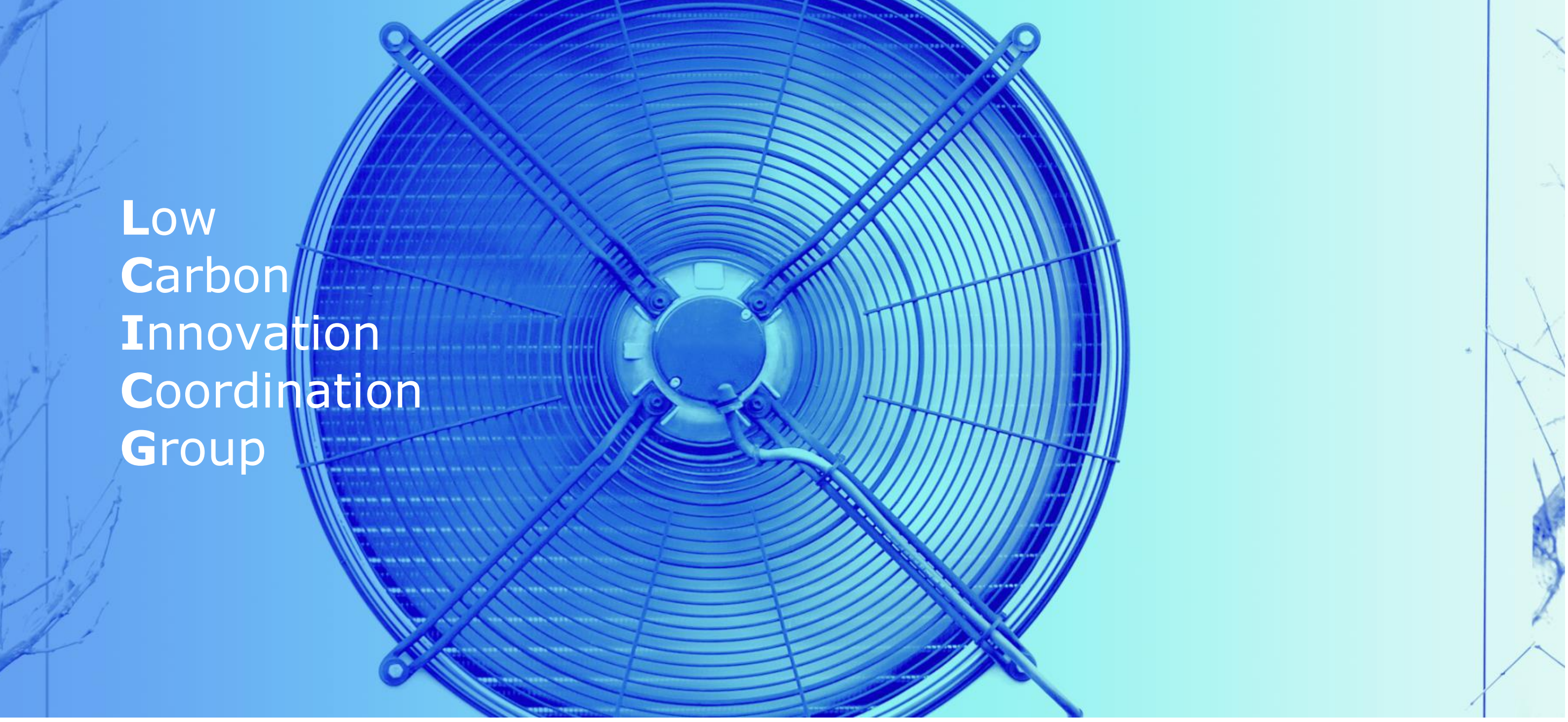

Low
Carbon
Innovation
Coordination
Group

Technology Innovation Needs Assessment (TINA)

Heat
Summary Report

March 2016

Background to Technology Innovation Needs Assessments

The TINAs are a collaborative effort of the Low Carbon Innovation Co-ordination Group (LCICG), which is the coordination vehicle for the UK's major public sector backed funding and delivery bodies in the area of 'low carbon innovation'. Its core members (at the time of this document's completion) are the Department of Business, Innovation and Skills (BIS), the Department of Energy and Climate Change (DECC), the Energy Technologies Institute (ETI), the Engineering and Physical Sciences Research Council (EPSRC), Innovate UK, Scottish Enterprise, and the Scottish Government.

The TINAs aim to identify and value the key innovation needs of specific low carbon technology families to inform the prioritisation of public sector investment in low carbon innovation. Beyond innovation there are other barriers and opportunities in planning, the supply chain, related infrastructure and finance. These are not explicitly considered in the TINA's conclusion since they are the focus of other Government initiatives.

This document summarises the Heat TINA analysis.

The TINAs apply a consistent methodology across a diverse range of technologies, and a comparison of relative values across the different TINAs is as important as the examination of absolute values within each TINA.

The TINA analytical framework was developed and implemented by the Carbon Trust with contributions from all core LCICG members as well as input from numerous other expert individuals and organisations.

Disclaimer – the TINAs provide an independent analysis of innovation needs and a comparison between technologies. The TINAs' scenarios and associated values provide a framework to inform that analysis and those comparisons. The values are not predictions or targets and are not intended to describe or replace the published policies of any LCICG members. Any statements in the TINA do not necessarily represent the policies of LCICG members (or the UK Government).

Department for Business Innovation & Skills

Department of Energy & Climate Change

energy technologies institute

EPSRC Engineering and Physical Sciences Research Council

Innovate UK Technology Strategy Board

Scottish Enterprise

The Scottish Government Riaghaltas na h-Alba

This analysis was prepared for the LCICG by:

CARBON TRUST

Key findings

This TINA focuses on heat pumps, heat networks, and heat storage as three of the key heat technologies[1]. Innovation in these heat technologies represents a significant opportunity to help meet the UK's greenhouse gas (GHG) emissions targets, as well as providing value through cost reductions, amounting to potential savings for the energy system of c. £12 (£5–23) billion[2] by 2050. Innovation could help create business opportunities that could contribute total direct Gross Value Added (GVA) of c. £25 (£12–42) billion to UK gross domestic product (GDP) by 2050, whilst supporting c. 88,000 (41,000–153,000) direct jobs in 2050[3]. Public sector intervention will be required to unlock this value, as there are significant market barriers across the sector to overcome.

Potential role in the UK's energy system	• Nearly half of the energy we use in the UK is used for heating of one sort or another. Heat pumps, heat networks, and heat storage can offer many benefits to a low-carbon energy system: (i) heat pumps are potentially a very efficient means of delivering heat with low GHG emissions; (ii) heat networks can maximise system efficiency by leveraging and distributing a variety of different sources of excess heat to centres of demand and offer storage potential; (iii) heat pumps, heat networks, and heat storage can be integrated into the energy system to ease balancing requirements related to the very "peaky" nature of heat demand. • Heat pumps, heat networks, and heat storage can be significant contributors to the future energy system, delivering up to c. 80% of the entire UK heat demand by 2050. We estimate potential 2050 deployment levels of 99 (54-186) GW (76-261 TWh) for heat pumps, 47 (5-83) GW (7-117 TWh) for heat networks, and 3 (2-6) GW (3-9 TWh) for inter-seasonal heat storage.
Cutting costs by innovating	• Commercially available versions of all these technologies already exist, but all offer significant cost and performance improvement potential through further learning and innovation: – Heat pumps: Innovation in installation and heat pump technology offer the bulk of the potential; innovation (learning by research and development or learning-by-R&D) and process improvements (learning-by-doing) have the potential to drive down deployment costs by up to 21% by 2050. – Heat networks: Innovation in installation, design, and the heat interface unit offer the bulk of the potential. Innovation in design, whilst less technological, offers scope for cost reduction. Innovation (learning-by-R&D) and process improvements (learning-by-doing) have the potential to drive down deployment costs by up to 16%[1] by 2050. Waste heat recovery, and the integration of heat pumps and novel renewable sources, coinciding with electrification of heat, offer further system cost reduction opportunities. – Heat storage: For inter-seasonal storage, innovation in the heat/cold store can provide the bulk of the savings. Innovation (learning-by-R&D) and process improvements (learning-by-doing) have the potential to drive down deployment costs by up to 36% by 2050. • Depending on deployment levels, innovation and process improvements could deliver potential cumulative cost savings of £37 (£18–70) billion (bn) to 2050.
Green growth opportunity	• The heat market at present is dominated by foreign actors. There are UK actors, although these are less well known. If aggressive deployment occurs the UK could capture some of the market. Installation, design, and operation and maintenance (O&M) are likely to be important to the UK. • Whilst not currently a market leader in these heat technologies, the UK could capture c. 2% of the total global market with a cumulative size of £252 (121-416) bn to 2050. • If the UK successfully competes in the global market to achieve a c. 2% share, the heat market could contribute £25 (£12-42) bn of potential cumulative direct GVA to the UK economy to 2050. This GVA is split c. 75% towards activities in the UK and c. 25% towards export markets.

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[1] This TINA does not examine other heat based technologies. In addition it does not include a major switch from our local gas distribution network to a hydrogen based system. It is predicated on large reductions of natural gas in the gas grid. If such decarbonisation takes place then take up of heat pumps and heat networks for on gas grid properties could be low and the figures within this TINA may not be achieved.

[2] Cumulative (2015-2050) 2015 GBP discounted values for medium (low-high) UK deployment scenarios and a high innovation scenario.

[3] Cumulative (2015-2050) 2015 GBP discounted values for medium (low-high) global and UK deployment scenarios and a high innovation scenario.

The case for UK public sector intervention	• To unlock this opportunity there is a strong case for targeted public sector intervention to catalyse private sector investment – there are significant market failures to innovation in the design and installation for heat pumps, heat networks, and heat storage technologies, and the UK cannot exclusively rely on other countries to develop the technologies within the required timescales particularly as the UK housing stock, fabric, and energy use has its own unique set of varied characteristics. • The main market failures and barriers relate to: – Heat pumps: the lack of customer awareness, high upfront capital cost, uncertainty around potential energy savings, visual appearance constraints, and lack of knowledge amongst installers currently deter customers from switching to heat pumps. A number of infrastructure conditions also hamper deployment of heat pumps in the UK. The characteristics of the UK housing stock are not ideal for heat pumps, with high thermal loss and use of high temperature radiators. Development of hybrid or high temperature systems can make heat pumps more suitable for retrofit; encouragement to use lower temperature heating systems (e.g. underfloor heating) can foster a higher demand for conventional heat pumps. – Heat networks: High upfront capital costs, demand uncertainties, lack of incentives, lack of regulation, planning restrictions, lack of knowledge, and varied capability across local authorities and the UK supply chain, and low public awareness restrict the consenting and installation of heat networks. In addition to the above waste recovery is further restricted by a lack of strategic planning and regulations, and inhibited by infrastructure capable of processing low grade heat. – Inter-seasonal heat storage: high upfront capital cost, lack of customer acceptance, uncertainty around future heat demand, lack of design / installation expertise and complex planning regime currently deter the deployment of inter-seasonal heat storage. • In areas such as heat pump technologies, heat pump O&M, heat networks heat interface unit (HIU), controls, and pipes, the UK could rely on other countries to deliver the innovation required. There is a strong case for UK public sector intervention to drive innovation in areas including design and installation of heat pumps, heat storage, heat networks, and waste heat recovery in order to develop solutions that are suitable for UK specific conditions.
Potential priorities to deliver the greatest benefit to the UK	• Innovation areas offering the biggest benefit from UK public sector support are: – Building / networks-level demonstration of integrated heating systems consisting of heat networks, heat pumps, and heat storage (inter-seasonal). – Large scale domestic sector demonstrations to test design and installation solutions for heat pumps. – Research, development and demonstration (RD&D) of key heat pump components to reduce size and noise of heat pumps to make them more acceptable and suitable for retrofit; RD&D of "smart control systems" for heat pumps that can generate high quality data on performance, take into account customer preference, and building thermal performance to optimise heat pump performance and ease of use. – Developing 3rd and 4th generation heat networks within local areas capable of leveraging multiple heat sources, and 'smartly' responding to supply and demand, thus providing key grid and heat balancing effects. Unified and targeted national policies and comprehensive guidelines are required in order to achieve this. – RD&D to achieve cost reduction and performance improvement of inter-seasonal heat stores and heat extraction. • Supporting all of the innovation areas identified would require support in the tens of millions of GBP of public sector funding over the next 5-10 years.

Chart 1 Heat TINA summary

Sub-area	Variant/Focus	Value in meeting emissions targets at low cost £bn[1]	Value in business creation £bn[2]	Direct jobs supported in 2025/2050[3]	Key needs for UK public sector innovation activity/investment
Heat Pumps	**Key Components** (Heat Source, Pump Technology, Distribution, Controls)	2.3 (1.3-4.4)	10.6 (5.9-16.2)	15,000 / 37,000	• R&D and Design and demo of key components / processes: - Including noise reduction, size reduction, demand site management tools, facilitating heat distribution, user friendly controls, coefficient of performance (COP) improvements, novel component research. • Research data on heat pump performance, taking into account the fabric of the building and consumer behaviour and preferences.
	Auxiliary Items (Design, Installation, O&M)	3.3 (1.9-6.2)	7.1 (3.9-13.4)	8,000 / 28,000	• Large scale domestic sector demonstrations to test design and installation solutions and refine requirements for UK market roll-out.
Heat Networks	**Key Components** (Connection, HIU, Controls)	1.3 (0.0-2.3)	3.5 (1.3-5.5)	6,000 / 11,000	• Development of 4th generation networks. • Installation of 3rd/4th generation networks. • Research into insulation materials, joint closures and smart applications.
	Auxiliary Items (Design, Installation, O&M)	1.1 (0.0-2.0)	3.7 (1.1-6.0)	4,000 / 11,000	• RD&D and standardisation of design tools and making these widely available. • Front end load design, routing permissions, and waste heat recovery considerations.
Heat Storage[4]	**Key Components** (Heat/Cold Store, Controls)	0.6 (0.3-1.2)	0.6 (0.3-1.0)	800 / 1000	• R&D into key performance improvements e.g. minimal losses, rate of heat exchange. • R&D for early stage energy storage technologies incl. high-temperature PCM storage and thermal-chemical storage medium.
	Auxiliary Items (Design, Installation, O&M)	0.1 (0.0-0.1)	0.1 (0.0-0.2)	100 / 500	• Support targeted demonstration projects for more mature, but not yet widely deployed, energy storage technologies to document system performance and safety ratings.
System Integration	An integrated systems perspective is key to a successful transition to low carbon heat pathway.				• RD&D investigations with a view for system wide benefits. • Large scale district heating (DH) demonstrations that integrate heat pumps, heat networks and heat storage technologies. • Investigation on generation, distribution, storage and demand side response effects of heat.
Total[5]	**Value:**	**12** **(5-23)[6]**	**25** **(12-42)[7]**	**34,000 / 88,000**	

Benefit of UK public sector activity / investment[8]	High
	Medium
	Low

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[1] 2015-2050 value in meeting emissions at low cost estimates are built up from combining deployment scenarios taken from ETI's Energy System Modelling Environment (ESME) with an estimate of how much learning-by-R&D can reduce costs. Learning-by-R&D estimates are taken from an extensive literature review coupled with expert interviews and Carbon Trust analysis.

[2] 2015-2050 value in business creation is built up using IEA ETP 2014 global deployment scenarios, cost reduction scenarios, ONS figures, and adjusted downwards by 50% to account for displacement of other economic activity.

[3] Jobs supported in 2025 and 2050 are based on ONS figures. Jobs and GVA are direct and do not include indirect considerations.

[4] The TINA analysis only examines inter-seasonal heat storage. Daily heat storage has been omitted from the analysis due to its mature nature and difficulty to integrate into the UK housing stock.

[5] Due to rounding, the totals might not add up exactly.

[6] Performance improvement in heat pumps and heat network would lead to savings in fuel cost, the total cost savings of £12 (5-23) bn are inclusive of fuel cost savings of £3.3 (1.6-6.2) bn.

[7] 68% of the value is from domestic activities while 32% is from export.

[8] Also taking into account the extent of market failure and opportunity to rely on another country but without considering costs of the innovation support.

Heat plays a critical role in the UK energy system

Nearly half of the energy we use in the UK is used for heating of one sort or another[1], with demand assumed in modelling for this TINA at approximately 150-500TWh in 2050. The demand is highly "peaky" compared to other energy end uses in the UK, with much higher demand for heat during the coldest months of the year and during specific times of day. This high variability in demand across timescales of hours and seasons is a fundamental characteristic of heat delivery in the UK, with important implications for the technologies that can meet heat demand cost effectively.

Depending on the efficacy of energy efficiency and demand reduction measures, heat is expected to constitute between 19-44% of energy demand through to 2050.

Various technologies are potentially required to supply this heat demand through to 2050, including:

- Heat pumps (air source, ground source, water source, gas sorption, hybrid);
- Heat networks systems (in combination with industrial waste heat recovery, combined heat and power or CHP, biomass, geothermal, and other novel sources[2]);
- Solid biomass boilers;
- Solar thermal systems;
- Technology associated with renewable gas (e.g. biomethane) potentially for injecting into existing gas grid;
- High efficiency fossil fuel boilers;
- Heat storage (inter-seasonal and diurnal), which can play an important role in improving the effectiveness of heat supply technologies, and in balancing the overall heating system between peak and off-peak demand; and
- Other fuels such as hydrogen.

There are limited low carbon technology options for meeting the UK's heat needs, and all of these technologies face major challenges (some more technical than others) if they are to be widely deployed. Even relatively mature technologies such as heat pumps are not yet ready for broad adoption in the UK context. Moreover, the provision of heat is closely linked to the thermal performance of buildings where the use and retention of heat varies greatly. The transition from traditional gas boilers to low carbon heating options requires not only technology changes but also corresponding operational and behavioural changes.

This report focuses on the innovation potential in three of the core heat technology areas which appear to be persistently important to the UK heating system across a variety of future scenarios: heat pumps (air and ground source), heat networks (including waste heat recovery), and heat storage (inter-seasonal and diurnal). These technologies offer many benefits to a low-carbon energy system:

- Heat pumps are potentially very efficient and an efficient means of delivering heat with low GHG emissions;
- Heat networks can operate at high utilisation, are cost effective, and can maximise system efficiency by leveraging and distributing excess heat to centres of demand. They can also act as heat stores to coincide with increasing renewable sources; and
- System integration offers great potential; Heat pumps, heat networks, and heat storage can be combined and integrated into the energy system to ease balancing requirements related to the very "peaky" nature of heat demand.

It should be noted that this TINA does not examine other technologies beyond those listed directly above.

Innovation opportunities over the next 10 years have the potential to bring down the deployment costs of these heat technologies by up to c. 16%, with further savings after 2025 likely to bring down costs even further – potentially up to c. 31% by 2050. An integrated systems perspective approach is necessary, as heating systems that integrate heat networks, heat pumps, heat storage, and leverage waste heat have the

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[1] The Future of Heating – Meeting the Challenge (March 2013).

[2] The GLA Secondary Heat study in 2013 identified 11 sources classified under 'environmental', 'processes', and infrastructure sources. Please refer to the study for a full list.

potential to deliver benefits greater than the sum of each technology or component used.

Policy has a key role to play in enabling technology uptake: policy signifies government commitment and encourages private sector investment in innovations by creating additional market demand. Experts interviewed for this report commented that policies that provide additional incentives (e.g. Renewable Heat Incentive (RHI), Heat Network Delivery Unit (HNDU)), supportive planning regimes and innovation support (e.g. large scale demonstrations to support design and installation solutions) are key to promoting further uptake of these heat technologies.

We have determined three illustrative deployment scenarios (low-medium-high) for heat pumps, heat networks, and heat storage, assuming all of these technologies achieve their innovation potential. These scenarios are generated based on ETI ESME runs[1]. These scenarios aim to capture the full range of feasible deployment scenarios, and are neither forecasts for the UK nor targets for policy makers[2].

Heat pumps

Heat pumps can play a significant role in delivering space heating and hot water in the future. Major building retrofits and new construction can be attractive markets for heat pump deployment. Reduced size and noise of heat pumps can make them more suitable to retrofit. Better thermal performance from building fabric and reduced installation costs will improve cost-effectiveness of heat pumps.

- **Low scenario[3]** (12 TWh in 2025, 76 TWh in 2050): Strong constraints to heat pump deployment owing to other energy efficiency improvements (such as insulation) and service demand reductions. In the period to 2025, rapid growth of alternative renewable heat technologies (i.e. biomass heat, CHP). Heat pump deployment grows to cover 3% of heat demand by 2025 and 16% of heat demand by 2050.
- **Medium scenario** (21 TWh in 2025, 139 TWh in 2050): Heat pumps are deployed more extensively, but total heat demand is still low due to energy efficiency and service demand reductions. Alternatively, this can be conceived in terms of moderate demand reductions. Heat pump deployment grows to cover 5% of heat demand by 2025 and 28% of heat demand by 2050.
- **High scenario** (40 TWh in 2025, 261 TWh in 2050) Limited heat demand reduction (no price impact, efficiency measures only). Successful heat pump penetration in a wide range of building applications coupled with strong grid management. Heat pump deployment grows to cover 9% of heat demand by 2025 and 53% of heat demand by 2050.

Consumer acceptance will be an important challenge for widespread deployment of heat pumps. The incumbent gas boiler technology can deliver heat quickly and at high temperatures, whilst heat pumps require a long start time and operate most efficiently at lower temperatures. These limitations will require adaptation from consumers and “smart” controls that can anticipate user requirements for space heating and hot water.

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[1] Standard deterministic run with DECC/ETI parameters. This TINA in its low scenario assumes low carbon heat technologies are less prominent than assumed within the utilised ESME run. This low scenario overall represents 30% of final consumption in heat in 2050.

[2] By trying to capture the full range of uncertainty over the mid to long term to inform innovation policy, these indicative deployment levels were not precisely aligned with UK government’s short and mid-term targets.

[3] Low and high scenarios do not have a statistical basis, but are (in principle) meant to represent “feasible” outcomes *rather than* absolute “extremes”. It is worth noting that these scenarios do not include a hydrogen based economy which would entail significant differences in the adopted technologies.

Heat networks

Heat networks are a key enabler to a transition to low carbon heat. They are the mechanism to transport and interconnect heat from sources of supply (e.g. industrial waste heat, biomass, rivers, sewage, solar/geo thermal, heat pumps) to centres of demand. Heat networks can also act as large stores for heat and provide a key balancing role by collecting and dispatching heat when required[1]. There are currently relatively low levels of heat networks within the UK when compared with other countries. The current stock is ageing, low in capacity and small in footprint e.g. connecting discrete buildings as opposed to district, local area heat distribution. Easing planning considerations, strategic planning, future proofing for heat networks, and higher public sector ambition are key to deploying more networks across the UK[2]. The Greater London Authority is making good progress in deploying heat networks. Other cities have heat network schemes e.g. Nottingham, Sheffield, Glasgow, and Aberdeen, however increased activity and targeted action is required across other regions if deployment scenarios are to be met[3].

- **Low scenario** (4 TWh in 2025, 7 TWh in 2050): Some planning constraints on the availability of heat networks restrict future growth. Higher renewables generation, and fewer thermal plants available for waste heat. High energy efficiency improvements and demand reductions. Low availability of sustainable biomass. Heat network deployment covers 0.9% of heat demand by 2025 and 1.4% of heat demand by 2050.
- **Medium scenario** (9 TWh in 2025, 65 TWh in 2050): Supportive planning and regulatory framework. Moderate energy efficiency improvement and heat demand reduction. Availability of sufficient thermal plant in suitable locations. Medium availability of sustainable biomass. Heat network deployment grows to cover 2% of heat demand by 2025 and 13% of heat demand by 2050.
- **High scenario** (16 TWh in 2025, 117 TWh in 2050): High demand for heat and/or low take-up of insulation measure. Availability of thermal plant in suitable locations. Supportive planning and regulatory framework. High availability of sustainable biomass. Heat network deployment grows to cover 4% of heat demand by 2025 and 24% of heat demand by 2050.

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[1] Note: CHP district heating can also serve a balancing function, where plants can help compensate for intermittent electricity sources.

[2] Heat network deployment is further restricted in the UK due to the heavy dependency on regulated gas and electricity markets.

[3] The current demand from heat networks is estimate as between 4 and 6 TWh. There is a great deal of uncertainty around this estimate and will remain so until the data taken as part of the Heat Network Billing and Metering Regulations is collected and analysed.

Heat storage

For heat storage technologies, we have considered *diurnal* and *inter-seasonal* heat storage.

Diurnal heat storage can currently be delivered using sensible (e.g. water, sand, rocks), latent (based on phase change materials such as paraffin), and thermal-chemical heat storage technologies. Currently hot water tanks are used in the majority of buildings that have heat storage, and the technology is considered mature and no technical innovations are expected to significantly bring down costs[1]. Latent and thermal-chemical heat storage technologies can offer significantly higher heat storage density and can operate at much higher temperature than sensible heat storage, making them useful for applications such as incorporation into walls to increase thermal mass of buildings, or storage of a large amount of heat in a small space. However, both latent and thermal-chemical heat storage technologies are still in an early research phase and are not currently commercially available[2].

Inter-seasonal heat storage is used in Europe but is not yet widely deployed in the UK, and has significant innovation and cost reduction potential[3].

- **Low scenario** (0.4 TWh in 2025, 2.6 TWh in 2050): Strong constraints to heat pump deployment owing to technical and user issues would reduce heat storage requirement. In the period to 2025, rapid growth of alternative renewable heat technologies (i.e. biomass heat). Inter-seasonal heat storage deployment grows to cover 0.1% of heat demand by 2025 and 0.5% of heat demand by 2050.
- **Medium scenario** (0.7 TWh in 2025, 5 TWh in 2050): Strong demand reduction (both price impact and efficiency measures) and successful heat pump penetration in a range of building applications leading to higher needs of storage. Inter-seasonal heat storage deployment grows to cover 0.2% of heat demand by 2025 and 1.0% of heat demand by 2050.
- **High scenario** (1 TWh in 2025, 9 TWh in 2050): Limited heat demand reduction (efficiency measures only) and successful heat pump penetration in wide range of building applications coupled with strong grid management. Inter-seasonal heat storage deployment grows to cover 0.3 % of heat demand by 2025 and 1.9% of heat demand by 2050.

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[1] Whilst there is limited innovation potential in the technology, more work can be carried out to improve integration.

[2] Neither latent nor thermal-chemical heat storage technologies are currently commercially available in the UK. Due to the lack of data on capital costs, these technologies are not considered in the cost reduction analysis. However, it should be noted that that with innovation these technologies could feature within a future energy mix.

[3] Inter seasonal storage technologies include tank thermal energy stores (TTES), pit thermal energy stores (PTES), borehole thermal energy stores (BTES), and aquifer thermal energy stores (ATES). These can be found in Norway, Denmark, Sweden and Germany.

Cutting costs by innovating

Current costs

Heat pump and heat networks technologies are currently available with well understood costs that can serve as a basis for understanding innovation improvement potential. Heat storage technologies are also available with well understood costs, except the more advanced storage technologies (latent and thermal-chemical), which are not yet commercially available and whose cost reduction potential is not assessed in this report.

Heat pumps

A variety of heat pumps are available, and both absolute and levelised costs (and efficiency) depend on system specifications, including the heat source (air, ground or water), the size of the heat pump, the nature of the heat distribution system, the types of controls, and the method of installation. For the purpose of this analysis, we have used cost and efficiencies based on indicative air-source and ground-source heat pump (GSHP) technologies.

For domestic air-source heat pumps (AHSP)[1], we assume current installed capital costs of £863/kW, O&M of £12/kW/year, a coefficient of performance (CoP) of 2.71[2], the fuel cost over the lifetime of 17.5 years, and a load factor of 16%, which result in an estimated levelised cost of £98/MWh.

For commercial air-source heat pumps[3], we assume current capital costs of £1384/kW, O&M of £8.8/kW/year, a CoP of 2.71, the fuel cost over the lifetime of 17.5 years, and a load factor of 16%, which result in an estimated levelised cost of £117/MWh.

For ground-source heat pumps, we assume current capital costs of £1700/kW, O&M of £25/kW/year, a CoP of 3, the fuel cost over the lifetime of 17.5 years, and a load factor of 16%, which result in an estimated levelised cost of £134MWh. The largest components of total heat pump system cost are the heat pump technology itself, installation of the system, and the ongoing cost of fuel inputs (see ***Chart 2*** for an indicative breakdown).

Heat networks

Heat network systems also vary significantly in cost (the cost per metre of pipe varies significantly from rural areas to dense urban locations) and efficiency depending on the source of heat, the size of the network, the density of the areas they supply, and the specific technology used. For the purpose of this analysis, we have used cost and efficiencies based on an indicative heat networks system. Note that the analysis does not include innovation and cost improvement for the heat source as this is covered elsewhere. For our indicative heat networks[4], we assume current capital costs of £1400/kW[5], O&M of £10/kW/year, an efficiency of 85%, the fuel cost (waste heat) over the lifetime of 50 years, and a load factor of 20%, which result in a levelised cost of £36/MWh[6] (or £18/MWh excluding running costs). Excluding fuel costs, the largest components of total heat networks system cost are overground and underground connections (~30%), installation cost (25%), and interface with heat user (~15%).

Heat storage

As mentioned above, heat storage technologies vary greatly, as do their costs. For the purpose of this analysis, we have used cost and efficiencies based on an indicative heat storage system.

Inter-seasonal storage can already be provided through sensible heat technologies, and is likely to continue to be based on these technologies in the

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[1] Based on air-to-water heat pumps with capacity of 0 – 20kW; Sweett, *Research on cost and performance of heating and cooling technologies*, 2013 and DECC, Preliminary data from the RHPP heat pump metering programme, 2014.

[2] Mean seasonal Performance Factor (SPF) for ASHP as listed within the RHPP report.

[3] Based on air-to-water heat pumps with capacity of 20 – 100+kW; Sweett, *Research on cost and performance of heating and cooling technologies*, 2013.

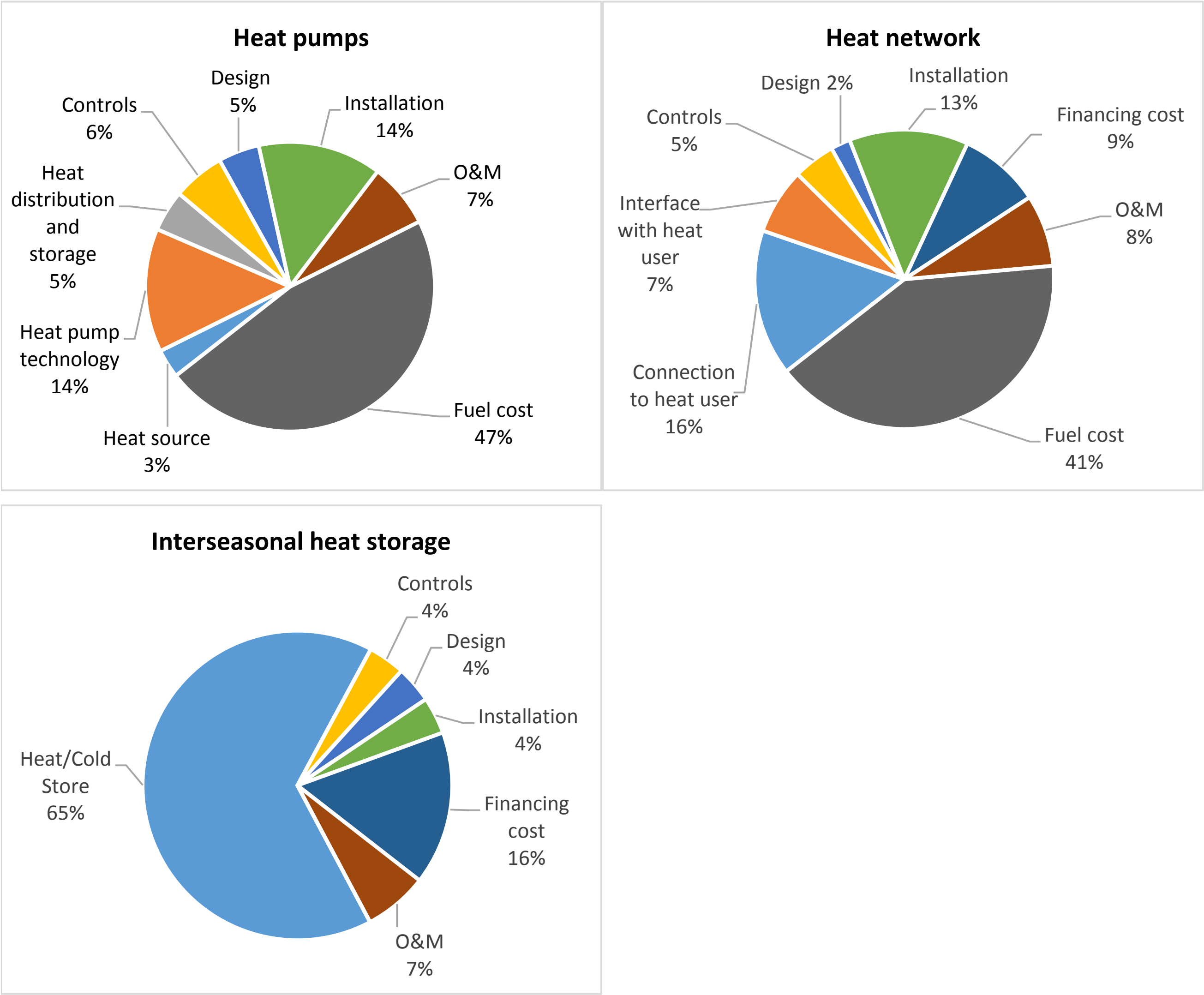
[4] Based on an archetype residential heat network; capital and operating costs based on DECC, *Assessment of the Costs, Performance, and Characteristics of UK Heat Networks,* 2015.

[5] Capital costs are representative of a small gas CHP scheme where there is limited civil works. Costs could be significantly higher for city wide schemes with extensive civil works.

[6] This is based on using waste heat from large thermal plants as the heat source. If we use biomass CHP or industrial process waste heat the current levelised cost would likely be 20-40% higher. Fuel cost is calculated using 20% of industrial grid electricity price. Inclusive of 5 year capital financing at 10% WACC (Weighted Average Cost of Capital), discounted back to 2015 at 3.5% social discount rate. The 2012 TINA heat network LCOE was calculated with 15% WACC over a 30 year term, without applying the 3.5% social discount rate.

future (since advanced storage technologies do not offer sufficient cost and performance benefits). For the purpose of this analysis we have looked at an indicative ground/aquifer system, assuming current capital costs of £1898/kW, O&M of £8.5/kW/year. Almost 85% of the system costs are from the heat/cold store, and only a small fraction is taken up by the controls, design, and installation.

Chart 2 Estimated components and composition of levelised cost[1] at 2015



Notes:

1. The LCOE calculation consists of CAPEX, financing cost, operating cost (fuel, operation, and maintenance).
2. Whilst financing is available for heat pumps this analysis judged there to be less of a need and greater challenges in securing financing than for heat networks and inter seasonal heat storage. It was therefore omitted from the LCOE calculation.

Sources: DECC / HM Treasury, *Green Book*, 2014; Sweett, *Research on the costs and performance of heating and cooling technologies*, 2013; DECC, *Preliminary data from the RHPP heat pump metering programme*, 2014; Delta-ee, *Potential cost reductions for Air Source Heat Pumps*, 2014; DECC, *Assessment of the Costs, Performance, and Characteristics of UK Heat Networks*, 2015; DECC Analysis Central Domestic Assumptions; Heat TINA 2012; Frontier Economics, Reducing the cost of capital for household low carbon investment decisions, 2014; expert interviews; and Carbon Trust analysis.

Cost savings through learning-by-R&D and learning-by-doing

Heat pumps

While heat pump technologies are relatively mature, there remains potential to significantly reduce the cost of heat delivered by heat pumps, as well as to make heat pumps more suitable to deployment in the UK. Improvements in heat pump performance and in the design and installation of the systems are the greatest contributors to this potential from innovation. Total potential deployment cost savings (learning-by-doing and R&D) of 9% are possible by 2025, and 21% by 2050[1].

Heat networks

The technology surrounding today's heat networks is quite mature and significant cost reductions are dependent on high levels of deployment, and are likely to occur predominantly through learning-by-doing. However, there are opportunities for technology innovation through R&D impact with the shift to 3rd and 4th generation heat networks[2], taking a systems perspective to technology adoption, and smart and intra system communication technologies and strategies. Furthermore, investigations into leveraging waste heat, accommodating renewable sources and the electrification of heat provide new opportunities for cost reduction if managed appropriately. Design, controls, interface and streamlined installation provide the greatest cost reduction opportunities. Total potential deployment cost savings of 8% are possible by 2025, and 16% by 2050[3]. As other countries revamp old networks and build new ones there is increasing opportunity for the UK heat networks sector to collaborate and learn from technological developments abroad.

Heat storage

For *diurnal heat storage*, hot water systems are mature and have no significant potential for improvements through innovation. For latent and thermal-chemical heat storage systems there remain significant innovation potential, but due to the lack of data they are not quantified in this report.

For *inter-seasonal heat storage*, innovations in heat extraction technologies and installation processes have the potential deliver significant cost reductions. Total potential deployment cost savings of 16% are possible by 2025, and 36% by 2050[4].

As an enabling technology, heat storage can have indirect benefits in enabling the deployment of other technologies. Heat storage can make heat networks more economical by allowing heat sources to operate more efficiently and reducing the need to build generation capacity to cover peak periods of heat demand. In addition, diurnal heat storage can help to improve the performance and consumer acceptance of heat pumps, which are less able to meet spikes in heat demand than incumbent gas boiler technology. As electric heat pumps become more common, heat storage can help reduce the costs of reinforcing electricity networks and generation capacity.

Chart 3 below shows the unit levelised cost reduction potential from 2015-2050 with breakdown of learning-by-R&D and learning-by-doing. Note that the proportion of cost reduction through learning-by-R&D that can be influenced by the UK Government is not broken down separately and is outside of the scope of this study.

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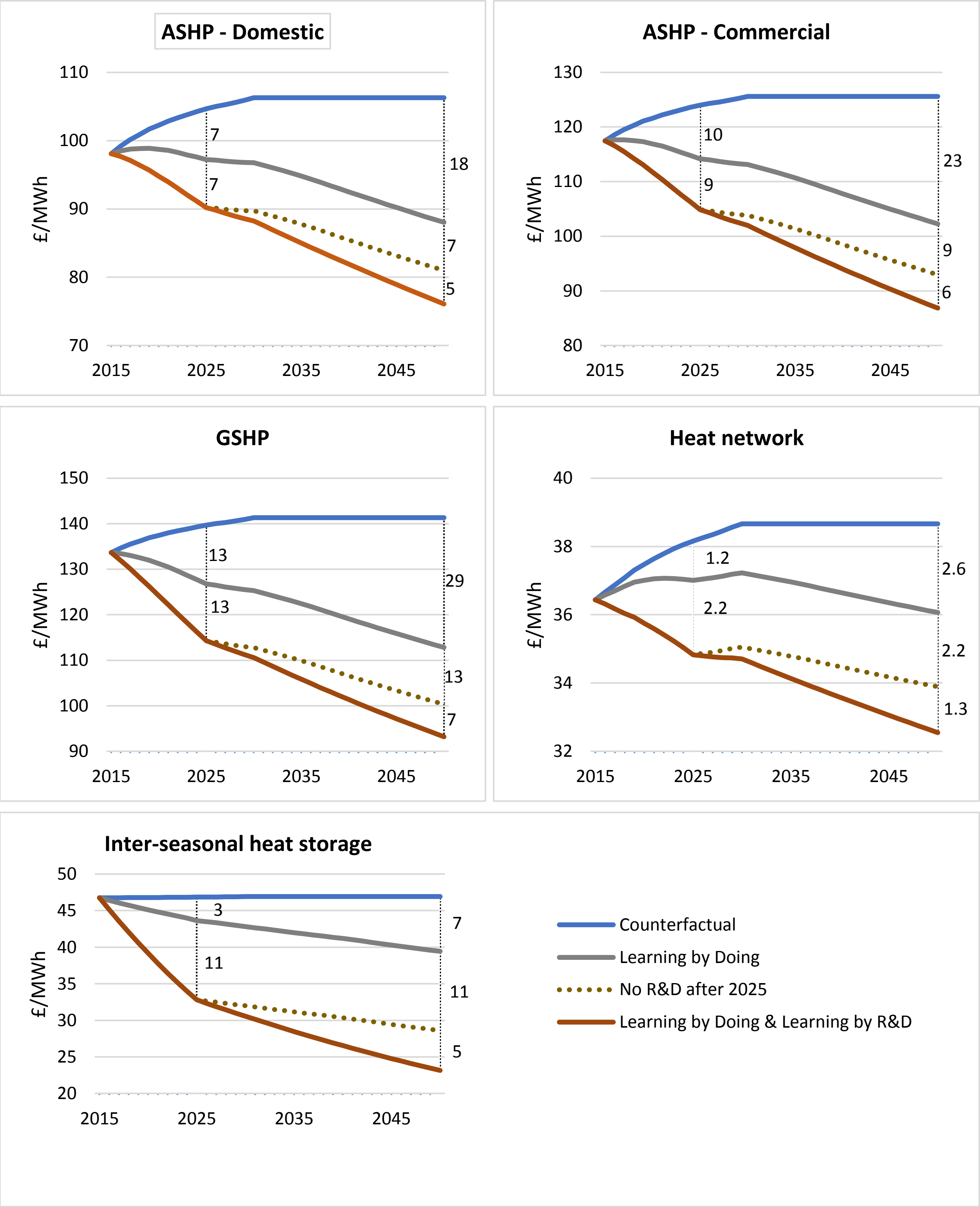
[1] High innovation scenario.

[2] 3rd generation heat networks are classified as prefabricated, pre-insulated, industrialised compact stations (with insulation), can integrate multiple sources, and contain metering and monitoring. 4th generation are classified as low energy demand, smart energy with optimum interaction of energy sources, distribution and consumption, and can allow for two way district heating. Innovation focus should remain on developing 4th generation, but there remains value in installing 3rd generation networks.

[3] Ibid

[4] Ibid

Chart 3 Estimated unit levelised cost[1] 2015-2050[2] with learning-by-R&D and learning-by-doing, in £/MWh



Notes:

1. The LCOE calculation consists of CAPEX, financing cost, operating cost (fuel, operation, and maintenance).
2. The cost reduction due to learning-by-R&D and learning-by-doing are dependent on the technology maturity. Extract from Jamasb, T, *"Technical Change Theory and Learning Curves", The Energy Journal 28(3),* 2007.

Sources: DECC / HM Treasury, *Green Book*, 2014; Sweett, *Research on the costs and performance of heating and cooling technologies*, 2013; DECC, *Preliminary data from the RHPP heat pump metering programme*, 2014; Delta-ee, *Potential cost reductions for Air Source Heat Pumps*, 2014; DECC, *Assessment of the Costs, Performance, and Characteristics of UK Heat Networks*, 2015; DECC Analysis Central Domestic Assumptions; Heat TINA 2012; Expert interviews; and Carbon Trust analysis.

Chart 4 Heat Pump potential cost savings from innovation (learning-by-R&D and learning-by-doing)

Sub-area	Type	Innovation impact potential on unit costs by ~2025[1]	Innovation impact potential on unit costs by 2050	What is needed (source of improvement potential)
Heat source	GSHP	c.7%	c.23%	▪ Ground replenishment methods and coupling with solar thermal to increase heat outputs, i.e. inject the excess heat collected from solar thermal in summer into the ground via a ground loop, so that better heat outputs can be obtained from the GSHP in winter. ▪ Methods for recovering rejected heat to help achieve higher CoP.
	ASHP	c.7%	c.23%	
Heat pump technology		c.20%	c.25%	▪ Mechanism to further improve CoP, including integration with solar PV, link with heat storage, use of better refrigerant. ▪ Improved compressor performance. ▪ Reduce noise and size, potentially by using more compact heat exchangers. ▪ Better expansion valves (moving from thermostatic to electric valves). ▪ Designs that reduce/eliminate superheat. ▪ Increasing the temperature of operating fluid returning to the heat pump to further improve CoP. ▪ Heat exchanger cleaning and de-icing techniques. ▪ Provision of cooling by reversing the refrigerant cycle to make heat pumps more versatile. ▪ Hybrid system consisting of a GSHP/ASHP and a gas boiler. ▪ Gas Sorption Heat Pumps have the potential to be the next generation of fossil fuel heating devices to replace condensing boilers. ▪ High temperature heat pumps as they can be an alternative to gas boilers.
Heat distribution	-	c.20%	c.23%	▪ Further integration with wet radiator systems will simplify transition from gas boiler heating systems. ▪ Incremental improvement through optimisation of heat system, especially in running it at a lower flow temperature, and with a smaller flow / return temperature gap. ▪ Small convector (fan based) radiators could negate the need for underfloor heating or large radiators for space heating.
Controls	-	c.15%	c.20%	▪ Ability to produce higher quality information for the user to understand heat pump performance and how to get the most out of the heat pumps. ▪ Optimise operating conditions of fans, compressors and heat exchangers according to air and room temperatures, and the optimisation of the thermodynamic cycle by decreasing condensing temperatures and increasing evaporation temperatures; improved real-time diagnostics to provide real-time feedback of system performance and algorithms to spot anomalies. ▪ Development of "smart" systems (e.g. next generation thermostats) including software and hardware. ▪ Demand side management tools and system control panels which are user friendly and require little or no intervention. ▪ Better integration with grid (demand response arrangements). ▪ Integrating control for hybrid system which can automatically select the most economical energy source and has the ability to adjust the bivalence point to optimise heat pump performance and energy savings.
Design & installation	-	c.23%	c.40%	▪ More efficient ground loop installation for GSHP with possible transfer of drilling technologies from e.g. oil & gas or fibre optic installation. ▪ Technology to improve understanding of ground condition. ▪ Standard design tools. ▪ Better integration of all sub-areas within design planning and integration with heat technologies such as heat storage and heat networks. ▪ Innovation to simplify installation processes; standard fittings and connectors, which are compatible with existing infrastructure. ▪ Improved monitoring and control philosophy.
O&M	Fixed	c.30%	c.30%	▪ No major technological innovations expected, however incremental improvements in reliability and better installation are expected to reduce costs from breakdowns and the need for maintenance.
	Variable	c.30%	c.30%	
Total[2]		c.9%	c.21%	

[1] The innovation impact potential represents what experts deem to be "aspirational but feasible", and will form the central scenario for our modelling, our innovation goals, and our value assessments. Figures presented above will form the high innovation scenario. The cost saving numbers are inclusive of both learning-by-R&D and learning-by-doing.

[2] Total cost savings percentages include fuel cost, which is not shown in the table.

Sources: University of Warwick, *Gas Driven Heat Pumps: Market potential, support measures and barriers to development of the UK market,* 2013; IEA Heat Pump Programme*; Better thermal technologies for existing buildings,* 2015; DECC, *The Future of Heating: Meeting the Challenge,* 2013; *UKERC Energy Strategy Under Uncertainties,* 2014, *The LCICG's Strategic Framework*, 2014.

Chart 5 Heat networks potential cost savings from innovation (learning-by-R&D and learning-by-doing)[1]

Sub-area	**Type**	**Innovation impact potential on unit costs by ~2025[2]**	**Innovation impact potential on unit costs by 2050**	**What is needed (source of improvement potential)**
Heat Source	▪ Waste heat ▪ Solar thermal ▪ Heat store ▪ Heat pumps ▪ Gas CHP	▨	▨	▪ Improved heat source will impact the design of the networks and system. ▪ 3rd and 4th generation networks enable greater application of waste heat, large scale heat pumps, and other sources. ▪ There is an opportunity for the fabric of buildings to become a heat source (e.g. coating technologies, solar transpire collectors). This requires further research.
Design	▨	c.28%	c.35%	▪ Design optimisation to operate with lower temperatures, pressures, and minimise standing and pumping loses [e.g. direct connections, designing HIUs to minimise return temperatures]. All of these aim to reduce the parasitic losses in the system due to pumping less water around the networks. ▪ System design/ engineering approach to allow integration of renewables, waste heat, thermal systems (e.g. AM12 on CHP for buildings, and AM15 on biomass heating), cooling, large scale heat pumps, storage, and novel component technologies. ▪ Improved collaboration on design guidance and business model practises e.g. best practise manual, principals of design, and procurement guidelines. ▪ Design for maintenance; incl. tools to understand and design system integration. ▪ Expansion of the Building Installation Modelling (BIM) tool will allow partners to cooperate on a common platform and realise system effects. ▪ Alarm system (early warning of failure) will reduce O&M requirements. ▪ Focus on industrial sized heat networks design and shift to electrification of heat.
Connection to heat user	▪ Underground pipes ▪ Overground pipes	c.3%	c.3%	▪ In many ways the DH pipe products utilised today are already optimised by using thin wall steel tubing, highly efficient polyurethane insulation and a high degree of pre-fabrication of components and joint closures. ▪ 3rd and 4th generation networks that transport lower temperature, 'smart' and system integrated. These need to conform to UK health regulations. ▪ 'Smart' networks that have the ability to anticipate usage through data collection. ▪ Lower temperature heat sources and front end loading the choice of heat source within the system design might allow for smaller pipes and alternative materials. ▪ Improved insulation within steel and plastic pipes (e.g. polybutene) will increase system efficiency. Joint closure improvements are important to keep the pipes air tight to avoid moisture creep and erosion. ▪ FEL routing permissions (e.g. railway, waterway and road crossings) will minimise costs. Over ground solutions can be integrated into the building fabric.
Interface with heat user	▪ Hydraulic interface unit (HIU), the same for each variant of heat source	c.20%	c.50%	▪ This is a fairly mature area with products available on short lead times and to different levels of specification. ▪ Use of common components, more automated assembly and novel component design to achieve more than one function from a single item to reduce assembly costs and enable a more compact unit. ▪ Innovation in the heat metering/monitoring systems; better wireless technology integration; standardisation of heat exchangers at the interface. ▪ Lower temperature emitter systems and improved building control. ▪ Improved design and configuration for direct building connections (by passing HIU).
Controls	▨	c.17%	c.25%	▪ Improved performance feedback sensors/performance diagnostics and intelligent demand management systems for integration in smart thermal networks will improve overall efficiency and knowledge on cost reductions. ▪ Smart/ integrated metering; improved communications between controls, and multiple point across the wider system (e.g. internet of things) can improve distribution of heat, reduce losses and costs across larger networks. E.g. Leveraging smart apps to smartly share information from the user and the network back to energy centre + controls/HIU.

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[1] Source: GLA, *Secondary Heat,* 2013; GLA, *The London Plan,* 2015; IRENA, *Solar Heating and Cooling for Residential Applications,* 2015; UNEP, *District Energy in Cities*, 2015; DECC, *The Future of Heating,* 2013; *Invest in Heat Networks Scotland,* 2015; ETI, *Smart Systems and Heat,* 2015; Expert interviews; Carbon Trust Analysis.

[2] The innovation impact potential represents what experts deem to be "aspirational but feasible", and will form the central scenario for our modelling, our innovation goals, and our value assessments. Figures presented above will form the high innovation scenario. The cost saving numbers are inclusive of both learning-by-R&D and learning-by-doing.

[3] Total cost savings percentages include fuel cost, which is not shown in the table.

Chart 5 continued from the previous page.

Sub-area	Type	Innovation impact potential on unit costs by ~2025[1]	Innovation impact potential on unit costs by 2050	What is needed (source of improvement potential)
Installation	▪ Under ground ▪ Over ground	c.15%	c.20%	▪ New methods for jointing of steel pipe using mechanical coupling or automatic welding which may result in greater use of twin pipes and shorten construction times. Greater collaboration with engineering contractors is required. ▪ Improved sub terrain, infrastructure and earthwork considerations (e.g. Survey methods, GIS mapping, 3D modelling, sensing technologies, crossings, horizontal directional drilling (HDD)). ▪ Cost effective and FEL route selection (traffic management, road and train crossings, through lofts, basements etc.). The issues are not technical as such but legal and logistical, however if integrated into planning considerations-especially in urban would reduce costs. Collaboration with utilities and other civil construction activities (e.g. water/broadband) could minimise costs and disruption. ▪ For underground systems installation costs can be reduced by the use of "cold laying", i.e. Installing the two pipes vertically above each other (rather than next to each other) to reduce trench width, and making greater use of excavated material for backfilling. ▪ Use of twin pipes (two carrier pipes in one casing) could reduce costs by reducing installation time, and limit lengthy branch connections to buildings. ▪ For over ground systems combining the laying of heat networks pipes with the upgrade of the fabric efficiency of existing buildings (e.g. external wall insulation) could provide significant cost savings.
O&M	▨	c.18%	c.20%	▪ O&M System optimisation through better design and control systems; Optimising operating temperatures and pressures; greater use of direct connections; Improved Building Management Systems, and uptake of SCADA and industrial control systems will be important as increasingly complex and smarter heat networks are deployed. ▪ Software tools can minimise O&M maintenance requirements e.g. Energy control solutions that provide supervisory systems, monitor performance of the system, will allow for remote reconfiguration, and ease human intensive intervention. ▪ Build-up of skill base to improve installation and maintenance operations.
Total[3]	▨	c.8%	c.16%	

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[1] The innovation impact potential represents what experts deem to be "aspirational but feasible", and will form the central scenario for our modelling, our innovation goals, and our value assessments. Figures presented above will form the high innovation scenario. The cost saving numbers are inclusive of both learning-by-R&D and learning-by-doing.

[3] Total cost savings percentages include fuel cost, which is not shown in the table.

Chart 6: Waste Heat Recovery Requirements[1]

Sub-area	Type	What is needed (source of improvement potential)
Recovery	▪ For power stations ▪ For industrial processes	▪ There is limited scope for technology innovation in the steam cycle itself as the process is well understood and has been in use for many years in large continental district heating schemes. ▪ Consideration of heat potential in future geographical planning of power stations, and including CHP ready considerations. ▪ 'Future proofing' for waste heat recovery should be included in planning permission at large. ▪ The customers for waste heat recovery technology (the large utilities) are technically sophisticated and application level development is not required. ▪ Further development is likely to centre on detailed engineering assessment of the potential for waste heat recovery at specific sites (including considerations of the local demand for heat). ▪ The optimum approach to recovering heat from a coal or gas power station fitted with pre or post combustion carbon capture including the potential for heat recovery from the CO2 compression process may require further design work. ▪ New approaches to recover heat from flue gases using corrosion resistant materials may be a limited exception. ▪ In practise opportunity for secondary heat from industrial process may be smaller due to operational efficiencies being realised through optimised design at the plant, the large distance from plants to centres of heat demand (note many plants are not CHP ready). ▪ Heat is commonly recovered from refrigeration and cooling systems, for example in catering companies and opportunities remain within shopping centres or densely packed urban areas (e.g. Canary Wharf). Excluded from analysis as whilst it may be viable in theory often in practise it is to small scale, or just not undertaken. ▪ Transport systems and sewage can provide good CoP, however the current opportunities remain niche. ▪ Investigations into the interaction with Carbon Capture and Storage (CCS) will be required as CCS grows. ▪ Regulation to dis-incentivise heat waste would strongly encourage uptake of heat recovery within the UK. ▪ Investigation into leveraging to sewage sourced heat pumps and Organic Rankine Cycles for heat recovery. ▪ Strategic planning of future power stations and industrial plans that are close (e.g. within max 100km) of a major heat demand centre. ▪ Regulations and increased guidance surrounding the integration into waste heat within future infrastructure, industrial builds. Requirements for new plants to be CHP ready. ▪ Improved understanding of the reliability of sources and how this could complement grid management.
Connection to heat store or user	▪ Underground pipes ▪ Overground pipes	
Controls		
Installation	▪ From low pressure turbine ▪ From between high pressure and low pressure turbine ▪ Coupled with heat pumps	
Design and O&M	▪ Design, operation and maintenance are similar irrespective of recovery method	

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[1] A number of enablers for waste recovery are required. These can be summarised as efficient long distance heat transfer (heat networks), control strategies, building design to accommodate low heat, heat storage, strategic planning, EU and international collaboration. No cost reductions for waste heat recovery are estimated within the TINA due to low levels of adoption and lack of expert opinion within this area. Note: Heat waste recovery is further analysed within the Industrial TINA.

Sources: Literature review covering inter alia: GLA, *Secondary Heat*, 2013; GLA, *The London Plan,* 2015; UNEP, *District Energy in Cities*, 2015; DECC, *The Future of Heating*, 2013; *Invest in Heat Networks Scotland,* 2015; Expert Interviews; Carbon Trust analysis.

Chart 7 Diurnal heat storage[1] potential cost savings from innovation (learning-by-R&D and learning-by-doing)

Sub-area	Innovation impact potential on unit costs by ~2025[2]	Innovation impact potential on unit costs by 2050	Energy system benefits additional to available technology	What is needed (source of improvement potential)
Heat store	N/A	N/A	▪ Additional system benefits of daily heat storage: ▪ reduce peak load on network ▪ reduce peak capacity ▪ generation flexibility ▪ increase efficiency ▪ Owing to performance and acceptability issues with heat pumps using existing water storage (e.g. space requirements), innovation could significantly increase uptake of daily storage and hence bring *additional* system benefits.	▪ Incorporation of micro-encapsulated phase change materials (PCM) e.g. paraffin wax, into walls to increase the thermal mass and capacity of buildings. ▪ High temperature PCM applications. ▪ Of the heat storage technologies, thermochemical systems are the least developed and research is required to identify and develop suitable materials for use as thermochemical heat stores.
Extraction	N/A	N/A		▪ Research is required to enable systems designs to be produced to achieve or come close to theoretical performance in terms of charge / discharge rate for PCM. ▪ Improve the rate of heat transfer (or chemical reaction) of PCMs and thermo-chemical systems. ▪ Innovations in the materials themselves and/or the containment systems could help optimise the rates of heat transfer in order to extract the maximum value from the storage capacity.
Installation	N/A	N/A		▪ N/A
Design and O&M	N/A	N/A		▪ N/A
Total	N/A	N/A		

[1] This summary table refers to latent / thermo-chemical heat storage technologies only as sensible heat storage technologies are considered mature and well-established and no technical innovations are expected to significantly bring down costs.

[2] Neither latent nor thermal-chemical heat storage technologies are currently commercially available in the UK. Due to the lack of data on capital costs, the cost reduction potential are not considered in this report.

Sources: UK Energy Research Centre, *The Future Role of Thermal Energy Storage in the UK Energy System*, 2014; *The Future of Heating: Meeting the Challenge*, 2013; IEA-ETSAP and IRENA, *Thermal Energy Storage: Technology Brief*, 2013; ETI, *Decarbonising Heat for UK Homes*, 2015; Innovate UK, *Retrofit for the future*, 2014.

Chart 8 Inter-seasonal heat storage potential cost savings from innovation (learning-by-R&D and learning-by-doing)

Sub-area	Innovation impact potential on unit costs by ~2025[1]	Innovation impact potential on unit costs by 2050	Energy system benefits additional to available technology	What is needed (source of improvement potential)
Heat store	c.30%	c.55%	▪ Additional system benefits of inter-seasonal heat storage: ▪ reduce plant capacity; ▪ improve plant efficiency; and ▪ maximise revenue from energy generation. ▪ While cost improvement potential exists from innovation in inter-seasonal storage, there are few if any cases where deployable levels of inter-seasonal heat storage capacity depend on innovation. ▪ For the purposes of this work, we have assumed that innovation is not a critical enabler to the deployment of inter-seasonal heat storage, and have therefore assigned no additional energy system benefits to innovation.	▪ Large constructed stores are new system types for which cost reduction potential is significant from design optimisation rather than radical innovation. ▪ Potential for innovation in liners for steel / concrete tanks to improve insulation and reduce leakage. ▪ Better understanding of the natural system (e.g. aquifer) conditions / flow to optimise system performance. ▪ Development of new materials with improved thermal properties. ▪ Deep geothermal storage.
Extraction	c.30%	c.39%		▪ Cheaper and more efficient heat pumps and heat exchangers. ▪ Improved charge and discharge characteristics. ▪ As the heat source can become depleted, the heat pump may require a hybrid system to upgrade heat produced.
Controls	c.30%	c.33%		▪ Better understanding of heat pump, tank and building performance to optimize system performance. ▪ Improve controls to be more user-friendly and require no or little user intervention.
Installation	c.30%	c.39%		▪ More efficient (and cost effective) civil works. ▪ Cheaper ground loop installation.
Design and O&M	c.30%	c.33%		▪ Integration of different technologies and systems so that they work in an optimal, energy efficient manner (e.g. different heat sources and heat sources in a single system). ▪ Designs to achieve optimal sizing and modularity.
Total[2]	c.16%	c.36%		

[1] The innovation impact potential represents what experts deem to be “aspirational but feasible”, and will form the central scenario for our modelling, our innovation goals, and our value assessments. Figures presented above will form the high innovation scenario. The cost saving numbers are inclusive of both learning-by-R&D and learning-by-doing.

Sources: UK Energy Research Centre, *The Future Role of Thermal Energy Storage in the UK Energy System*, 2014; IEA-ETSAP and IRENA, *Thermal Energy Storage: Technology Brief*, 2013.

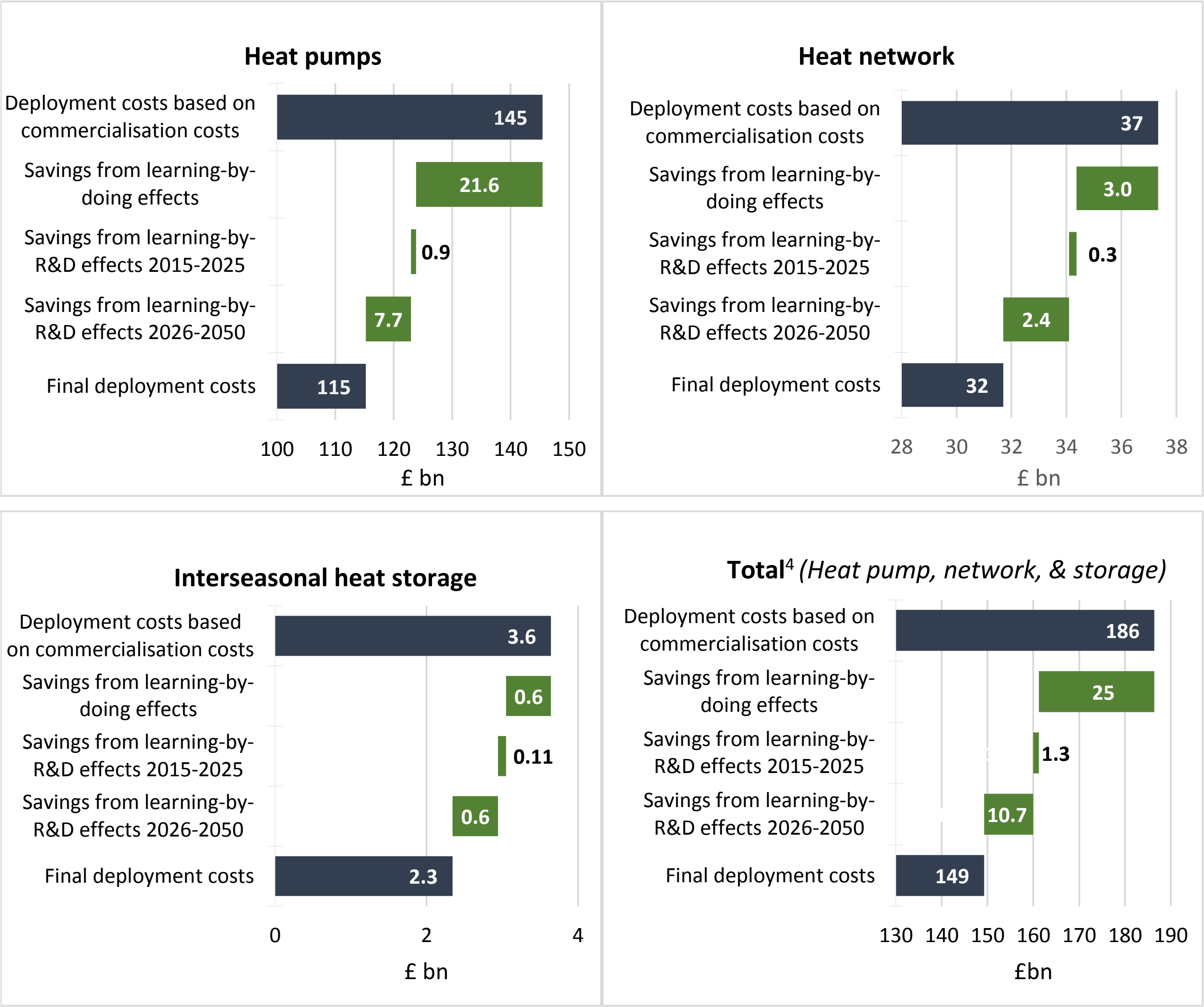
[2] Total cost savings percentages include fuel cost, which is not shown in the table.

These innovation improvements create significant value in meeting emissions and energy security targets at lowest cost

Based on our estimates for cost and efficiency improvements, and our scenarios for deployment (taking into account emissions constraints), we calculate the potential savings in energy system costs through innovation.

In our medium deployment scenario, the identified innovation opportunities can lead to potential savings of £12 bn in deployment costs over 2015-2050 through learning-by-R&D. As shown in ***Chart 9*** below, £1.3 bn of potential savings from learning-by-R&D are achievable by 2025. An additional £10.7 bn can potentially be saved from ongoing learning-by-R&D post 2025. The £12 bn potential cost saving from R&D is in addition to the £25 bn potential cost saving from learning-by-doing. These savings estimates use an 'inflexible deployment' counterfactual i.e. the deployment costs for this technology without cost reduction are compared with the deployment costs with cost reduction without considering any feedback between costs and deployment. The savings opportunity can be further broken down by each sub-area, as shown in ***Chart 10***.

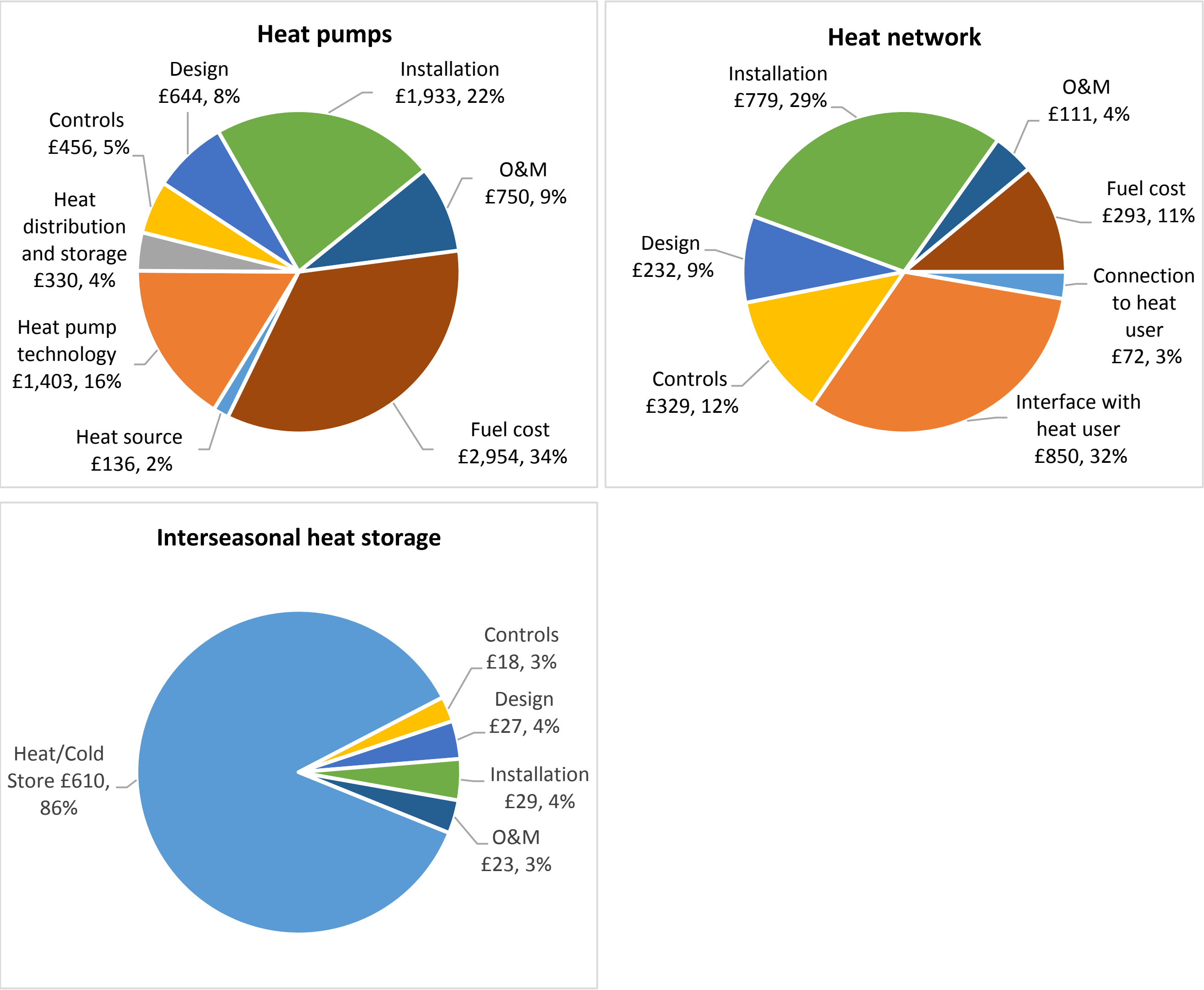
Chart 9 Potential cost savings from 2015 to 2050[1,2,3,] £bn



Notes

1. Deployment costs are i.e. cumulative unit costs installed between 2015-2050 discounted to 2015 using the social discount rate, 3.5% to 2045, and 3.0% 2045-2050.
2. Deployment scenarios are generated using ESME for UK scenarios and IEA ETP (2015) for global scenario.
3. Figures presented above are medium deployment and medium innovation scenario.
4. Total includes heat pumps, heat network, and inter-seasonal heat storage.

Chart 10 Potential cost savings from 2015 to 2050 by sub-area, £m[1,2]



Notes

1. Cumulative unit cost savings of capital and operating costs between 2015-2050 discounted to 2015 using the social discount rate, 3.5% to 2045, and 3.0% 2045-2050.
2. Cost savings under medium deployment and medium innovation scenario.

Sources: Expert interviews; Carbon Trust analysis.

Green growth opportunity

Global heat technologies market

Estimates of global deployment of heat technologies by 2050 range from 18,000-25,000TWh[1]:

- **Low scenario:** The world stays on a path to 6 degrees Celsius increase in global average temperatures and/or few constraints on nuclear and CCS, and/or electricity demand is low. Heat pump demand 1,180TWh by 2025, 6,441TWh by 2050. Heat networks demand 1,691TWh by 2025, 5,918TWh by 2050. Inter-seasonal heat storage demand 66TWh by 2025, 230TWh by 2050.
- **Medium scenario:** The world stays on a 4^0C temperature increase and few constraints of nuclear and CCS. Heat pump demand 3,210TWh by 2025, 11,234TWh by 2050. Heat networks demand 2,355TWh by 2025, 8,423TWh by 2050. Inter-seasonal heat storage demand 128TWh by 2025, 447TWh by 2050.
- **High scenario:** The world keeps on a 2^0C temperature increase and there are strong constraints on nuclear and CCS. Heat pump demand 4,280TWh by 2025, 14,979TWh by 2050. Heat networks demand 3,019TWh by 2025, 10,567TWh by 2050. Inter-seasonal heat storage demand 188TWh by 2025, 657TWh by 2050.

Based on these scenarios and the expected costs of these technologies, we have estimated the cumulative, discounted global market turnover to 2050 that is accessible to UK to be £252 (121-416) bn.

The UK could be a niche player in the heat pump, heat networks and heat storage markets

The UK can compete in some areas of these markets but its current capabilities and strong international competition suggest that it will not be a dominant exporter.

Heat pumps

Whilst the UK has a few active players (e.g. Calorex, Kensa), there is strong regional competition in the market from Sweden, Germany, Denmark, as well as global competition, especially from the Far East. These countries have led the world in RD&D to date. Hence, the UK's competitive advantage in the export market is assessed as low to medium, with ~3% share in the global tradable market.

Heat networks

The UK has relatively low capabilities in the main aspects of heat networks which are traded, including controls, connection, and interface with users. In these areas, countries such as Denmark, Germany, Austria and Sweden currently lead in the European market. These countries have also led the world in RD&D to date. Moreover, those utilities with the most project development experience also tend to be outside the UK, although UK-based utilities and project developers have shown interest they seem likely to be focussed on the domestic market. The one potential exception may be in heat networks design, where UK based engineering companies have the capabilities to compete in performing feasibility studies and design work. Heat networks controls is a potential strength in Scotland that could be developed and exploited. As a result, the UK's potential competitive advantage in export markets has been assessed as low in most areas, with a 1-3% share in the global market.

Heat storage

In the latent and thermo-chemical daily heat storage market, the key players are outside the UK (e.g. BASF, Samsung) and there are currently no strong competitors. Whilst the UK have research capabilities it could leverage, the market is at a very early stage. As a result, the UK's potential competitive advantage is assessed as low, with 1-3% share in the global tradable market.

In the inter-seasonal heat storage market, most major operators are not UK based and other countries have led in developing and deploying early projects. As a result, the UK's potential competitive market is assessed as low to medium, with 1-3% share in the global tradable market.

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[1] ETP, IEA 2015, Carbon Trust Analysis.

£12-42 bn contribution to the UK economy

The GVA to the UK economy is calculated by:

1. Multiplying the accessible market by the UK's competitive advantage to give the tradable turnover captured by the UK.
2. Adding the non-tradable portion of the market that relates specifically to UK deployment to give the non-tradable turnover captured by the UK.
3. Turnover figures are then multiplied by a GVA: Turnover ratio[1] (which differs by technology) and a displacement factor[2] to give GVA figures.

The cumulative turnover that is accessible to the UK could be as big as £252 (121-416) bn for the global market on the three type of heat technologies, of which 68% are contributed by domestic activities and 32% by the export market outside of UK.

If the UK successfully competes in the global market to achieve the market share above, then heat technologies could contribute potential cumulative GVA of £50 (24-84) bn to 2050.

It may be appropriate to apply an additional displacement effect since part of the value created in the heat sector will be due to a shift of resources and thus partly cancelled out by loss of value in other sectors. Expert opinion has roughly assessed this effect to be between 25% and 75%, so we have applied a flat 50%. Including this displacement factor, heat technologies would still make a net potential contribution of £0.8 (0.4–1.3) bn[3] in GVA per annum by 2050, a potential cumulative contribution of £25 (12-42) bn[4] to 2050.

Chart 11 Heating technology contribution[5]

Technology	Cumulative market turnover	Domestic/ Export split	Cumulative GVA	Jobs supported in 2025/2050,
Heat pumps	£183 (102-302) bn	57%:43%	£18 (10-30) bn	23,000/65,000
Heat networks	£64 (18-106) bn	85%:15%	£7 (2-12) bn	11,000/22,000
Inter-seasonal heat storage	£4 (2-8) bn	81%:19%	£0.6 (0.3-1.1) bn	900/1800
Total[6]	**£252 (121-416) bn**		**£25 (12-42) bn**	**34,000/88,000**

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[1] ONS, *UK Non-Financial Business Economy (Annual Business Survey)*, 2012.

[2] Part of the value created in the heat technology market will be due to a shift of resources from elsewhere in the economy and thus is partly cancelled out by loss of value in other sectors. Expert opinion has roughly assessed this effect to be between 25% and 75%, so we have applied a flat rate of 50%.

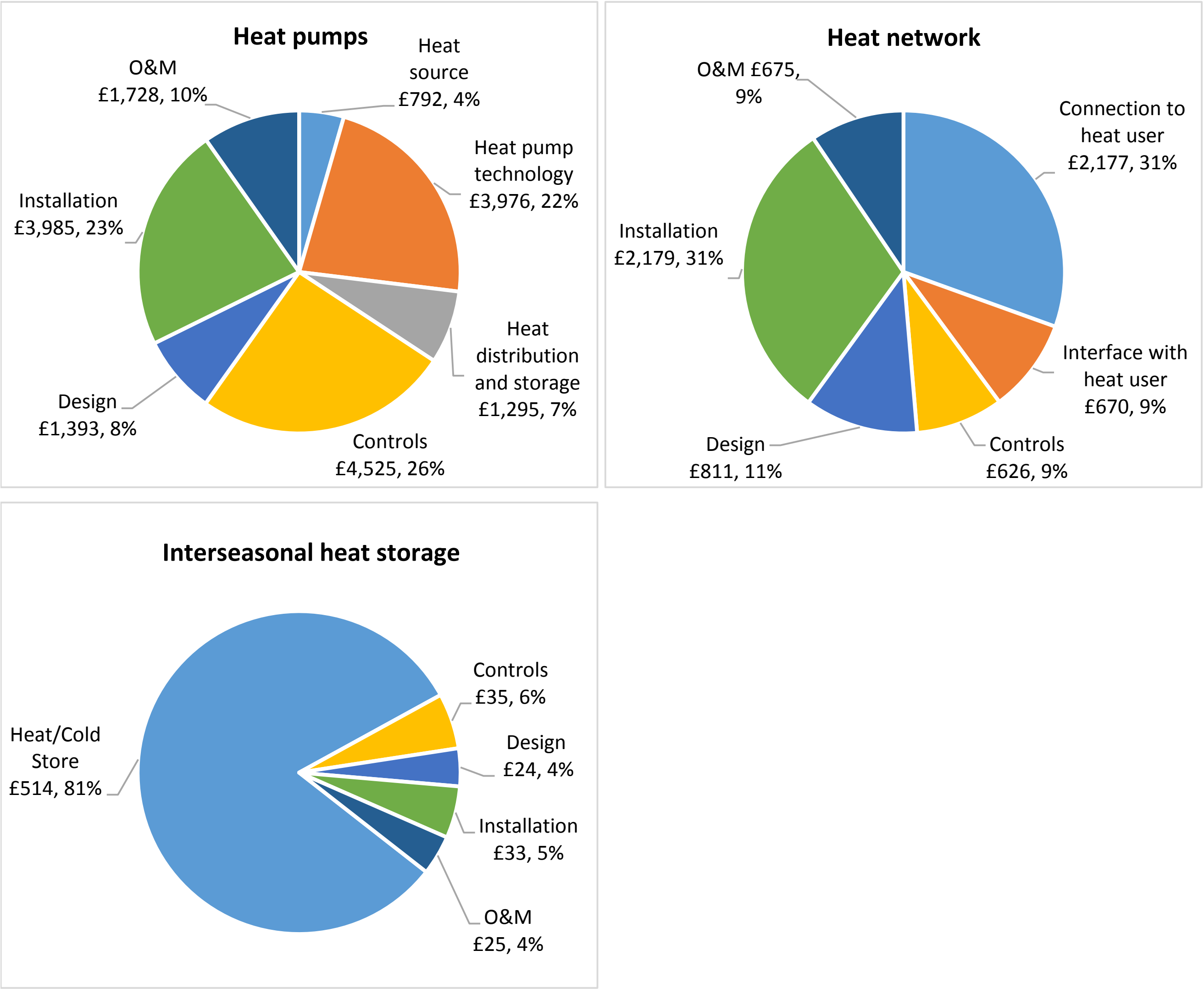
[3] Discounted at 3.5% to 2045, and 3.0% between 2045 and 2050, in line with HMT guidelines.

[4] Medium (Low – High) deployment scenarios.

[5] 2015-2050 value in business creation is built up using IEA ETP 2014 global deployment scenarios multiplied by relevant unit costs for each year with different cost reduction scenarios. Estimates of the share of global activity that is accessible to the UK and estimates of the UK's competitive position deliver a share of global turnover by sub-area that the UK could capture. ONS figures for the relevant share of GVA in turnover for each sub area then deliver an estimated GVA figure, which is adjusted downwards by 50% to account for displacement of other economic activity.

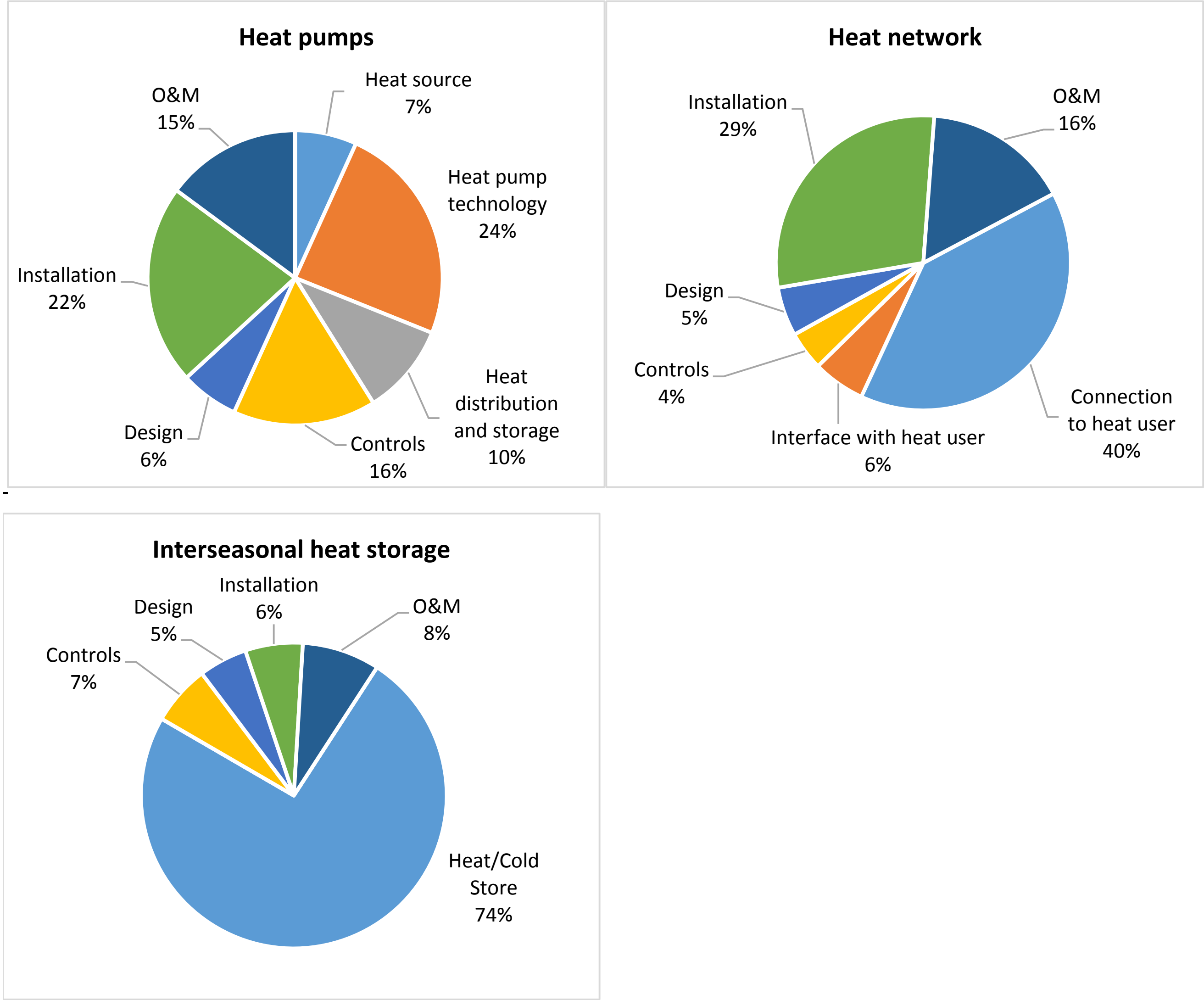
[6] Due to rounding, the totals might not add up.

Chart 12 Estimated breakdown of cumulative GVA per sub area, in £m (2015-2050, discounted, medium scenario)



Sources: ONS, *UK Non-Financial Business Economy (Annual Business Survey)*, 2012; Expert interviews; Carbon Trust analysis.

Chart 13 Estimated breakdown of total jobs supported per sub area (2050, medium scenario)[1]



Notes

1. Jobs supported in 2025 and 2050 are based on using ONS 'jobs per £ million turnover' figures for each sub area based on the market turnover captured by the UK. These numbers are explicitly linked to deployment, if deployment does not occur then these numbers won't be realised.

Sources: ONS*, UK Non-Financial Business Economy (Annual Business Survey),* 2012; Expert interviews; Carbon Trust analysis.

The case for UK public sector intervention

Public sector activity / support is required to unlock this opportunity – both the £12 (5-23) bn potential reduction in the costs to the energy system to 2050 from learning-by-R&D, and the £25 (12-42) bn potential net contribution to UK GDP from new business creation.

The TINAs aim to prioritise innovation support. A number of considerations are taken into account. These are the extent of the market failures and barriers, the opportunity to rely on other countries or industries to drive innovation, the potential benefit in terms of cost reduction to the energy system, and economic benefits[1]. These are summarised in Chart 17.

Market failures and barriers impeding innovation

There are a number of overall market failures, as well as barriers for specific innovation areas for heat pumps, heat networks and heat storage. These are summarised in Chart 14 below.

Across heat pumps and heat networks the majority of the market failures surround market demand, supply, and infrastructure conditions. The market failures are less significant across the technology component due to high technology maturity levels, high adoption in other countries, and cross over with other sectors.

- Heat pumps are inhibited by the current characteristics of the UK housing stock.
- Heat networks roll out is restricted by high capital costs and difficulties in obtaining planning permission.
- Development of inter-seasonal heat storage is restricted high be capital costs.

Chart 14 Market failures and barriers for heat pumps

Sub-area	**What market failures and barriers exist?**	**Assessment**
Market demand conditions	• **High upfront cost** makes heat pumps appear unattractive compared to gas boilers; limited available data and modelling tools make it difficult to assess long term cost savings from heat pumps versus traditional means of heating. • **Low consumer acceptance**. Research found that over 80% of homeowners had heard of condensing gas boilers and solar thermal, yet just <50% had heard of GSHP and <33% had heard of ASHPs. • **Limited ability for users to assess the performance of heat pumps systems** limits pressure for innovation from the market and awareness among end users of technology benefits. • **Limited opportunities for replacing heating systems.** Gas boilers have long useful lives of 10-15 years, whilst non-domestic gas boilers can last for 25 years or more. Homeowners would only consider replacing their heating system if it needed significant repairs or servicing. • **Carbon abatement benefits and life-cycle efficiency savings from HPs not internalised.** RHI provides limited incentives for HP innovation and has not been effective in increasing deployment.	**Critical**
Infrastructure conditions	• **Characteristics of the existing housing stock.** The UK's existing housing stock includes a significant proportion of old properties, which tend to be inefficient. Standard heat pumps work best in well insulated, thermally efficient properties, so maintenance work to increase the efficiency of a property is often carried out before installation.. • **Widespread use of heating systems with high flow / return temperature** which is not suitable for heat pumps. • **Lack of space** for heat pumps. • **Planning constraints** currently remain for ASHPs. • **Lack of clear direction on management of grid issue** may limit incentives to innovate. • **Limited access to 3-phase electricity** to accommodate increased load and starting current of the compressor.	**Critical**
Supply conditions	• **Lack of appropriate advice and comparative information for consumer** limited availability of trusted advice on appropriate technologies; where information is available it tends to be generic. • **Lack of demonstration on a domestic scale** leading to a lack of understanding of effects of deployment on the supply infrastructure. • **Lack of skilled installers** and associated monitoring, training and quality assurance; poor reputation from older installations.	**Moderate**

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[1] Prioritisations featured within this TINA are the result of a stakeholder engagement exercise, literature review and leveraging internal LCICG intelligence.

Sub-area	What market failures and barriers exist?	Assessment
Innovation areas		
HP technology	• Suppliers use heat pump performance metrics that do not reflect real life usage in the UK.	**Minor**
Design & installation	• **Split incentives** between installers vs consumers. • **Little incentive to improve quality**, training etc. as **lack of information** available to consumer about comparative performances. • **Uniqueness of installations** does not incentivise innovation as detailed measurements required. • Small scale and low level of technical sophistication means installers have **limited funds or capability** to develop new installation methods (e.g. lower cost boreholes).	**Critical**
Controls	• **Split incentives** – limited incentive for installer / designer to optimise controller, benefits are accrued by the consumer and performance is not transparent. • **Complexity of technology/asymmetric** knowledge between supplier and consumer on performance and interaction with building keeps incentive for innovation low. • **Lack of knowledge** about consumer behaviour.	**Minor**
O&M	• **Lack of co-ordination** with installation and design practices. • **Knowledge asymmetry** - No legal obligation/standard or certification.	**Moderate**

Sources: DECC, *The Future of Heating: Meeting the Challenge,* 2013; UKERC, *UKERC Energy Strategy Under Uncertainties*, 2014; Expert interviews; Carbon Trust analysis.

Chart 15 Market failures and barriers for heat networks

Sub-area	What market failures and barriers exist?	Assessment
Market demand conditions	• **Lack of long term certainty over heat demand and heat source** compared with the length of life of the network (~30-50 years). Further uncertainty exists about the carbon saving potential from CHP as a source. Current energy pricing regimes and historic market structures (e.g. lock-in) favor other options. • **Overall lack of experience and knowledge** about DH schemes (pricing, design, processes etc.) in the UK from investors and developers, resulting in high perceived project risks. This area has seen recent improvement but still remains problematic and has restricted deployment to one off 'pilot' projects. • **Lack of co-ordination between decision-makers** e.g. Local authorities and developers have conflicting targets, performance metrics, and timeframes. • **Carbon abatement benefits not internalised** e.g. Sweden introduced a Carbon Tax in 1991, Denmark also policy drives for energy independence since 70s. • **High upfront capital costs associated with construction** of plant, heat network and connections, compared with low capex for gas heating; shortage of available financing with unacceptable internal rate of return (IRR). • **Lack of public awareness on the technology, benefits, disruption and tariffs.** Whilst improving this is still low. In addition developer impact on value [pricing and control] remains an issue. • **Lack of transparency** on heat tariffs across the market. The recent creation of the Heat Trust aims to improve the channelling and structuring of complaints within the sector. • **Lack of/split incentives.** High investments, low returns, uncertain or moving planning regulations, lack of guidelines inhibit private and public sectors. More stringent policies exist in some local authorities. Targeted and national wide regulation could help secure low cost capital and increase investor confidence.	**Critical**
Infrastructure conditions	• **Planning constraints, inconsistencies and lack of integrated infrastructure.** Conflict exists with incentives to install electric heating into new build, rather than DH/CHP alternatives; also Merton rule whereby some local authorities (LAs) allow use of low carbon sources rather than just renewables while others do not – this lack of clarity often leads developers to avoid CHP or gas-based district heating options. Further problems with grid access, interconnection and planning exists. • **Mapping networks opportunities** still lacking despite increased work in energy masterplans by the HDNU. • **Complexity due to uniqueness of UK housing stock** e.g. lower heat densities and higher costs than successful EU countries; retrofitting appropriate in building heat distribution and interface issues. • **Complexity/co-ordination issues around interaction with grid** and demand management. Electricity market and CHP electricity system integration issues; licensing restrictions; increasing uptake of heat pumps and biomass boilers might decrease RHI funding availability.	**Critical / significant failure**

Sub-area	What market failures and barriers exist?	Assessment
Supply conditions	- **Lack of local expertise and established supply chain.** Upskilling of resource is required if large scale rollout is to be achieved, this also applies to staff within local authorities [collaboration between energy service companies (ESCOs) and Local Authorities is challenging]; network development costs are higher in UK; historically issues around limited stocks, import availability, manufacturing and O&M capacity. - **Heavily dependent on overseas manufacturers.** - **Insufficient standardisation in contract structures for developers;** has improved but lacking overall. - **Data and accounting challenges.** There is a lack of consistent data, and an agreed methodology to account for overall systems effects, benefits, and positive externalities. - **Lack of successful demonstration;** Market potential and applicability is still unproven in minds of some developers and LAs.	**Moderate/ Critical**
Innovation areas	▨	▨
Connection with heat user	- **Limited market failures exist** within the component technology of the pipes. Technology advances will still occur yet these are being driven by manufactures.	**Minor**
Design & installation & O&M	- **Lack of infrastructure planning coordination** inhibits innovation required to integrate renewable sources, and industrial waste heat. - **Overall lack of UK experience** to achieve mass market growth. Particularly problematic across installation of networks and commissioning of the system. - Major design, build, operators are present in the UK (including Veolia, EDF, etc.), have access to innovations and engineering expertise from the more active and innovative continental Europe market.	**Minor /Moderate**
Interface with heat user	- **Limited market demand at present in the UK.** Outside the UK markets are more active and hence more competitive, with stronger incentive to innovate for players such as Danfoss (Denmark) and Meibes (Germany). - **Consumers lack of knowledge** on how to effectively operate the systems, tariffs, and fixed or variable elements of operating the networks. - **Minor Design failures**- Heat losses occur within buildings due to poorly installed secondary distributions systems.	**Minor**
Controls	- **Limited market failures exist:** controls are well established, and systems in place to integrate push to 'smart networks'. - **Knowledge gaps** on behalf of consumer and operation contractors on full application and benefits of the controls.	**Minor**

Sources: Expert interviews; Literature review (inter alia): DECC, *Research into Barriers to Deployment of District Heating*, 2013; UNEP, *District Energy in Cities: Unlocking the Potential for Energy Efficiency and Renewable Energy*, 2015; ETI, *Smart Systems and Heat*, 2015; Carbon Trust analysis.

Chart 16 Market failures and barriers in heat storage

Sub-area	What market failures and barriers exist?	Assessment
Heat store	*Inter-seasonal* • **High costs** of installing an inter-seasonal heat storage system. • **Lack of demand certainty** as currently unclear to what extent inter-seasonal stores have a role in the energy system. • **Complexity** around systems integration with other technologies (e.g. heat networks and heat pumps and electricity market). *Latent / thermo-chemical daily* • **Uncertainty in technological performance** to date, there are very few PCM based thermal energy systems deployed and their long term performance is unproven; thermo-chemical heat storage technologies are at the early stages of R&D. • **Lack of public awareness / acceptance** potential barrier until certain safety issues resolved.	**Significant** **Significant**
Design and O&M	*Inter-seasonal* • **Lack of knowledge and experience** about inter-seasonal heat storage systems. • **Lack of knowledge** about systems integration (e.g. grid, other heat/enabling technologies, domestic build) and overall costs. • **Complex planning regime** and a lack of data to enable adequate planning. *Latent / thermo-chemical daily* • **Lack of knowledge and experience** about latent heat storage systems; thermo-chemical heat storage technologies are still in early R&D phase. • **Lack of knowledge/complexity** in systems integration and understanding overall costs.	**Critical** **Critical**
Controls	• **Split incentives** – limited incentive for installer / designer to optimise controls, as benefits are accrued by the consumer and performance is not transparent. • **Complexity of technology/Asymmetric knowledge** between supplier and consumer on performance and interaction with building/other technologies keeps incentive for innovation low. • **Lack of tools to interpret performance data** in order to improve performance.	**Significant**
Installation	*Inter-seasonal* • **Lack of knowledge/experience** in constructing large scale stores. • High capital costs as few market players/low demand. *Latent / thermo-chemical daily* • **Complexity and lack of knowledge** about advanced technologies and optimising performance through installation process. • **Split incentives** between installers (quick fit) vs optimised performance for consumers.	**Minor** **Minor**

Sources: UK Energy Research Centre, *The Future Role of Thermal Energy Storage in the UK Energy System*, 2014; IEA-ETSAP and IRENA, *Thermal Energy Storage: Technology Brief*, 2013; Expert interviews; Carbon Trust analysis.

The UK can rely on other countries to deliver innovation in many of the standard component technologies, but not in design, installation, and operation

For most areas in heat, technologies are sufficiently generic and other countries (e.g. Japan, Germany, Canada, USA, China, and Balkan and Scandinavian territories) are driving innovation at a pace likely to suffice for UK needs. These areas are:

- Heat pump technologies and heat pump O&M.
- Heat interface (i.e. hydraulic interface unit), controls, and pipes for heat networks.

It is important to note that even in these areas, a lack of UK activity would probably have a negative impact on competitive advantage, capacity, and the ability to create new business opportunities. Moreover, there is always a risk that delays to progress in other countries could make such reliance costly to the UK. Nevertheless, the UK should avoid duplicating work likely to be well advanced in other countries without strong justification.

In other areas, the UK could rely on other countries, but there may be specific elements where the UK will want to drive developments at a faster pace and in a more specific direction than is likely otherwise. These areas are:

- Heat pump, heat networks, and heat storage controls;
- Heat networks controls, operations, and leveraging waste heat sources and system integration into district energy; and
- Latent / thermo-chemical heat storage materials and inter-seasonal heat stores.

In the final set of areas, the UK has specific application needs which mean that achieving value to the UK will require UK-led efforts. This is due to housing stock and grid characteristics and grid infrastructure that are unique to the UK.

- Design and installation of heat pump and heat storage systems – innovation improvements will need to be appropriate for the UK housing stock.
- Design and installation of heat networks and waste recovery – innovation improvements will need to be fully integrated with UK specific built environment and energy system arrangements.

Potential priorities to deliver the greatest benefit to the UK

The UK needs to focus its resources on the areas of innovation with the biggest relative benefit to the UK and where there are not existing or planned initiatives (both in the UK and abroad). The LCICG has identified and prioritised these innovation areas.

Innovation areas with the biggest relative benefit from UK public sector activity/investment

The LCICG has identified the areas of innovation with the highest relative benefit from UK public sector activity/investment[1].

These have been prioritised by identifying those areas that best meet the following criteria:

- Value in meeting emissions targets at lowest cost;
- Value in business creation;
- Extent of the market failure and barriers; and
- Opportunity to rely on another country or industry to drive innovation.

The highest priorities are improvements in the design and installation of heat pumps, deploying 3rd and 4th generation networks that are ‘smart’ and ready to integrate and dispatch a wide range of heat sources, development of advanced heat/cold store, and the design and operations of heat storage. The next priorities are improved heat pump technologies, improved heat pump controls, the development of advanced diurnal heat stores, and future proofing heat sources for networks connection and readying the UK housing stock and planning regimes for networks deployment.

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[1] Without considering costs – these are considered in the final prioritisation.

Chart 17 Benefit of UK public sector activity by sub-area and technology type

Sub-area[1]	Value in meeting emissions targets at lowest cost (£ billion)[2]	Value in business creation (£ billion)	Extent of market failure	Opportunity to rely on others	**Benefit of UK public sector support (without considering costs)**
Heat pumps					
Heat source	0.1 (0.1-0.3)	0.8 (0.4-1.5)	No failure	No	N/A
Heat pump technology	1.4 (0.8-2.6)	4.0 (2.2-6.5)	Minor	Yes / In part	Low-Medium
Heat distribution	0.3 (0.2-0.6)	1.3 (0.7-2.2)	No failure	In part	Low
Controls	0.5 (0.2-0.9)	4.5 (2.6-6.0)	Minor	In part	Medium
Design & Installation	2.5 (1.5-4.8)	5.4 (3.0-10.1)	Critical	No	High
O&M	0.8 (0.4-1.4)	1.7 (0.9-3.3)	Moderate	Yes	Low-Medium
Market demand conditions	▨	▨	Critical	No	High
Infrastructure conditions			Critical	No	High
Supply conditions			Moderate	In part	Medium
Heat Networks					
Connection to User	0.1 (0.0-0.1)	2.2 (0.6-3.6)	Minor	Yes	Low
Design, Installation, O&M	1.1 (0.0-2.0)	3.7 (1.1-6.0)	Moderate	No	High
HIU	0.9 (0.0-1.6)	0.7 (0.2-1.1)	Minor	In part	Low
Controls	0.3 (0.0-0.6)	0.6 (0.5-0.8)	Minor	Yes	Low-Medium
Market demand conditions	▨	▨	Critical	No	High
Infrastructure conditions			Significant	No	High
Supply conditions			Moderate	Yes/In part	Medium
Heat storage					
Heat/cold store (incl. extraction)	0.6 (0.3–1.2)	0.5 (0.3–0.9)	Significant	In part	Medium
Design, O&M	0.05 (0.02–0.09)	0.05 (0.02-0.09)	Critical	No	Medium
Controls	0.02 (0.01–0.03)	0.04 (0.02–0.06)	Significant	Yes	Low-Medium
Installation	0.03 (0.02–0.05)	0.03 (0.02–0.06)	Minor	In part	Low

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[1] Whilst not technical in nature, market demand, infrastructure and supply conditions require public sector intervention to rectify the market failure.

[2] Fuel cost savings of £3.0 (1.6-5.6) bn for heat pumps and £0.3 (0.03-0.6) bn for heat network are excluded from this figure.

Existing innovation support

Most UK activity is through project-based funding to project-specific partners, generally research institutes, and companies. Various publicly funded entities drive UK support for RD&D in heat, with different focus: the Department of Energy and Climate Change (DECC), the Energy Technologies Institute (ETI), Innovate UK, and EPSRC.

A number of research entities, such as i-STUTE and Tyndall Centres, are leading RD&D efforts in heat technologies in the UK.

In addition, the UK plays an active role in European RD&D activities led by IEA and Horizon 2020.

The UK is supporting many of the areas highlighted above. This is through a combination of policies to incentivise demand, supply-side innovation programmes to 'push' technology and support for enablers (***Charts 18, 19, 20***).

Potential priorities for public sector innovation support

In the sections above, we identified the key innovation needs and the market barriers hindering these innovations. This analysis points to a number of priorities for public sector innovation support:

- Improvements in the design and installation of heat pumps;
- Design, development and installation of 3rd and 4th generation heat networks and leveraging waste heat and novel heat sources;
- Development of advanced heat/cold store; and
- Design and operations of heat storage.

There is the need for an integrated system perspective approach to heat. Therefore future innovation support should aim to encourage cross sector and integrated heat solutions, and draw out system effects. This will be aided if regulations and guidelines and support mechanisms at large are aligned and coordinated. An overarching priority is to allocate funding to a number of large demonstrators that bring together large scale heat pumps, novel heat networks, combined cooling and a range of heat sources.

Beyond the support for these priority areas a coherent and aligned funding approach is required across funders of low carbon innovation. Doing so will increase chances of meeting the potential benefits highlighted within this TINA.

Charts 18, 19, 20 outline how the potential innovation priorities align against each technology sub-area, the scale of public funding for each, the current activities/investment in each area, and potential, future activities.

Note, the scale of public funding is indicative only. It serves to provide an order of magnitude perspective on the scale of public funding (existing and future) potentially required over the next 5 to 10 years to address each need. The current activities listed in the below tables support innovation to a varying degree. Furthermore some activities cover heat as a whole as opposed to simply providing support for a discrete area.

Chart 18 Potential heat pump innovation priorities and support

Component	Potential innovation priorities	Indicative scale of public funding[1]	Example of current activities[2]	Future potential activities
Heat pump technology	▪ Components adapted to UK environment. ▪ Sensors and "smart" controls to make heat pumps more user friendly whilst optimising performance. ▪ Improvement of heat pump performance.	Tens of £ millions	▪ i-Stute activities on sorption heat pumps ▪ EPSRC funded projects on electric and sorption heat pumps for heat networks	▪ R&D and demo of key components / processes: - Reduce noise of heat pumps to make them more acceptable to consumers. - Reduce size of heat pumps to make them easier to retrofit, and more visually attractive. - Demand side management tools and system control panels which are user-friendly and require little or no intervention from the consumer. - Improve heat pump coefficient of performance (COP). - Novel heat pump technology improvements. - Facilitated and optimised heat distribution systems. ▪ Research to generate higher quality data on heat pump performance, taking into account the fabric of the building and consumer behaviour and preferences.
Design & installation	▪ Scalable / simpler approach to heat pump installation.	Tens of £ millions	• Energy Performance of Buildings Directive • Eco-design and Energy labelling legislations • RHI	▪ Large scale domestic sector demonstrations to test design and installation solutions and refine requirements for market roll-out. ▪ Study to improve understanding of ground condition for GSHP installation. ▪ Further research on solutions that are likely to be acceptable to the UK market, especially those that allow for direct gas boiler replacements. ▪ Research to develop more flexible options for heat pump integration into different types of buildings.
System level integration	• Understanding of system performance and real mass-market consumer behaviour. • Encouragement of space heating at lower temperatures.	£ Millions	• iStute • ETI's Smart Systems and Heat programme • EU Horizon 2020 • IEA Heat Pump programme	▪ Building / network-level demonstration of integrated renewable heating systems paired with targeted R&D. ▪ Help inform design of effective products. ▪ Influence RD&D of components. ▪ Encourage replacement of old and inefficient boilers.
Fuel-driven heat pumps / high temperature heat pumps	• Further development to improve efficiency and reduce cost of sorption HPs. • Development and demonstration of high temperature heat pump technologies.	£ Millions	• IEA Heat Pump programme	▪ Development of quality label similar to EHPA quality label for electrically-driven compression heat pumps. ▪ Domestic sector demonstration to improve retrofit with existing heating systems and improve performance for sorption HPs. ▪ Further RD&D of high temperature heat pumps and domestic sector demonstration to improve retrofit with existing heating systems.

1 Provides an order of magnitude perspective on the scale of public funding (existing and future) potentially required over the next 5 to 10 years to address each need.

Sources: DECC, *The Future of Heating: Meeting the Challenge,* 2013; *The LCICG's Strategic Framework,* 2014; *Better thermal technologies for existing buildings,* 2015; IEA Heat Pump Programme; Expert interviews.

Chart 19 Potential heat networks innovation priorities and support

Component	Potential innovation priorities	Indicative scale of public funding[1]	Example of current activities [2]	Future potential activities
Design, installation, and O&M	▪ Tools to maximise efficiency and accuracy of measurement of a 'neighbourhood' characteristics and building's interior to optimise design of heat system. ▪ Tools to help better design and install networks. ▪ Improved access to /better data ▪ Development of cheaper installation processes tailored to the UK build. ▪ Best practise for collaboration with utilities, design and business models.	£ Millions	▪ HNDU ▪ Heat Network Partnership for Scotland ▪ The Heat Trust ▪ Heat Network innovation competition ▪ The Heat Networks Demonstration competition ▪ Scotland's Energy Efficiency Programme ▪ SALIX energy efficiency ▪ District Heating Loan Fund ▪ District Heating Loan Scheme ▪ Low carbon infrastructure transition programme ▪ RHI ▪ Heat Pathway Scenarios Model (HPSM) • Renewable Energy Investment Fund • ETI feasibility study • IEA DHC	• Develop large scale 3rd / 4th generation district network and pilot within city centre heat networks (e.g. beyond hospitals and universities). • Development, capacity building and demonstration of design and siting tools, potentially in combination with planned commercial heat networks projects / large scale demos. • Conduct analysis and trials into the impact of material performance optimisation (e.g. insulation, joint closures, pipes, erosion effects). • Improved data and standardisation of assumptions within feasibility studies. • Investigation into key planning (e.g. FEL routing considerations), and business model factors (e.g. ESCO collaboration) that progress a theoretical study to a detailed design and tender. • Investigate and map the opportunity for heat energy centres serving local areas and energy system interaction within networks and the grid at large. • Measurement of extended life cycles, design integration, installation of heat networks.
Integration of heating systems	▪ Integration of novel sources and technologies within networks e.g. heat pumps, waste recovery, Solar, Biomass, Cooling and investigation into resulting system effects. ▪ Increased knowledge on distribution of excess heat to buildings and impacts on the heat system. ▪ Leveraging heat networks as heat stores for balancing the grid. ▪ Assessment of heat networks potential within the heat/energy system.	Tens of £ Millions		▪ Include feedback into energy system modelling initiatives to better understand transition of heat into the wider energy system. ▪ Investigate and document best practise systems approach, strategic planning assistance, and phase installation. ▪ Investigation into improved integration of stakeholder industries (Heat sources, skills, materials, R&D focus) to align objectives and improve overall performance. ▪ Investigation into the integration of heat sources (including and beyond CHP), with the grid, buildings (e.g. utilising the fabric of the building) and future infrastructure plans (e.g. schools, manufacturing sites) to generate and store heat. ▪ Development of small networks to form larger ones and their role within the local/regional grid. Design a new method to engage the value chain at large, and future proof sources for potential heat networks integration.
Regulations, Guidelines and Capacity Building	• Planning regulations to be put into place to drive deployments of heat networks. • Strategic heat networks vision. • Standards of operations - create tools to produce better designs, and contracts. • Guidance on technical requirements • De-risking schemes.	Low £ millions		▪ Investigation into environmental cost benefits of heat networks systems to inform policy. ▪ Integrating networks and waste recovery into local planning, and system approach to spatial plans. ▪ Develop a comprehensive and coordinated UK heat policy framework and vision to increase a systems approach and mass deployment of networks. ▪ Increased engagement between local authorities, ESCO's, public and central government is required. This can be enhanced though adoption of international best practise. ▪ Update/creation of local heat roadmaps and plans to ensure interlinks between regulations, policy, industry guidance, energy production, community district energy needs. ▪ Training programs to improve Local Authority knowledge on Heat Networks and ESCO models and partnerships. Further training of engineers and maintenance contractors.

[1] Provides an order of magnitude perspective on the scale of public funding (existing and future) potentially required over the next 5 to 10 years to address each need.

[2] The current activities support to a varying degree innovation and deployment within heat networks. Sources: Expert interviews programme covering a number of consultancies and academia and LCICG experts; UNEP, *District Energy in Cities: Unlocking the potential for Energy Efficiency and Renewable Energy*, 2015; ETI, *Smart Systems and Heat*, 2015; DECC, *Assessment of the costs, performance and characteristics of UK heat networks*, 2015; *Delivering UK Energy investment: Networks,* 2015; DECC, *The potential for recovering heat and using surplus heat from industry*, 2014; Scottish Government, *Heat Partnership for Scotland*, 2015; IFC, *Unlocking the potential for private sector participation in district heating*, 2015; GLA, *Secondary waste heat sources*, 2013; Carbon Trust Analysis.

Chart 20 Potential heat storage innovation priorities and support

Component	Potential innovation priorities	Indicative scale of public funding[1]	Example of current activities	Future potential activities
Design, operation and integration of advanced daily heat stores	Development of high density, smaller heat stores with a higher rate of heat exchange which are suitable to domestic consumer or large scale networks operations.	Tens of £ millions	▪ DECC Advanced Heat Storage competition ▪ ETI Smart Systems & Heat ▪ EPSRC SUPERGEN ▪ Energy Storage hub	▪ Targeted RD&D activities focused on optimising the performance of integrated systems through early demonstration and related storage and networks component R&D. ▪ Support targeted demonstration projects for more mature, but not yet widely deployed, energy storage technologies to document system performance and safety ratings.
System-level integration and design solutions	▪ Allow effective design of products and energy networks components. ▪ Encourage replacement of old and inefficient boilers.	Tens of £ millions	None	▪ Building and networks-level demonstration of integrated renewable heating systems. ▪ Research to examine system performance and real mass-market consumer behaviour.
Early stage heat storage technologies	• High temperature thermal storage systems. • Hybrid storage systems.	£ Millions	None	R&D for early stage energy storage technologies including technology breakthroughs in high-temperature thermal storage systems and systems that incorporate the use of both electricity and thermal energy storage (i.e. hybrid systems) to maximise resource use efficiency.
Inter-seasonal heat store extraction	Development and cost reductions in inter-seasonal heat store and extraction technologies.	High £ millions to low tens of £ millions	None	R&D to achieve cost reductions and key performance developments e.g. minimal losses, rate of heat exchange.

1 Provides an order of magnitude perspective on the scale of public funding (existing and future) potentially required over the next 5 to 10 years to address each need

Sources: IEA, *Energy Storage Technology Roadmap*, 2014; *LCICG Strategic Framework*, 2014; UK Energy Research Centre, *The Future Role of Thermal Energy Storage in the UK Energy System*, 2014.

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