UK market share remains at 95% by 2050 as this component is assumed to have low tradability.
Hydrogen boilers (goods)	1,200	56.4% (gas boilers)	56.4%	680	230	Building on strength in the UK's domestic gas boiler industry and early innovation in hydrogen boilers, UK businesses could reach more than 50% of the domestic market.
Hydrogen boiler O&M	2,000	95% (gas boilers)	95%	1,900	820	The UK market share remains at 95% by 2050 as this component is assumed to have low tradability.
Hydrogen boiler installation	860	95% (gas boilers)	95%	820	360	The UK market share remains at 95% by 2050 as this component is assumed to have low tradability.

Note: * Future market shares are not a forecast, but what UK business opportunities could be potentially in the context of the EINAs. The possible market share of the UK, and rationale for the impact of innovation, are based on PRODCOM analysis and additional market research. N/A indicates data is not available.

Source: Vivid Economics

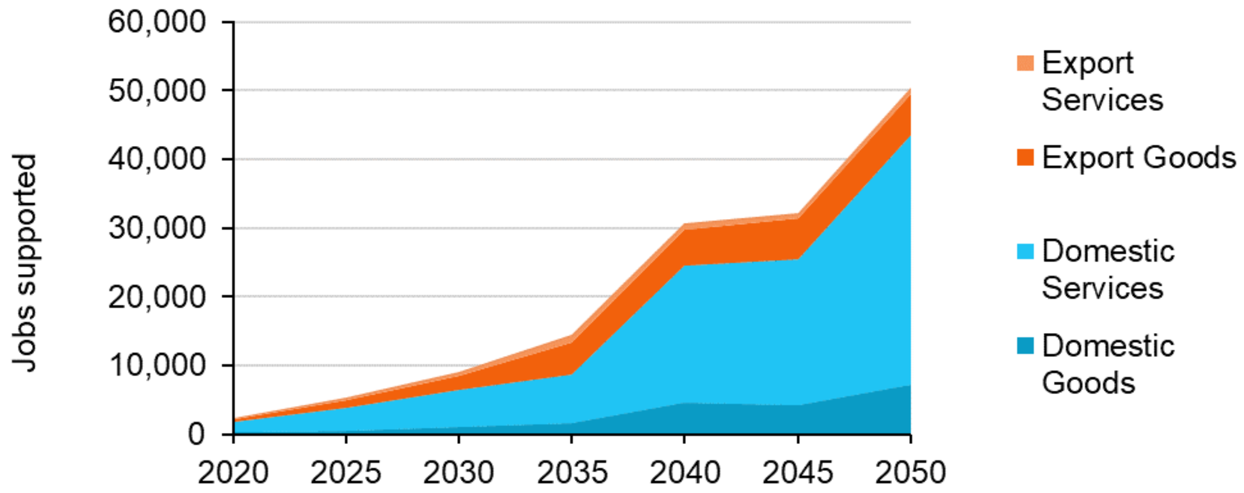
Figure 5 **GVA from export and domestic markets – low-carbon heating and cooling**



Note: *Values are in constant prices.*

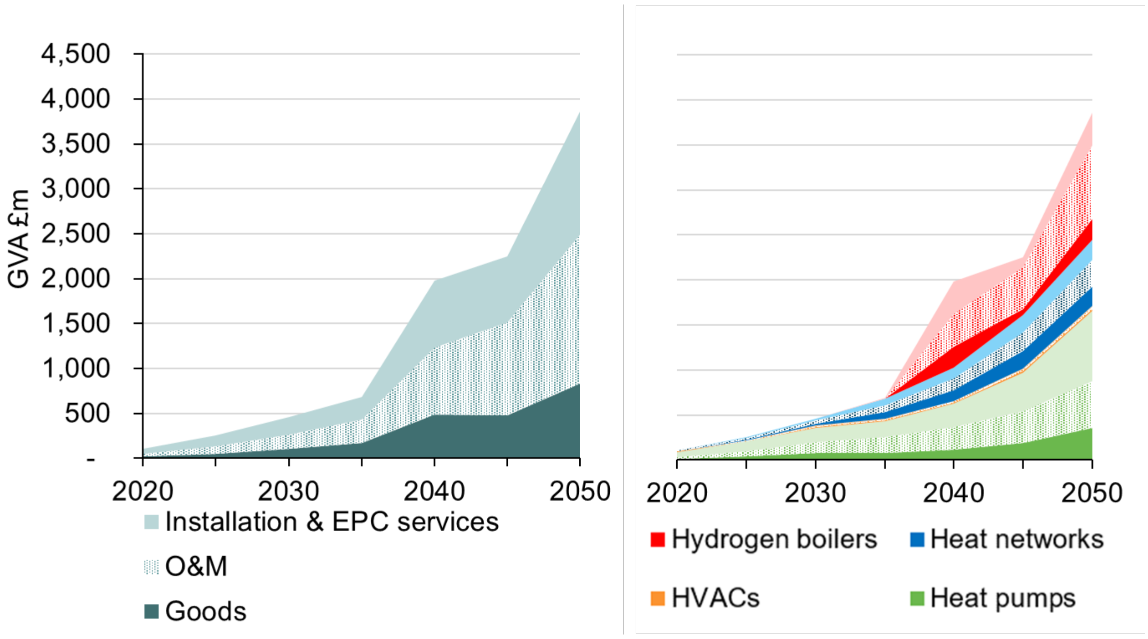
Source: *Vivid Economics*

Figure 6 **Jobs supported from export and domestic markets – low-carbon heating and cooling**



Source: *Vivid Economics*

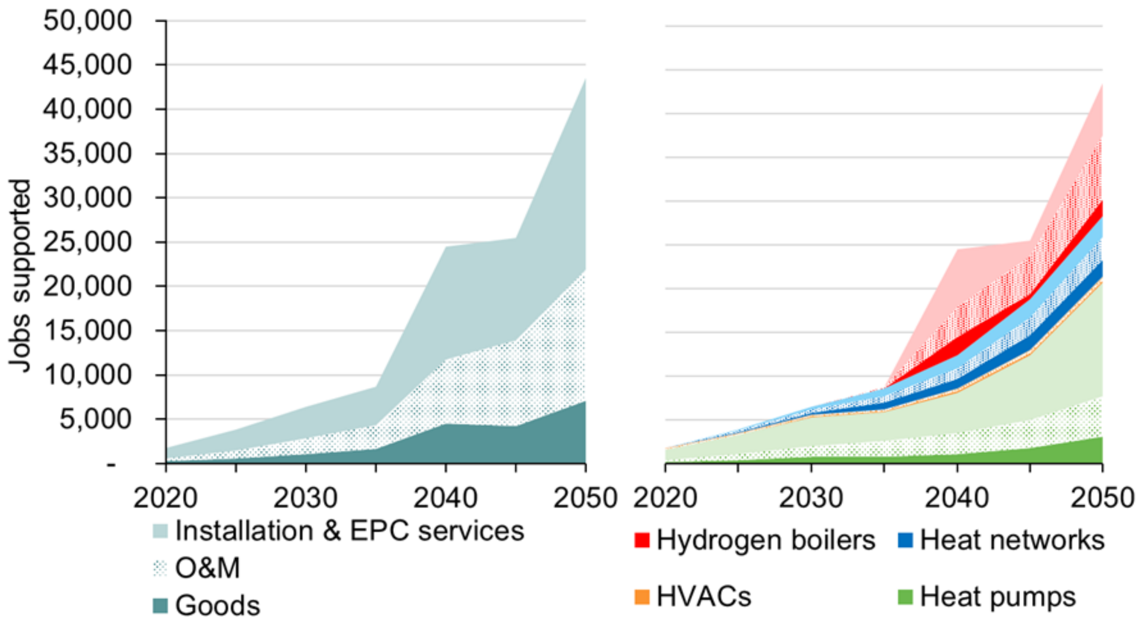
Figure 7 **GVA from domestic markets by component – low-carbon heating and cooling**



Note: *Values are in constant prices. In right hand graphs, dashed stacks represent GVA associated with O&M, light coloured are GVA associated with installation, and dark colours are associated with goods*

Source: *Vivid Economics*

Figure 8 **Jobs supported from domestic markets by component – low-carbon heating and cooling**



Note: *In right hand graph, dashed stacks represent jobs associated with O&M, light coloured are jobs associated with installation, and dark colours are associated with goods*

Source: *Vivid Economics*

Business opportunity deep dive: Developing a heat pump supply chain

Heat pump deployment in the UK is limited compared with local competitors. In 2017, the UK had an installed heat pump stock of 183,000[96], of an EU total of 10.6 million. This is much less than local competitors such as France (2 million) and Germany (947,000). Domestic deployment is often key in establishing supply chains for new technologies, and countries with early deployment can go on to export successfully, as seen by France's heat pump industry.

Gas boilers are an established technology in the UK and are extremely competitive, which may hinder development of a heat pump supply chain. The UK boiler market is the biggest in the world (the annual market value for boilers in the UK is around £2.5-£3 billion).[97]. The upfront cost of a gas boiler is estimated at around £1,570.[98]. A heat pump deployed to a new building has an upfront cost of £5,925, and a heat pump fitted in an existing building costs £8,975. In addition, the UK's electricity to gas price ratio ranges between approximately 4-5. This means a typical current heat pump with a coefficient of performance of less than 3 would enjoy no operational cost savings over a gas boiler. Expert consultation indicates close to 80% of boiler replacements are emergencies, which limits switching in these conditions.

Innovation may unlock heat pump deployment opportunities, but barriers exist to wide-scale uptake. It is important for heat pumps to be installed to the highest standards for optimum performance. Instances of poor design and commissioning to date have generated some consumer mistrust.[99]. Policies such as the Renewable Heat Incentive (RHI) offer limited upfront assistance, leading to long payback periods on investments such as heat pumps. In comparison, France, which has seen a much higher deployment of heat pumps to date, has an upfront tax incentive of 30% for heat pump installations through the CITE initiative.[100]. Market barriers to innovation are discussed in more detail later in the report.

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[96] EHPA (2018); http://www.stats.ehpa.org/hp_sales/country_cards/
[97] BEIS (2017), "Heat in Buildings" https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651853/Boiler_Plus_final_policy_and_consultation_response.pdf
[98] Element Energy (2016): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf
[99] Energy Saving Trust (2013). The heat is on heat pump field trials phase 2. Available at: https://www.energysavingtrust.org.uk/sites/default/files/reports/TheHeatisOnweb%281%29.pdf
[100] Ministry of Ecological and Solidarity Transition: https://www.ecologique-solidaire.gouv.fr/aides-financieres-renovation-energetique

Despite this, ongoing innovation in the UK presents opportunities to develop domestic deployment before creating export opportunities. The UK's best-selling heat pump is manufactured in the UK.[101]. In addition, some SMEs have made technological breakthroughs and are deploying domestically, with a view to export to local markets.

Niche production in the UK is likely to be small-scale, whereas mass-market pumps tend to be produced large-scale. Heat pumps and HVACs manufactured in the UK will likely be produced on a small scale. Mass-market heat pumps are likely to be manufactured at scale – recent plants have a capacity of up to 40,000 annually.[102]. Therefore, any business opportunities for the UK are relatively dependent on a few investment decisions in large-scale plants.

[101] ACR News (2013): http://www.acr-news.com/mitsubishis-livingston-expansion-celebrates-20-years-in-scotland
[102] Panasonic Plzen plant: https://www.czechinvest.org/en/Homepage/News/October-2018/Panasonic%E2%80%99s-Plzen-plant-opens-new-heat-pump-production-line

Market barriers to innovation within low carbon heating and cooling technologies

Introduction

Box 11. **Objective of the market barrier analysis**

Market barriers prevent firms from innovating in areas that could have significant UK system benefits or unlock large business opportunities. Market barriers can either increase the private cost of innovation to levels that prevent innovation or limit the ability of private sector players to capture the benefits of their innovation, reducing the incentive to innovate.

Government support is needed when market barriers are significant, and they cannot be overcome by the private sector or international partners. The main market barriers identified by industry are listed in Table 17, along with an assessment of whether HMG needs to intervene.

Market barriers for low carbon heating and cooling technologies

The main barriers to innovation in low carbon heating and cooling are focussed on deployment limitations. Deployment is driven by awareness, costs, and the price of alternative heat sources. HMG can play a role by providing incentives for consumers and certainty for the sector. Most innovation in the UK is led by research institutes and industry. Publicly funded entities that drive RD&D in low carbon heating and cooling are the BEIS and UK Research and Innovation. Examples of HMG support initiatives are the RHI and the Heat Networks Investment Project (HNIP).[103].

Table 17 lists the main market barriers in low carbon heating technologies, along with an assessment of whether HMG needs to intervene to enable

[103] HMG, Domestic Renewable Heat Incentive (RHI), n.d. https://www.gov.uk/domestic-renewable-heat-incentive
HMG (2018). Delivering Financial Support for Heat Networks, https://www.gov.uk/government/publications/heat-networks-investment-project-hnip-scheme-overview
BEIS (2018). Heat networks: ensuring sustained investment and protecting consumers, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/774586/heat-networks-ensuring-sustained-investment-protecting-consumers.pdf

innovation. For each identified market barrier, an assessment of the need for government intervention is provided.

The assessment categories are low, moderate, severe, and critical.

- **Low** implies that without HMG intervention, innovation, investment, and deployment will continue at the same levels, driven by a well-functioning industry and international partners.
- **Moderate** implies that without HMG intervention, innovation, investment, and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
- **Severe** implies that without HMG intervention, innovation, investment, and deployment are significantly constrained and will only occur in certain market segments or must be adjusted for UK market.
- **Critical** implies that without HMG intervention, innovation, investment, and deployment will not occur in the UK.

Table 17. **Market barriers**

	Market barriers to low carbon heating and cooling	Need for HMG support
Heat pumps	**Uncertain future demand due to low consumer awareness** and insufficient incentives for consumers to switch to heat pumps.	Critical
	High capital costs of heat pumps, lack of tax incentives, and complicated financial support systems.	Critical
	Limited opportunities for replacing heating systems, as homeowners only consider replacement if significant repairs are needed.	Severe
	Inefficiencies and heating systems in old housing stock limit benefits from heat pumps and prevent rapid uptake (only affects a segment of the market).	Moderate
	Lack of skilled installers with poor reputation from old installations; insufficient incentives for installers to upskill.	Moderate
Heat networks	**Unestablished policy framework and regulatory barriers** prevent critical mass for deployment.	Critical
	Lack of clear direction on management of grid access and capacity prevent deployment at scale.	Severe
	High upfront capital costs associated with construction of plant, heat network, and connections, compared with low capex for gas heating.	Severe
	Lack of local expertise and established supply chain, upskilling is required if large-scale rollout is to be achieved.	Moderate
Heat storage	**High costs of medium- to long-term heat storage,** and uncertain revenue stream.	Moderate
Hydrogen boilers	**High upfront and running costs due to lower technological maturity and hydrogen being more expensive than natural gas;** societal benefits are not reflected in the price which limits incentives for consumers to switch	Moderate

Source: Vivid Economics analysis and stakeholder input

Box 12. **Industry workshop feedback**

Industry experts raised several areas that require HMG support. The main barriers to low carbon heating and cooling are barriers to deployment. Much of the innovation in the sector is driven by EU directives.[104].

For heat pumps, the main barrier to innovation is market creation. Uncertain future demand discourages investment and innovation, as returns are volatile.

- One of the main reasons for uncertain demand for heat pumps is low customer awareness and acceptance. 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. Visual appearance of heat pumps presents a constraint to consumer acceptance. Carbon abatement and air quality benefits do not enter the purchasing decision of consumers.
- Heat pumps require high upfront investments of around £7,000 to £8,000, which can be unaffordable for consumers. In the absence of tax incentives and effective financing schemes, these costs can be prohibitive. Countries with higher levels of deployment, such as France, offer tax reductions and a more favourable electricity to gas price ratio.[105].
- Replacement is often required only when the existing heating system needs substantial repair. In these situations, consumers prefer a quick fix instead of thinking comprehensively about the options available.
- Building regulations penalise the use of reversible pumps that offer heating and cooling for domestic buildings by assigning a lower efficiency rating. Offering heating and cooling together would enhance demand.
- A share of the existing housing stock has low levels of insulation and inefficient thermal systems. This creates inefficiencies in heating more broadly and is not a barrier for heat pumps specifically. However, maintenance work to increase the efficiency of a property is often carried out before installation, increasing the cost for the consumer. Opportunities to overcome this barrier are to better understand the interaction between building fabric and heating system upgrades, moving away from low-temperature heat pumps, and offering more flexibility in the RHI. Industry noted that only a share of old houses is affected by this barrier.
- There is a lack of local skilled installers and they suffer from poor reputations arising from old installations. This is partly due to both limited current demand and to installers not being sufficiently involved in the policy process. As a result, they are not being provided with enough incentive to offer heat pump installation services and to upskill. The severity of this barrier varies by geography.

For district heating systems, changes to the regulatory system would offer opportunities for deployment at scale.

- Coordination and strategic alignment between planning regulations and climate policy is needed to create a critical mass for deployment. Industry found the Green Deal ineffective due to its fragmented nature, which made it difficult for homeowners, landlords, and tenants to benefit from it.
- The RHI requires adjustments to effectively support deployment at scale. The non-domestic RHI is relevant to help finance a low-carbon heat source supplying to a heat network. However, it does not offer substantial support for deployment as it currently does not offer reductions to the upfront capex. Industry needs regulatory support when heat networks are being built across railway networks. Currently, district heating developers are left to negotiate with national rail on a case-by-case basis.
- Grid access and capacity present barriers to deployment at scale. The grid does not have the capacity for whole neighbourhoods to be converted to electricity. This is not a key barrier now but will be critical for wider deployment.
- High upfront capital costs associated with the construction of plants, heat networks, and connections, compared with low capex for gas heating, disincentivise investment. Financial products are insufficient to overcome this.
- There is a lack of local expertise and no established supply chain to provide deployment at scale. Upskilling is required if large-scale rollout is to be achieved.
- Lack of extensive technical research and dissemination, for example on heat demand profiles, prevents deployment.

For storage, the main barriers are high capital costs for medium- to long-term heat storage.

- High capital costs for medium- to long-term heat storage, and the lack of a clear revenue stream, limit incentives for investment.
- The lack of knowledge about available storage technologies and applications limits deployment.

Market barriers specific to cooling or hydrogen boilers were not discussed in the workshop.

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[104] See for example European Commission, Heating and cooling, n.d., https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling
[105] For example, the “Coup de puce” offer premiums for heat pump installations and the “Crédit d'impôt pour la transition énergétique” offers tax breaks.

International opportunities for collaboration

There are potential international opportunities to collaboratively innovate, but also threats from international innovation and competition.

- While being competitors, the UK can learn from countries that have achieved high levels of deployment, such as France, Denmark, and the Netherlands. Mechanisms applied in these countries are tax benefits for the use of heat pumps or penalising the use of gas, making heat pumps more attractive for consumers.[106].
- Outside the UK, markets are more active and hence more competitive, with stronger incentive to innovate. The UK can rely on other countries to deliver innovation in many of the standard component technologies. However, design, installation, and operation require local expertise.

[106] Since the introduction of the carbon tax in Sweden, fuel oil for heating has been displaced by district heating (mainly biomass) and electric heating (shift from electric resistive heating to heat pumps explained by the separate electricity tax and the relative efficiency of heat pumps). See: German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), The Carbon Tax in Sweden, 2018, https://www.euki.de/wp-content/uploads/2018/09/fact-sheet-carbontax-se.pdf

Appendix 1: Organisations at the workshop

- Association for Decentralised Energy
- Atkins Global
- BRE
- Daikin
- Former President, Heat Pump Association
- FVB
- ICAX
- Pinnacle Power
- University of Birmingham
- University of Ulster
- Vattenfall
- Vital Energy
- University of Warwick

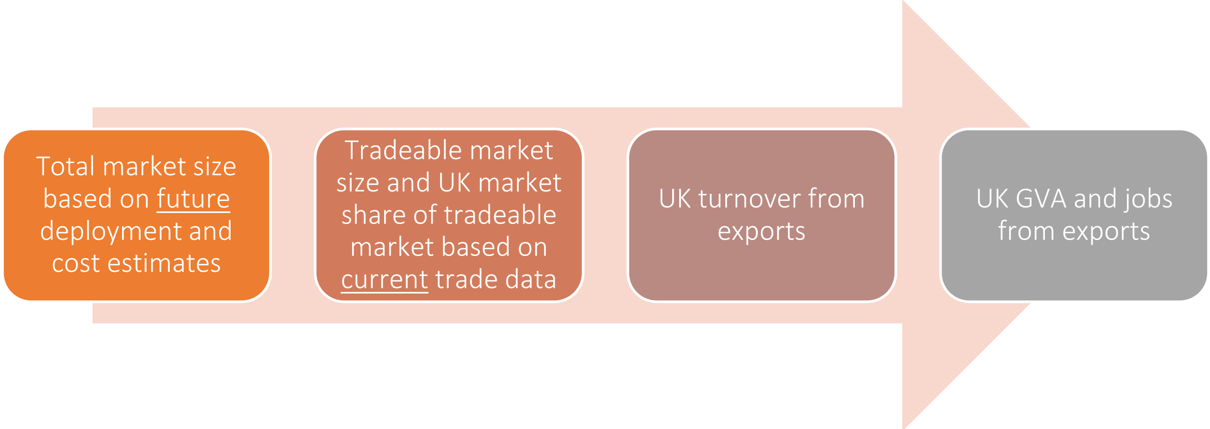
Appendix 2: Business opportunities methodology

Methodology for export business opportunity analysis

In identifying export opportunities for the UK, the EINA process uses a common methodology to ensure comparability of results:

- The **global and regional markets** to 2050 are sized based on deployment forecasts, which come from the IEA when available. For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market.
- The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs created**.

Figure 9 **Methodology for assessing export opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Export business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade data, where available. If the technology is immature or export levels are low, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to reach a market share in the EU and RoW by 2050. The potential future market share is intended as an ambitious, but realistic, scenario. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is ‘world leading’.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.
- Market share assumptions are validated at a workshop with expert stakeholders and adjusted based on stakeholder input.

Export business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The EINA methodology does not quantify opportunities associated with installation and operation and maintenance as these are typically performed locally. Exceptions are made if these types of services are specialised, such as in offshore wind.
- The key services to consider are based on desk research and verified through an expert workshop.
- The services considered in the CCUS EINA export analysis are EPCm services, transport and storage services.

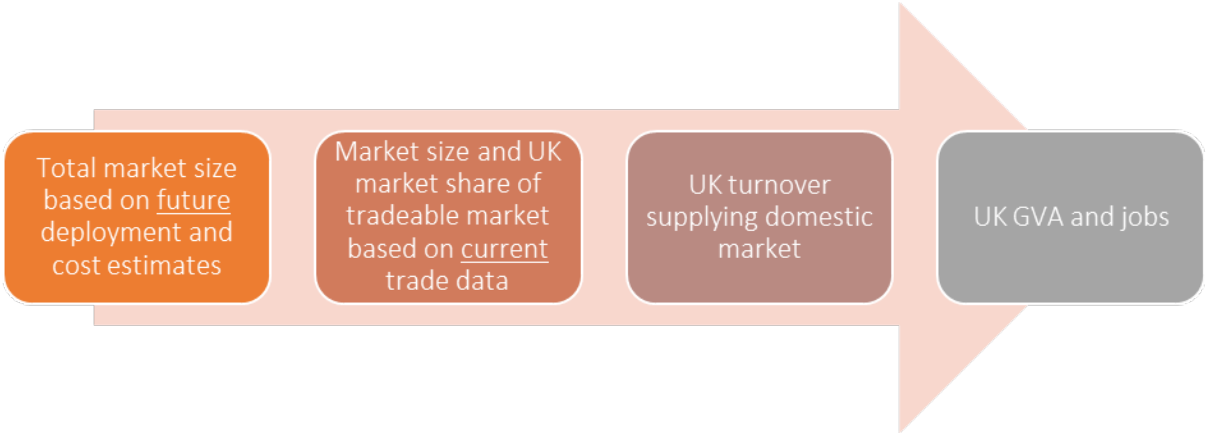
Methodology for domestic business opportunity analysis

To estimate the size of domestic business opportunities for the UK, the EINA methodology, as developed to size export opportunities, is adapted. The domestic analysis leans heavily on insight gleaned from the export analysis, particularly in estimating UK competitiveness and ability to capture market share in its domestic market. To estimate the domestic opportunity, the following methodology is used:

- The **domestic market** to 2050 is sized based on deployment and cost estimates. Deployment estimates are based on ESME modelling used for the EINAs and cost estimates are equal to those from the export work, and based on analysis for each of the EINA sub-themes.[107] For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the UK's market is likely accessible for foreign firms (e.g. electric vehicles), and how much is likely to be exclusively provided by UK companies (e.g. heat pump installation).
- For the traded share of the UK market, the UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- To estimate **UK captured turnover** the traded and non-traded markets are summed.
    - The UK's captured turnover of the UK traded market is estimated by multiplying the tradeable market by the UK's market share.
    - The UK's turnover from the non-traded market is equal to the size of the non-traded market.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs supported**.

Figure 10 **Methodology for assessing domestic business opportunities**

[107] For detail on cost estimates used, please refer to the Excel calculators provided for each sub-theme, and the individual sub-theme reports.



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Domestic business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade (import) and domestic production data, where available. If the technology is immature, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to potentially increase its market share in its domestic market. This estimate is informed by the previously performed export analysis. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.

Domestic business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The domestic assessment explicitly quantifies services such as O&M and installation, which are typically not traded but can support a large number of jobs associated with e.g. heat pumps. For these services, the estimate of potential service jobs supported is based on:
    - An estimate of the total turnover and GVA associated with the service

   - A ratio of GVA/jobs (adjusted for productivity increases) in analogous existing service sectors based on ONS data.
- The key services to consider are based on desk research, verified through stakeholder workshops.

Worked example

1. The **global and regional markets** to 2050 are sized based on illustrative deployment forecasts, which come from ESME when available.[108] For example, deployment of nuclear power (37 GW by 2050) is multiplied by O&M costs (~12% of total plant costs) to obtain annual turnover for the nuclear O&M market (~£2.5 billion by 2050).
2. The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market. In the case of nuclear O&M, tradability is 0% being as it is not tradeable. For the domestic analysis, tradability does not directly feed into our model, but is vital to provide insight on the share of the domestic market UK firms will capture.
3. The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below. For example, for nuclear O&M the UK domestic market share is 100% because the component is not tradeable and therefore foreign firms do not capture some of the value.
4. The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**. For nuclear O&M, market turnover (~£2.5 billion) is multiplied by the UK market share (95%) of O&M to obtain UK-captured turnover (~£2.5 billion by 2050).
5. The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by labour productivity figures for that sector to obtain **jobs supported**. For example, appropriate Standard Industrial Classification (SIC) codes are chosen for nuclear O&M. This leads to a GVA / turnover multiplier (49%) that is multiplied by market turnover (~£2.5 billion) to isolate GVA (~£1 billion by 2050), which is then divided by labour productivity (~70,000 GVA / worker by 2050) to isolate jobs supported (~16,000 jobs by 2050).

[108] If deployment information is not available from the IEA, alternative projections from, for example, Bloomberg are used. Please see individual sub-theme reports for further detail.

Appendix 3: Assessment of business opportunities uncertainty

The assessment of business opportunities in the long term, associated with new technologies is uncertain. This assessment does not attempt to forecast what will happen. Instead, the business opportunity assessment attempts to provide a realistic and consistent assessment, based on current information, on the business opportunities that could be captured by the UK. Whether these opportunities are indeed realised depends on domestic and international developments, political decisions, macro-economic conditions, and numerous other complex variables.

As this assessment is not intended as a full forecast, a formal quantitative sensitivity analysis has not been performed. the below provides a high-level qualitative assessment of the uncertainty associated with the sized opportunity. Note, this is not an assessment of how likely the UK is to capture the opportunity, rather it is an assessment of the uncertainty range around the size of the opportunity. The assessment is based on three key factors driving the assessment

1. *The level of future deployment of the technology*. Technologies such as offshore wind are deployed at scale across different energy system modelling scenarios and hence considered relatively certain. In contrast, there is more uncertainty for e.g. hydrogen related technologies. The export analysis is based on 3 IEA scenarios (with numbers provided for the IEA ETP 2 degree scenario). Domestic analysis is based on a single ESME run used across the EINA process.
2. *The potential domestic market share* the UK can capture. This assessment attempts to estimate a plausible market share for the UK across relevant markets. Where this can be based on longstanding trade relationships and industries, this assessment is considered more robust.
3. *Future technology costs and production techniques* are a key driver of the future turnover, gross value added and jobs associated with a technology. For immature technologies for which manufacturing techniques may, for example, become highly automated in future, future costs and jobs supported by the technology may be significantly lower than assessed.

The ratings in the table below are the judgement of Vivid analysts based on the above considerations. The analysts have worked across all sub-themes and the ratings should be considered as a judgement of the uncertainty around the size of the opportunity relative to other sub-themes. As a rough guide, we judge the uncertainty bands around the opportunity estimates as follows:

- **Green**: Size of the opportunity is clear (+/- 20%). Note, this does not imply the UK will indeed capture the opportunity.

- **Amber:** Size of the opportunity is clear, but there are significant uncertainties (+/- 50%).
- **Red:** There are large uncertainties around market structure and whether the technology will be taken up at all in major markets. The opportunity could be a factor 2-3 larger or smaller than presented.

Table 18. **Assessment of uncertainty in business opportunities across sub-themes**

Sub-theme	Uncertainty rating	Comments
Biomass and bioenergy		• **Deployment**: Moderate deployment uncertainty; BECCS can produce negative emissions that have high value to the energy system under a deep decarbonisation pathway; there is moderate uncertainty as to whether BECCS will be used for hydrogen production, as in the ESME modelling, or for power generation. • **UK market share:** Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services and feedstocks. • **Costs and production techniques:** Relatively certain costs with most opportunities associated with labour input rather than immature technologies.
Building fabric		• **Deployment:** Depends on levels of retrofit that greatly exceed those seen to date. • **Market share:** Speculative for traded. However, majority of market untraded, highly likely captured domestically. • **Costs and production techniques:** High share of labour costs (independent of uncertain tech cost).
CCUS		• **Deployment:** Moderate deployment uncertainty; decarbonisation scenarios anticipate rapid uptake of CCUS, though there are few large-scale facilities today. • **Market share:** Moderate market share uncertainty; the UK is likely to be competitive in the storage of CO2 and EPCm services while component market shares are less certain given numerous technology choices and lack of clear competitors. • **Costs and production techniques:** Moderate cost uncertainty; the lack of large-scale facilities today makes estimating future costs difficult.
Heating and cooling		• **Deployment**: Expected to be deployed in most UK buildings by 2050. • **Market share:** some uncertainties, immaturity in markets such as for hydrogen boilers. • **Costs and production techniques:** Relatively certain given relative maturity of boilers and heat pumps. • **Deployment of hydrogen boilers or heat pumps** lead to similar opportunities for UK businesses, while heat networks present a 50 per cent smaller opportunity per household.
Hydrogen and fuel cells		• **Deployment**: Highly uncertain future deployment with a wide-range of 2050 hydrogen demand estimates across scenarios, particularly for export markets. • **UK market share**: Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services.

		• **Costs and production techniques:** Although deep uncertainty in future hydrogen production costs, for example electrolysis, most domestic costs are associated with labour input rather than equipment.
Industry		• **Deployment**: Relative certainty in deployment as it is based on the 2050 Roadmaps • **UK market share**: Some uncertainty due to poor quality of trade data that may not be representative of technologies within scope. • **Costs and production techniques:** Some uncertainty in costs, particularly for less mature technologies.
Light duty transport		• **Deployment**: Certainty in deployment; low-carbon vehicles will be required in any deep decarbonisation scenario. • **UK market share**: Speculative market share for a relatively immature market; a small number of uncertain future FDI investment decisions generates high uncertainty in overall business opportunities. • **Costs and production techniques:** Highly uncertain future costs, with substantial falls in battery costs a key enabler of BEV uptake.
Nuclear fission		• **Deployment**: Moderate uncertainty in future deployment with some proposed nuclear plants recently cancelled • **UK market share**: Relatively certain market shares based on robust estimates of current nuclear activity; market share growth is dependent on uncertain development of UK reactor IP; however, most business opportunities are associated with untraded activity or areas where the UK has existing strength • **Costs and production techniques:** Uncertain costs for nuclear new build, with dangers of construction overrun; deep uncertainty in costs for immature nuclear technologies, for example SMRs and AMRs.
Offshore wind		• **Deployment**: Offshore wind will be required in any deep decarbonisation scenario, with clear government commitments. • **UK market share**: Expected growth in current market shares given commitments and progress to date. • **Costs and production techniques:** Costs are relatively certain, with clear pathways to 2050.
Tidal stream		• **Deployment**: Global sites for tidal stream are relatively limited, and hence the potential market size well established. • **UK market share**: Although the market is immature, the UK has a an established (and competitive) position. • **Costs and production techniques:** Costs are relatively certain, although the impact of potential scale production is hard to anticipate.
Smart systems		• **Deployment**: High deployment uncertainty given immaturity of smart system market today and evolving business models and regulatory framework. • **UK market share**: Moderate uncertainty given immaturity of the market today and scalable nature of digital smart technologies, though there is UK leadership in aggregation services and V2G charging. • **Costs and production techniques**: Moderate uncertainty of cost reductions of batteries and V2G and smart chargers, though costs are expected to continue to fall.

Source: Vivid Economics

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