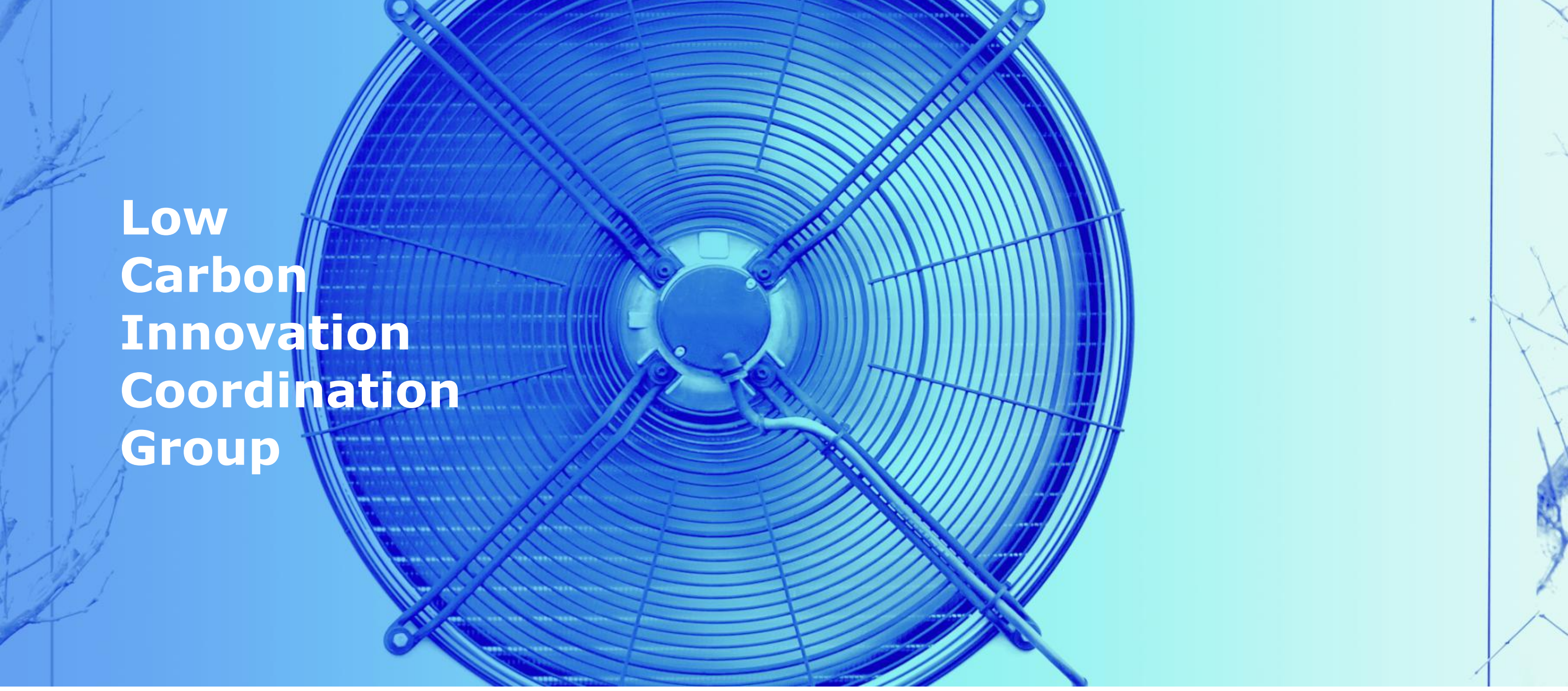

Technology Innovation Needs Assessment (TINA)

Heat
Summary Report

September 2012

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 are the Department of Energy and Climate Change (DECC), the Department of Business, Innovation and Skills (BIS), the Engineering and Physical Sciences Research Council (EPSRC), the Energy Technologies Institute (ETI), the Technology Strategy Board (TSB), the Scottish Government, Scottish Enterprise, and the Carbon Trust. The LCICG also has a number of associate members, including the Governments of Wales and Northern Ireland, Ofgem, the Crown Estate, UKTI, the Department for Transport, the Department for Communities and Local Government, the Ministry of Defence, and the Department for Environment, Food and Rural Affairs.

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 and draws on a much more detailed TINA analysis pack which will be published separately.

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. Expert input, technical analysis, and modelling support for this TINA were provided by AECOM.

DEPARTMENT OF ENERGY & CLIMATE CHANGE

BIS Department for Business Innovation & Skills

Research Councils UK Energy For a Low Carbon Future

CARBON TRUST

energy technologies institute

Technology Strategy Board Driving Innovation

The Scottish Government

Scottish Enterprise

Key findings

This TINA focuses on heat pumps, heat networks and heat storage as three key heat technologies that could play a key role in meeting UK and global heat demand in an emissions constrained future. Innovation in these technologies could reduce UK energy system costs by £14-66bn[1] to 2050, with heat storage also offering additional value by enabling other system adjustments. Innovation can also help create a UK industry with the potential to contribute further economic value of £2-12bn to 2050. Significant private sector investment in innovation, catalysed by public sector support where there are market failures, can deliver the bulk of these benefits with strong value for money.

Potential role in the UK's energy system	• Heat pumps, heat networks and heat storage offer many benefits to a low-carbon energy and economic system: (i) heat pumps are a potentially very cost-effective means of delivering heat with low or zero GHG emissions; (ii) heat pumps also can accommodate a variety of electricity generation sources; (iii) heat storage and heat networks can be integrated into the energy system to ease balancing requirements related to the very "peaky" nature of heat demand • Energy system modelling suggests they can be significant contributors to the future energy system, delivering anywhere from one-third to almost the entire heat demand by 2050. We estimate potential 2050 deployments levels of 70-240GW (100-340TWh) for heat pumps, 10-95GW (20-200TWh) for heat networks, and 6-190GW for heat storage. This depends primarily on the extent of demand reductions, the availability of biomass (a key competing heat technology), the balancing requirements of the energy system, and to some extent the relative success of these technologies to each other
Cutting costs by innovating	• Commercially available versions of all these technologies already exist, but all offer large cost and performance improvement potential through further innovation: – Heat pumps: Innovation in the heat pump technology and in the design & installation of systems offer the bulk of the potential, with estimated system cost savings to 2050 of £21bn (£11 – 39bn)[1] – Heat networks: Innovation in design & installation, and in the interface with the heat user offer the most of potential, with estimated system cost savings to 2050 of £6bn (£2 – 15bn) – Heat storage: Innovation in advanced (daily) heat stores, large-scale heat extraction technologies, and installation processes offer the bulk of the potential, with estimated system cost savings to 2050 of £3bn (£0.5 – 11bn), split fairly evenly across daily and interseasonal storage. Moreover, the additional enabling value are estimated to be *at least* of the same order of magnitude • Critically, achieving much of the innovation potential involves integrating heat systems either with the built environment (e.g. design and installation improvement opportunities) or with each other
Green growth opportunity	• Although global markets for these technologies are potentially enormous, many of these markets are not widely tradable, either because they are inherently local (e.g. installation) or involve large equipment that is typically traded only regionally. Hence, their potential contribution to net UK economic activity is inherently limited • While not currently world leaders, UK suppliers could still play a significant role in certain markets, with a 4-9% share in some specific European markets • If innovation helps the UK successfully compete in these markets, then the related industries could contribute £2 – 12bn to UK GDP up to 2050 (with displacement effect)
The case for UK public sector intervention	• Public sector activity is critical to unlocking the biggest opportunities – although in some areas the UK may be able to rely on other countries to drive this innovation – Market failures include uncertain demand (externality effect), infrastructure and planning requirements (public good effect), split incentives, and co-ordination failures – In core component areas (e.g. heat pump technology) the UK *could* rely on other countries, but there is a strong case for UK public sector support in design, installation and system integration
Potential priorities to deliver the greatest benefit to the UK	• The innovation areas with the biggest benefit to the UK can be naturally grouped into two large programme areas, where significant synergies exists: – Heat pump demonstrations (at varying scales) that include the development of improved design and installation, potentially integrated with (advanced) daily heat storage; with RD&D of improved heat pump components and advanced storage materials sitting alongside or within sub-trials – Large scale demonstration project(s) for heat networks in combination with alternative (low-emission) generation sources and/or integrated with large-scale heat storage, with the R&D of improved design and installation, heat store and extraction technologies sitting alongside • Supporting all of the UK's priority innovation areas would require tens to hundreds of millions of GBP over the next 5-10 years (leveraging 2-3 times that in private sector funding)

[1] Cumulative (2010-2050) present discounted values in low-high scenarios for the savings from driven by 'learning by research' (see below)

Chart 1. Heat TINA summary

Sub-area	Focus	Value in meeting emissions targets at low cost £bn	Value in business creation £bn	Key needs for public sector innovation activity/investment
Heat pumps	Key components	12 (6 – 22)	3 (1 – 5)	R&D and early demo of key components / processes: • Novel heat pump technology, improvements to existing technologies • Control philosophy and monitoring methods • Design / installation processes, and grid integration
	Design, installation and O&M (domestic)	9 (5 – 17)	Non-tradable	• Large scale domestic sector demonstrations to test design and installation solutions (arising from early trials) and refine requirements for market roll-out
	Design, installation and O&M (service sector)			• Small scale service sector demonstration to evaluate current performance and check applicability of learning from domestic sector
Heat networks	Key components	2 (1 – 5)	0.6 (0.3 – 1.7)	• R&D and early demo of key components / processes: Controls, hydraulic interface unit (HIU), connection to user (e.g. pipes)
	Design and installation	4 (1 – 10) + Enabling benefits for system balancing, etc.	0.2 (0.1 – 0.6) [NB: largely non-tradable]	• Development and demonstration of tools, potentially in combination with planned *commercial* heat network projects, or else in combination with large scale demos (see below)
	Integration of heating systems			• Large-scale demonstration projects to prove viability (and better understand system benefits) of key functionality for advanced heat network capabilities, including integration of large-scale heat storage and/or the use of low-emission heat sources • *Include feedback into energy system modelling initiatives to better understand transition of heat and other energy systems*
Daily heat storage	Development, design and O&M	1.4 (0.1 – 6.8) + Enabling benefits for deployment of heat pumps	1.4 (0.3 – 4.3)	• Small scale demonstration of integrated systems (potentially using advanced heat stores such as phase-change stores) to optimise performance of thermal storage and heat pumps
	Advanced daily heat/cold store			• R&D to achieve cost reductions and key performance developments, e.g. increase stability, rate of heat exchange
Interseasonal heat storage	Heat store and extraction	0.8 (0.2 – 2.5)	0.3 (0.1 – 1.1)	• R&D to achieve cost reductions and key performance developments, e.g. minimal losses, rate of heat exchange
	Controls, installation, design and O&M	0.7 (0.2 – 2.2)	0.1 (0.0 – 0.3)	• Improved heat metering , system design, and operational strategies to enhance system performance • More efficient and cost-effective civil works and ground loop installation
Total	**Value:**	**£30bn (14 – 66)**	**£6bn (2 – 12)**	**5-10 year investment in the hundreds of millions of GBP (programmes of material impact in individual areas in the millions to tens of millions of pounds)**

Benefit of UK public sector activity/investment[2]	
	High
	Medium
	Low

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[2] 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 will play a critical role in the UK energy system

Space and water heating (excluding industrial process heat) account for about a quarter of UK energy consumption today, with demand of approximately 550-600 TWh per year. This demand is highly “peaky” compared to other energy end uses in the UK, with much higher demand for heat during the coldest months and days 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 delievery in the UK, with important implications for the technologies that can meet heat demand cost-effectively. Through to 2050, heat is expected to continue to constitute about one quarter of overall energy demand through to 2050. Nevertheless, a great deal of uncertainty exists about the absolute level of heat demand (depending on the efficacy of energy efficiency and demand reduction measures) with estimates ranging from a slight increase on today, to a reduction of almost 50%.

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

- air and ground source heat pumps
- heat network systems (in combination with industrial waste heat, power station heat recovery, or community scale CHP)
- solid biomass boilers
- natural gas, bio-gas, and potentially (direct) hydrogen micro-CHP
- solar thermal systems
- high efficiency fossil fuel boilers, and
- heat storage (large and small scale), which could 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).

Owing to the large amount of uncertainty, conceivable scenarios exist in which all/most of these technologies could play a significant role in the coming decades. However, there are limited low carbon technology options for meeting the UK’s heat needs, and all of these technologies face major challenges if they are to be widely deployed. Even relatively mature and cost-effective technologies such as heat pumps are not yet proven to be ready for broad adoption in the UK context. It is therefore important to highlight that significant gaps still exist in the evidence base, and that continued technical assessments alongside more detailed energy system modelling is recommended to narrow down this degree of uncertainty.

This report focuses on the innovation potential in three 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 (and waste heat recovery), and heat storage (at various scales). These technologies offer many benefits to a low-carbon energy and economic system: (i) heat pumps are a potentially very cost-effective means of delivering heat with low or zero GHG emissions; (ii) heat pumps also can accommodate a variety of electricity generation sources; (iii) heat storage and heat networks can be integrated into the energy system to ease balancing requirements related to the very “peaky” nature of heat demand..

Several other heat technologies are not considered directly in this TINA. A separate bioenergy TINA will consider biomass-based heat, since its potential depends more on the system of biomass availability and best-use than it does on the heat system. This bioenergy TINA will include analysis on the potential for biomass for industrial process heat and CHP applications. We have not considered natural gas or hydrogen based micro-CHP, but would recommend this for further study in subsequent work. Similarly, while this TINA does not specifically analyse innovation in solar thermal technologies, we do consider the the role of heat storage as a key enabler of solar thermal. We would recommend further analysis on solar thermal thechnology in subsequent work. Electric resistive heat could also potentially play a role in the future low carbon UK energy system, but we excluded this technology from the heat TINA due to its relatively limited innovation potential.

Heat pumps, heat networks and heat storage could be deployed extensively by 2050

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 were generated based on CCC MARKAL runs for the fourth carbon budgets, DECC 2050 calculator scenarios, customised runs of the ESME model for this work, and various other available scenarios from the literature[3]. This determines how much capacity is required across the generation mix to meet energy demand and emissions reduction targets at lowest cost based on the constraints outlined above.

Although innovation itself will play an important role in enabling the deployment of these technologies (by reducing cost and improving efficiency), our scenarios focus on the potential impact of exogenous factors such as the success of energy efficiency and demand reduction measures, the availability of biomass, the relative success of renewables vs. thermal plant generation, and the price of fossil fuels. Hence, all of these scenarios assume innovation is successful, and the

[3] "The UK Supply Curve for Renewable Heat", NERA/AEA, July 2009; “The Potential and Costs of District Heating”, Poyry and Faber Maunsell/AECom, April 2009; “In Depth Technology Innovation Assessment: Heat Storage”, AEA, March 2011

scenario ranges reflect true exogenous uncertainty to the deployment of the technologies.

Given the large potential for innovation improvement (see below) and the complex system implications of different alternatives (e.g. on electricity transmission and distribution costs), the relative competitiveness of different heat options (both those analysed here, and others) remains highly uncertain. Nevertheless, our currently available models indicate that (assuming similar innovation success) all of the technologies analysed here could be at large scale, and often in combination. In the case of storage, there is significant complementarity with both heat pumps and heat networks. Between heat pumps and heat networks, they each have advantages in different built environments, and can in some cases be complementary technologies. This reflected in the fact that they all have significant deployment in the medium scenario, which is used as the central scenario for the TINA analyses.

Heat pumps

Under all future scenarios, heat pumps are likely to play a significant role in delivering heat. Major building retrofits and new construction will be the most attractive markets for heat pump deployment. Better thermal performance from building fabric and reduced installation costs will improve the cost-effectiveness of heat pumps in major retrofits and new construction. There is also an important distinction between the markets for air source heat pumps (ASHPs) and ground source heat pumps (GSHPs). GSHPs will be suited mostly to rural environments where there is sufficient space for installing ground loops, while ASHPs will be more suited to urban locations. Across all markets for heat pumps, the extent of potential deployment remains uncertain, but even in a low scenario significant deployment is expected.

- **Low** (12TWh in 2020; 100TWh in 2050): Total heat demand is significantly reduced due to energy efficiency improvements (such as insulation and other building fabric improvements) and service demand reductions. Moreover, alternative heat technologies (e.g. heat networks and community scale CHP, biomass boilers, and electric resistive heat) prove viable and competitive. Heat pump deployment still grows to cover ~2% of heat demand (12 TWh) by 2020 and roughly one-third of heat demand (100 TWh) by 2050. This is a level of deployment consistent with heat pumps being taken up predominately/exclusively in more sparsely populated rural areas. As we will address later in this TINA, daily heat storage can enable heat pump deployment by helping to overcome consumer acceptance barriers and improving heat pump performance. If storage turns out to be essential for heat pump deployment and compact advanced heat stores cannot be deployed, heat pump uptake could be limited to rural areas where there is sufficient space for bulkier hot water storage systems.
- **Medium** (26TWh in 2020; 180TWh 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 heat pump deployment combined with only moderate demand reductions. Heat pump deployment grows to 4% of heat demand (26 TWh) by 2020 and 35-55% of heat demand (180 TWh) by 2050. This is a level of deployment consistent with heat pumps being taken up in both rural areas and in some suburban areas (predominantly detached houses).
- **High** (35TWh in 2020; 340TWh in 2050): Heat pumps are deployed extensively and total heat demand is high due to a lack of significant progress in energy efficiency or service demand reductions. Heat pump deployment grows to 6% of heat demand (35 TWh) by 2020 and 60-70% of heat demand (340 TWh) by 2050. This is a level of deployment consistent with heat pumps being taken up in both rural areas and suburban areas (including semi-detached housing).

Consumer acceptance will be an important challenge for the widespread deployment of heat pumps. The incumbent gas boiler technology can deliver heat quickly and high temperatures, allowing end users to rapidly heat a space or replenish domestic hot water tanks. It is not technically feasible or economic to install heat pumps that deliver heat at the same high rate, and heat pumps operate most efficiently at lower temperatures. These limitations will require both some adaptation from consumers and improved controls that anticipate when end users will need access to space heating and domestic hot water. Heat storage also can help to meet peak heat demands, a key enabling benefit that we address in later sections of this TINA.

Heat networks

Heat networks deployment is subject to even greater uncertainty owing to wider dependence on external conditions, including the available sources of heat (e.g. waste heat vs. CHP plant vs. large-scale heat pumps), and the significant planning and coordination complexities involved in such large (often community scale) projects:

- **Low** (9TWh in 2020; 22TWh in 2050): Heat networks face continued challenges in planning approval, energy efficiency and demand reduction measures are successful, and/or the availability of thermal plant and biomass for heat and power are limited. This scenario represents heat network deployment levels growing slightly from UK historic experience (reaching up to 5% of heat demand in 2050), with some new networks being created to replace aging district heating installations.
- **Medium** (17TWh in 2020; 77TWh in 2050): The planning and regulatory regime is supportive of heat network development, but success in energy efficiency and demand reduction, combined with lower sustainable biomass availability and reduced thermal plant availability put some constraints on the cost-effective deployment potential. Heat networks supply about 15-25% of heat demand in 2050.
- **High** (27TWh in 2020; 208TWh in 2050): The planning and regulatory regime is supportive of heat network development, and there is less than expected improvement in energy efficiency and demand reduction, and high availability of sustainable biomass and thermal plant. Heat networks supply 40% of heat demand in 2050.

For heat networks, there remains potential for a “very low” scenario (near zero deployment) and potentially a “very high” scenario (with perhaps 50% higher deployment than the current high scenario). The former would likely involve a complete impasse in network development owing to planning complexities, or extraordinary energy efficiency improvements, demand reductions, and heat pump penetration. The latter would likely involve both strongly coordinated utilisation of waste heat and planning of network and thermal plant development, as well as the relative failure of small-scale heat pumps to achieve deployment potential. At this stage, there is insufficient evidence that a very high deployment scenario is feasible, but this could change subject to further evaluation of the potential opportunity, especially in terraced and semi-detached housing in areas with lower density of heat demand (e.g. below 2000KW/km^2).

Heat storage

Heat storage technologies vary greatly, including sensible heat[4] storage (e.g., water and gravel), phase changing materials (e.g. salt hydrates and paraffin wax products), adsorption/absorption processes, and chemical reactions.

Daily heat storage can currently be provided through sensible heat technologies, with hot water tanks already available in the majority of buildings. Innovation potential in these technologies is limited, and we do not model their continued future deployment as part of this work. However, space and performance advantages mean that other forms of advanced storage could add significant value in certain building types, especially in combination with heat pumps (where storage benefits are greater). Hence, this work looks at the potential deployment of advanced storage technologies, which has the potential to grow significantly from near zero levels today. As already noted, heat demand is extremely variable over seasons and times of day, with much higher demand in the winter months and during daytime hours. Moreover, the efficiency of heat pumps decreases when ambient outdoor temperatures are lower, meaning their efficiency is lowest when heat demand is highest. Therefore, there is a potentially important role for daily heat storage in enabling the deployment and cost-effective operation of heat pumps.

Interseasonal storage can also be provided through sensible heat technologies, and is likely to continue to be based on these technologies in the future, since advanced storage technologies do not offer space and performance benefits commensurate with costs. Nevertheless, such long-term, sensible heat storage technologies are not yet widely deployed, and still have significant innovation potential. Hence, this work looks at the innovation improvement potential of such interseasonal heat storage, and the potential deployment growth in the coming decades.

We explicitly model daily and interseasonal (long-term) storage. A third category (‘weekly shifting’) of heat storage may be relevant for coverage of generation gaps due to variable sources (e.g. two weeks without wind). The benefits of this ‘weekly’ heat storage could be seen as an added benefit of long-term storage systems, as well as a secondary application for large commercial or district storage systems used primarily for daily balancing. Hence, our innovation value estimates should cover the benefits of ‘weekly’ storage, and such applications should be considered part of the innovation opportunities.

In all scenarios we model growth in daily storage as growing with greater deployment of heat pumps (and potentially solar thermal systems). We model growth in interseasonal storage as growing with the amount of heat

[4] Sensible heat refers to heat that changes the temperature of a material. For example, increasing water to a higher temperature to store heat for later use is a form of sensible heat storage. In contrast, much of the heat stored in a phase change material is latent heat that does not increase the temperature of the material but rather changes its state from solid to liquid.

recovery, heat networks, and penetration of ground source heat pumps (GSHPs). As such, the scenarios for heat storage reflect the scenarios outlined above:

- **Low**: Advanced daily heat storage is largely unnecessary, as heat pump deployment is limited to buildings with space for water tank storage. Deployment is estimated at close to zero (0 GW by 2020 and 3 GW by 2050). Interseasonal heat storage grows (in line with developments in GSHPs and heat networks) with capacity of 0.2 GW by 2020 and 3.1 GW by 2050. These deployments reflect scenarios with very high efficiency improvements and demand reductions, and where natural gas, biogas and potentially hydrogen heat provide a relatively high proportion of demand.
- **Medium**: Advanced daily heat storage grows in importance owing to more widespread heat pump deployment in space-limited settings, with 1 GW by 2020 and 32 GW by 2050. Interseasonal storage grows to 0.8 GW by 2020 and 12.8 GW by 2050, owing to moderate penetration of GSHPs and heat networks. These deployments reflect scenarios with moderate efficiency improvements and demand reductions.
- **High**: Advanced daily heat storage becomes critical owing to very large penetration of both heat pumps and solar thermal in space-limited settings, with 4 GW by 2020 and 151 GW by 2050. Interseasonal storage grows to 2.8 GW by 2020 and 41.9 GW by 2050, with high deployment of GSHPs, solar thermal and heat networks. Both deployments reflect scenarios with high heat demand.

Cutting cost through innovation

Current costs

Heat pump and heat network technologies are currently available with well understood costs that can serve as a basis for understanding innovation improvement potential. Heat storage technologies also exist, although more advanced storage technologies have not been proven at scale, and assessing their ‘current’ costs is inherently more speculative.

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 technologies. For air-source heat pumps, we assume current capital costs (excluding heat distribution) of £600/KW, O&M of £9/KW/year, a coefficient of performance (CoP) of 2.2, and a load factor of 16%, which results in an estimated levelised cost of £115/MWh. For ground-source heat pumps, we assume current capital costs (excluding heat distribution) of £1500/KW, O&M of £9/KW/year, a coefficient of performance (COP) of 2.5, and a load factor of 16%, which results in an estimated levelised cost of £200MWh. The largest components of total heat pump system cost are the heat pump technology itself, installation of the system, and the on-going cost of fuel inputs (see Chart 2 for an indicative breakdown).

Chart 2. Heat pump sub-areas

Sub-area	Descriptions	Share of cost
Heat source	Heat pumps extract heat from the heat source and pump that heat into the building. Ground source heat pumps (GSHPs), air source heat pumps (ASHPs), and water source heat pumps (WSHPs) are variants.	c. 10%
Heat pump technology	Compressor heat pumps consist of a mechanical compressor, an evaporator, a condenser and an expansion valve, and are generally electrically powered. They make up about 95% of all heat pumps. Other heat pump technologies, including absorption and Vuilleumier heat pumps are also common variants.	c. 20%
Heat distribution	For space heat, heat distribution can be via under floor heating, low temperature radiators, or through warm air heating. Heat pumps can also be used to provide domestic hot water, either providing domestic hot water directly (with reduction in COP) or by pre-heating the hot water tank, which is then topped up by conventional heating.	Highly variable
Controls	Includes temperature measurements, sensors, control algorithm, management system and heat meters.	c. 5%
Installation	**Heat pump:** ASHP requires installation of a unit external to the building, GSHP requires drilling/trenching for ground loop, WSHP requires laying of water loop (including trenching). **Distribution:** Under floor heating is difficult and expensive to retrofit, more feasible for new build or major refurbishment. Low temperature radiators require heating distribution system upgrade for retrofit.	c. 20% (c.15% ASHP c.37% GSHP)
Design	Includes system design, specification and commissioning and involves integration of all aspects (e.g. heat demand pattern, ground survey, distribution/storage system, controls, physical installation, sometimes integration with other (renewable) heating system like solar thermal).	c. 3%
Operation & Maintenance	Includes yearly maintenance of the heat pump, periodic cleaning of heat exchangers and distribution system.	c. 4%
Fuel Input	Heat pumps require an input of fuel to operate. Compressor heat pumps are powered by electricity, while absorption heat pumps are generally powered by natural gas. In a future where hydrogen gas is readily available from renewable sources, existing absorption heat pumps may be powered by hydrogen.	c. 38% (c.45% ASHP c.23% GSHP)

Heat networks

Heat network systems also vary significantly in cost and efficiency depending on the source of heat, the size of the network, the heat 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 network system. Note that this work does not look at innovation and cost improvement for the heat source, but only the network. There are a number of potential heat sources, including (among others) industrial waste heat, power station heat recovery, community CHP, or heat pumps that could supply heat networks. For our indicative heat network, we assume current capital costs of £1000/KW, O&M of £10/KW/year, an efficiency of 90%, and a load factor of 25%, which results in a levelised cost of £83/MWh[5] (or £65/MWh excluding running costs). Excluding fuel costs, the largest components of total heat network system cost are installation (~40%), overground and underground connections (~30%), 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. For *daily heat storage* we us phase changing materials as our indicative technology for advanced heat storage. For this indicative technology, we assume "current" capital costs of £530/KW for small scale systems (suitable to homes) and £35/KW for larger scale systems (suitable for commercial premises). For advanced forms of daily heat storage, 80-85% of the cost of the system is in the heat store itself, with design and installation accounting for the other 15-20%.

Interseasonal storage can already be provided through sensible heat technologies, and is likely to continue to be based on these technologies in the future (since advanced storage technologies don't offer sufficient cost and performance benefits). It is important to recognise that the costs of interseasonal heat storage systems vary considerably depending on functionality, geology, and other factors. For the purpose of this analysis, we have looked at two indicative systems based on ground/aquifer and gravel/water storage. For our indicative ground/aquifer system, we assume current capital costs of £1000/KW, O&M of £10/KW/year. Almost half of the system costs are from extraction systems to take heat out of the store, almost half are from system installation, and only a small fraction is taken up by the store, controls, and design. For our indicative gravel/water system, we assume current capital costs of £700/KW, O&M of £7/KW/year. About 15% of the system costs are from the heat store, ~35% from extraction systems to take heat out of the store, about half are from system installation, and only a small fraction is taken up by the controls and design.

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[5] This is based on using waste heat from large thermal plant as the heat source. If we use biomass CHP or industrial process waste the current levelised cost would likely be 20-40% higher. For the purpose of this paper, we will show levelised *capital* costs only, since this illustrates the impact of innovation, without the uncertainty about fuel source or fuel costs

Cost savings through innovation

Heat pumps, heat networks and heat storage technologies have very distinct innovation needs, but all offer large cost and performance improvement potential through further innovation.

Heat pumps

Innovation has the potential to significantly reduce the cost of heat delivered by heat pumps, due both to potential improvements in system efficiency (improved coefficients of performance) and to reductions in the total installed costs of heat pumps (see Chart 3). Improvements in heat pump technology and in the design and installation of systems are the largest contributors to this potential from innovation. Collectively, total system cost improvements of around 30% and 40% are possible by 2020 and 2050, respectively. Foreseeable efficiency improvements by 2020 are possible largely as a result of better system design and installation that bring actual in-use efficiency performance up to the name plate coefficients of performance (COPs) for deployed systems. While we have summarised innovation in heat pumps overall, there are important differences in innovation needs for new build versus retrofit markets and for ASHPs versus GSHPs. Critically, to achieve significant uptake in retrofit markets, design and installation costs and heat pump efficiency will need to improve greatly to make up for inherent cost and efficiency disadvantages in retrofit installations.

Chart 3. Heat pump innovation needs and improvement potential

Sub-area	Sub area type	Innovation impact potential (by 2020)	Innovation impact potential by 2050	What is needed (source of improvement potential)
Heat Source	-	18% cost reduction	18% cost reduction	▪ 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 ▪ Reduce size of exhaust air heat pumps ▪ Incremental improvement primarily through “learning by doing”
Heat pump technology	▪ Compressor HP ▪ Absorption HP	30% cost reduction 30% cost reduction 38% reduction in fuel consumption (efficiency improvements)	50% cost reduction 50% cost reduction 44% reduction in fuel consumption (efficiency improvements)	▪ Improved compressor performance ▪ Better expansion valves (moving from thermostatic to electric valves) ▪ Designs that reduce/eliminate superheat ▪ More efficient operating fluid (e.g. improved refrigerant) ▪ Use of compact heat exchangers to reduce systems’ physical size ▪ Heat exchanger cleaning and de-icing techniques ▪ Adsorption, Vuilleumier, chemical reaction are still at early research stage but are unlikely to have a major role in the future due to low COPs (<1.6). Adsorption could however be deployed usefully in combination with waste heat recovery
Heat distribution and storage	-	18% cost reduction	18% cost reduction	▪ Incremental improvement through optimisation of heat system ▪ Improvements predominantly from “learning by doing”
Controls	▪ Standard ▪ Incl. smart metering and monitoring	30% cost reduction	50% cost reduction	▪ Lower component costs ▪ Improved interaction with other services ▪ Integration with grid
Design and Installation	▪ Cheaper installation and design ▪ Optimise system design, installation and controls	21% reduction in installation costs 38% reduction in fuel consumption (efficiency improvements)	35% reduction in installation costs 44% reduction in fuel consumption (efficiency improvements)	▪ More efficient ground loop installation ▪ Possible transfer of drilling technologies from e.g. oil & gas or fibre optic installation ▪ New design tools ▪ Better integration of all sub-areas ▪ Improved monitoring and control philosophy (e.g., include constant, unimodal, or bimodal operation)
O&M	▪ Fixed cost ▪ Variable cost	30% cost reduction 30% cost reduction	50% cost reduction 50% cost reduction	▪ 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
Total		**c.30%**	**c.40%**	

Heat networks

Although heat networks are already widely deployed, and in some respects quite a mature technology (e.g. heat network pipe products have already achieved very large improvements), there remains significant cost reduction potential, especially in the installation and interface with heat user (which represent a large proportion of overall costs). Collectively, total system cost improvements of around 25% and 34% are possible by 2020 and 2050, respectively (*excluding* any improvements in heat source).

Further efficiency improvements might also be possible through innovation that reduces heat loss or enhances extraction at the HIU. These have not been modeled in this work, and their value would depend greatly on the expected fuel source and its cost. Nevertheless, these additional benefits could be seen as further supporting the case for innovation related to the interface with heat user.

Chart 4. Heat networks innovation needs and improvement potential

Sub-area	Sub area type	Innovation impact potential (by 2020)	Innovation impact potential by 2050	What is needed (source of improvement potential)
Connection to heat user	▪ Underground pipes ▪ Over ground pipes	-	-	▪ Heat network pipe products are largely already optimised by using thin wall steel tubing, highly efficient polyurethane insulation and a high degree of pre-fabrication of components and joint closures
Interface with heat user	▪ Hydraulic interface unit (HIU)	40% cost reduction	50% cost reduction	▪ Reduce costs through greater 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
Controls	-	45% cost reduction	50% cost reduction	▪ Innovations would be part of hydraulic interface unit improvements
Design	▪ Standard ▪ Incl. smart metering and monitoring	28% cost reduction	35% cost reduction	▪ Optimising operating temperatures and pressures, greater use of direct connections, designing HIUs to minimise return temperatures, designing heating systems to operate with lower temperatures and greater temperature difference. All of these aim to reduce the parasitic losses in the system due to pumping less water around the network
Installation	▪ Underground	35% cost reduction	50% cost reduction	▪ New methods for jointing of steel pipe using mechanical coupling or automatic welding for greater use of twin pipes and shorten construction times ▪ For over ground systems combining the laying of heat network pipes with the upgrade of the fabric efficiency of existing buildings (e.g. external wall insulation) could provide significant cost savings ▪ For underground systems, costs can be reduced by using “cold laying”, i.e. Installing the two pipes vertically above 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) would reduce costs by reducing installation time ▪ Cost effective route selection (through lofts, basements etc.) to reduce civil costs. The issues are not technical as such but legal and logistical
O&M		18% cost reduction	18% cost reduction	▪ System optimisation ▪ Improvements primarily through ”learning by doing”
Total		**c.25%**	**c.34%**	

Heat storage

For *daily storage*, while hot water systems are mature and have no significant potential for improvements through innovation, there remains very high innovation potential for advanced heat stores. Costs of advanced stores (>80% of total advanced storage system costs) could come down by 40% and 50% by 2020 and 2050 respectively, driving the bulk of improvement potential. Design and operations and maintenance costs could also come down by a third, although they represent a small percentage of costs (See Chart 5).

It is important to note that as an enabling technology, heat storage can have indirect benefits in enabling the deployment of other key technologies. Heat storage can help make heat networks more economical by allowing heat sources to operate more efficiently and reducing the need to build heat generation capacity to cover peak periods of heat demand. In addition, daily heat storage can help to improve the performance and consumer acceptability of heat pumps, which are less able to meet spikes in heat demand than the incumbent gas boiler technology. And as electric heat pumps become more common, heat storage can help to reduce the costs of reinforcing electricity networks and generation capacity. For these reasons, 'lynch pin' innovations that unlock the deployment of daily heat storage in combination with other key technologies will have indirect value additional to their direct value in reducing the cost of storage. This is particularly true for advanced daily storage, which allows heat to be stored in a much more compact system and at lower temperatures, reducing losses. Advanced storage thus makes heat storage possible in space-limited settings, and can therefore significantly increase the deployability of heat pumps. Hence, this analysis will also make a rough calculation of these indirect benefits (see next section).

Chart 5. Daily heat storage innovation needs and improvement potential

Sub-area	Variant	Innovation impact potential (on cost reduction)		Energy system benefits additional to available technology	What is needed (source of improvement potential)
		by ~2020	by 2050		
Heat/ cold store	▪ Water ▪ 'Advanced' materials (e.g., PCMs, Sorption, Chemical)	- 40%	- 50%	▪ 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 ▪ These benefits are calculated separately, and added to the cost analysis below	▪ Water storage tanks are very well established, no technical innovations are expected to significantly bring down their cost ▪ Stable and cheap advanced storage materials in suitable temperature range ▪ 'Advanced' storage materials are assumed to be deployed only once cost/performance is equivalent to that of hot water tanks, and all improvement is additional to this "existing alternative"
Extraction	▪ Some advanced storage materials (e.g. PCM, chemicals)	-	-		▪ Need to improve the rate of heat transfer (or chemical reaction) of PCMs and chemical systems so that the storage can be used effectively ▪ 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 ▪ *NB: Where extraction difficult/costly because of the properties of the store material, the innovation is considered as innovation to the heat store itself and not the extraction technology*
Installation		-	-		▪ Installation of systems with advanced materials will require better skilled contractors, but no innovation in the installation process itself
Design and O&M	▪ Domestic ▪ Commercial	25% 25%	30% 30%		▪ No cost has been associated with design for domestic systems as these are an "off the shelf" product ▪ A relatively small reduction in design costs has been assumed for commercial/DH size storage as its wide spread use in combination with DH systems may result in the better understanding of the technology and therefore reduce design time
Total		**c. 30%**	**c.38%**		

For *interseasonal storage*, innovation continues to have large potential in reducing costs even though it is unlikely to require very advanced (and early stage) materials. In particular, later stage innovation in heat extraction technologies and installation processes could reduce the bulk of system costs by about a third (See Chart 6).

As with daily heat storage, interseasonal heat storage also serves as an enabling technology, with indirect benefits in enabling other key technologies (e.g. heat networks), and reducing the requirement for additional back up capacity. Nevertheless, there were no innovations seen as 'lynch pin' in that they significantly facilitate additional interseasonal heat storage not technical possible with current technologies. As a result, we limit our calculation of the benefits of innovation to the cost savings impact. This does not mean that indirect enabling benefits do not exist (and are certainly relevant for policies encouraging deployment), but rather that innovation is not critical to achieving these indirect benefits.

Chart 6. Interseasonal heat storage innovation needs and improvement potential

Sub-area	Variant	Innovation impact potential (on cost reduction)		Energy system benefits additional to available technology	What is needed (source of improvement potential)
		by ~2020	by 2050		
Heat/cold store	▪ Ground / aquifer ▪ Earth / gravel bank	- 25%	- 35%	▪ Additional system benefits of interseasonal heat storage: – reduce plant capacity – improve plant efficiency – maximise revenue from energy generation ▪ While cost improvement potential exists from innovation in interseasonal storage, there are few if any cases where deployable levels of interseasonal 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 interseasonal heat storage, and have therefore assigned no additional energy system benefits to innovation	▪ Simply heat extracted from ground – no changes in source ▪ Large constructed stores are new system types for which reduction potential is significant from design optimisation rather than radical innovation ▪ *NB: PCMs, Sorption and Chemicals have less performance advantages in interseasonal storage and large cost gaps before reaching parity with sensible stores – <u>This works considers them unsuitable for this application</u>*
Extraction	▪ GSHP/WSHP ▪ Earth / gravel bank heat exchanger	25% 25%	35% 35%		▪ Cheaper and more efficient heat pumps and heat exchangers
Controls	▪ Similar irrespective of storage type	25%	30%		▪ Improve heat meters ▪ Improve controls, coupled with improved operational strategy, to enhance system performance
Installation	▪ Underground ▪ Overground	25% -	30% -		▪ More efficient (and cost effective) civil works ▪ Cheaper ground loop installation
Design and O&M	▪ Similar irrespective of storage type	25%	30%		▪ Integrated system design and control, to achieve optimal operation
Total		**c.24%**	**c.32%**		

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

Based on our cost and efficiency improvements, and our scenarios for potential deployment (assuming successful innovation), we calculate the potential savings in energy system costs through innovation in each of the three technology areas. These savings were calculated against a counterfactual case in which no innovation occurs[6]. We then refine this to look at a counterfactual where 'learning by doing' occurs independently from 'learning by research' (see below).

Under our medium deployment scenarios, and assuming full innovation potential is realised, innovation in heat pumps, heat networks and heat storage could reduce the energy system costs through 2050 by £35bn, £7.4bn and £4.9bn respectively. This total of £47.5bn in cost reductions include maximum innovation potential, combining 'learning by research' (driven by RD&D spending) and 'learning by doing' (achieved through the incremental learning associate with increased deployment alone)[7]. For the remainder of the report we include *only* those savings enabled by 'learning by research' (additional to 'learning by doing'), which points more specifically at the value from RD&D.

'Learning by research' drives about two-thirds of the overall innovation potential through 2050, accounting for £30bn of the full savings (£21.1bn, £5.5bn and £3.0bn in heat pumps, heat networks and heat storage respectively). Reflecting the deployment scenarios and relative uncertainty (discussed above), the spread across the low-high range is widest for heat storage, followed by heat networks, and then is narrowest for heat pumps (See Chart 7).

We have also provided a rough estimate of the innovation (learning by research) potential by specific technology sub-area/component within heat pumps, heat networks and heat storage. These estimates help highlight where RD&D could have the biggest impact in reducing costs and/or improving efficiency.

6 This 'inflexible deployment' method does not allow for complex interactions across technology areas (e.g. substitution between deployment of heat pumps and district heating in the context of alternative developments in electric heating or bioenergy derived heat). While technically possible, a more sophisticated 'perfect system optimisation' counterfactual would add enormous complexity, require very uncertain assumptions about the likelihood of innovation success across technologies, and would not substantively affect the conclusions of this report. Moreover, while this estimation method potentially overestimates innovation value (see Offshore Wind and Marine Energy TINA reports), modelling work to date suggests that this overestimation is likely to be small. This is due to the fact that there are few (if any) alternative low-emission heat technologies likely to be attractive at large scale vis-à-vis the technologies examined here.

7 As defined in Jamasb, T. (2007), Technical Change Theory and Learning Curves: Patterns of Progress in Energy Technologies, The Energy Journal, Vol. 28, Issue 3, 45-65.

Heat pumps

Across the sub-areas of heat pumps, innovation in the heat pump technology and in the design & installation of systems are estimated to have the largest potential value, due to their high costs are relatively large impact on the efficiency of the heat pump system. About 40-45% of these cost savings derive from efficiency improvements (i.e. improvements in the actual coefficient of performance). These improvements are expected to be driven by improvements in the heat pump technology (roughly two-thirds of the improvement), and by improvements in the design and installation of the system (roughly one-third of the improvement). Chart 8 shows the breakdown by sub-area/component.

Between air-source and ground-source heat pumps, the value of innovation is roughly assessed to be 60% in the former and 40% in the latter. However, this split should be treated as very rough, since it is driven primarily by the relative deployment of air-source versus ground-source heat pumps, which remains highly uncertain.

Heat networks

Across the sub-areas of heat networks, innovation in the design & installation of systems, and in the interface with the user (i.e. the hydraulic interface unit) are estimated to have the largest potential value, due to their high costs are relatively large improvement potential. Chart 9 shows the breakdown by sub-area/component.

Heat storage

In heat storage, roughly similar savings are estimated to come from daily and interseasonal heat storage. For interseasonal heat storage, the low, medium and high scenarios show potential innovation value of £0.4bn, £1.6bn and £4.8bn respectively, most of which comes from improvements to the heat store and heat extraction (~50% of total), or from design, installation and controls (~45% of total).

For daily heat storage, the low, medium and high scenarios show potential innovation value of £0.1bn, £1.4bn and £6.8bn respectively, with >95% of these savings coming from advances in the heat store (i.e. making it suitable for premises where space is limited).

Moreover, in the case of daily heat storage, there are *additional benefits as an enabling technology*. These benefits may be much larger than the direct cost-improvement benefits just discussed. In particular, daily storage may help to facilitate greater deployment of heat pumps (and perhaps solar thermal heat). In the case of heat pumps, their particular suitability to some built environments, and their *relative* cost-effectiveness (owing to very high potential efficiencies), makes them a relatively low-cost abatement technology from a system perspective. Hence, enablers of greater and faster heat pump deployment are potentially very valuable in reducing energy system costs.

For example, rough energy system modelling undertaken for this work shows that enabling 5 million additional homes to have heat pumps would saving energy system costs of ~£10-25bn (cumulative discounted value through 2050). Even accounting for the extra cost of daily storage, this system level savings could provide value of £5-15bn. By way of comparison, in moving from our low to medium deployment scenario there would be roughly this amount of new heat pump installations, and in moving from our medium to high deployment scenarios there would be roughly double this number of heat pump installations (i.e. 10 million additional installations). This suggests that the enabling benefits of daily heat storage are similar to, if not significantly greater than the direct benefits from cost savings.[8] This further strengthens the case for innovation in daily heat storage, and potentially puts it value on par with the estimated value of innovation from heat pumps themselves.

[8] Note that a similar, but more limited analysis by AEA ('In Depth Technology Innovation Assessment: Heat Storage' April 2011) looking specifically at the additional cost savings effect from reduced peak energy consumption estimated enabled savings of ~£5bn. This further supports our conclusion that enabling value significantly strengthens the case for innovation in daily heat storage.

Chart 7. Value in meeting emissions and energy security targets at lowest cost (cumulative 2010-50, discounted[9] 2010 GBP)

	Value from total innovation potential to 2050	Value from 'learning by doing' to 2050	Value from 'learning by research' to 2050		
	Medium scenario	**Medium scenario**	*Low scenario*	**Medium scenario**	*High scenario*
Heat pumps	**35.2**	**14.1**	*11.4*	**21.1**	*39.3*
Heat networks	**7.4**	**1.9**	*2.2*	**5.5**	*15.0*
Heat storage	**4.9**	**2.0**	*0.5*	**3.0**	*11.6*

Chart 8. Heat pumps – Value in meeting emissions and energy security targets at lowest cost by sub-area(cumulative 2010-50, discounted 2010 GBP)

Sub-area/ component	Value from 'learning by research' to 2050		
	Low scenario	**Medium scenario**	*High scenario*
Design & installation	*4.4*	**8.1**	*15.1*
Controls	*0.7*	**1.3**	*2.4*
Heat pump technology	*5.5*	**10.3**	*19.1*
Operation & maintenance	*0.8*	**1.4**	*2.6*

Chart 9. Heat networks – Value in meeting emissions and energy security targets at lowest cost by sub-area (cumulative 2010-50, discounted 2010 GBP)

Sub-area/ component	Value from 'learning by research' to 2050		
	Low scenario	**Medium scenario**	*High scenario*
Design & installation	*1.3*	**3.5**	*9.5*
Controls	*0.2*	**0.6**	*1.6*
Interface with user	*0.5*	**1.3**	*3.6*
Operation & maintenance	*0.04*	**0.1**	*0.3*

[9] Discounted at 3.5% to 2035, and 3.0% between 2035 and 2050, in line with HMT guidelines

Green Growth Opportunity

Sizable global markets could develop in heat pumps, heat networks and heat storage

Large deployment of heat technologies is expected to be required globally in the coming decades, with markets for heat pumps, heat networks, and water-tank based heat storage already well developed. We look at three indicative scenarios which drive our assessment of the potential size of the global market:

- **Low scenario** – There is great success in achieving energy efficiency improvements and large demand reductions. Gas-based heating and/or conductive electric heating remain predominant. This could also be a scenario where there is some failure in reaching global emissions reduction targets.
  - ***Heat pumps*** (325GW by 2020, 1,211GW by 2050) – Represents annual growth of 3.5% against current deployment, and is roughly one-quarter of the deployment in the IEA BLUE MAP scenario
  - ***Heat networks*** (680GW by 2020, 850GW by 2050) – Assumes no decline in countries with high penetration (e.g. “transition economies”), and annual growth of 3.0% to 2020, and 1.5% to 2050 in growing markets; roughly one-third of the deployment calculation based on IEA BLUE MAP scenario
  - ***Heat storage*** (Advanced daily: 10GW by 2020, 88GW by 2050; Interseasonal: 7GW by 2020, 69GW by 2050) – Assumes penetration limited to very niche applications since emissions targets not constrained enough to require the system flexibility associated with heat storage
- **Medium scenario** – Scenarios vary by technology, but are generally in line large demand reductions and/or meeting are 2050 target to reduce global emissions to 2005 levels.
  - ***Heat pumps*** (480GW by 2020, 2,510GW by 2050) – Based on the IEA ACT Map scenario, where 2050 global emissions are kept to 2005 levels, with deployment roughly 60% of that in the IEA BLUE Map
  - ***Heat networks*** (775GW by 2020, 1,250TW by 2050) – Growing markets reach a level of penetration roughly equivalent to that of Europe, with annual growth of ~3.5% to 2050; represents roughly one-half of the deployment calculation based on IEA BLUE MAP scenario
  - ***Heat storage*** (Advanced daily: 113GW by 2020, 944GW by 2050; Interseasonal: 29GW by 2020, 267GW by 2050) – Deployment in line with complementary developments in heat pump, solar thermal and heat network deployments, with moderate storage penetration.
- **High scenario** – Scenarios vary by technology, but generally in line with meeting IEA BLUE Map scenario, where 2050 global emissions are reduced by 50% versus 2005 levels.
  - ***Heat pumps*** (675GW by 2020, 4,130GW by 2050) – Based on the IEA BLUE Map scenario, with ~40% of global heat demand being met by heat pumps
  - ***Heat networks*** (1000GW by 2020, 2,500GW by 2050) – All suitable markets reach a level of penetration roughly equivalent to that of Europe leading countries, with annual growth of 2.0%-3.5% in “transition economies”, and 4.0%-7.0% in growing markets; represents a deployment calculation in line with IEA BLUE MAP scenario
  - ***Heat storage*** (Advanced daily: 361GW by 2020, 3,010GW by 2050; Interseasonal: 100GW by 2020, 935GW by 2050) – Deployment in line with complementary developments in heat pump, solar thermal and heat network deployments, with relatively high storage penetration owing to stronger emissions reduction constraints

Based on these scenarios and the expected cost of these technologies (as described above), we have estimated the market turnover to 2050 (excluding O&M). Across all three technology areas, we estimate that the global market turnover by 2050 could grow to £50bn – £300bn (£125bn in medium scenario) (real, undiscounted value). This represents potential cumulative (between 2010 and 2050), discounted turnover of £550bn-£3,500bn (£1,500bn in medium scenario), and cumulative discounted gross value added (GVA)[10] of £275bn-£1,700bn (£750bn in medium scenario). Since GVA is better than market turnover as an indicator of the actual contribution of business activity to the economy, we use it to drive our analysis and conclusions below. Finally, it is important to take into account that a large portion of these markets (generally >80%) will not be “tradable”, and hence will not constitute exportable markets with strong business creation potential. This is due to the fact that a large proportion of market value is in local products and services such as installation, or in large pieces of kit and heavy materials which are unlikely to be exported beyond regional markets. See Charts 10 & 11 for a breakdown by technology area.

[10] Although these sectors are not sufficiently developed to know the precise ratio of GVA to turnover, we estimate the likely GVA-turnover ratio for each technology area by using the current GVA-turnover ratio in similar industries

Chart 10. Estimated market turnover by technology area

	Estimated market turnover in 2050 (£bn, real undiscounted)			Estimated market turnover 2010-2050 (£bn, real, cumulative discounted)		
	Low scenario	**Medium scenario**	*High scenario*	*Low scenario*	**Medium scenario**	*High scenario*
Heat pumps	*33*	*76*	*130*	*390*	**900**	*1,500*
Heat networks	*10*	*26*	*77*	*130*	**340**	*990*
Advanced daily heat storage	*2*	*18*	*45*	*20*	**190**	*600*
Interseasonal heat storage	*2*	*9*	*36*	*30*	**110**	*400*

Chart 11. Estimated gross value added by technology area, total and tradable market

	Estimated market GVA 2010-2050 (£bn, real, cumulative discounted)			Estimated market GVA 2010-2050 that is "tradable" (£bn, real, cumulative discounted)		
	Low scenario	**Medium scenario**	*High scenario*	*Low scenario*	**Medium scenario**	*High scenario*
Heat pumps	*190*	**440**	*750*	*32*	**74**	*126*
Heat networks	*60*	**160**	*475*	*11*	**28**	*83*
Advanced daily heat storage	*10*	**95**	*300*	*2*	**21**	*71*
Interseasonal heat storage	*15*	**55**	*200*	*3*	**12**	*38*

The UK could be a niche player in these markets

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

Heat pumps: In the heat pump technology, the UK has a few active players (e.g. Calorex, Kensa Engineering, TEV, and Colt International), as well as interest from international players (e.g. Mitsubishi) in basing their regional manufacturing in the UK. There are also some players in key parts of the supply chain (e.g. Copeland in scroll compressors), and various UK-based boiler manufacturers have relevant capabilities (e.g. Baxi, Vaillant, Worcester-Bosch, and Dimplex). In the area of controls, there are also a number of UK players (e.g. Sunvic, Potterton and ACL Drayton), as well as Honeywell (US company) with a strong UK base. Nevertheless, there is strong regional competition in the market from Sweden, Germany, and Denmark, as well as global competition, especially from the Far East. Moreover, these countries have also led the world in RD&D to date. Hence, the UK's potential competitive advantage in export markets is assessed as low to medium, with ~3% share in markets that are global (e.g. controls), and a ~9% share in the European regional market.

Heat networks: The UK has relatively low capabilities in the main aspects of heat networks which are traded, including controls, as well as the connection and interface with the user. In these areas, Countries like Germany, Denmark, Austria, and Sweden currently 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 network design, where UK based engineering companies have the capabilities to compete in performing feasibility studies and design work (e.g. AECOM, Arup, Buro Happold, and Ramboll). As a result, the UK's potential competitive advantage in export markets has been assessed as low in most areas (and low-medium in the niche design market), with 5-6% share in the European regional market.

Heat storage: In *advanced daily heat storage*, the key PCM players are outside the UK (e.g. BASF, Samsung), and there are no currently strong competitors. However, the market is at a very early stage, and the UK does have research capabilities it could leverage, as well as some established hot water tank manufacturers who could potentially enter the market. As a result, the UK's potential competitive advantage in export markets is assessed as low to medium, with 7-9% share in the European regional market. In *interseasonal heat storage*, the UK has some domestic players (e.g. ICAX) and a burgeoning domestic market. However, most major operators are not UK based (e.g. Vaillant, Stiebel Eltron) and other countries have led in developing early projects. As a result, the UK's potential competitive advantage in export markets is assessed as low to medium, with 7-9% share in the European regional market.

£2 – 12bn net contribution to the UK economy

If the UK successfully competes to achieve the market shares described, then these three heat sectors could make a cumulative contribution of c.£10bn (£4 – 24bn) to 2050.

It may be appropriate to apply an additional displacement effect since part of the value created in the export market will be due to a shift of resources and thus cancelled out by loss of value in other sectors. Expert opinion has roughly assessed this effect to be between 25% and 75%. Including a 50% displacement factor, these three heat sectors would make a cumulative net contribution of c.£5bn (£2 – 12bn) to 2050.

Chart 12 combines the above assessment of UK competitive advantage, with the market value estimates to give an estimate of the business value creation potential in the different technology areas. On the whole, all three areas offer moderate business value creation opportunities. Heat pumps offer the biggest opportunity, driven primarily by the size of the tradable market. Advanced daily heat storage also offers a large opportunity, but with much greater uncertainty.

Chart 12. Estimated UK business value creation potential

	Est. contribution to UK GDP 2010-2050, £bn, real, discounted			Est. net contribution to UK GDP 2010-2050, £bn, real, discounted			Major sub-sector opportunities for UK business
	Low scenario	**Medium scenario**	*High scenario*	*Low scenario*	**Medium scenario**	*High scenario*	
Heat pumps	*2.4*	**5.2**	*9.0*	*1.2*	**2.6**	*4.5*	Heat pump technology, followed by controls
Heat networks	*0.5*	**1.4**	*4.0*	*0.3*	**0.7**	*2.0*	Connection to the user, followed by interface with the user and project design
Advanced daily heat storage	*0.7*	**2.9**	*8.6*	*0.3*	**1.4**	*4.3*	Heat store technology
Interseasonal heat storage	*0.2*	**0.8**	*2.8*	*0.1*	**0.4**	*1.4*	Heat extraction technology , followed by project design

The case for public sector activity

Public sector activity is required to unlock much of the opportunity in heat, particularly in terms of the £34bn in savings to the UK energy system through learning by research (in the medium scenario), but also in terms of the opportunity to create £5bn in net business value (medium scenario).

Market failures and barriers impeding innovation

A number of market failures impact innovation and deployment across the heat technologies covered here.

- **Policy dependent demand and uncertain support levels (externalities) –** Significant deployment across the heat technologies examined here will require support mechanisms to make them competitive with existing technologies (with relatively high emissions), and internalise the social cost of CO_2. Various UK policies exist to address this including the Renewable Heat Incentive, the Code for Sustainable Homes, . Nevertheless, such incentives are difficult to perfectly calibrate across technologies, and are subject to high perceived political risk. This makes returns uncertain, and reduces the incentive for RD&D in these technology areas.
- **Barriers to developing novel/innovative concepts (spillover risks)** – Although many of these technology areas have already been commercialised, most of them have earlier stage developments that could reduce costs and improve efficiency. The high uncertainty of the success of these developments, the long lead times, and the resulting spillover risks mean that individual companies lack confidence in their ability to generate or capture returns on investment.
- **Split/misaligned incentives**: Between landlords and tenants, there is a disincentive for landlords to bear the investment cost when it is difficult to recoup the benefit to tenants in lower energy bills. While policies like the Green Deal should address this issue to some extent, it is expected to continue to dampen demand for innovation improvements.

In each of the technology areas, there are also specific market failures and barriers with particular impact. In **heat pumps and daily heat storage**, the key market barriers are:

- **Knowledge asymmetry**: Between the customer and the supplier, the customer does not have enough information to judge the impact of design and installation on system performance, and the supplier doesn't have enough information to charge based on energy saved. While policies exist to alleviate this issue (e.g. Microgeneration Strategy), it remains difficult for consumers to evaluate different quotes for heat pump installation, and provides little incentive to designers and installers to improve the quality of their work.
- **Health and safety requirements**: Advanced daily storage is likely to encounter safety issues which involve government regulatory intervention, and add uncertainty to the timing and extent of penetration for new technologies.
- **Coordination failures across a fragmented supply chain (high "transaction costs"):** The complexity of the technology, and the strong divisions between designers, suppliers, installers, and operators (often consumer themselves) inhibits feedback on performance and makes it difficult/costly to drive and coordinate innovation across different players in the supply chain.
- **Infrastructure dependency on electric grid development:** Access to reliable electricity at peak demand periods, and potential access to 3-phase electricity (to accommodate increased load and starting current of the compressor) would make heat pumps (and innovation in heat pumps) more attractive, but rely on uncertain public sector infrastructure investment.
- **Consumer acceptance (imperfect information, misaligned incentives, externalities)**: Although potentially addressable by the market (in the long-run), an important barrier related to heat pumps is consumer acceptance of significantly different product and service features. Heat pumps are operated quite differently from the incumbent technology, and require some customer adjustment. Moreover, most boiler purchases are "distressed purchases" that occur when old equipment has failed. Consumers would have to change those purchase patterns to allow for heat pump deployment. These factors reinforce the issues related to **Policy dependent demand and uncertain support levels** (discussed above).

In **heat networks and interseasonal heat storage**, the key market barriers are:

- **Infrastructure dependency on uncertain public support:** In the case of large district heating systems, publically coordinated infrastructure development is required. This introduces uncertainty regarding the success and pace of development, which discourages both project and technology developers, and reduces incentives for innovation.
- **Uncertain environmental impacts and planning approval (co-ordination failures):** Heat networks and large-scale storage involve broad community impacts, which raise various environmental issues and require uncertain planning approval. This introduces uncertainty, and reduces incentives for on innovation.
- **High upfront capital costs:** Although potentially addressable by the market and/or Green Investment

Bank funding, the large capital costs associated with construction of plant, heat network, storage sites and connections often face larger financing hurdles which further increase the risks, and reduce the incentives for innovation.

- **Lack of emissions-reduction policy certainty, and the related uncertainty over heat demand and heat source:** The long lifetime of a heat network and large-scale storage site (>40 years) requires certainty about the heat demand and heat source. In the absence of a clear and credible pathway for a low-emission pathway, these things are subject to more uncertainty than in the past which further increases risk, and reduces the incentives for innovation.
- **Complexity of technology integration and coordination failures across the energy system:** Successful deployment and optimisation of heat networks and large scale heat storage requires integration into other elements of the energy system (e.g. electricity network development, demand management systems). Difficulty coordinating across diverse sectors means it is more costly to drive innovation, especially in design.

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

Different heat component technologies vary greatly in the extent to which the UK could rely on other countries to intervene in tackling these market failures, and in driving innovation with the focus, and at the pace, required to achieve the value potential to the UK.

In some areas, technologies are sufficiently generic and other countries are driving innovation at a pace likely to suffice for UK needs. These areas are:

- Heat pump technology – Currently being driven by other leading markets (e.g. Japan)
- The heat interface (i.e. hydraulic interface unit) in heat networks – Currently being driven by other leading markets (e.g. Northern Europe)

It is important to note that even in these areas, a lack of UK activity would probably have a negative effect on competitive advantage, and the ability to create new business opportunities. Moreover, there is always a risk that delays to progress in other countries (owing to a weakened commitment to tackling climate change, budgetary cut backs, or problems with public acceptance and local planning) could make such reliance costly to the UK. Nevertheless, the UK should avoid replicating work likely to be well advanced in other countries without strong justification.

In additional areas, the UK could rely in part 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. And once again, a lack of UK activity would probably have a negative effect on competitive advantage, and the ability to create new business opportunities. These areas are:

- Advanced heat storage materials – Activity exists overseas, but it is not clear that it will develop at a pace commensurate with the UK's deployment need
- Interseasonal heat stores – Activity exists overseas, but it may not be optimally suited to UK conditions
- Heat network installation and connection technologies – Activity exists overseas, but it may not be optimally suited to UK conditions
- Heat pump, network, and storage controls – Activity exists overseas, but it may not be optimally suited to UK conditions

In a final set of areas, the UK has specific application needs which mean that achieving value to the UK is likely to require UK led efforts:

- Design of heat networks and large-scale heat storage – Innovation improvements will need to be fully integrated with unique UK built environment and energy system arrangements
- Design and installation of heat pump and/or daily storage systems – Innovation improvements will need to be appropriate for UK buildings, and transferable to the UK supply chain

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) that meet the innovation needs. The LCICG has identified a set of prioritised innovation areas.

Innovation areas with the biggest relative benefit from UK supported activity/investments

The LCICG has identified the technology and sub-system/component areas with the highest potential benefit from UK public sector activity/investment in innovation (Chart 13)[11].

These areas have been prioritised according to the following criteria:

- value in meeting emissions targets at lowest cost
- value in business creation
- extent of market failure
- opportunity to rely on another country

The highest priorities are improvements in the design and installation of heat pumps, and in the design and installation of heat networks, where there is high value potential, critical market failures and low ability to rely on others. The next priorities are improved heat pump technologies (driven by the large value potential), the development of advanced daily heat stores, and various developments related to interseasonal heat storage (both of which are driven by value potential and the criticality of the market failures).

Existing innovation support

Most UK activity is through project-based funding to project-specific partners, generally companies and universities/research institutes. Various publicly funded entities drive UK support for RD&D in heat, with different area of focus: The Department of Energy and Climate Change, the Energy Technologies Institute, the Technology Strategy Board, and the Research Councils (the latter three funded through the Department of Business, Innovation and Skills).

DECC and the TSB have led various projects focussed on heat pumps:

- DECC has an on-going programme of field trials in conjunction with the Energy Savings Trust, focussed primarily on understanding the in-use performance of domestic heat pumps, and identifying the key improvement areas
- The TBS Retrofit fit for the Future programme has supported projects related to improved design and installation methods with some relevance to domestic heat pumps

ETI, EPSRC and UKERC have led research programmes related to heat storage:

- ETI has led a feasibility study on large-scale thermal storage (aquifers) from waste heat
- EPSRC has funded a range of R&D projects into advanced thermal storage technologies
- UKERC has led more overarching research into the potential use of thermal storage in the energy system at different scales

Potential priorities for public sector innovation support

In the sections above, we identified the areas of innovation with the highest potential benefit from UK public sector activity/investment, and looked at the breadth of existing UK support. These point to a number of priorities areas for potential public sector activity/investment by technology area (see Chart 14). Many priority areas group naturally together into two large programme areas, where significant synergies exists:

1. Heat pump demonstrations (at varying scales) that include the development of improved design and installation, whether standalone or integrated with (advanced) daily heat storage, and offer potential platforms for the trialling of improved heat pump components (e.g. controls) and advanced storage materials
2. Large scale demonstration project(s) for heat networks in combination with alternative (low-emission) generation sources and/or integrated with large-scale heat storage, with the potential to also serve as a platform for the development of improved design and installation methods, as well as improved heat store and extraction technologies

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

Chart 13. Benefit of UK public sector activity/investment by sub-area and technology type

Category	Energy system value (£bn)	Business creation value (£bn)	Can We Rely On Someone Else	Market failure	Innovation Priority Area?
Heat pumps					
Design, installation, O&M	9.5 (5.1 - 17.7)	Non-tradable	No	Critical	High
Controls	1.3 (0.7 - 2.4)	0.5 (0.2 - 0.8)	In part	Moderate	Low-Medium
Heat pump technology	10.3 (5.5 - 19.1)	2.2 (1.0 - 3.7)	Yes	Moderate	Medium
Total:	***21.1 (11.4 – 39.3)***	***2.6 (1.2 – 4.5)***			
Heat networks					
Design, installation, O&M	3.6 (1.3 - 9.8)	0.1 (0.04 - 0.3)	No	Critical	Medium-High
Controls	0.6 (0.2 - 1.6)	0.1 (0.02 - 0.2)	In part	Moderate	Low-Medium
Interface with user	1.3 (0.5 - 3.6)	0.1 (0.05 - 0.4)	Yes	Moderate	Low
Connection to user	-	0.4 (0.2 – 1.1)	In part	Moderate	Low
Total:	***5.5 (2.2 – 15.0)***	***0.7 (0.3 – 2.0)***			
Advanced daily storage					
Heat store	1.4 (0.1 - 6.7)	1.4 (0.3 - 4.3)	In part	Critical	Medium
Total:	***1.4 (0.1 – 6.8)***	***1.4 (0.3 – 4.3)***			
Interseasonal storage					
Heat store and extraction	0.8 (0.2 - 2.5)	0.3 (0.1 - 1.1)	In part	Critical	Medium
Design, installation and controls	0.7 (0.2 - 2.2)	0.1 (0.0 - 0.3)	No	Critical	Medium
Total:	***1.5 (0.4 – 4.8)***	***0.4 (0.1 – 1.4)***			

Chart 14. Potential heat innovation priorities and support

	Potential innovation priorities	Indicative scale of public funding (£)[1]	Current activities/investments	Future potential activities
Heat Pumps				
▪ Key components / processes improvements	▪ Components and processes adapted to UK environment	▪ Millions	▪ None	R&D and early demo of key components / processes: ▪ Design / installation processes, and grid integration ▪ Control philosophy and monitoring methods ▪ Novel heat pump technology improvements
▪ Domestic heat pumps	▪ Scalable approach to heat pump installation	▪ Low tens of millions	▪ DECC/EST field trials ▪ TSB Retrofit for the Future	▪ Large scale domestic sector demonstrations to test design and installation solutions (arising from early trials) and refine requirements for market roll-out
▪ Service sector heat pumps	▪ Understand current in-use performance and identify innovation needs	▪ High millions	▪ None	▪ Small scale service sector demonstration to evaluate current performance and check applicability of learning from domestic sector
Heat Networks				
▪ Design and installation	▪ Tools to maximise efficiency and accuracy of measurement of a "neighbourhood" characteristics and building's interior to optimise design of heat system ▪ Development of cheaper installation methods suitable to UK built environment	▪ Millions	▪ None	▪ Development and demonstration of tools, potentially in combination with planned *commercial* heat network projects, or else in combination with large scale demos (see below)
▪ Integration of heating systems	▪ Integrating heat networks with alternative generation sources (e.g. large scale heat pumps or solar thermal) ▪ Integrating heat networks / waste heat recovery with large scale storage	▪ High tens of millions (per project)	▪ ETI feasibility study	▪ Large-scale demonstration projects to prove viability (and better understand system benefits) of key functionality for advanced heat network capabilities, including integration of large-scale heat storage and/or the use of low-emission heat sources ▪ *Include feedback into energy system modelling initiatives to better understand transition of heat and other energy systems*
Heat Storage				
▪ Design and O&M for daily heat storage	▪ Prove viability of integrated daily storage with heat pumps, and identify innovation needs	▪ High millions to low tens of millions	▪ None	▪ Small scale demonstration of integrated systems (potentially using advanced heat stores) to optimise performance of thermal storage and heat pumps
▪ Advanced daily heat/cold store	▪ Development and cost reductions in advanced storage materials	▪ Millions	▪ EPSRC sponsored R&D projects	▪ R&D to achieve cost reductions and key performance developments, e.g. increase stability, rate of heat exchange
▪ Interseasonal heat store and extraction	▪ Development and cost reductions in interseasonal 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

Source: Expert interviews, Carbon Trust analysis

[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.

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