energy technologies institute

UK NETWORKS TRANSITION CHALLENGES

Heat

An insights report from the Energy Technologies Institute

Contents

INTRODUCTION

Any move to a low carbon UK energy system that uses new and more varied sources of energy generation will require investment and an upgrade of the current energy network infrastructure.

At ETI we see there are three key challenges to transitioning UK networks for a wider adoption of low carbon sources. These are:

1. A need to adapt and enhance the existing network infrastructure to absorb new forms of energy generation.
2. The creation of efficient and effective new network infrastructure to deliver new forms of energy generation.
3. The integration of energy networks so the UK can optimise the use and performance of energy generated across a number of different energy vectors, effectively and efficiently.

Our analysis in this area has pointed to the fact that we see there is real value in the UK employing a multi-vector approach to its energy supply, both from the perspective of transitioning to a low carbon energy system, but also in a manner that is convenient and affordable to the end consumer.

To make this a reality whole energy system thinking is critical. Analysing the interactions between networks (as well as with the wider energy system) and how today's network infrastructure will influence the infrastructure that will be needed in the future is central to this because the challenge is one of knowing where, when and to what extent to enhance the network.

Today, current governance and regulatory frameworks are simply not designed to enable and incentivise the radical transformation that will be needed to move to a low carbon solution.

Against this backdrop, the ETI recommends the following actions should be taken to effectively transition to a low carbon energy system with a network infrastructure that delivers for future generations.

1. The UK should incentivise and target investment to allow it to adapt and enhance existing networks.
2. Alongside this the UK needs to make clear decisions upon what and where they want new networks to operate and invest in them accordingly.
3. The UK should design network infrastructures to ensure that they work together efficiently across multiple vectors in real time – providing an economic and consumer solution to the delivery of low carbon energy.

Whilst we advocate the systems-wide approach, this insight report looks in more detail at the challenges faced in the UK in delivering extensive deployment of efficient and effective heat network infrastructure to provide a low carbon solution and allowing heat networks to form a strong component of a multi-vector approach to UK energy infrastructure.

INTRODUCTION
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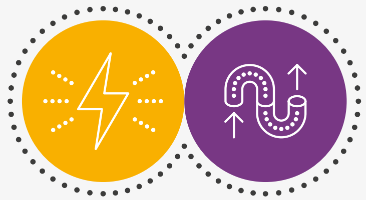
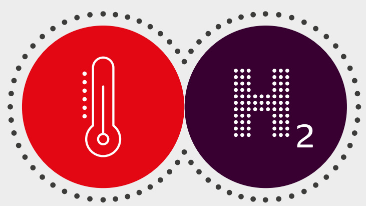
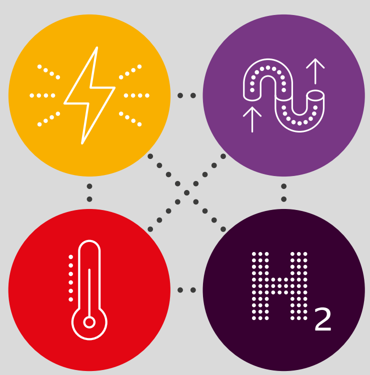
Challenge one
Adapting and enhancing existing network infrastructures



Challenge two
Enabling creation of efficient and effective new network infrastructures



Challenge three
Integrating new and existing networks to enable optimisation across vectors



HEAT NETWORKS, WHERE ARE WE NOW?

There are roughly 2000 heat networks in the UK; however, this remains a niche means of providing heating to homes and other buildings, serving less than 2% of UK domestic demand. The largest networks are in Nottingham and Sheffield but these are each less than 100km in total length and serve only a small fraction of their respective city's heat needs. Heat networks are more widespread in a number of other countries (e.g. Denmark, Finland and Sweden); a mixture of cultural, climatic and economic reasons driving their adoption there. The decisions to pursue heat networks in these countries have been reinforced through a mixture of government support, community ownership models and taxation on alternatives such as gas.

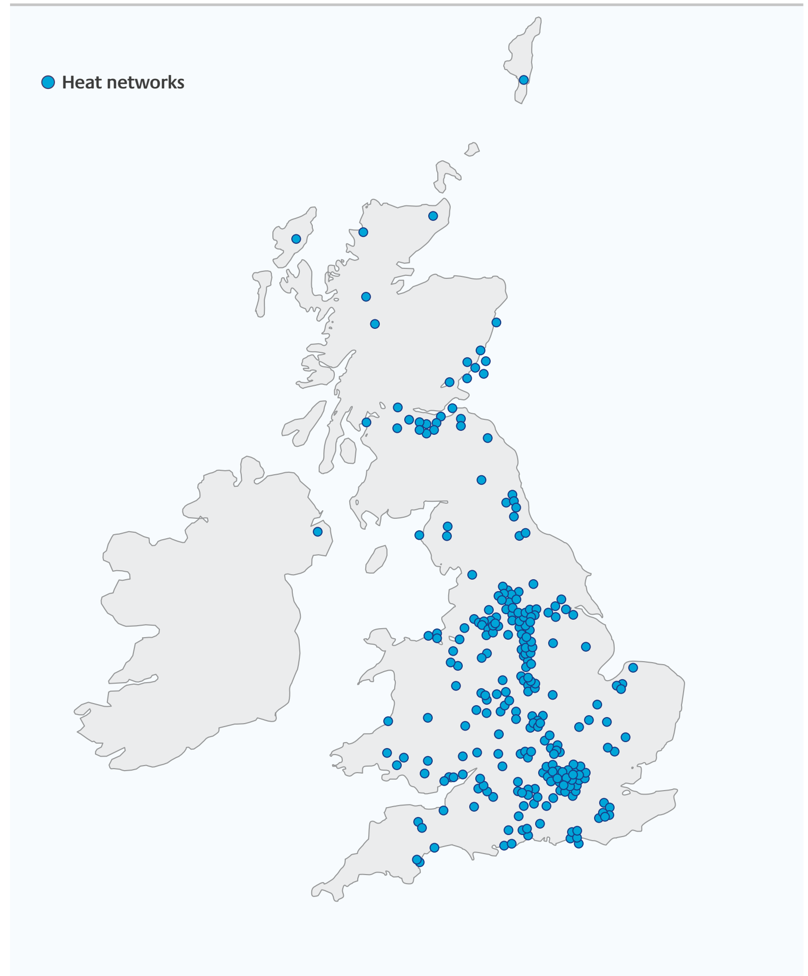
By contrast, the dominance of gas in the UK, following the large-scale investments in the infrastructure to support it and the UK's historically low costs of gas supply, has proved a barrier for heat networks to date. With gas established as the major incumbent technology in the UK, heat networks will need a particularly compelling proposition (e.g. offer more comfort, a better value proposition or be mandated) before consumers can be expected to adopt them ahead of gas boilers. This situation has been exacerbated by poor experiences of some of the heat networks built in the latter decades of the 20th century. These are by no means pervasive and modern examples, in particular, (such as those at the former Olympic Park and the Bunhill development in Islington) have proved that heat networks remain a viable option for the UK.

Those that do exist almost exclusively serve urban areas, to which they are well suited. Their ability to carry large amounts of heat means they can cater to high heat loads. They are limited in their ability to serve more rural areas due to the relatively high costs of the networks themselves, making them more suited to loads in close proximity. Depending on their heat source they can also respond to high variability in demand, such as buildings which experience large changes in demand or those that are less able to retain their heat (currently the bulk of UK housing stock).

The majority of heat networks are currently fed by gas-fuelled combined heat and power (CHP) systems and/or large-scale boilers (fuelled by gas or sometimes biomass), typically located within, or close to, the area that is being served. These are normally designed to take their heat from the CHP system with the boiler acting as a backup or supporting when loads are too high for the CHP system to meet on its own.

A facet of heat networks is that they are capable of being served by a multitude of heat sources, so they are also not limited to the heat source they were initially connected to. As well as gas-fuelled sources, the heat supply can come from biomass, waste incineration, large-scale heat pumps (land or marine), geothermal sources, or waste heat from other sources (e.g. industry or power). As with electricity, the carbon intensity of heat supply for heat networks is ultimately a factor of the heat source. Deployment of heat networks needs to be consistent with long-term decarbonisation goals which means that even if they start off supplied by gas, low carbon alternatives and how they can be incorporated over the life of the heat network, need to be considered from the outset.

Figure 1
Locations of existing heat networks in the UK[1]



1 Recreated using data supplied by DECC (2012)

HOW MIGHT THINGS CHANGE?

In this report we have used the ETI's published scenarios, which illustrate how the wider energy system might evolve, as a basis for exploring how we might need to invest in heat networks. The scenarios themselves have been developed from extensive analysis of the overall energy system and how it might have to develop out to 2050 in order to meet the UK's greenhouse gas emissions targets. The underlying analysis covers, amongst other things: how technologies might develop; how they would need to interact with each other as part of an overall energy system; practical roll-out timeframes for those technologies; potential constraints on energy resources; operational constraints and, not least, changes in energy demands and customer expectations.

Two scenarios are depicted which offer contrasting pictures of the UK energy system evolution to 2050. These are referred to as **clockwork** and **patchwork** and are plausible and self-consistent examples of how the energy system might evolve to meet the UK's 2050 greenhouse gas emissions targets. They are not forecasts but portray distinct (yet not exhaustive) ways in which heat networks could need to be developed, offering a means to explore a range of challenges that they might face.

Clockwork	Patchwork
Large-scale heat networks are deployed across urban and suburban areas, in line with a national strategic plan to transition the heating sector.	Local schemes drive the deployment of small and medium-scale heat networks in urban areas on an ad-hoc basis. Some adjacent networks merge.
From 2020 heat network deployment more than doubles every decade.	Over time heat networks adapt to accommodate changes to heat supply type and, in some instances, location.
These networks connect to both centralised and distributed power stations for heat supply.	Gas-fuelled combined heat and power (CHP) is the initial heat source of choice alongside biomass for commercial applications.
Heat offtake from some large-scale power stations is transmitted over long distances (up to 30km) to reach demand centres.	The emergence of viable smart energy solutions and changes to network regulations in the 2020s and 2030s allows excess electricity from these CHP systems to indirectly support heat pump deployment in rural areas.
Small modular reactors may offer an alternative heat source in other locations, particularly where heat demand is lower[2].	The evolution of smart energy solutions to optimise energy supply across networks accelerates the deployment of heat networks.
Heat network and power station deployment is coordinated to meet investment requirements (power station deployment in turn aligns with wider growth in electricity demand).	By 2040 efforts to decarbonise further lead to the integration of lower carbon forms of heat supply appropriate to each local area, including large-scale marine heat pumps (powered by a now even more decarbonised electricity network) and advanced geothermal systems.
By 2050 about one-third of all heat in the UK (over 110TWh) is delivered by heat networks.	Heat networks continue to grow and by 2050 over 50TWh of heat is delivered by heat networks a year.

2 Middleton, M. (2015). The role for nuclear within a low carbon energy system. [online]. Available at: http://www.eti.co.uk/insights/the-role-for-nuclear-within-a-low-carbon-energy-system

HOW MIGHT THINGS CHANGE?

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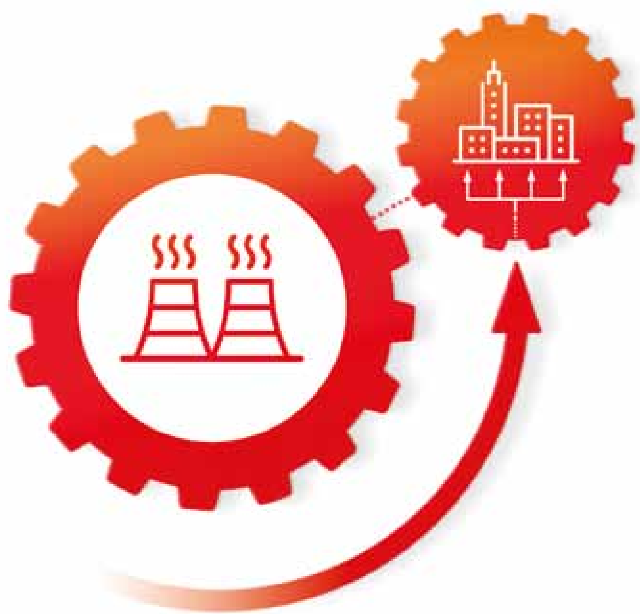


CLOCKWORK

The national strategic plan for the transition of the heat sector in the clockwork scenario requires large-scale heat networks to be deployed in cities and towns, replacing the gas distribution system in these areas, over a period of decades. Significantly, heat for these is supplied from thermal power generation, through both large-scale centralised plants and smaller scale and more distributed plants[3]. In many instances, this requires transmission of heat over relatively long distances (sometimes up to 30km)[4] to connect the power stations to the heat networks.

PATCHWORK

In patchwork, local initiatives drive switchover of heat supply requiring deployment of small and medium-scale heat networks in those towns and cities. Many of these are initially supplied by gas-fuelled CHP. Over time, these networks need to adapt; merging and expanding where the opportunity arises and/or integrating alternative lower carbon forms of heat supply, appropriate to the local area, including large-scale marine heat pumps, and advanced geothermal systems.

3/4 Middleton, M. (2015). The role for nuclear within a low carbon energy system. [online]. Available at: http://www.eti.co.uk/insights/the-role-for-nuclear-within-a-low-carbon-energy-system

WHAT DOES THIS MEAN FOR HEAT NETWORKS?

UK consumers have relatively little experience of heat networks (and not all of that is positive) and are reasonably happy with the status quo (mainly gas boilers) but if heating is to be decarbonised then heat networks will need to develop and grow from serving less than 2% of domestic demand to potentially almost half by 2050. Unlike electricity and gas networks these are not well established networks in the UK. Adding to this challenge is that the majority of heat networks being installed or planned to be installed are for new housing developments.

The greatest potential for heat networks (and where there are fewest alternative viable low carbon options) lies in connecting existing properties, notably in towns and cities, particularly where the properties have high heat demands and there is limited opportunity for those properties to be made more efficient. Installing heat networks to connect existing buildings (as opposed to new developments) presents additional challenges, not least negotiating these already crowded and heavily populated areas and the cost this incurs. In addition to property types, decisions about exactly where to deploy heat networks will need to take account of factors such as local geography, the state of other energy networks in the area that could help to meet heating needs, wider energy system development (including both energy cost and carbon intensity), and customer acceptance. Critically, heat networks will need to be cost-competitive with the alternatives, as well as ensuring efficient heat delivery and being an effective part of an appealing consumer proposition[5 6]. At present the prevalence of the gas network and effectiveness of gas at meeting heating needs is a major barrier to heat network deployment.

ETI Project:
Macro Distributed Energy

This project quantified the opportunity for Macro level Distributed Energy (DE) across the UK. It studied energy demand such as residential accommodation, local services, hospitals, business parks and equipment, and developed a software methodology to analyse local combinations of sites and technologies. A number of technology development and demonstration opportunities were identified.

The findings from this project are now being distilled into our Energy Storage and Distribution and Smart Systems and Heat programmes.

5 Douglas, J. (2015). Decarbonising Heat for UK Homes. [online]. Available at: http://www.eti.co.uk/insights/heat-insight-decarbonising-heat-for-uk-homes

6 Lipson, M. (2015). Consumer challenges for low carbon heat. [online]. Available at: http://www.eti.co.uk/insights/smart-systems-and-heat-consumer-challenges-for-low-carbon-heat

Cost reduction and technology advancement

ETI analysis indicates heat networks would already be cost-competitive replacement heating solutions in some places[7]. Reducing their cost, however, will be necessary to increase the number of those locations. A significant proportion of their overall cost is down to the upfront capital cost and in particular the installation of the pipework. Whilst current approaches, technologies and costs are manageable for a limited number of locations, for mass roll-out of this technology to be realised in the UK, steps will need to be taken towards greater industrialisation to lower costs. This might include identifying and developing advanced installation approaches to, for example, reduce waste. Reducing disruption above ground, especially to traffic, is also an important opportunity.

Increasingly, local authorities are recognising this as an unwelcome cost and in some cases are putting in place measures to penalise undue disruption. Improving civil engineering practices and excavation techniques in support of this further enhances the opportunity, particularly where this can increase the speed or precision of the process. This can be aided by measures to examine what lies below the surface, both to understand the near surface geology and the existing services that reside there. New materials are another area of opportunity and could also offer benefits elsewhere within the district heat system, e.g. by allowing installation approaches to be used that would not otherwise be possible or by reducing heat losses. More cost-effective routing and connection options for the piping systems can help to reduce waste both in terms of materials and time. The logistics of switching over from incumbent energy supplies, especially gas supply (as electricity supplies to homes would still need to be retained), is also another area that could be improved.

Figure 2
ETI analysis of areas offering the potential to reduce the cost of heat networks

Advanced installation approaches
- Reducing waste, effort, errors
- Utilising greater automation
- Reducing in-trench welding

Reduced above ground disruption
- Utilising tunnelling methods
- Employing advance planning and sequencing approaches

Improved excavation
- Accelerating the process and reducing delays
- Increasing precision
- Reducing labour costs

Sub-surface detection
- Locating existing buried services
- Assessing deeper geology prior to excavation
- Monitoring of buried services

Alternative materials
- Aiding installation
- Avoiding in-trench welding
- Increasing system efficiency

Improved routing
- Combining connections
- Utilising advanced modelling and analysis tools

7 Macro DE project. ETI funded project delivered by Caterpillar, EDF, The University of Manchester and MKN. (2012).

WHAT DOES THIS MEAN FOR HEAT NETWORKS?

Continued ›

Advances in each of these areas will need to be robustly evaluated to understand how much impact they can deliver given the variety of locations heat networks could be deployed in. Once it has been established which are the most promising, then it will also be necessary to develop the technologies and approaches for use in the field.

Reducing the underlying cost of deployment and increasing the certainty of that cost, has the added benefit of reducing risk for investors. This in turn offers the prospect of lower finance costs for developers or whichever organisation procures the heat network, delivering a compound benefit.

ETI Project:
Heat Infrastructure Development

This project is seeking to identify the innovative solutions needed to deliver major reductions in the capital cost of heat network infrastructure and accelerate its deployment.

Examining the technical, process and system developments needed to deliver a step change reduction in the capital costs, along with cost estimates and timeframes for undertaking these developments.

Supply chain scale-up

An industry supply chain will need to be developed and scaled up to meet market requirements. This would need to enable growth in heat networks from serving less than 2% to as much as 40% of home heating needs by 2050. This increased level of deployment would need to be delivered in less time than the existing level of deployment was reached (i.e. around 50 years[8]).

Technology and process advances should help, providing the adopted solutions are scalable. It will also be necessary for the industrial supply chain to be proficient with the advances that are developed and to be at a sufficient level of maturity to deliver this reliably.

There will need to be a sufficiently large supply chain, including design, manufacturing, equipment, logistics and skilled people on the ground to ensure overall deployment targets are met. This both represents a challenge and an enormous market opportunity.

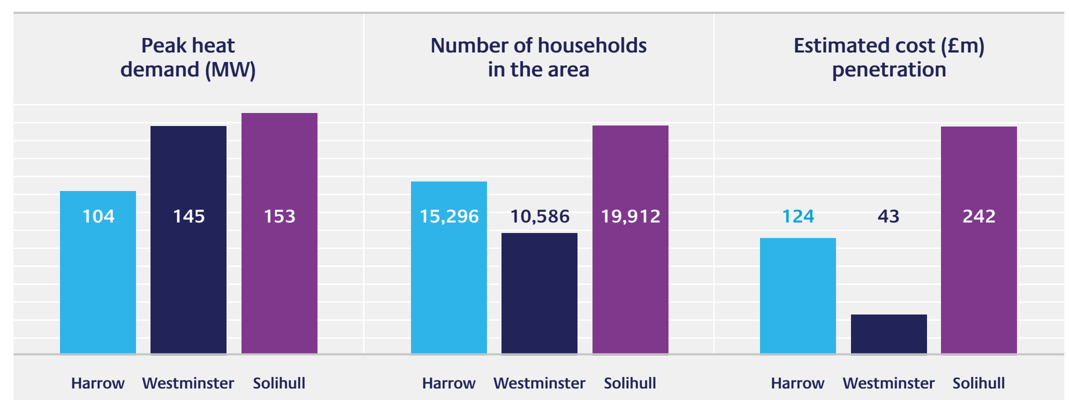
The early part of any roll-out will inevitably be slower but will allow the supply chain to develop and stakeholders to become familiar with both the technology and the processes. Early experiences will shape the perception and future potential market share of heat networks.

Adoption

The economics of heat networks mean that they are more cost-effective the more properties they can connect to for a given pipe length – hence being more suited to denser urban areas than very dispersed areas. Figure 3 offers examples of heat network layouts for three different locations, illustrating how designs can vary based on local conditions. As might be expected, the costs of these networks would also vary markedly, despite comparable peak heat demands and numbers of households (see Figure 4).

Figure 3
Heat network designs for three characteristic UK locations, generated as part of the ETI's Macro DE project[9]

Figure 4
Heat network designs for three characteristic UK locations, generated as part of the ETI's Macro DE project[10]



8 Department of Energy and Climate Change. (2015). Delivering UK Energy Investment: Networks

9/10 Macro Distributed Energy project. ETI funded project delivered by Caterpillar, EDF, The University of Manchester and MKN. (2012).

WHAT DOES THIS MEAN FOR HEAT NETWORKS?

Continued ›

Another aspect of this is if a heat network is deployed in a given area it will be important to connect up as many properties in that area as possible for it to be most cost-effective (see Figure 5). How this is achieved will in part depend on the reasoning behind the deployment of the heat network and the alternative options (if any) available to those who live within the area. Consumer acceptance will be a factor in this. Building confidence in the capability of the system and being able to properly integrate this heat supply solution into broader value offerings will be critical[11].

Figure 5

Estimated capex savings per household from connecting 100% of properties in the three areas shown in Figure 3 versus connecting 80% of properties

Allied to this will be how the level of competition between energy suppliers is viewed. In part this will depend on the regulatory position that emerges and as it stands there is limited regulation in relation to heat networks. Consumers typically have a long-term (multi-year) contract with the energy service company (ESCo) who is in charge of managing the network and its supply. Unlike with electricity and gas networks there is currently no opportunity to switch to an alternative supplier. The small size of current heat networks in the UK makes it less feasible to operate with multiple suppliers. Whether heat networks reach sufficient size and, for example, have sufficient diversity of heat sources to make this more feasible remains to be seen. This clearly raises competition and monopoly questions. How this is dealt with will have a critical effect on the success of heat networks. A delicate balance will need to be struck that both ensures consumer interests are met and provides the opportunity for the sector to grow sustainably. It will be important that regulators do not act too quickly to impose restrictions that might limit innovation and stymie growth in the sector. This is particularly acute given the wide range of areas for technological and process development that could emerge.

11 Lipson, M. (2015). Consumer challenges for low carbon heat. [online]. Available at: http://www.eti.co.uk/insights/smart-systems-and-heat-consumer-challenges-for-low-carbon-heat

INTEGRATING WITH THE WIDER ENERGY SYSTEM

It is clear that heat networks could provide important benefits in terms of decarbonisation and long-term fuel source flexibility. As such, it will be imperative that the opportunity to integrate future lower carbon fuel sources is maximised. This will need to be considered in the construction of the heat network and energy centres and in the design of the market and policy frameworks that will influence longer-term decisions. For example, appropriate signals about both local developments and wider energy system evolution, e.g. longer-term decarbonisation of the electricity network and the availability of recoverable heat, would be expected to facilitate this.

Regulatory and market structures will play a part in how the range of energy sources a heat network can draw upon will be utilised. It will be important that frameworks around this are constructed to encourage sustainable and economic use of fuel sources, whilst also maximising the long-term emissions benefits that heat networks can bring. There will also be effects from and on electricity and gas markets. This will need to be accounted for in the design of the frameworks.

Interactions with the electricity network

Heat networks fed from combined heat and power (CHP) sources will, by their nature, produce electricity. In meeting heating needs, the amount of electricity produced, however, would far exceed local electricity demand. For the electricity to be cost-effectively utilised a concurrent electrical demand elsewhere would be required. With sufficient electrified heating (e.g. through heat pumps) there is the likelihood that such an electrical demand would occur over the same periods[12]. Viewing the need to meet electrified heating demands from an electricity-only perspective would place significant emphasis on investing in and building sufficient seasonal and peaking generation capacity. Taking a broader system perspective, however, highlights the opportunity for surplus and timely electricity from CHP systems, to offset the need for additional generation capacity.

With sufficiently decarbonised electricity there is the potential, in some locations, for technologies such as large-scale marine heat pumps to produce the heat for heat networks. The viability of this will depend on both the cost-effectiveness of the heat pumps by that point and there being sufficient electricity generation capacity. It will also require there to be sufficient capacity in the local electricity network to supply the heat pumps at the coldest times of the year.

12 The size and climate of the UK mean that heat demands across the country broadly occur at the same time of day and year.

ETI Project:
Multi-Vector Integration

This project aims to understand the opportunity for, and implications of moving to, more integrated multi-vector networks. This will include:

- Identifying the ways in which different networks could interact, e.g. one network providing peak capacity support for another;
- Determining how prominent these interdependencies could be;
- Examining what the effects on each of the networks would be; and
- Identifying any technology and/or operational opportunities that would facilitate any increased integration between vectors that may emerge

future networks

ETI Project:
Enabling Efficient Low Carbon Networks

This project will build an understanding of options for reforming governance, market and regulatory arrangements to enable efficient investment in low carbon energy network infrastructures

This report is available online as a downloadable PDF: http://www.eti.co.uk/library/enabling-efficient-networks-for-low-carbon-futures

future networks

Interactions with the gas network

In becoming a major heating solution, heat networks would both displace and potentially rely on gas.

The most promising locations for the deployment of heat networks are in locations where gas is currently the dominant means of supplying heat. In replacing the gas supply to premises, the installation of heat networks would require any existing gas network connections to those premises to be decommissioned. The logistics of switching over from one supply to another will need to be managed to ensure occupants do not suffer a loss of required service.

Whilst the deployment of heat networks would require the gas network connections to premises to be decommissioned, in circumstances where gas CHP is the heating source for the heat network, a portion of the gas network would still be required to supply the CHP systems. Gas CHP fuelled heat networks are a valuable means for reducing CO_2 emissions over the coming decades. In order to meet 2050 emissions targets, however, it is likely that these systems would need to be replaced or supplemented by lower carbon options. If replaced entirely this would then require the previously retained portion of the gas network to also be decommissioned.

INTEGRATING WITH THE WIDER ENERGY SYSTEM
Continued ›

Interactions between heat networks

Consideration around wider energy system developments may also need to take account of developments in relation to adjacent heat networks and, in particular, the opportunity to integrate these as they grow. Conversely, under a more centrally coordinated heat network programme, challenges lie in the development of heat transmission lines to connect up to thermal power stations.

Interactions with power generation

Connecting up to thermal power stations would require joint identification of suitable power stations, accompanying heat demand locations (see figure 6) and the pipeline routes that would connect them.

This may be more feasible for some types of plants than others. Small modular nuclear reactors (SMRs), for example, could be easier to connect up than large nuclear or CCS-connected power stations, though all are plausible. SMRs have the potential to be deployed at more sites possibly closer to towns or cities (see Figure 7), and also have lower heat output so are more suited to smaller towns[13]. Both of these factors reduce the need for long heat transmission lines.

Delivering these types of solutions would require the development of market, policy, regulatory and business model frameworks to enable power generation to be developed in line with heat networks and ensure the effective operation of both.

ETI Project:
Energypath Networks

A software tool to design cost-effective local energy systems for the UK.

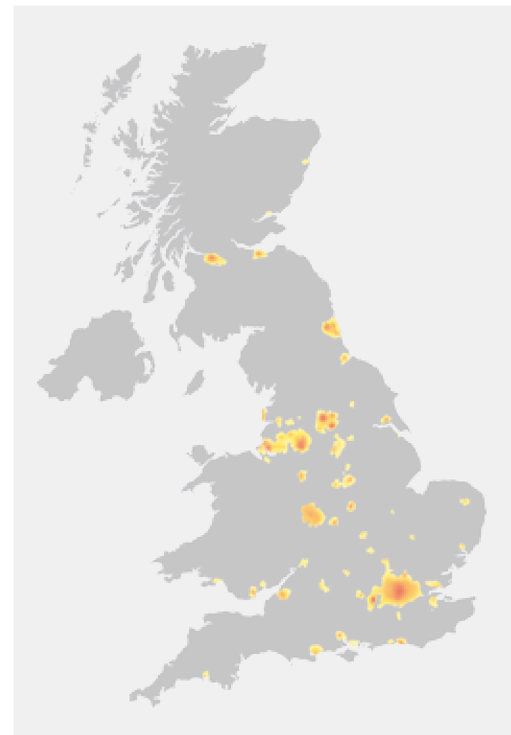
Designed in partnership with local authorities.

Demonstrating the capability to create future-proof and economic local heating solutions for the UK.

ETI Project:
System Requirements for Alternative Nuclear Technologies

This project captured high-level technical performance characteristics and business-case parameters for small modular reactors. It compared these characteristics with other technologies capable of providing power and/or heat. This project and the data created has been used to determine the potential value of SMRs to the future UK energy system.

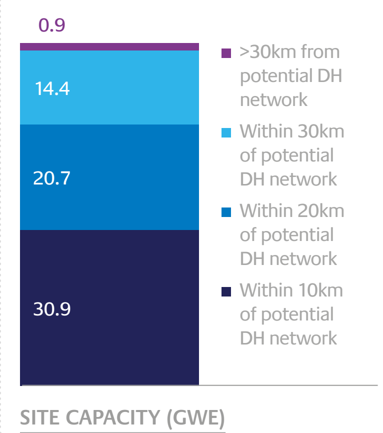
Figure 6
Areas in the UK where heat networks energised by 100MWe SMRs could potentially be deployed[14]



ETI Project:
Power Plant Siting Study

This research project considered the impact of siting constraints on the location of new low carbon nuclear and fossil-fuelled power stations.

Figure 7
Distance of potential SMR capacity (identified in Power Plant Siting Study[15]) to respective local district heat networks (identified in the Alternative Nuclear Technologies project[16])



13 Middleton, M. (2015). The role for nuclear within a low carbon energy system. [online]. Available at: http://www.eti.co.uk/insights/the-role-for-nuclear-within-a-low-carbon-energy-system

14/16 System Requirements for Alternative Nuclear Technologies. ETI funded project delivered by Mott MacDonald. (2015).

15 Power Plant Siting Study. ETI funded project delivered by Atkins. (2015).

SUMMARY

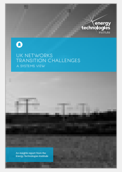
Heat networks have the potential to deliver low carbon heat to a significant proportion of homes and businesses that would be difficult to decarbonise by other means. Doing so requires the creation of new network infrastructure. For this to be effective, deployment will need to be targeted to suitable areas, catering predominantly to existing buildings in denser areas. This is a shift in focus for the heat network industry much of which is set up to serve new developments.

Several key challenges need to be addressed: reducing the cost of heat networks (particularly the upfront cost of procuring and installing heat networks) through technology and process advances; building a supply chain to significantly increase deployment (reaching as much as 20x current levels, in a shorter time than current levels were reached); and encouraging adoption amongst industry and consumers. Transitioning large proportions of UK heat demand over to heat networks will also require managing interactions between other parts of the energy system which, depending on the approach taken, could involve electricity networks, gas networks, other heat networks and the power generation sector.

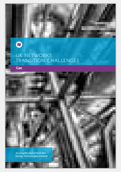
Delivering this will require market and regulatory arrangements that:

- Enable clear decision-making and incentivise investment to create efficiently configured heat networks;
- Encourage (or even mandate) adoption amongst customers;
- Ensure technology and process advances are compatible with the qualities of heat networks (notably the ability to deliver large quantities of heat, long-asset life and fuel source flexibility) that contribute to making them a compelling proposition.
- Deliver effective management of the changeover of heat supply networks and systems; and
- Ensure that network infrastructures are designed and work together efficiently across vectors in real time.

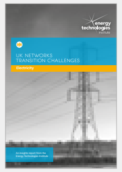
FURTHER READING



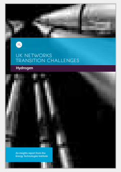
UK Networks Transition Challenges – A systems view
http://www.eti.co.uk/insights/network-transitions



UK Networks Transition Challenges – Gas
http://www.eti.co.uk/insights/network-gas



UK Networks Transition Challenges – Electricity
http://www.eti.co.uk/insights/network-electricity



UK Networks Transition Challenges – Hydrogen
http://www.eti.co.uk/insights/network-hydrogen

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