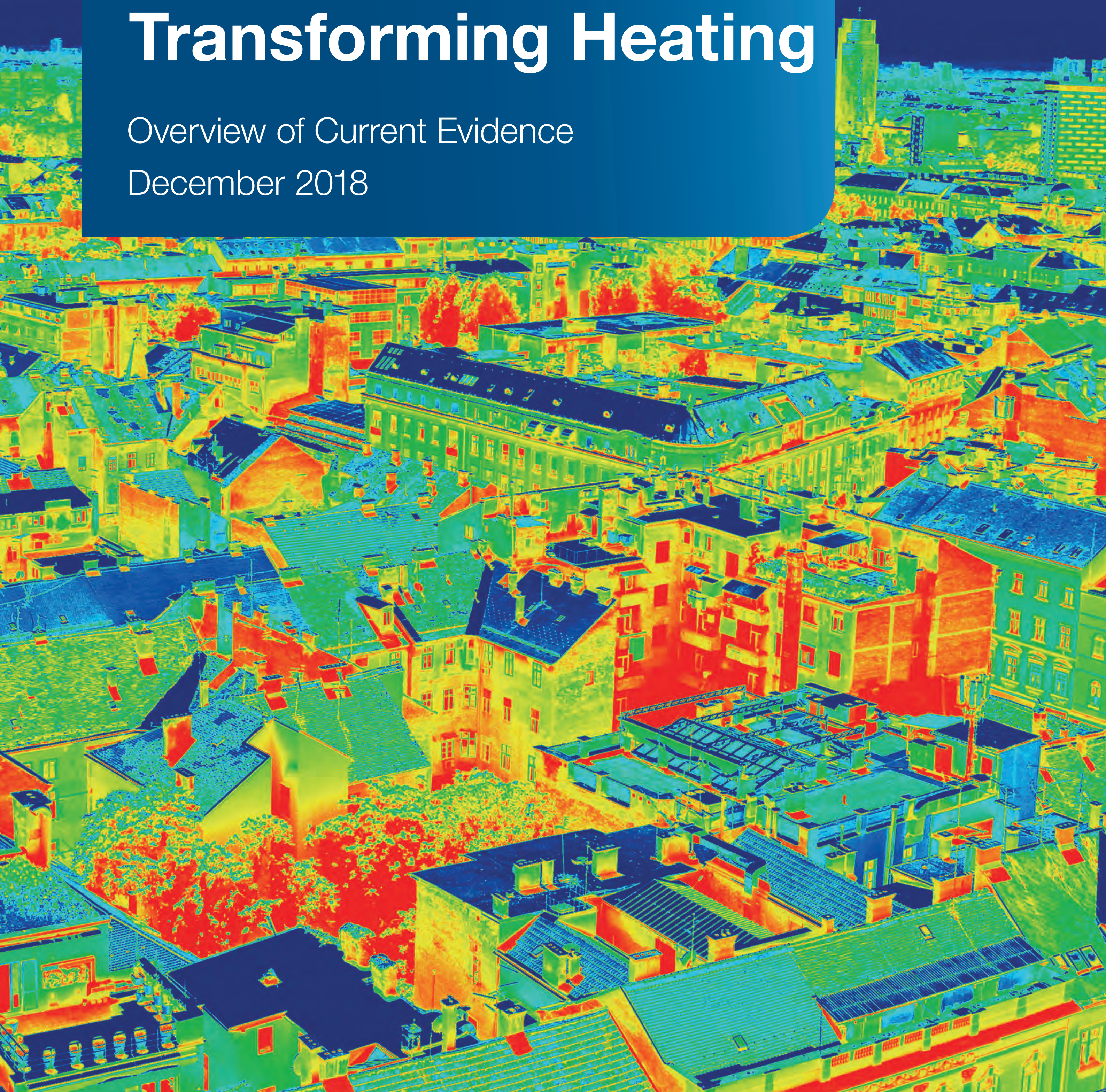
Department for
Business, Energy
& Industrial Strategy

Clean Growth - Transforming Heating

Overview of Current Evidence

December 2018



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1. Executive Summary

Introduction

1.1 Heating is central to our lives. In our homes, we rely on it for comfort, cooking and washing. Businesses need heating and cooling for productive workplaces and heat is integral to many industrial processes. It is the biggest reason we consume energy in our society.

1.2 Heat accounts for over a third of the UK's greenhouse gas emissions. Under the Climate Change Act 2008, the Government has committed to reducing annual greenhouse gas emissions by at least 80% by 2050 and has recently sought advice from the Committee on Climate Change as to when the UK should achieve net zero emissions across the economy. Meeting our existing Climate Change Act commitments will require decarbonising nearly all heat in buildings and most industrial processes. If we fall short of this, deeper emissions reductions will need to be made in sectors that may prove less cost-effective to decarbonise, such as agriculture.

1.3 Over recent years, lower carbon technologies have provided an increasing proportion of our nation's heating. Electric heat pumps and biomass boilers are used in many homes and businesses and increasing volumes of biomethane are blended with natural gas in the gas grid. Meanwhile a substantial number of customers, particularly in premises off the gas grid, continue to use direct electric heating systems which have become cleaner as the power sector continues to decarbonise.

1.4 However, heating remains the largest source of our greenhouse gas emissions. Most of the heating in our buildings and industries is delivered by fossil fuels; natural gas remains the predominant source of heating for the vast majority of customers connected to the grid. The prevalence of the gas grid presents a particular challenge to the UK in enabling the necessary shift to low carbon heat. Whichever approaches are taken, the way heating is supplied to nearly 24 million homes, businesses and industrial users connected to the gas grid will need to change.[1] Ensuring this transition is as smooth as possible represents a major national challenge over the coming years.

The Government's approach to heat decarbonisation

1.5 The Government has emphasised the central importance of decarbonising heat to achieve our Industrial Strategy and clean growth objectives, as we transition to a low carbon economy. The Government's approach to heat decarbonisation encompasses a range of programmes and initiatives, underpinned by **innovation** and "**learning by doing**", which aims to achieve:

- **a reduction in heat demand, by seeking to:**
  - build a market for energy efficiency, particularly among owner occupiers;
  - improve the way businesses use energy, to support delivery of our ambition to reduce business energy use by 20% by 2030;

1 Department for Business, Energy and Industrial Strategy (2018) Sub-national electricity and gas consumption statistics https://www.gov.uk/government/statistics/sub-national-electricity-and-gas-consumption-summary-report-2016.

- improve the energy efficiency of new and existing buildings via updates to building standards and through the Industrial Strategy Buildings Mission, to halve the energy used in new buildings by 2030; and,
- work with industry to reduce energy demand through the £18m Industrial Heat Recovery Support Programme and the £315m Industrial Energy Transformation Fund.

- **substantial growth in no or low-regrets low carbon heating in the shorter term by supporting the deployment of**:
  - heat networks: the Heat Networks Investment Project (HNIP) is a Government Major Project which will invest £320m of capital funding in heat network projects through grants and loans. This is provided as 'gap funding' to leverage around £1bn of private and other investment, and pave the way for the continued growth of the UK heat networks market; and,
  - lower carbon heating solutions: through the Renewable Heat Incentive we are spending £4.5bn between 2016 and 2021 to support innovative low carbon heat technologies in homes and businesses, such as heat pumps, biomass boilers and solar water heaters. We have also reformed the Renewable Heat Incentive to focus the scheme towards long term decarbonisation through greater uptake of technologies such as heat pumps and biomethane. Beyond the Renewable Heat Incentive, our ambition is to phase out the installation of high carbon fossil fuel heating in buildings off the gas grid during the 2020s, starting with new buildings.

- **a new long-term policy framework for heat**: to bring about and support the national transition required to meet our long-term emissions reduction commitments. This framework must:
  - ensure that appropriate support is in place for consumers;
  - enable the most cost-effective transition across energy industries and infrastructure; and,
  - contend with the uncertainties arising from the multi-decade heat decarbonisation timetable. Advances in technologies may open up new solutions, and economy-wide developments such as the decarbonisation of transport and power generation may alter the feasibility of others.

How this report helps

1.6 On 7th December, the Government published two reports focussed on encouraging substantial growth in low carbon heating in the shorter term:

- The **Government's response to a Future Framework for Heat in Buildings Call for Evidence** – setting out the first steps to phasing out the installation of high carbon fossil fuel heating systems in off gas grid properties.
- **A Future Market Framework for Heat Networks** – setting out the Government's priorities for regulation of the heat networks sector as well as wider policies to drive sustained investment, ensure consumers are adequately protected and that the sector continues to decarbonise.

Figure 1.1 Our current policy approach

Decisive Near – Term Action

Targeted policies with near-term benefits, while supporting long-term options.

e.g. Heat Networks, Renewable Heat Incentive, Future Framework for Heat in Buildings, Buildings Mission

Energy Efficiency and Optimisation

Lower demand reduces emissions and fuel costs.

We are supporting e.g. smarter systems, more efficient buildings, increased heat recovery in industry

Development of Long Term Options

Decarbonising heat by 2050 will require a transformational change. Working with stakeholders to build the evidence base and identify the right solutions

1.7 **This document** looks further ahead to support the development of a long-term policy framework for heat. We have reviewed the expanding evidence base on options for achieving long-term heat decarbonisation. This report gives an overview of the key issues arising from our review and seeks to:

- highlight the different characteristics of the main alternative sources of low carbon heat and the approaches to achieving transformational change;
- set out strategically important issues, “strategic inferences”, which we have drawn from the evidence available to help focus the development of our long term policy framework; and,
- identify key areas that require further exploration to inform the development of a new long-term policy framework for heat.

1.8 The evidence reviewed in this report and the priority areas for further action and development are likely to be of interest and application in various ways across the UK. We will continue to work closely with colleagues in the Devolved Administrations as we develop a long-term policy framework for heat.

Strategic inferences

1.9 The bulk of this report (Chapters 4 and 5) is dedicated to presenting an overview of our review of the evidence on the options for decarbonising heat. In conducting our review, we have sought to consider as comprehensive a range of sources as practicable.

1.10 The complexity and breadth of issues involved is reflected in the diversity of research and studies originating from authors spanning academia, technical experts, non-governmental organisations and think tanks. Where there is growing consensus on issues raised from across these sources, we have sought to highlight these as strategic inferences which we believe are important considerations for shaping the development of our long term policy framework. These strategic inferences, detailed in Chapters 4 and 5, are summarised in Table 1.1 below.

Table 1.1 Selected strategic inferences

- Given the size of heat as a proportion of UK energy demand, the decarbonisation of heat will have broad impacts across the whole energy system – **these need to be understood and anticipated to ensure the key parameters of security and resilience are maintained**.

- There are a range of technologies which have the potential to offer low carbon heating choices in the future, but **there is no consensus on which technologies will be able to achieve this most economically and effectively** at the scale required.

- From our review of the evidence so far, **technologies using electricity, hydrogen and bioenergy all have the potential to make important contributions to the transition to low carbon heating**.

- **Widespread use of electric heating has the potential to deliver very deep reductions in carbon emissions, extending beyond the levels likely to be required by 2050 to enable the UK to meet the economy wide emissions reductions committed to under the Climate Change Act**. However, this potential is dependent on:
  - the **development of new, and reinforcement of existing infrastructure to generate, store and distribute low carbon electricity**;
  - **innovations in demand reduction, system flexibility and energy storage** to help manage the greatly increased demands on the electricity system; and,
  - the **extent to which a minority of buildings and some heating processes are likely to be unsuitable** for switching to electric solutions.

- **Widespread use of hydrogen also has the potential to deliver deep reductions in carbon emissions**, consistent with our 2050 commitments, subject to:
  - **establishing the feasibility of safely** converting the gas grid;
  - **the development of significant new infrastructure**, including a new transmission system, hydrogen production and storage facilities, and **sufficient carbon capture and storage capacity**; and,
  - **sourcing a secure supply of natural gas** to meet a significant increase in demand.

- **The ultimate depth of the emissions reduction potential of hydrogen is unclear** – currently limited by the practical feasibility of producing sufficient volumes of very low carbon hydrogen and the potential for methane leakage.

- **Bioenergy has potential to make substantial contributions to emissions reductions from heating** through a variety of applications, including the production of **biomethane** for use in the gas grid. **The scale of emissions reduction potential is limited by the volume of biomass available, the prioritisation of its use across the energy economy** and life-cycle emissions from production.

- **Given the diversity of heat demand, no one solution can provide the best option for everyone – a mix of technologies and customer options will need to be available**. While this is widely understood, there is much less clarity about the overall balance of technologies we are likely to see in the future, and the scale of consequent changes in demand for different fuels and infrastructure requirements. **The role of strategic decision making and planning in enabling the most cost-effective outcomes will need to be assessed**.

- Decarbonising heat will bring **extensive change for consumers**.

  – **electrification requires changes to all gas appliances**, and many buildings converting to heat pumps will require additional insultation, hot water storage, and larger radiators. **Hybrid heat pumps may reduce the level of in-home change**, and therefore disruption required; and,

  – **hydrogen would also require the replacement of all appliances, but likely with similar products to their existing gas appliances**. The **main disruption is likely during conversion** which may require multiple home visits and new gas pipework, and consumers may not be able to choose the timing of conversion.

- **Public awareness** of the need to decarbonise heat, and the potential impacts of doing so, remains low. This **needs to change to enable a fully informed debate about long term options**.

- Whilst estimates of the costs and benefits of these options are subject to significant uncertainty, published studies estimating the costs of a range of pathways for decarbonising heat indicate **there is not yet a clear basis for determining which approaches are likely to be the most cost-effective overal**l.

- All approaches will require very substantial new capital investment – **continuing innovation and market development will be important in driving down costs and raising performance efficiencies of different low carbon heating technologies**. How these costs are distributed across society and the economy will also be a key question.

- A combination of technologies will be required to achieve deep decarbonisation in industry. **Improving the evidence base on the potential solutions for decarbonising industry and building the case for investment in industrial decarbonisation solutions, will be essential**.

- Extensive planning and co-ordination is likely to be required to deliver change cost effectively with minimum disruption to consumers. **A comprehensive policy framework is needed to address barriers to take up, provide options to consumers, and support to ensure fairness across society.**

Developing a new policy framework

1.11 Building on the strategic inferences identified from our review, in Chapter 6 of this report, we set out key areas we believe require further action and exploration to inform the development of a new long term policy framework for heat.

1.12 It is an open question as to what form this new long term policy framework might take, but we believe it must be informed by stronger evidence on the impacts of different approaches to decarbonising heat, greater confidence as to how effectively important barriers can be overcome, and much wider public engagement.

1.13 Table 1.2 below summarises priority areas we believe require further development across industry, academia and the public sector over the next 2–5 years. The actions identified, whilst not exhaustive, represent a very substantial and wide ranging programme which reflects key priorities for the activity required.

1.14 **We will build on these actions, taking into account the views we receive in response to this report, and the outcomes of the next Spending Review, to develop a new roadmap for policy on heat decarbonisation. We aim to publish this roadmap within eighteen months**.

Table 1.2 Initial next steps to develop a long-term policy framework

Expanding low carbon heating

- To enable the heat sector to make a full contribution towards meeting out carbon budgets during the 2020s, **low carbon heating technologies and supply chains will need to be further developed**. The Government will support this by:
  - considering how future support for low carbon heating technologies may be best targeted as part of the next Spending Review;
  - consulting in 2019 on a package of measures to drive change in the off gas grid heating market;
  - in 2019, consulting on Part L of the Building Regulations in relation to England, covering energy performance of buildings;
  - taking forward the Buildings Mission, to halve the energy used in new buildings, including launching a design competition for the Home of the Future in 2019;
  - announcing the successful applicants from the first Heat Networks Investment Project funding round, and Round 8 of the Heat Networks Delivery Unit funding, in Spring 2019; and,
  - subject to further consultation, developing a market framework that will ensure consumers receive sufficient protection; build investment in the sector; and, maximise the potential decarbonisation benefits of heat networks.

Promoting innovation

- Innovation will be particularly important to reduce key risks and uncertainties with different technologies and the barriers to consumer take up. Building on our existing programmes, the **Government will step up innovation work on low carbon heating in partnership with industry, academia and other partners**.
- We invite views on priorities for further development and proving of emerging technologies, and will increase efforts to promote a common agenda for research and development across the public sector, academia and industry.

Industrial heating

- The Government will develop a framework to support the decarbonisation of heavy industry. Key steps in the development of this framework include:
  - consulting on the Industrial Energy Transformation Fund during 2019;
  - progressing the actions set out in the *UK Carbon Capture Usage and Storage Action Plan*; and,
  - delivering our Clean Growth Grand Challenge Mission, to establish the world's first net zero carbon industrial cluster by 2040, and at least one low carbon cluster by 2030. We will provide further details on our delivery plan for this Mission in 2019.

Table 1.2 continued...

Developing a new policy framework – electric heating

- Widescale electrification of heating would represent a fundamental shift in our energy demand, with major implications for our energy systems. These potential implications, and how the electricity system in particular might best respond to them, need to be better understood. We will work with colleagues from across industry and academia to:
  - **improve understanding of potential future requirements for electricity generation and network reinforcement** under different circumstances, and **how these might be cost effectively and practicably met**; and,
  - explore the potential for more sophisticated systems modelling work, informed by broader demonstration and trialling work, to **improve understanding of the potential of flexibility systems**.
- The changes involved for consumers in a potential shift to electric heating can represent a significant barrier. **We will develop plans for a substantial new project to demonstrate modern electric heating solutions across a range of building types and consumers**.

Developing a new policy framework – hydrogen for heat

- Options for making greater use of hydrogen in relation to heating would all involve changes which need to be much better understood. All require rigorous technical investigation, development and testing alongside improving understanding of how they could be delivered in practice, and the impacts, costs and barriers. **We will work in partnership with industry, academia and other key stakeholders to build up a comprehensive programme of work to demonstrate the technical and practical feasibility of using hydrogen in place of natural gas for heating. We will seek to gain greater assurance of the costs, benefits and impacts, including on the wider energy system, and the practical delivery implications, to enable a more informed debate on the potential of using hydrogen for heat.**
- Key immediate priorities for investigation and testing under this programme for us to progress include:
  - testing and demonstrating the safety of hydrogen in buildings through the Hy4Heat programme;
  - improving understanding and accelerating the development of low carbon hydrogen production methods through our Hydrogen Supply Competition;
  - exploring the potential for hydrogen in industrial processes as part of our Industrial Fuel Switching programme; and,
  - as set out in the *UK Carbon Capture Usage and Storage Action Plan*, considering, in association with the Health and Safety Executive, the inclusion of a percentage of low carbon hydrogen in gas networks, within the context of strategic decisions for the long term decarbonisation of heat for buildings and industry, and the potential for an emerging hydrogen economy.

Table 1.2 continued...

Developing a new policy framework – bioenergy

- In relation to the use of bioenergy for heat, the **potential for expanding the supply of biomass in ways which are sustainable and affordable**, and the **competition for limited bioenergy resources** in the future remain the most critical questions.
- There are a range of new and emerging technologies, such as gasification, which have the potential to enable greater biogas production using a wider range of feedstocks cost-effectively. **We will continue to consider how innovation could play a role in encouraging technologies which enable more efficient production, deeper emission reductions and use a wider range of feedstocks cost-effectively**.

Developing a new policy framework – overall

- The scale and complexity of the transformation required to decarbonise heat means there will need to be further thinking about the policy framework for heat. This work must include, amongst other considerations:
  - **learning from relevant experience in the UK and internationally**;
  - **thinking broadly about fundamental aspects of the future policy framework**, for example where the framework should facilitate the market to determine outcomes and conversely, where policy or regulatory intervention might have to be more prescriptive to ensure efficient or fair outcomes;
  - **questioning where relevant policy making** powers and other responsibilities are best exercised;
  - **increasing wider public awareness of low carbon heating**, and its importance for our wider climate commitments – to achieve this, we will explore options for engaging stakeholders and the wider public in the development of heat policy;
  - **continuing to explore and evaluate evidence** from third parties, recognising the increasing commercial significance of policy decisions and therefore evolving stakeholder interests and the impact this may have on the quality of evidence, something which we have considered carefully in our review of the evidence for this report; and,
  - **facilitating greater exchange and testing of stakeholders' views and analysis**, to promote transparency in the discussion of key issues and challenges. We would welcome suggestions on how this might practicably be organised.

Your views

1.15 We welcome views on the strategic inferences we have identified, the priority areas we believe require further development to inform a long term policy framework, on any important omissions, on the parties who may be best placed to deliver in these areas, and on opportunities for enhancing co-ordination. Please send your views to us at heatpolicy@beis.gov.uk by 22nd February 2019.

1.16 There is wide agreement among commentators on the need to learn more over the coming years about the different options available, testing out different technologies and "learning by doing" as far as possible. This report aims to be the starting point in establishing a clearer common agenda for attention across industry, academia and the public sector, to ensure that effort and resources are effectively and efficiently applied to the most important and urgent issues on long term heat decarbonisation.

Context – Heat in the UK Today

2. Context – Heat in the UK Today

Emissions from heat

2.1 The UK is at the forefront of the global shift towards a low carbon future. Clean growth – reducing our greenhouse gas emissions while growing the economy – is at the heart of our Industrial Strategy, and so far, we have been among the most successful countries in the developed world in this respect. Since 1990, we have cut emissions by 42% while our economy has grown by two thirds.[2] This means we have reduced emissions faster and seen growth in our national income greater than any other G7 nation in this period. This success has been delivered predominantly through the rapid modernisation of our power sector and reductions in waste and industry emissions.[3]

2.2 Emissions from heat are the single biggest contributor to UK emissions. As shown in Figure 2.1, in 2016, they accounted for

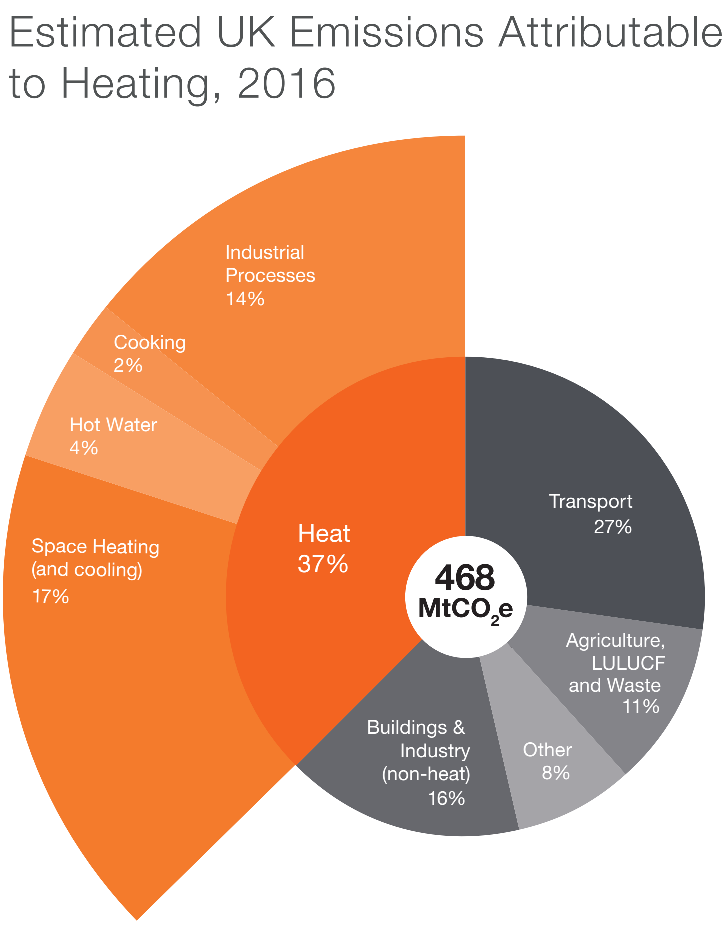

Figure 2.1 UK emissions in 2016 across different sectors[4]

2 Department for Business, Energy and Industrial Strategy (2017) Clean Growth Strategy https://www.gov.uk/government/publications/clean-growth-strategy.

3 Department for Business, Energy and Industrial Strategy (2017) Clean Growth Strategy https://www.gov.uk/government/publications/clean-growth-strategy.

4 BEIS estimates derived from ECUK 2018, Final UK greenhouse gas emissions national statistics: 1990–2016, Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal. Percentages may not sum to 100% due to rounding.

37% of UK emissions. The decarbonisation success seen in the power sector must now be replicated in heating if we are to meet our climate change commitments.

2.3 Under the Climate Change Act 2008 the Government has committed to reducing annual greenhouse gas emissions by at least 80% by 2050 compared to 1990 levels. However, as the evidence base grows on the implications of limiting global warming to 1.5 degrees above pre-industrial levels, the Government has sought updated advice from the Committee on Climate Change on the UK's long term emission reduction targets.[5] This advice will include a recommendation as to when the UK should achieve a net zero target in order to contribute to the global ambitions set out in the Paris Agreement.

2.4 Achieving these emissions reductions will require decarbonisation efforts across the economy. The Clean Growth Strategy[6] sets out proposals for taking this agenda forward during the 2020s, while the recent Road to Zero[7] document outlines how the Government will support the transition to zero emission road transport and reduce emissions from conventional vehicles.

2.5 While this document is primarily about heat, the transition to low carbon heating will need to be achieved together with the decarbonisation of other sectors. This will enable synergies to be exploited, while also ensuring our low carbon infrastructure has the capacity to meet the demands of consumers across the economy.

How we use heat today

2.6 Heat is the largest energy consuming sector in the UK today (see Figure 2.2). Whilst progress has been made to reduce demand for heat, and further reductions will be delivered through improvements to the energy efficiency of our buildings and industrial processes, remaining heat demand must be met by low carbon sources if we are to meet our legally binding emissions reduction commitment.

2.7 Overall demand for heat, and therefore natural gas, in homes is falling as a result of increasing energy efficiency. Total household electricity and gas consumption has fallen by 17% over the last decade (see Figure 2.3) despite a growth in the number of households in the UK over this period. The energy efficiency of non-domestic buildings has also improved, with emissions 18% lower in 2015 compared with 1990 levels.[8]

5 Intergovernmental Panel on Climate Change (2018) Global Warming of 1.5 °C http://www.ipcc.ch/report/sr15/
6 Department for Business, Energy and Industrial Strategy (2017) Clean Growth Strategy https://www.gov.uk/government/publications/clean-growth-strategy.
7 Department for Transport (2018) The Road to Zero https://www.gov.uk/government/publications/reducing-emissions-from-road-transport-road-to-zero-strategy.
8 BEIS (2017) Final UK greenhouse gas emissions national statistics: 1990–2015 https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2015.

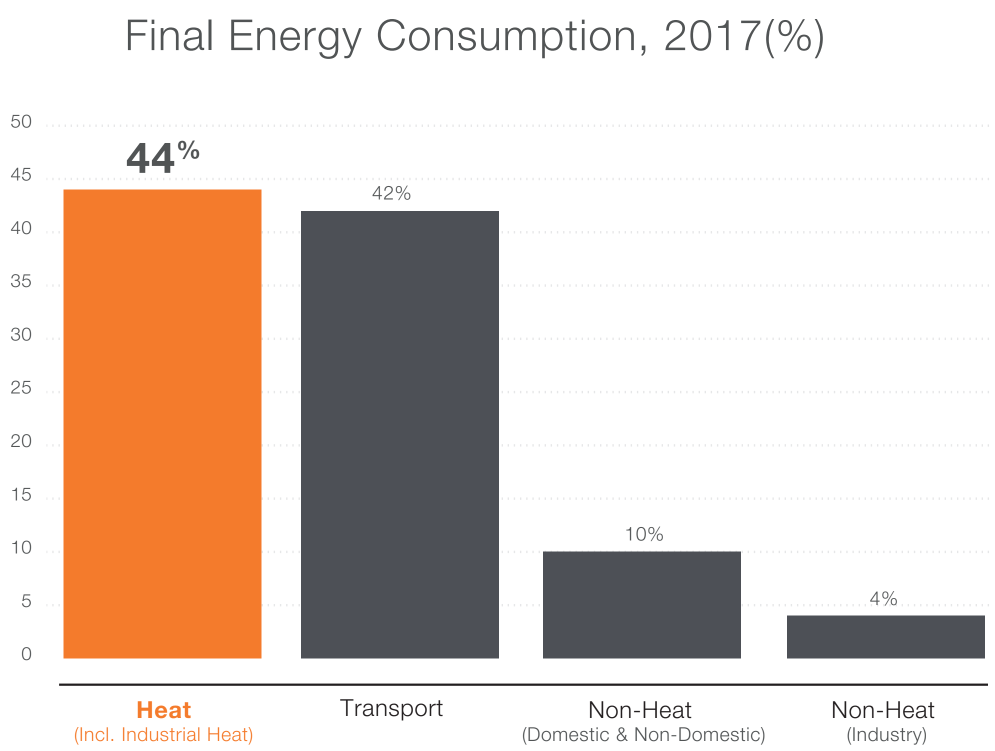

Figure 2.2 Final energy consumption (in primary energy equivalents), 2017[9]

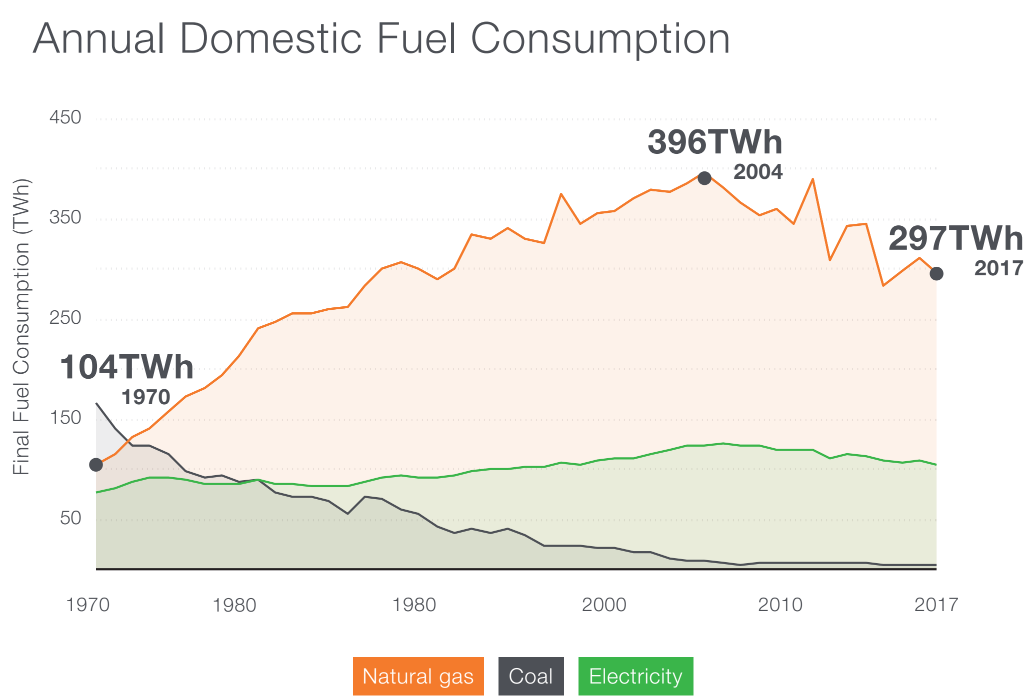

Figure 2.3 annual domestic gas consumption (1970–2017)[10]

9 ECUK (2018) 'Heat' in chart above includes cooling & ventilation https://www.gov.uk/government/statistics/energy-consumption-in-the-uk.

10 ECUK (2018) https://www.gov.uk/government/statistics/energy-consumption-in-the-uk.

2.8 These savings have been driven by a combination of:

- tighter building and product standards and, in particular, more efficient boilers;
- the uptake of insulation and other energy efficiency measures; and,
- greater consumer awareness of the potential for energy savings.

2.9 In industry, efficiency gains have reduced costs and improved productivity. By way of illustration, each tonne of steel produced in the UK requires 40% less energy to produce than 40 years ago.[11]

2.10 Consumers of heat are often considered in three broad groups: domestic, non-domestic, and industrial. As shown in Figure 2.4, domestic consumers are the largest users of energy for heat, responsible for almost 60% of final energy consumption.[12] This demand is primarily to keep homes warm but also for cooking and the generation of hot water.

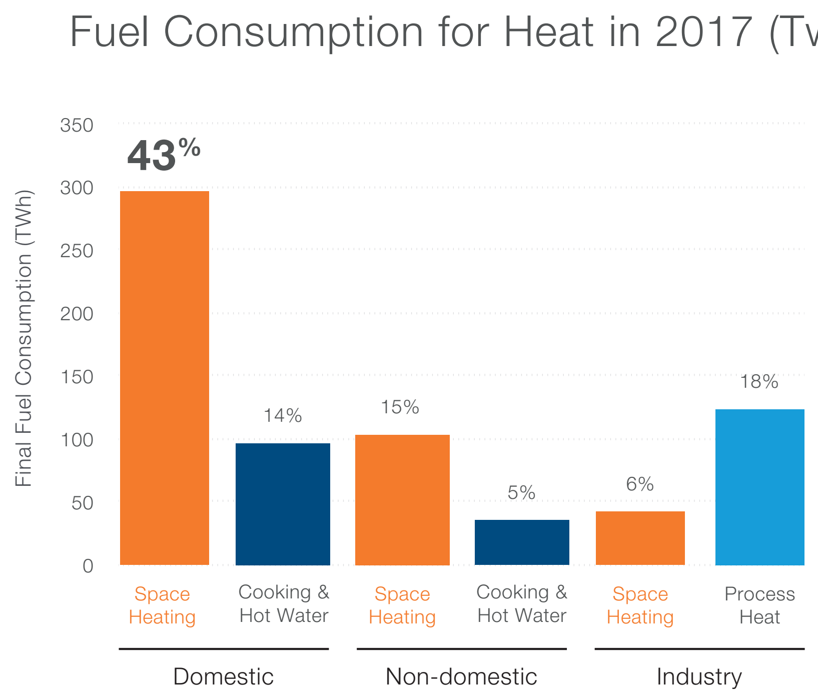

Figure 2.4 Fuel consumption for heat in 2017 (TWh). Percentages may not sum to 100% due to rounding

11 WSP and Parsons Brinckerhoff & DNV GL (2015) Report prepared for DECC & BIS: Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 (Iron and Steel document) https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050.

12 Department for Business, Energy and Industrial Strategy (2018) Energy Consumption in the UK https://www.gov.uk/government/statistics/energy-consumption-in-the-uk.

2.11 Non-domestic users also predominantly use heat to keep buildings, such as workplaces and public spaces, warm, for example museums, libraries and hospitals. Hot water use is particularly significant in the health, hospitality, emergency services and education sectors, driven by demand for washing facilities. Cooking and catering require heat and are important for many businesses, especially those in the hospitality sector.

2.12 In both domestic and non-domestic sectors, the demand for space cooling in buildings is currently very small (estimated at ~1% of the total final fuel consumption in 2017) and primarily met through electric air conditioning.[13] This could increase significantly in the future with the wider implementation of energy efficiency measures in buildings and the impacts of climate change.[14]

2.13 As shown in Figure 2.4 industry accounts for around 24% of all heat use in the UK. Industry typically uses heat for two purposes: to heat and cool buildings, and for the processes used to manufacture products. The majority of heat demand in industry is to serve industrial processes to manufacture goods. The heat requirements for industrial processes can vary significantly in terms of the temperatures required, the technologies used to generate heat, and whether heating occurs directly or indirectly. Blast furnaces for example provide direct heat at extremely high temperatures in the iron making process, whereas steam is used to provide indirect heating at much lower temperatures in, for example, food thawing processes.

2.14 Whilst the ways we use heat today are generally well understood, there are many factors that influence future heat demand; including population and economic growth, changes in climate, energy efficiency deployment and building standards, and new technologies (such as smart technologies and demand-side response). The implications of those factors for heat demand in the future are cuncertain, but demand in the future is likely to look different to today.

2.15 The number of households in the UK is projected to rise from ~28 million to ~31 million between today and 2037.[15] However, as new homes are more energy efficient than older buildings, and because of our Clean Growth Strategy ambition to deploy energy efficiency measures across buildings, the amount of energy needed for heating per home will decrease on today's levels.[16]

2.16 UK climate projections also suggest that UK climate conditions could alter heat demand in two ways: by increasing winter mean temperature, and therefore decreasing annual heat demand, and by increasing summer mean temperature. Estimates suggest that, by 2070, summer temperatures could be up to 5.4°C warmer, and winter temperatures could be up to 4.2°C warmer.[17]

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13 Department for Business, Energy and Industrial Strategy (2018), Energy Consumption in the UK (ECUK) Table 1.04 https://www.gov.uk/government/statistics/energy-consumption-in-the-uk.

14 National Grid (retrieved October 2018) Our Energy Insights http://fes.nationalgrid.com/media/1243/ac-2050-v21.pdf.

15 Office for National Statistics (2018) Household projections for England https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/householdprojectionsforengland.

16 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

17 Met Office (2018) UK Climate Projections https://www.metoffice.gov.uk/news/releases/2018/ukcp18-launch-pr

2.17 The evidence on future cooling demand in the UK is currently limited. However, National Grid have previously estimated uptake of air conditioners in the domestic sector to be 18 million units by 2050, compared to less than one million today. They estimate that this would add 19 – 39GW of peak electricity demand on a typical August weekend compared to electricity demand today.[18]

Sources of heat

2.18 In the UK, gas has become the predominant source of heating, with the vast majority of customers connected to the GB gas grid. Approximately 85% of UK households and 65% of non-domestic buildings use natural gas for heating. Natural gas also makes up over 40% of industrial energy consumption.[19] Meeting our greenhouse gas emissions reduction targets therefore requires a fundamental shift away from the use of natural gas.

2.19 Our reliance on natural gas is a relatively recent phenomenon. Historically, the UK was largely dependent on town gas, which was largely derived from coal and distributed by low-pressure local networks. The UK transitioned away from town gas to natural gas from the late 1960s following the discovery of major gas reserves in the North Sea. The extensive gas grid we have today comprises 7,600km of transmission and 284,000km of distribution pipelines,[20] and is connected to 24 million homes and businesses.[21]

2.20 The availability of large reserves of North Sea natural gas has resulted in the UK having a relatively high dependency on natural gas for heating. The same is true for The Netherlands which has also benefited from natural gas reserves, as shown in Figure 2.5.

18 National Grid (2018) Future Energy Scenarios http://fes.nationalgrid.com/media/1243/ac-2050-v21.pdf.
19 Ofgem (2018) Network Price controls and you: fast facts https://www.ofgem.gov.uk/publications-and-updates/network-price-controls-and-you-fast-facts.
20 National Grid (2017) Gas Ten Year Statement https://www.nationalgrid.com/sites/default/files/documents/GTYS%20 2017_1.pdf.
21 Department for Business, Energy and Industrial Strategy (2018) Sub-national electricity and gas consumption statistics https://www.gov.uk/government/statistics/sub-national-electricity-and-gas-consumption-summary-report-2016

Fuel Share for Residential and Commercial Heating Demand

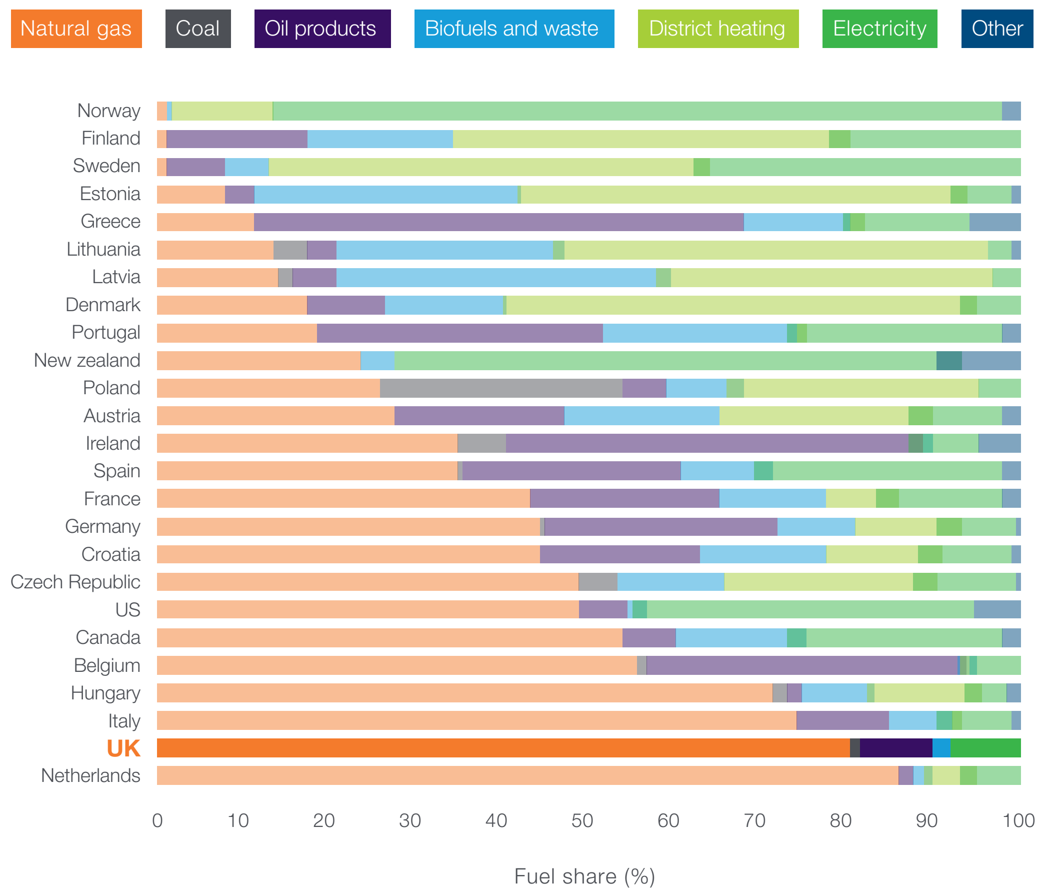


Figure 2.5 Fuel share for residential and commercial heating demand in a number of OECD countries[22]

22 Vivid Economics for the Department for Business Energy and Industrial Strategy (2018) International Comparisons of Heating, Cooling and Heat Decarbonisation Policies.

2.21 Despite the dominance of natural gas, many buildings use other forms of heat:

- **Domestic heating**: As shown in Figure 2.6, ~15% of households (3.5 million) in England are not connected to the gas grid and make use of a range of different energy sources.[23] Around half of these use electricity as their main source of heating.[24] They typically rely on electric storage heaters, although increasing numbers now make use of heat pumps. 1.1 million households use heating oil; the remainder rely on a combination of liquid petroleum gas (LPG), solid fuels (including biomass) and heat networks, which supply heating or cooling from a central source to multiple buildings or sites.[25]

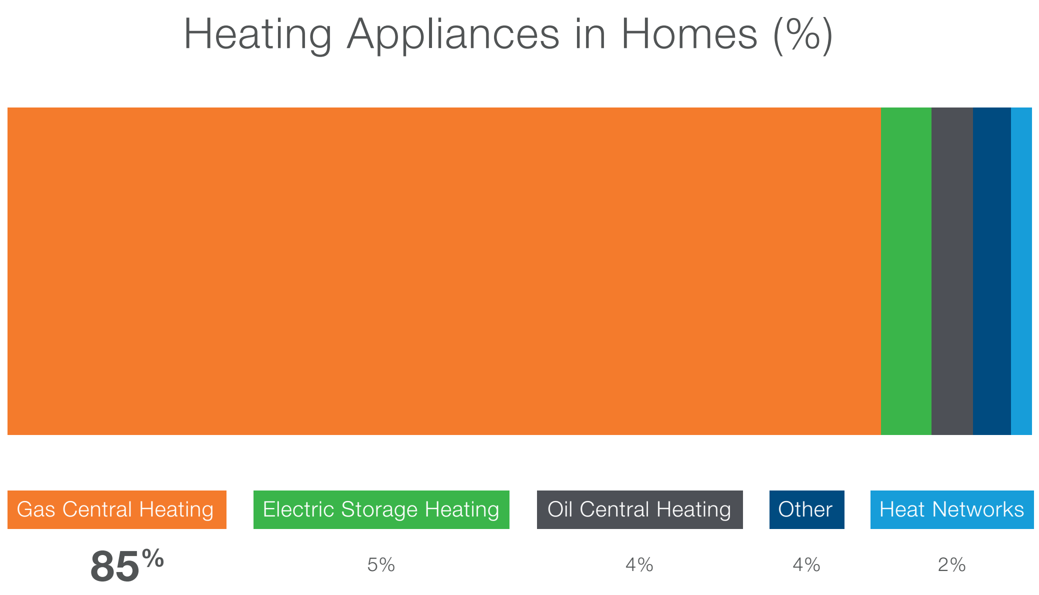


Figure 2.6 Space heating appliances in homes in 2016[26]

23 Based on ONS data. Office for National Statistics (2016) Household projections for England https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/householdprojectionsforengland.

24 OFGEM (2015) Insights paper on households with electric and other non-gas heating https://www.ofgem.gov.uk/ofgem-publications/98027/insightspaperonhouseholdswithelectricandothernon-gasheating-pdf.

25 BEIS analysis based on the English Housing Survey and devolved equivalents: Ministry of Housing, Communities & Local Government (2013) https://www.gov.uk/government/collections/english-housing-survey.

26 Ministry of Housing, Communities and Local Government (2018) English Housing Survey 2016: Energy Efficiency https://www.gov.uk/government/collections/english-housing-survey; https://www.gov.uk/government/statistics/english-housing-survey-2016-energy-efficiency. The English Housing Survey defines communal as where heat is generated in a centralized location for residential space and water heating. This could be from a central boiler using any fuel which supplies a number of dwellings, waste heat from power stations distributed through community heating or a local combined heat and power system.

- **Non-domestic**: Around 13% of overall non-domestic energy consumption for heat is provided by oil or liquid petroleum gas. Oil represents about 9% by end use of heating, hot water and cooking across the non-domestic sector.[27] In the services sector, electricity is more prevalent than in the domestic sector; this is possibly due to the wider use of electric air-conditioning systems and the need for cooling.[28]

- **Industry**: Industry relies on a range of energy sources for heating, as shown in Figure 2.7, with needs determined by the temperature or process required. For example, the production of iron normally uses coal, whereas high quantities of electricity are needed for aluminium smelting.[29] In addition, some processes rely on freezing or sub-zero temperatures, typically provided by electricity. Whilst the range of fuels used is similar for industry and the domestic and non-domestic sectors the proportions are different, and natural gas in particular plays a much smaller role than in the domestic and non-domestic sectors.

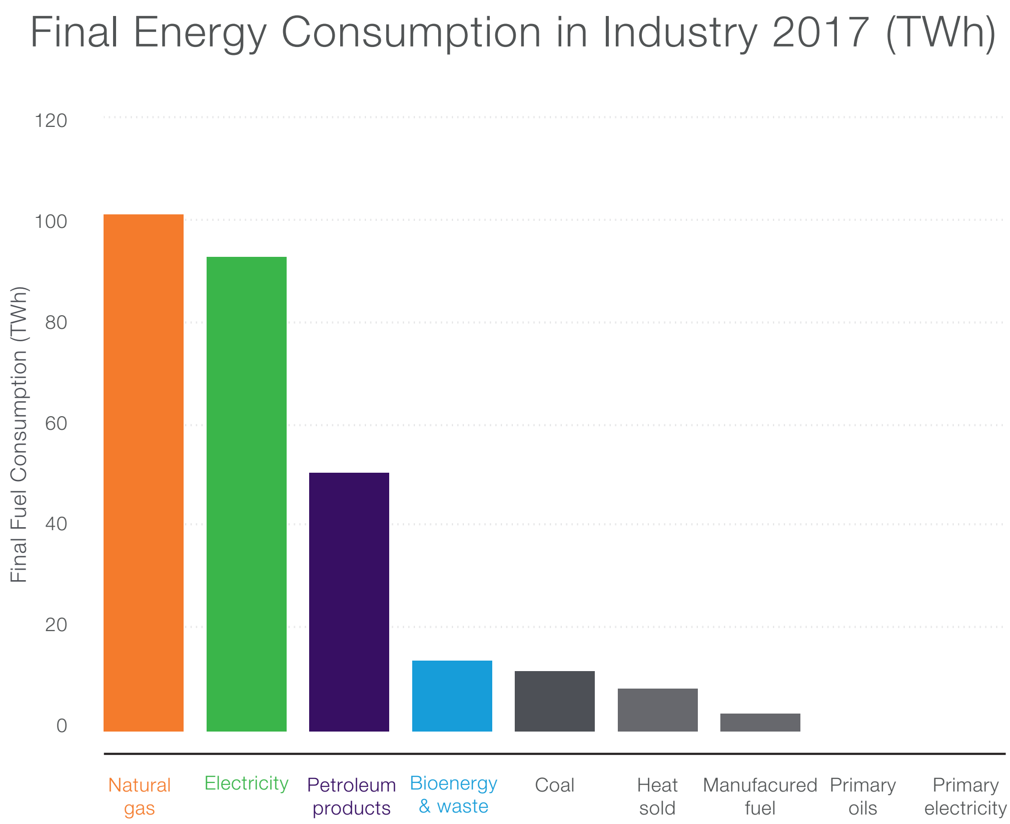


Figure 2.7 Industrial energy sources for heating[30]

27 Department for Business, Energy and Industrial Strategy (2018) Energy Consumption in the UK https://www.gov.uk/government/statistics/energy-consumption-in-the-uk.

28 UK Energy Research Centre (2018) A Transformation to Sustainable Heating in the UK: risks and opportunities http://www.ukerc.ac.uk/publications/sustainable-heating-in-the-uk-risks-and-opportunities.html.

29 UK Energy Research Centre (2018) A Transformation to Sustainable Heating in the UK: risks and opportunities http://www.ukerc.ac.uk/publications/sustainable-heating-in-the-uk-risks-and-opportunities.html.

30 Digest of UK Energy Statistics for Department for Business, Energy and Industrial Strategy (2018) Digest of UK Energy Statistics (DUKES) 2018: Tables 1.1–1.3, main chapters and annexes https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2018-main-report.

2.22 In addition to heating, we currently use natural gas supplied by the gas grid for electricity generation, with around a third of current gas demand being used in the power sector. This is expected to reduce in the future as the power sector decarbonises. A small amount of gas is also employed for non-energy uses including as a raw material to make products including fertiliser, plastics, pharmaceuticals, fabrics and household chemicals.

When we use heat

2.23 Heat demand is highly variable throughout the day and year. The gas system has been designed with the capacity to manage the peaks and troughs of our demands for heat effectively and cheaply.

2.24 The pattern of heat demand is driven by domestic space heating needs and reflects typical daily lifestyle patterns. Whilst there is inherent flexibility within the natural gas grid (the pressure within the pipes can be varied within certain safety and technical boundaries, therefore granting a degree of flexibility within the day), flexibility and responsiveness to demand fluctuations is also necessary from supply sources.

2.25 There is also a huge shift in heat demand across the year that follows seasonal temperature change. Heat demand can peak at around 3.5TWh in winter days, over seven times higher than some summer days. In comparison, as shown in Figure 2.8, electricity demand remains relatively constant with peaks rarely exceeding 1TWh.

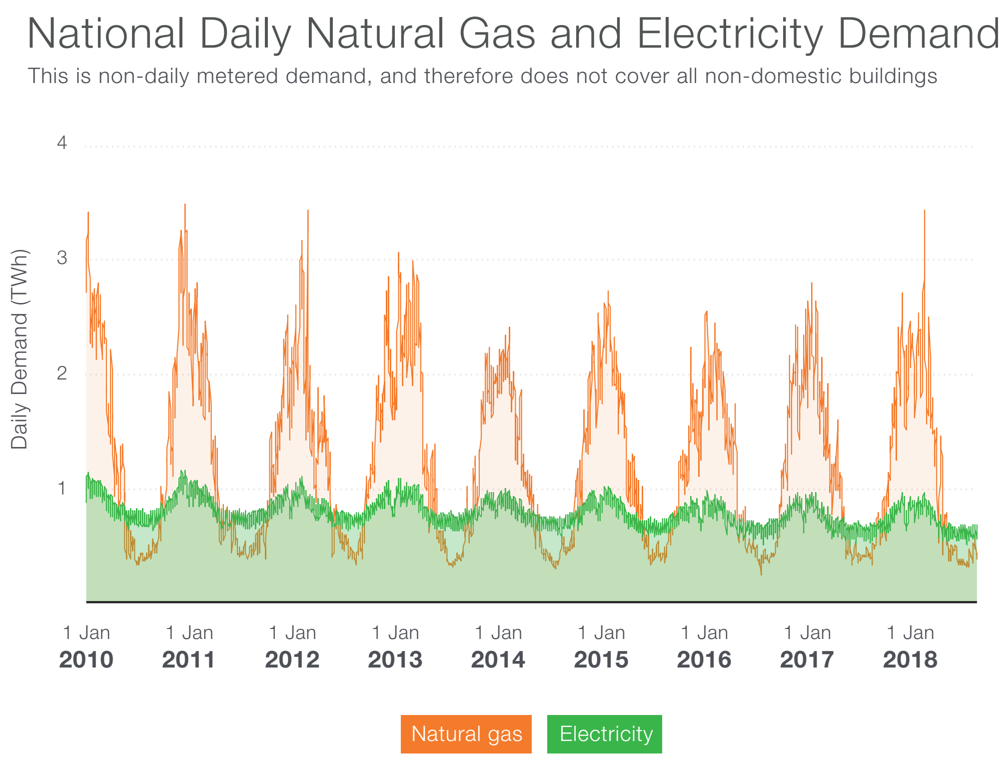


Figure 2.8 Non-daily metered gas demand and national electricity demand (2010-2018)

The challenge of decarbonising heat

2.26 The necessary shift away from our current reliance on natural gas as a heating fuel presents a significant challenge to the UK.

2.27 Meeting this challenge will entail major transformation. It will include disruption for consumers and wide-ranging change for our energy system and markets. Moreover, change of this scale and breadth will require a level of coordination beyond most public policy change programmes. The scale of change involved for consumers, alongside our energy system and infrastructure, means that heating is arguably the most difficult of the major energy consuming sectors of the economy to decarbonise.

2.28 Unlike decarbonisation of the power sector, decarbonising heat at scale will have a direct impact on consumers, requiring changes to the vast majority of the heating systems currently in buildings and industrial sites. The changes will likely include higher capital and running costs, within-building adjustments, and changes to consumers' heating behaviours. Overcoming these potential barriers to consumer action will be fundamental to achieving a successful transition.

2.29 With such marked implications across society, any change will need to be informed by wide public and consumer engagement. As discussed further in Chapters 5 and 6, a key strategic challenge to decarbonising heat is the current low level of awareness of the need for this transformational change.

2.30 Meeting the heat decarbonisation challenge will also require low carbon systems that meet the diverse range of uses of heat across our homes, workplaces and industry. No single technology will be able to meet the needs of all consumers.

2.31 Like the transition to low carbon electricity generation, the transition to low carbon heating will require major changes in our energy production industries and distribution systems. A major shift to using electricity for heating rather than gas would require much more low carbon generation capacity. Large scale use of hydrogen for heating would require a huge amount of additional hydrogen production capacity. Lead times for infrastructure change on this scale will be long.

2.32 The transition to low carbon heating will also require huge expansion of the currently small low carbon heating goods and services market to ensure sufficient supply – the Energy Technologies Institute estimates that 20,000 households per week would need to be switched from the gas grid to low carbon heating between 2025 and 2050 to meet our current decarbonisation commitments.[31] Whilst delivering this expansion will be challenging, it could bring with it the creation of skilled clean growth jobs.

2.33 Coordinating change across multiple actors, markets and time horizons will be a key challenge requiring joined-up action across industry, academia and the public sector, to develop innovative solutions. New frameworks of law and governance may be required to enable change and to manage effectively the risks and complexities involved.

31 Energy Technologies Institute (2015) Smart Systems and Heat Decarbonising Heat for UK Homes http://www.eti.co.uk/wp-content/uploads/2015/03/Smart-Systems-and-Heat-Decarbonising-Heat-for-UK-Homes-1.pdf.

The opportunities in decarbonising heat

2.34 Change on this scale will involve huge opportunities as well as challenges. The Government's Industrial Strategy emphasises the opportunities for UK industries, businesses and workers as we and the other major economies around the world decarbonise. As we transition to low carbon heating, opportunities for UK companies will open up, particularly as they develop skills, capabilities and products that can be marketed at home and abroad.

2.35 The UK has strategically important expertise in heating technologies and fuels. The electricity, gas and steam and air conditioning supply sectors, a significant proportion of which is heat-related, together generate annual revenues of ~£100bn and employ almost 150,000 people. They continue to grow with a 15% and 8% increase in employment and turnover respectively between 2011 and 2016.[32]

2.36 An estimated $13.5 trn of public and private investment will be required in the global energy sector, including heating, between 2015 and 2030 if the signatories to the Paris Agreement are to meet their national targets.[33] This creates the potential for significant export opportunities. Goods and services related to low carbon heating are likely to be in demand across the world and could be supplied by UK businesses.

2.37 Ricardo Energy & Environment, in their work for the Committee on Climate Change, estimate the low carbon economy in the UK could grow 11% per year between 2015 and 2030, four times faster than the rest of the economy, and could deliver between £60bn and £170bn of export sales by 2030.[34]

2.38 Transitioning to low carbon heat will make a critical contribution to achieving our Industrial Strategy ambitions, in addition to minimising our contribution to global climate change and its impacts, bringing benefits across our society, as brought to widespread attention through the *Stern Review*.[35]

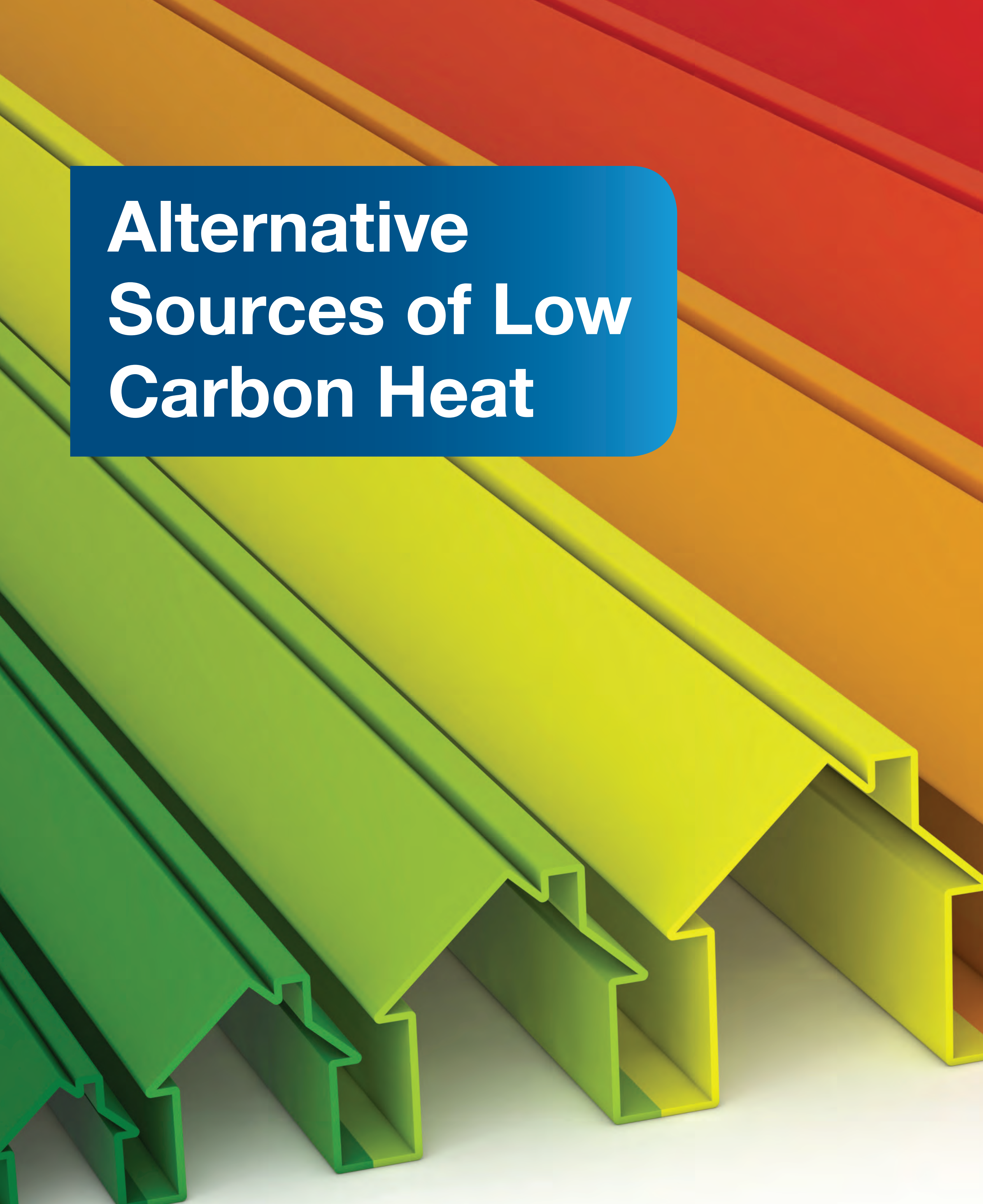
32 Office for National Statistics (2018) Non-financial business economy, UK: Sections A to S https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/datasets/uknonfinancialbusinesseconomyannualbusinesssurveysectionsas.

33 International Energy Agency (2015) World Energy Outlook https://www.iea.org/publications/freepublications/publication/WEO2015.pdf.

34 Ricardo Energy and Environment for the Committee on Climate Change (2017) UK business opportunities of moving to a low-carbon economy (supporting data tables) www.theccc.org.uk/publication/uk-energy-prices-and-bills-2017-report-supporting-research/.

35 Nicholas Stern, London School of Economics (2006) Stern Review: The Economics of Climate Change http://www.lse.ac.uk/GranthamInstitute/publication/the-economics-of-climate-change-the-stern-review/.

Alternative Sources of Low Carbon Heat



3. Alternative Sources of Low Carbon Heat

Introduction

3.1 We are making progress in reducing carbon emissions from heating, particularly through improving the energy efficiency of our buildings and industrial processes, and increasing the uptake of low carbon heating in new build and off gas grid areas. However, transformational change will be needed to meet our longer term commitments. This will require a fundamental shift away from fossil fuels for heating to other energy sources.

3.2 There are a range of low carbon heat sources that could play a part in this transformational shift. Electricity, hydrogen and bioenergy have the potential to play a strategic role in long term heat decarbonisation, while technologies such as heat networks could play an important enabling role.

3.3 Electricity and bioenergy already contribute to reducing greenhouse gas emissions from heat, while hydrogen – although not currently proven as a fuel for heat in buildings – has emerged as an increasingly prominent option.

Low carbon electricity

3.4 Electricity is an established solution for enabling low carbon heating both in the UK and internationally. As shown in Figure 2.5, some countries have already made significant progress in electrifying heat. The Netherlands,the only country with a greater dependence on natural gas than the UK, is also moving in this direction.[36] Electric heating appliances produce no direct greenhouse gas emissions to the atmosphere, however emissions are currently produced during the generation of electricity. While the role of electricity in the UK heat market is currently dwarfed by natural gas – in 2017, 13% of heat was provided by electricity in comparison with 67% from natural gas – as the power sector continues to decarbonise it has the potential to play an increasing role in decarbonising heat.[37]

3.5 There is a range of technologies that can be used to convert electricity to heat. Heat pumps transfer heat from a low temperature source such as ambient air, water, the ground or waste heat, and raise it to a higher useful temperature.[38] They represent an efficient use of energy. For example, for every unit of energy used by a heat pump, typically around 2.5 units of heating are generated with an air source and 2.7 with a ground source.[39] Efficiency depends on outside air temperature, but with correct system design, installation and operation, higher efficiencies are possible.

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36 Vivid Economics for Department for Business, Energy and Industrial Strategy (2018) International Comparisons of Heating, Cooling and Heat Decarbonisation Policies https://www.gov.uk/government/publications/international-comparisons-of-heating-cooling-and-heat-decarbonisation-policies.

37 Department for Business, Energy and Industrial Strategy (2018) Energy Consumption in the UK 2018 https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

38 Department for Business, Energy and Industrial Strategy (2016) Evidence Gathering – Low Carbon Heating Technologies https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/565248/Heat_Pumps_Combined_Summary_report_-_FINAL.pdf.

39 UCL Energy Institute (2017) Final report on the analysis of heat pump data from the renewable heat premium payment (RHPP) scheme https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/606818/DECC_RHPP_161214_Final_Report_v1-13.pdf.

3.6 In part due to their efficient use of energy, the Committee on Climate Change has focused on heat pumps as the primary low carbon option for most buildings off the gas grid in the UK.[40]

3.7 Heat pumps are already widely used in other countries including Sweden, where 38% of heating is fuelled by electricity, and increasingly France, which is now one of the largest EU markets for heat pumps with sales increasing to nearly 160,000 units per annum by 2015[41] In China, sales of air source heat pumps have risen from 10,000s to over one million for space heating in 3 years.[42] As of October 2018, there were approximately 46,000 heat pump installations in Great Britain supported through the Renewable Heat Incentive scheme.[43]

3.8 Heat pumps can also be combined with other technologies, usually a gas boiler, to create a hybrid heat pump. Hybrid heat pumps allow buildings to generate heat from either electricity or gas rather than relying solely on electricity.

3.9 Direct electric heating systems, such as storage heaters, can also be used to convert electricity to heat. As referenced in Element Energy & E4Tech's work for the National Infrastructure Commission, whilst they are less efficient than heat pumps, they can be applied across most of the UK's building stock without the need for the energy efficiency upgrades which may be required with heat pumps.[44]

Hydrogen

3.10 In the last five years increasing attention has been given to the role hydrogen could play in decarbonising heat. The combustion of hydrogen produces no direct greenhouse gas emissions; however, as with other fuels, the potential for eliminating carbon emissions may vary depending on the methods of production.

3.11 Whilst there are multiple methods for producing hydrogen, the most established production methods are methane reformation (MR) and electrolysis.[45] The key characteristics of hydrogen production technologies are outlined in the *Emissions Reduction Potential and Environmental Impacts* section of Chapter 4.

3.12 Historically, hydrogen played a key role in heating in the UK, making up approximately 50% of town gas. However, following the switch to natural gas, the safety of using higher concentrations of hydrogen in the current gas system, including appliances, needs to be proven.

3.13 Some countries have already practically demonstrated hydrogen for heat by blending it into their existing natural gas networks, albeit it at low levels – limited to 2% in Denmark and up to 5% in Germany.[46]

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

41 Vivid Economics for Department for Business, Energy and Industrial Strategy (2018) International Comparisons of Heating, Cooling and Heat Decarbonisation Policies https://www.gov.uk/government/publications/international-comparisons-of-heating-cooling-and-heat-decarbonisation-policies.

42 China IOL, via Delta EE (2018) Chinese heat pumps sales.

43 Department for Business, Energy and Industrial Strategy (2018) Non-domestic and domestic Renewable Heat Incentive (RHI) monthly deployment data October https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/757939/RHI_monthly_official_statistics_tables_Oct_2018_publication.xlsx.

44 Element Energy and E4Tech for the National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

45 The Royal Society (2018) Options for producing low-carbon hydrogen at scale https://royalsociety.org/topics-policy/projects/low-carbon-energy-programme/hydrogen-production/.

46 Netherlands Enterprise Agency (2017). The effects of hydrogen injection in natural gas networks for the Dutch underground storages https://www.rvo.nl/file/effects-hydrogen-injection-natural-gas-networks-dutch-underground-storages.

3.14 There is growing interest in understanding how much hydrogen existing gas networks can tolerate without modification to the grid or appliances. The Committee on Climate Change suggest two potential benefits of blending during a transitional phase to more widespread use. Firstly, it offers potential for reducing the carbon content of the grid in the short-term, without significant infrastructure changes, as long as the hydrogen used is produced in a low carbon way. However, the Committee on Climate Change notes that because the energy content of hydrogen compared to methane is approximately a third lower, a 20% blend would only enable carbon savings of between 4–6% to be achieved, depending on the carbon intensity of the hydrogen used.[47] Without carbon capture use and storage (CCUS), hydrogen production from methane increases emissions. Policy Exchange suggest that without CCUS, blending 20% of hydrogen produced from natural gas steam methane reformation or coal gasification may increase overall emissions by 1.7% or 3.5% respectively, as compared against current lifecycle emissions of natural gas used in the gas network.[48]

3.15 The Committee on Climate Change also suggest that hydrogen blending, alongside other measures, could play a role in building hydrogen production supply chains by proving a steady demand for the hydrogen produced.[49] In the UK, the use of hydrogen in the gas supply is limited to less than 0.1%. HyDeploy, a project funded by Ofgem's Gas Network Innovation Competition, Cadent and Northern Gas Networks, aims to establish the potential for blending hydrogen up to 20% into the natural gas supply.[50]

3.16 Full conversion of the gas grid to run on hydrogen, to achieve greater emissions reductions of the scale needed to meet our Climate Change Act commitments, is widely discussed as an option for decarbonising heat. Physical testing and trialling is required to prove the safety and feasibility of converting the gas system to hydrogen. Subject to this, however, as described in several studies, a conversion of the gas grid to hydrogen could take a variety of forms, from full conversion of the GB gas network, to a more regional approach where individual sections of the grid are converted. Some suggest hydrogen use may be potentially focused on cities or in regions where there are assets that could assist the transition, such as existing natural gas import terminals and proximity to off-shore carbon storage sites.[51,52] The potential for hydrogen to support decarbonisation of industrial emissions is also widely described.

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47 Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.

48 Policy Exchange (2018) Fuelling the Future https://policyexchange.org.uk/publication/fuelling-the-future/.

49 Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.

50 HyDeploy (retrieved November 2018) https://hydeploy.co.uk/about/.

51 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf; Wales & West Utilities (2017) On the road to a green energy UK: Integrated gas & electricity networks support the journey https://www.wwutilities.co.uk/media/2405/on-the-road-to-a-green-energy-uk.pdf.

52 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/imperial-college-2018-analysis-of-alternative-uk-heat-decarbonisation-pathways/.

3.17 Whichever form full conversion might take, it is generally considered that a new transmission network would be required and consumers on the gas grid would need to replace or adapt their gas appliances.[53] Following the lead of H21, most commentators agree that much of the existing gas distribution network – once fitted with polyethylene pipes under the current Iron Mains Replacement Programme – could be suitable for transporting hydrogen with relatively minor additional modifications and conversion work.[54]

3.18 Boilers are currently the cheapest way to produce heat from gas, therefore most commentary on hydrogen for heat is focused on their use. However, other technologies fuelled by hydrogen could potentially be used to provide space heating and hot water, such as gas driven heat pumps and hybrid heat pumps, fuel cells[55] and gas engine combined heat and power units.[56]

Bioenergy

3.19 Bioenergy currently plays a role in providing low carbon energy from organic compounds (biomass) for transport, electricity and heat. When used for heat, biomass can be used as a fuel for biomass boilers, heat networks, process heating in industry and in the production of biogas. In this report we focus on biogas because of its unique ability to be used in the existing gas grid infrastructure. Other types of bioenergy for heat are not covered in detail in this document, but are considered as part of our next steps to phase out the installation of high carbon fossil fuel heating in buildings off the gas grid during the 2020s.

3.20 Biogas is a renewable energy source comprising any low carbon gas that is generated from biomass. One such biogas is biomethane, which is chemically identical to methane and can be used as a replacement for natural gas in the gas grid using common appliances such as gas boilers. It is also possible to make other low carbon gases from biomass, including hydrogen and propane. Biogas can be produced in significant quantities from anaerobic digestion and gasification processes.[57]

53 H21 North of England (2018) H21 Report https://northerngasnetworks.co.uk/h21-noe/H21-NoE-23Nov18-v1.0.pdf.
54 For example: H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf; Policy Exchange (2018) Fuelling the Future https://policyexchange.org.uk/publication/fuelling-the-future/; KPMG (2016) 2050 Energy Scenarios https://www.energynetworks.org/assets/files/gas/futures/KPMG%20Future%20of%20Gas%20Main%20report%20plus%20appendices%20FINAL.pdf.
55 A handful of domestic fuel cell heating systems which run on natural gas (which is converted to hydrogen in the unit) are currently on the market in the UK. These are typically coupled with a gas boiler to provide space heating and hot water, and also provide electricity to the home.
56 Gas engine CHP generates both heat and power. Several natural gas micro-CHP products based on stirling and internal combustion engine technology are available in the UK.
57 Ecofys (2018) Our Vision https://www.gasforclimate2050.eu/our-vision

3.21 In the UK, anaerobic digestion is the only biogas production technology currently used to inject biomethane into the gas grid. It also produces local heat, electricity and transport fuel. Almost half of all biogas produced globally is produced in Europe.[58] According to the European Biogas Association, the UK is one of the top three EU biogas producers.[59]

3.22 Most anaerobic digesters use food and farm wastes and some UK-produced crops such as maize. As well as biogas, the digester process produces two by-products; carbondioxide and digestate, which is used in agricultural settings as a fertiliser.

3.23 Gasification that produces biogas as a fuel is not yet a commercialised technology in the UK. There is one commercial plant in Sweden, and a handful of pilot plants in Europe, including one demonstration plant being developed in the UK. There are no known examples outside Europe.[60] The process of gasification converts biomass into a mixture of gases which can be made into a wide range of products, including biogas. As with anaerobic digestion, carbon dioxide is produced as a by-product. The most suitable feedstocks for bio-gasification are dry biomass, such as the renewable portion of residual wastes, forest and agricultural residues or energy crops.

3.24 The carbon dioxide by-product from biogas technologies could be used with carbon capture and storage technology or used in industry (such as the manufacture of food and drinks) or used to make more biogas.[61] When captured, the carbon that was previously in the atmosphere would now be stored elsewhere, resulting in a net removal of emissions known as 'negative carbon emissions'.

3.25 In the UK, biogas deployment has not focused on a single sector, but has been incentivised for heat, power and transport.[62] In the heating sector, the Renewable Heat Incentive has offered support for biogas for localised use, and for biomethane injection into the gas grid. Estimates suggest that the 85 operational biomethane plants account for around a half of biogas supply in the UK, and that Renewable Heat Incentive support could result in 6.9TWh biomethane produced by 2020/21, which is equivalent to around 1% of total gas supply.[63]

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58 World Bioenergy Association (2017) WBA Global Bioenergy Statistics https://worldbioenergy.org/.uploads/WBA%20GBS%202017_hq.pdf.

59 European Biogas Association (retrieved October 2018) http://european-biogas.eu/.

60 Summary of deployment status of gasification used to produce biogas can be found in: Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy (2018) Innovation and assessment for biomass heat https://www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat.
The UK demonstration plant can be found at: Go Green Gas (retrieved October 2018) https://gogreengas.com.

61 Anaerobic Digestion and Bioresources Association (retrieved October 2018) Power to BioGas http://adbioresources.org/news/power-to-gas-in-anaerobic-digestion-power-to-biogas.

62 Incentive schemes include the Non-Domestic Renewable Heat Incentive (RHI): Ofgem (retrieved November 2018) https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi; Contracts for Difference: Department for Business, Energy and Industrial Strategy (retrieved October 2018) https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference; the Renewables Obligation: Ofgem (retrieved October 2018) https://www.ofgem.gov.uk/environmental-programmes/ro; the Feed in Tariff: Ofgem (retrieved December 2018) https://www.ofgem.gov.uk/environmental-programmes/fit; the Renewable Transport Fuel Obligation: Department for Transport (retrieved October 2018) https://www.gov.uk/guidance/renewable-transport-fuels-obligation.

63 Department for Business, Energy and Industrial Strategy (2018) RHI monthly deployment data: October 2018 https://www.gov.uk/government/statistics/rhi-monthly-deployment-data-october-2018; Department for Business, Energy and Industrial Strategy (2018) The Renewable Heat Incentive: A reformed and refocused scheme (2018) https://www.gov.uk/government/consultations/the-renewable-heat-incentive-a-reformed-and-refocused-scheme.

3.26 The roles biogas could play in heat decarbonisation vary considerably with the volume of biomass available for use in energy and where it is prioritised across the energy system. There are diverse and complex factors bearing on these questions. Across the many published studies there is extensive analysis of the potential for technical, commercial, political and policy developments and of how these could influence: the supply of sustainable feedstocks in the UK and internationally; the way bioenergy resources are distributed in the future between the heating, transport and power sectors, and the cost-effectiveness of biogas production at substantially larger volumes.[64]

3.27 It is widely recognised that levels of sustainable biomass are likely to be constrained. Key studies which estimate biomass availability for energy, such as those from Ricardo,[65] the International Renewable Energy Agency,[66] and the Energy Technologies Institute,[67] reflect only supply that they consider to be within sustainable limits. There are major differences in biomass estimates in published studies, reflecting the high levels of uncertainty. However, the latest evidence review undertaken by the Committee on Climate Change indicates that sustainable supply could meet 5–15% of the UK's primary energy demand.[68]

3.28 Studies considering decarbonisation across the economy, including work undertaken by the Energy Technologies Institute, and the Committee on Climate Change, highlight the importance of bioenergy to reduce the costs of decarbonising UK energy systems, but consider that it is necessary to prioritise biomass where it has the greatest decarbonisation impact, such as its use with carbon capture, usage and storage (CCUS).[69]

64 For a summary of key evidence on sustainable feedstock supply and cost effective scale up for BEIS, see: Ecofys (2018) Bioenergy heat pathways to 2050: rapid evidence assessment – summary report https://www.gov.uk/government/publications/bioenergy-heat-pathways-to-2050-rapid-evidence-assessment; Ecofys and E4Tech for Department for Business, Energy and Industrial Strategy (2018) Innovation needs assessment for biomass heat https://www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat. For the latest reviews on evidence relating to the trade-offs of using bioenergy in the heat, power and transport sector see: Energy Systems Catapult for Energy Technology Institute (2018) The Role for Bioenergy in Decarbonising the UK Energy System: Findings from the ETI bioenergy programme https://www.eti.co.uk/insights/the-role-for-bioenergy-in-decarbonising-the-uk-energy-system-findings-from-the-eti-bioenergy-programme; Committee on Climate Change (2018) Biomass in a low-carbon economy https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/; Committee on Climate Change (2018) Land use: Reducing emissions and preparing for climate change https://www.theccc.org.uk/publication/land-use-reducing-emissions-and-preparing-for-climate-change/.

65 Ricardo Energy and Environment (2017) UK and Global Bioenergy Resource Model https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model.

66 International Renewable Energy Agency (2014) Global Bioenergy Supply and Demand Projections: A working paper for Remap 2030 http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/IRENA_REmap_2030_Biomass_paper_2014.pdf.

67 Energy Technologies Institute (2015) Enabling UK Biomass https://www.eti.co.uk/insights/bioenergy-enabling-uk-biomass.

68 Committee on Climate Change (2018) Biomass in a low-carbon economy https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/.

69 Energy Technologies Institute (2015) Insights into the future UK Bioenergy sector, gained using the ETI's Bioenergy Value Chain Model (BVCM) https://www.eti.co.uk/insights/bioenergy-insights-into-the-future-uk-bioenergy-sector-gained-using-the-etis-bioenergy-value-chain-model-bvcm; Catapult Energy Systems (retrieved October 2018) Whole Energy Systems Analysis https://es.catapult.org.uk/projects/whole-energy-systems-analysis/.

3.29 Other commentators have argued that biomethane could make a useful contribution to low carbon heating because of its ability to mix with natural gas in the gas grid. Current estimates of the potential supply of biogas available for use in heat by 2050 vary widely from around 20TWh,[70] to 67 TWh,[71] depending on which feedstocks are assumed to be available. The review of bioenergy undertaken by Anthesis and E4 Tech for Cadent suggested that 100TWh of biogas could be feasible from UK supplies if new biogas technology was deployed – equivalent to around one third of current household gas use.[72,73] The uncertainty in biogas availability is discussed further in the *Energy System Impacts section* of Chapter 4.

Heat networks

3.30 In tandem with these different low carbon heat sources, heat networks also have the potential to play a key role in decarbonising heat.

3.31 Heat networks are distribution systems of pipes that take heating or cooling from a central source and deliver it to multiple customers such as in public sector buildings, shops and offices, sport facilities, universities and domestic buildings. Some of the cheaper forms of low carbon heat only come at scale (e.g. recovering heat from industry, energy from waste) and a heat network is required to make them viable. The sector needs to grow rapidly from a relatively small base if we are to meet our carbon targets in a cost-effective way.[74] Well designed and operated heat networks can mean lower bills for consumers, and they are particularly well-suited to denser urban areas where heat networks are generally more cost effective.[75]

70 Imperial College London for Committee on Climate Change (2018) Cleaning up the UK's heating systems: new insights into low-carbon heat https://www.theccc.org.uk/2018/09/10/cleaning-up-the-uks-heating-systems-new-insights-on-low-carbon-heat/.

71 Element Energy & E4tech for the National Infrastructure Commission (2018) Cost analysis of future heat infrastructure options https://www.nic.org.uk/supporting-documents/cost-analysis-of-future-heat-infrastructure-options/.

72 Anthesis and E4Tech (2017) Renewable gas potential to 2050 https://cadentgas.com/about-us/the-future-role-of-gas/renewable-gas-potential.

73 Digest of UK Energy Statistics for Department for Business, Energy and Industrial Strategy (2018) Digest of UK Energy Statistics (DUKES): natural gas https://www.gov.uk/government/statistics/natural-gas-chapter-4-digest-of-united-kingdom-energy-statistics-dukes.

74 Element Energy (2015) Element Energy research on district heating for the CCC published alongside 5th Carbon Budget report http://www.element-energy.co.uk/2015/12/element-energy-research-on-district-heating-for-the-ccc-published-alongside-5th-carbon-budget-report/.

75 Competition and Markets Authority (2018) Heat networks market study: Final report (2018) https://www.gov.uk/cma-cases/heat-networks-market-study.

3.32 There are now around 14,000 heat networks across the UK, which supply around 2% of all heat demanded from UK homes, businesses and industry.[76] The Clean Growth Strategy presented an illustrative scenario which suggested heat networks could, by 2050, meet 17% of heat demand in homes and up to 24% of heat demand in business and public-sector buildings.[77] The Committee on Climate Change similarly suggest that around 18% of heat in buildings may need to be supplied by heat networks by 2050 if we are to meet our carbon budgets cost effectively.[78]

3.33 Once built, heat networks are not automatically low-carbon but they are a form of technology agnostic infrastructure to which lower carbon heat generation sources can later be readily plugged in with minimal disruption to consumers. While heat networks have a demonstrated ability to use biomass and heat pumps, as well as being the only demonstrated way to exploit at scale other low-carbon sources like waste-heat and energy-from-waste. There is little evidence on how hydrogen could be used in heat networks, whether combined heat and power conversions would be possible, and to what extent the current market for hydrogen-fuelled systems could grow in future.

3.34 Whilst currently 91% of heat networks are powered by gas, we envisage that more low-carbon fuel sources, like heat pumps and waste heat recovery, will be developed in the future and are seeking to encourage this through the design of the Heat Networks Investment Project and the future market framework for heat networks.[79]

3.35 In addition to the contributions that waste heat, enabled by heat networks, can make to achieving our emission reduction targets, other low carbon sources are also likely to make localised contributions such as solar thermal and geothermal – harnessing heat from the sun and earth. These sources are already contributing to delivering low carbon heating, albeit on a smaller scale than the potential strategic roles electrification, hydrogen and bioenergy may play.

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76 Department for Business, Energy and Industrial Strategy (2018) Heat Networks Statistics https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/712371/Heat_networks_data_tables_revised.xlsx; Department for Business, Energy and Industrial Strategy (2018) Energy Trends: March 2018, special feature article – experimental statistics on heat networks https://www.gov.uk/government/publications/energy-trends-march-2018-special-feature-article-experimental-statistics-on-heat-networks. The experimental statistics may not wholly reflect the true position of the current heat network market due to networks not reporting or providing incorrect returns.

77 Department for Business, Energy and Industrial Strategy (2017) Clean Growth Strategy https://www.gov.uk/government/publications/clean-growth-strategy.

78 Imperial College London for Committee on Climate Change (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

79 Department for Business, Energy and Industrial Strategy (2018) Heat networks: ensuring sustained investment and protecting consumers https://www.gov.uk/government/publications/heat-networks-developing-a-market-framework.

Discussion of the Evidence Base: Characteristics of Low Carbon Options

4. Discussion of the Evidence Base: Characteristics of Low Carbon Options

Introduction

4.1 As a foundation for our work to develop a new long term approach, we have reviewed the current evidence base and analysis relating to low carbon heating from as comprehensive a range of sources as practicable.

4.2 This chapter focuses on the different characteristics of the main alternative sources of low carbon heat i.e. electrification, hydrogen and biogas. Chapter 5 considers the evidence on approaches to achieving the transition to low carbon heating. In these chapters we:

- provide an overview of strategically important issues which our review has highlighted, and of the current evidence base;
- set out “strategic inferences” which we suggest can be drawn from the evidence available at this stage, to help focus the development of our policy framework.

4.3 We invite comments on our overview of the issues and evidence. We also invite views on the “strategic inferences” we have drawn out.

4.4 There is no single or simple way to discuss potential strategies for decarbonising heat:

- strategic options can be framed in very different ways – ranging from explicit technology and infrastructure choices, to technology-neutral policy approaches that engage markets, consumers and intermediaries in new ways;
- all options must be considered from a very wide range of perspectives, to understand the full costs, benefits, risks and opportunities across the economy and society;
- there is inherently a high degree of uncertainty about future opportunities and outcomes given the scale of change and the length of time involved; and,
- any successful change will depend on a diverse range of policy interventions, technology options and market developments acting in combination.

4.5 These complexities are reflected in the diversity of research and studies considering the problem of decarbonising heat. Some focus on particular options or technologies, such as the H21 North of England report which investigates the feasibility of converting the gas grid to hydrogen.[80] Others focus on particular issues as they apply across a range of options, such as household finances[81] or infrastructure requirements.[82] Other studies have sought to make high level assessments of the overall costs and benefits of alternative decarbonisation pathways and scenarios.[83]

80 H21 North of England (2018) https://northerngasnetworks.co.uk/h21-noe/H21-NoE-23Nov18-v1.0.pdf.
81 National Energy Action (2017) Heat Decarbonisation https://www.nea.org.uk/wp-content/uploads/2017/09/Heat-Decarbonisation-Report-2017.pdf.
82 Keith MacLean (2016) Managing Heat Decarbonisation https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf.
83 For example: Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/; National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/; KPMG (2016) 2050 Energy Scenarios https://www.energynetworks.org/assets/files/gas/futures/KPMG%20Future%20of%20Gas%20Main%20report%20plus%20appendices%20FINAL.pdf.

4.6 This chapter seeks to give fair coverage across the main issues identified in our review, while noting that no reasonably concise overview could be comprehensive. For simplicity we have grouped the issues discussed under the following headings:

- Decarbonisation pathways
- Emissions reduction potential and environmental impacts
- Economic costs and benefits
- Consumer experience
- Energy system impacts

4.7 The chapter also includes a discussion on the potential to decarbonise industrial heating. It focuses on industrial processes, which account for approximately 90% of industrial emissionsand the majority of industrial heat demand.[84] These present a different set of decarbonisation challenges from those relating to heat in buildings.

84 BEIS estimates derived from Energy Consumption in the UK (2018) https://www.gov.uk/government/statistics/energy-consumption-in-the-uk.

Decarbonisation pathways

Decarbonisation pathways

4.8 Our review of the evidence confirms there are a range of technologies which have the potential to offer low carbon heating choices in the future, but there is no consensus on which technologies will be able to achieve this most economically and effectively at the scale required over the coming decades.

4.9 There is general recognition that no one technology can provide the best solution for everyone. A mix of technologies and customer options will need to be available to cater for, amongst other things, consumers' different requirements, the variety of building types and conditions, and different local infrastructure provision and constraints.[85] The need to develop a range of options is an important consideration behind existing policy and will continue to be so.

4.10 However, this disguises more uncertain questions concerning the overall balance of technologies in the future, and the scale of consequent changes in demand for different fuels and infrastructure requirements. Few energy experts would envisage that any one heating technology in the future will be as dominant as natural gas combustion is today. However, different visions of the future imply very different requirements of our energy system. This in turn requires us to assess the role of strategic decision making and planning in enabling the most cost-effective outcomes.[86]

4.11 The document *The future of heating: meeting the challenge* published by the then Coalition Government in 2013, envisaged a scenario in which natural gas for heating is progressively replaced in the decades up to 2050: predominantly by a mix of electric heat pumps and, particularly in high density areas, heat networks.[87] In the years since that document was published, there has been increasing focus on the potential for the gas network to continue supplying a substantial proportion of our energy for heat in the longer term, through much greater use of biomethane and / or hydrogen.

4.12 Several recent studies have sought to compare electricity and hydrogen as alternative strategies for decarbonising heat. These include studies carried out for the Committee on Climate Change,[88] the National Infrastructure Commission[89] and the Energy Networks Association.[90] Each of these considers scenarios in which either the GB gas grid is converted to hydrogen, or the vast majority of heating in buildings switches from gas to electricity.

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85 Policy Exchange (2016) Too Hot to Handle? https://policyexchange.org.uk/publication/too-hot-to-handle/.
86 Energy Technologies Institute (2015) Options, Choices, Actions https://www.eti.co.uk/insights/options-choices-actions-uk-scenarios-for-a-low-carbon-energy-system.
87 Department for Energy and Climate Change (2013) The Future of Heating: Meeting the Challenge https://www.gov.uk/government/publications/the-future-of-heating-meeting-the-challenge.
88 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.
89 National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.
90 KPMG (2016) 2050 Energy Scenarioshttps://www.energynetworks.org/assets/files/gas/futures/KPMG%20Future%20of%20Gas%20Main%20report%20plus%20appendices%20FINAL.pdf.

4.13 Such polarised scenarios are inevitably simplified for the purposes of analysis, rather than intended to capture the full complexity of real-world outcomes. However, various commentators have suggested that a fundamental strategic choice will need to be made between a predominantly hydrogen pathway and a predominantly electric pathway.

4.14 A number of studies have sought to model the costs and benefits of mixed scenarios, in which both electricity and biogas play a substantial part, delivered through a variety of heating appliance technologies and district heat networks.[91] Such scenarios are sometimes represented as bottom up rather than top down, and conceived as determined more by individual consumer choices than strategic design.

4.15 Other studies consider scenarios where densely populated urban areas use hydrogen and new, or more rural developments utilise electric or district heating,[92] thereby avoiding disruptive electricity network reinforcement in urban centres.

4.16 In a similar vein, there is a growing body of work considering the potential for greater decentralisation of energy strategies including for heat. The report *Managing Heat Decarbonisation*, for example, proposes that methods of delivery of low carbon heating are established and decided locally.[93] Policy Exchange proposes the creation of market conditions that enable market participants and consumers to decide the most cost-effective routes to decarbonisation.[94] The potential for Local Government, Enterprise Partnerships and other local organisations in promoting heat decarbonisation is discussed further in Chapter 5 of this report.

4.17 Relatively few studies of decarbonisation pathways have sought to model in any detail the transition and implementation processes involved. However, the Leeds H21 study provides an in-depth analysis of the technical and economic feasibility of converting the city of Leeds to 100% hydrogen.[95] A variety of studies have sought in different ways to assess the effort needed to reinforce the electricity distribution system to deliver electric heating scenarios.[96] The report *Managing Heat Decarbonisation* examines key delivery challenges involved in reinforcing the electricity network, converting the gas grid and extending heat networks.[97]

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91 For example: Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/; Policy Exchange (2016) Too Hot to Handle? https://policyexchange.org.uk/publication/too-hot-to-handle/; Energy Technologies Institute (2015) Options, Choices, Actions https://www.eti.co.uk/insights/options-choices-actions-uk-scenarios-for-a-low-carbon-energy-system.

92 Scotia Gas Networks (2018) The Future of Gas Networks https://www.sgn.co.uk/uploadedFiles/Marketing/Pages/Publications/Docs-Environment/SGN-The-future-of-gas-networks.pdf.

93 Keith MacLean et al (2016) Managing Heat Decarbonisation https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf.

94 Policy Exchange (2016) Too Hot to Handle? https://policyexchange.org.uk/publication/too-hot-to-handle/.

95 H21 Leeds City Gate (2016) https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf.

96 For example: Impact of Electric Vehicle and Heat Pump Loads on Network Demand Profiles (2014) https://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-(LCL)/Project-Documents/LCL%20Learning%20Report%20-%20B2%20-%20Impact%20of%20Electric%20Vehicles%20and%20Heat%20Pump%20loads%20on%20network%20demand%20profiles.pdf; Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/; Delta EE for the Department for Business, Energy and Industrial Strategy (2018) Technical Feasibility of Electric Heating in Rural Off Gas Grid Dwellings https://www.gov.uk/government/publications/electric-heating-in-rural-off-gas-grid-dwellings-technical-feasibility.

97 Keith MacLean et al (2016) Managing Heat Decarbonisation https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf.

Emissions reduction potential and environmental impact

Strategic inferences: Emissions reduction potential and environmental impacts

- We need to achieve deep reductions in the greenhouse gas emissions from heat to meet our emission reduction commitments. Technologies using electricity, hydrogen and biogas all have the potential to make important contributions to the transition to low carbon heating.

- Electric heating has the potential to deliver very deep reductions in carbon emissions, extending substantially beyond the levels likely to be needed to enable the UK to meet the economy wide reductions required by 2050 under the Climate Change Act. However, this potential is dependent on the generation of sufficient low carbon electricity and the development of the necessary infrastructure to generate, store and distribute it. The reduction potential is also limited to the extent that a minority of buildings and some heating processes are likely to be unsuitable for switching to electric solutions.

- Hydrogen also has the potential to deliver very deep reductions in carbon emissions, consistent with our 2050 emission reduction commitments However, there is a clear dependency on establishing the feasibility of converting the gas grid safely and on the availability of sufficient feedstock, carbon capture, transport and storage capacity. Current evidence suggests that cost-effectively achieving emissions reductions consistent with our current 2050 commitments through hydrogen is likely to be heavily reliant on methane reformation with carbon capture and storage.

- The ultimate depth of the emissions reduction potential through hydrogen conversion is unclear. Currently it is limited by the practical feasibility of producing sufficient volumes of very low carbon hydrogen from methane reformation and the potential for methane leakage in the production and supply chain. This places a focus on the technical potential and cost of minimising such limitations, the potential to offset residual emissions through negative emissions technologies, and the potential for renewable hydrogen production technologies to be delivered cost-effectively at a large scale.

- Bioenergy has potential to make substantial contributions to emissions reductions from heating through a variety of applications, including the production of biomethane for use in the gas grid. The scale of emissions reduction potential is limited by the volume of biomass available, the prioritisation of its use across the energy economy and life-cycle emissions from production. It is not considered a potential stand-alone solution for heat decarbonisation for these reasons.

- Biogas has a variety of wider potential negative and positive impacts on the environment mainly resulting from its production and use. These need to be carefully managed across the supply chain, and standards will need to keep pace with research and innovation. Compliance will need to be monitored effectively, especially if imports are used. The extent to which methane leakage could undermine greenhouse gas emission reduction is uncertain and requires further analysis.

4.18 This section looks at the potential impacts on the environment from electrification, hydrogen conversion and bioenergy approaches to heating. In the discussion below we start by considering their potential to reduce greenhouse gas emissions from heat. We then discuss the evidence on any wider environmental impacts, such as air and noise pollution.

4.19 The pace and scale of emissions reductions required from our heating sectors will ultimately be determined by what is needed to achieve the nation's overall environmental goals and obligations, including:

- the legal obligations of the Climate Change Act 2008, which currently requires the UK to reduce total greenhouse gas emissions by at least 80% by 2050, compared to 1990 levels. In addition, under the Climate Change Act, legally binding Carbon Budgets have also been set by Parliament for the period up to 2032;
- the UK's international obligations, including our commitments under the 2015 Paris Agreement;
- the Committee on Climate Change's advice, due by the end of March 2019, on whether the 2050 Climate Change Act target should be reviewed to meet international climate targets set out in the Paris Agreement; and on setting a date for achieving net zero greenhouse gas emissions from across the economy;
- wider environmental legislative and policy frameworks, including the Environmental Protection Act 1990, the Government's 25-year Environment plan[98] and the Government's pending Clean Air Strategy 2018.[99]

4.20 We cannot precisely determine the depth of greenhouse gas emissions reductions needed across the heat sector to meet our climate change commitments. This depends on a wide range of factors, including the level of the UK's overall target and the relative cost-effectiveness of emissions reductions in the most difficult to decarbonise activities in our economy, as well as the potential contribution of any emerging negative emissions technologies. However, the Government underlined the essential scale of the challenge in the Clean Growth Strategy. The Strategy reaffirmed that meeting our current 2050 obligations implies decarbonising nearly all heat in buildings and most industrial processes.[100]

4.21 By replacing natural gas heating systems, each of the main potential low carbon energy sources for heat – electricity, hydrogen and bioenergy – offers the potential for reductions in the UK's carbon emissions. However, there are also potential limitations to the pace and scale of emissions reductions that can be delivered cost effectively by the transition to these energy sources. The causes and implications of these limitations are different in each case. The differences in the characteristics of the emissions reduction opportunities and constraints between the different technologies are likely to be important considerations in developing a new long term policy framework.

98 HM Government (2018) 25 Year Environment Plan https://www.gov.uk/government/publications/25-year-environment-plan.
99 HM Government (2018) Air quality: draft Clean Air Strategy 2018 https://consult.defra.gov.uk/environmental-quality/clean-air-strategy-consultation/.
100 Department for Business, Energy and Industrial Strategy (2017) Clean Growth Strategy https://www.gov.uk/government/publications/clean-growth-strategy.

Electrification

4.22 The use of electric heating appliances produces no direct greenhouse gas emissions to the atmosphere at final use. Instead, emissions are produced when generating electricity through different technologies.

4.23 Carbon dioxide and other emissions are produced in the generation of electricity from fossil fuels, and this has historically contributed a major proportion of the UK's total carbon emissions. The emissions reduction potential of electric heating could be constrained by the availability of sufficient low carbon electricity to meet demand. The total emissions reduction potential of electric heating could also, in principle at least, be limited by the adaptability of certain buildings or industrial heating processes.

4.24 The overriding factor determining the level of emissions associated with electric heating is therefore the way the electricity is generated. The carbon intensity of electricity generation has reduced substantially over the last decade, particularly with the phasing out of coal use and the rapid expansion of renewables.[101] Projections for the next decade estimate further sharp falls in the carbon intensity of electricity.[102] However, a major shift from gas to electric heating would result in proportionately very significant increases in both total demand for electricity and requirements for peak generation capacity. This would require a major expansion of low carbon electricity generating capacity from renewable, nuclear or abated fossil fuel installations to achieve the necessary emissions reductions.

4.25 The scale and pace of the expansion required in generating capacity is inherently difficult to estimate. It will be influenced by a complex range of variables, including the scale of increases in both the total volume and the peaks in demand which we might expect to result from mass use of electric heating, and how the electricity system could most effectively develop to manage these changes. To a large extent, these factors depend on the particular technologies installed, the performance of these technologies, and how consumers use them in the future – this is discussed further in the *Energy system impacts* section of this chapter.

4.26 A number of studies have estimated the overall carbon intensity of electricity under predominantly electric heating scenarios. Their figures are broadly similar and are consistent with deep reductions in emissions from heat. For example, the scenario analysis conducted for the National Infrastructure Commission assumes a figure of 30gCO2/kWh by 2050,[103] while National Grid's Future Energy projections outlines a 20gCO2/kWh intensity.[104] In comparison, the current carbon intensity of electricity, based on the grid average generation-based emissions factor, is around 200gCO2/kWh.[105] A study by the Committee on Climate Change informed by extensive new electricity system modelling carried out by Imperial College, explores the potential for electrifying heat to deliver

101 Department for Business, Energy and Industrial Strategy (2018) UK Greenhouse Gas Emissions Statistics 2016 https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2016.

102 Department for Business, Energy and Industrial Strategy (2018) Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal.

103 National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

104 National Grid (2018) Future Energy Scenarios http://fes.nationalgrid.com/fes-document/.

105 Department for Business, Energy and Industrial Strategy (2018) Updated energy and emissions projections: 2017 https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2017.

even greater emissions reductions, which may be required by an economy-wide net zero target.[106]

4.27 Relatively few studies have sought to assess, in detail, the practical challenges and options for achieving the expansion of low carbon generation required by mass electric heating. There is undoubtedly scope for further in-depth analysis. However, the same Committee on Climate Change study supports the view that the electrification of heat, using wider deployment of interconnection and other flexibility technologies, could be a cost-effective means of contributing to net zero targets relative to other approaches studied.

4.28 In addition to electric heating, work undertaken recently by the National Infrastructure Commission, the Committee on Climate Change and BEIS discusses the potential for the use of hybrid heat pumps at scale to be in line with the Government's 2050 commitment, and potentially deeper targets, if supported by low carbon gas (for instance, biogas or hydrogen in place of natural gas).[107] The level of carbon savings achieved through hybrid heat pumps would depend on: the relative proportions of heat demand met by gas and electricity,[108] the relative levels of power sector decarbonisation,[109] and the carbon content of the gas grid.[110]

4.29 In terms of wider environmental impacts, the conversion of electricity to heat results in no direct emissions of air pollutants; unlike natural gas, the combustion of which releases low levels of air pollutants such as NOx, PM2.5 and SO2 emissions.[111] Where hybrid heat pumps utilise biogas they will also be subject to the environmental impacts applicable to these gasses.

Hydrogen conversion

4.30 The combustion of hydrogen produces no greenhouse gas emissions.[112] However, the established methods for producing hydrogen on a large-scale use fossil fuels as the feedstock and emit carbon dioxide as a by-product.[113] In order to contribute to emissions reduction, hydrogen produced in these ways would depend on carbon capture at the hydrogen conversion plant, and the development of extensive carbon transport and storage infrastructure.

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106 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

107 Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/; National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

108 Element Energy (2017) Hybrid Heat Pumps Study https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf; National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

109 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

110 National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/; Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

111 Department for Business Energy Industry and Skills (retrieved October 2018) http://naei.beis.gov.uk/.

112 Sustainable Gas Institute, Imperial College London (2017) A greener gas grid: What are the options? https://www.sustainablegasinstitute.org/a-greener-gas-grid/.

113 Friends of the Earth (2018) Delivering on the Paris Climate Agreement – the future of home heating https://cdn.friendsoftheearth.uk/sites/default/files/downloads/Future%20of%20Heating_August_2018.pdf.

4.31 A range of studies have calculated that replacing natural gas with hydrogen in our gas distribution network would enable us to reduce emissions from heating consistent with our 2050 carbon targets, provided that methane reformation with carbon capture, usage and storage (CCUS) is employed.[114] These studies assume that the large majority, or all, of the hydrogen required is produced through methane reformation, using natural gas as the feedstock. For example, the Committee on Climate Change take the view that methane reformation is likely to be the only viable technology for producing hydrogen at the scale necessary to meet heat demand in the UK.[115] Methane reformation plants are an established technology in commercial operation and exist in the UK today. Currently there are several large-scale plants with carbon capture and storage in operation internationally,[116] although actual capture rates are currently lower than the levels assumed in many studies.[117]

4.32 The potential for achieving deeper emissions reductions beyond the UK's current 2050 targets has not been as widely discussed. However, beyond a certain point, reducing emissions from hydrogen production processes based on methane reformation with carbon capture and storage is likely to be practically very challenging, given current limitations to cost-effective carbon capture rates and the potential for supply chain emissions, for example from methane leakage.[118,119] There are a variety of alternative technologies for producing hydrogen which do not rely on natural gas or other fossil fuel feedstocks and which have potential to be associated with lower levels of carbon emissions, but their ability to deliver deeper emissions reductions at the scale needed for heat is currently unclear.[120]

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114 For example: H21 Leeds City Gate (2016) https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf; Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/; National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

115 Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.

116 H21 North of England (2018) H21 Report https://northerngasnetworks.co.uk/h21-noe/H21-NoE-23Nov18-v1.0.pdf

117 Both the Quest and the Air Products steam methane reformation capture approximately 1Mtpa, see: Global CC Institute (retrieved November 2018) Large-scale CCS facilities https://www.globalccsinstitute.com/projects/large-scale-ccs-projects.

118 Increasing methane leakage rates by 1% of gas demand could increase carbon emissions by 37% Balcombe et al. (2018) The carbon credentials of hydrogen gas networks and supply chains https://www.sciencedirect.com/science/article/pii/S1364032118302983.

119 See for example: Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/; Sustainable Gas Institute (2015) White Paper 1: Methane & CO2 emissions from the natural gas supply chain https://www.sustainablegasinstitute.org/white-paper-1/.

120 The Royal Society (2018) Options for producing low-carbon hydrogen at scale https://royalsociety.org/topics-policy/projects/low-carbon-energy-programme/hydrogen-production/; Sustainable Gas Institute (2017) A Greener Gas Grid https://www.sustainablegasinstitute.org/a-greener-gas-grid/.

4.33 The small-scale production of hydrogen via electrolysis is a proven technology and the carbon intensity of the resulting hydrogen depends on the carbon intensity of the additional electricity used to produce it.[121] Emissions could be produced in the generation of the electricity used, so large increases in low carbon or negative carbon sources of electricity would be required to achieve the emissions reduction levels consistent with our 2050 targets – this is discussed further in the *Energy system impacts* section of this chapter. A second key challenge to the production of hydrogen through electrolysis at scale is its likely cost effectiveness compared to alternatives.[122] Production from electrolysis powered by excess renewable generation at times of oversupply could be much cheaper. However, studies, including the Policy Exchange report *Fuelling the Future*, suggest that it may be infeasible for the volume of excess supply from renewable generation to be sufficient to power hydrogen production on a very large scale even in the long term.[123] Policy Exchange estimate that even if curtailment reaches a high level of 75 TWh by 2050 and heat demand stays relatively constant, hydrogen from electrolysis using curtailed wind could only provide approximately 14% of the UK domestic heating load.[124]

4.34 Various commentators have noted the possibility of importing low carbon hydrogen produced by electrolysis from regions where renewable solar energy might become very cheap in the future. The energy requirements for the compression and transportation of hydrogen over long distances would need to be accounted for when considering the emissions saving potential of these imports. However, as far as we are aware, there is little evidence or analysis currently available to help assess such production and transport possibilities. Further, whilst the international supply of hydrogen from electrolysis is conceivable, international demand for hydrogen must also be considered – it is unlikely that the UK would be the only country competing for such supplies. What this regional or global competition could mean for availability and price needs to be better understood.

4.35 Hydrogen might also potentially be produced through gasification of biomass. Combined with carbon capture and storage this process has the potential to generate negative emissions. Analysis by the Committee on Climate Change and the Energy Technologies Institute favours hydrogen production as one of the biomass routes with the greatest emission reduction potential. With constrained available supply and many potential uses for hydrogen, its best use would need to be considered across the economy.[125]

121 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

122 Sustainable Gas Institute (2017) A greener gas grid what are the options? https://www.sustainablegasinstitute.org/a-greener-gas-grid/; Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

123 Policy Exchange (2018) Fuelling the future https://policyexchange.org.uk/publication/fuelling-the-future/; Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

124 Policy Exchange (2018) Fuelling the future https://policyexchange.org.uk/publication/fuelling-the-future/.

125 Committee on Climate Change (2018) Biomass in a low carbon economy https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/; Energy Technology institute (2018) The role for bioenergy in decarbonising the UK energy system https://www.eti.co.uk/insights/the-role-for-bioenergy-in-decarbonising-the-uk-energy-system-findings-from-the-eti-bioenergy-programme.

4.36 Coal can be gasified to produce hydrogen and, similarly to methane reformation, would need to be combined with CCUS to contribute to greenhouse gas emissions reductions. The Committee on Climate Change estimate the cost of coal gasification to be higher than that of methane reformation and only offer emissions savings of 7–56% compared to natural gas. They therefore do not consider it a viable means of low carbon hydrogen production in the UK.[126]

4.37 Fundamentally, the feasibility of emissions reductions from replacing natural gas with hydrogen on this scale depends on first establishing the safety and practicality of converting the gas network, and consumers' premises. This is discussed in further detail later in this chapter. The Government and the gas network operators have begun preparing for the physical tests and trials which would be required.[127]

4.38 Hydrogen could leak into the atmosphere during its production, distribution and use and there is evidence that hydrogen gas has an indirect warming effect and may slow the repair of the ozone layer.[128] While these impacts are thought to be small, the evidence is limited, and uncertainties remain.

4.39 In terms of wider environmental impacts, given that the use of low carbon hydrogen for heating is at an exploratory stage, evidence on the potential environmental impacts and possible mitigations is limited. One study suggests that a range of air pollutants may be associated with hydrogen production through methane reformation, including nitrogen oxides, sulphur oxides, volatile organic compounds and particulate matter.[129] Both methane reformation and electrolysis require water as a feedstock, although evidence is limited on the strains, if any, this could place on water resources.[130] The production of hydrogen using bioenergy will involve similar environmental considerations as those discussed in the context of bioenergy as detailed later in this section of the report.

4.40 As highlighted in a study by Kiwa, the combustion of hydrogen could also result in increased emission of nitrous oxides compared to combusting natural gas.[131] The Hy4Heat project is developing and testing domestic hydrogen appliances to better understand the potential level of these emissions for difference appliance designs and the trade off between the cost, efficiency and emissions.

126 Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.

127 Northern Gas Networks (2017) Gas NIC submission: Northern Gas Networks – H21 https://www.ofgem.gov.uk/publications-and-updates/gas-nic-submission-northern-gas-networks-h21; Hy4Heat (retrieved November 2018) https://www.hy4heat.info/.

128 Derwent (2018) Atmospheric Impacts of Hydrogen https://www.gov.uk/government/publications/atmospheric-impacts-of-hydrogen-literature-review.

129 Young et al (2017) Creation Of Unit Process Data For Life Cycle Assessment Of Steam Methane Reforming And Petroleum Refining https://greet.es.anl.gov/files/air_pollutants_smr_petroleum.

130 Department for Business, Energy and Industrial Strategy (2018) Hydrogen supply chain evidence base https://www.gov.uk/government/publications/hydrogen-supply-chain-evidence-base.

131 Kiwa for the Department of Energy and Climate Change (2016) Hydrogen Appliances: Desk study on the development of the supply chain for 100% hydrogen-fired domestic and commercial appliances https://www.gov.uk/government/publications/hydrogen-appliances-desk-study-on-the-development-of-the-supply-chain-for-100-hydrogen-fired-domestic-and-commercial-appliances; Frazer-Nash (2018) Appraisal of Domestic Hydrogen Appliances https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/699685/Hydrogen_Appliances-For_Publication-14-02-2018-PDF.pdf.

Bioenergy

4.41 The potential for bioenergy to contribute to greenhouse gas emissions reductions from heating is dependent on a number of factors, including: the availability of biomass feedstocks for use in heating, the lifecycle emissions associated with production of bioenergy, and additional emissions (or emission savings) that arise indirectly as a result of its production.

4.42 Biogas is generally considered to be a low-carbon fuel. When burned for energy, the emissions released are balanced out by the carbon dioxide captured through the growth of the biogas feedstock.[132] Estimating emissions associated with biogas production is inherently uncertain and may vary greatly due to the many ways in which feedstocks can be grown, transported and processed to produce biogas.[133]

4.43 There are many lifecycle carbon savings assessment methodologies for bioenergy, which have a huge variation of scope and methods, and produce a wide range of results. The most widely recognised is the large body of work undertaken by the European Commission's Joint Research Committee (JRC)[134] and Member States,[135,136] who have estimated emissions from a range of bioenergy pathways, including biogas production. The analysis shows that biomethane can achieve high greenhouse gas savings compared to fossil fuels, but variation between individual pathways is wide. Where supply is from wastes, biomethane can achieve savings greater than 100%. However, for biogas produced from maize, where digestate is stored in open tanks, biogas could achieve poor greenhouse gas savings compared to fossil fuels.[137]

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132 Committee on Climate Change (2011) Bioenergy Review https://www.theccc.org.uk/publication/bioenergy-review/.
133 National Non-Food Crops Centre (2016) Assessment of Impact on Biogas Producers of Proposed Changes to Sustainability Criteria https://www.nnfcc.co.uk/publications/report-impact-biogas-sustainability-criteria.
134 Joint Research Committee (2018) Sustainability criteria https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/sustainability-criteria; Joint Research Committee (2017) Solid and gaseous bioenergy pathways: input values and GHG emissions: Calculated according to methodology set in COM(2016) 767: Version 2 https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/solid-and-gaseous-bioenergy-pathways-input-values-and-ghg-emissions-calculated-according-0.
135 Biograce (retrieved October 2018) http://www.biograce.net/.
136 Ofgem (retrieved October 2018) The UK Solid and Gaseous Biomass Carbon Calculator https://www.ofgem.gov.uk/publications-and-updates/uk-solid-and-gaseous-biomass-carbon-calculator.
137 Joint Research Committee (2017) https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/solid-and-gaseous-bioenergy-pathways-input-values-and-ghg-emissions-calculated-according-0 (Table 104).

4.44 In terms of domestic feedstock supply, wastes and residues from agriculture and forestry tend to offer greater emission savings compared to crops.[138] Imported biomass can also deliver high greenhouse gas savings, but may result in additional greenhouse gas emissions during production and transportation compared to similar UK feedstocks. Widespread implementation of minimum greenhouse gas emission standards help to ensure that biomass achieves a saving of at least 60% from fossil fuels which could be tightened over time.[139]

4.45 Without careful control, the consequences of biogas use can extend beyond the impacts of production, transport and conversion to energy, and could result in further emissions. Analysis undertaken by BEIS,[140] the Energy Technologies Institute[141] and others,[142] have considered the scale and likelihood of impacts from forest management practices or direct or indirect land use change, which can be substantial. In some cases, emissions from fossil fuels can occur alongside the production and use of biogas, for instance propane is currently blended with biomethane to meet UK gas quality standards.[143] These fossil fuel derived energy sources have high greenhouse gas emissions,[144] which could make it more challenging to meet stretching greenhouse gas targets.

4.46 Methane leakage could occur during production of biomethane, or as it moves through the gas grid. This potentially reduces anticipated greenhouse savings as methane is a potent greenhouse gas.[145] Data relating to methane loss from natural gas and biomethane production may not be sufficient to form robust estimates of the impact of leakage in the context of potentially tighter emissions reduction requirements.[146]

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138 Joint Research Committee (2017) Solid and gaseous bioenergy pathways: input values and GHG emissions: Calculated according to methodology set in COM(2016) 767: Version 2 https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/solid-and-gaseous-bioenergy-pathways-input-values-and-ghg-emissions-calculated-according-0.
139 Main requirement and justification for the implementation of EU and UK schemes can be found at: European Commission (retrieved October 2018) https://ec.europa.eu/energy/en/topics/renewable-energy/biomass; Ofgem (2016) https://www.ofgem.gov.uk/ofgem-publications/89240/guidancevolume2v7finalmarch2016-pdf; Ofgem (2018) https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-sustainability-criteria.
140 Such as: Department of Energy and Climate Change (2014) https://www.gov.uk/government/publications/life-cycle-impacts-of-biomass-electricity-in-2020; Ricardo Energy and Environment for BEIS (2016) https://www.gov.uk/government/publications/use-of-high-carbon-north-american-woody-biomass-in-uk-electricity-generation.
141 Ecosystem Land Use Modelling and Soil Carbon Flux Trial (retrieved November 2018) http://www.elum.ac.uk/publications.
142 For example: Forest Research (retrieved October 2018) https://europeanclimate.org/wp-content/uploads/2018/05/CIB-Summary-report-for-ECF-v10.5-May-20181.pdf.
143 Northern Gas Networks (retrieved October 2018) http://biomethane.northerngasnetworks.co.uk/wp-content/uploads/2015/11/NGN-Biomethane-Full-document-low-res.pdf.
144 Department for Business, Energy and Industrial Strategy (retrieved October 2018) https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018.
145 Intergovernmental Panel on Climate Change (retrieved October 2018) https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html.
146 For example see evidence review: Imperial College London and Sustainable Gas Institute (2015) https://www.sustainablegasinstitute.org/pdf-form/?pdf=wp-content/uploads/2015/09/SGI_White_Paper_methane-and-CO2-emissions_WEB-FINAL.pdf.

4.47 There are potentially further emissions benefits from biogas that can result in the net removal of greenhouse gas emissions from the atmosphere. There is very little exploration of technologies compatible with carbon capture, usage and storage (CCUS) other than power and hydrogen, but the Energy Technologies Institute's modelling also identifies gasification to other fuels such as biomethane or transport fuels as CCUS compatible.[147] Other ways in which biogas production could lead to negative emissions are less well understood and warrant further consideration.[148] These include enabling land used to produce bioenergy to increase soil carbon and capturing the CO2 by-product from anaerobic digestion.

4.48 The production of biomass and the conversion of biomass into biogas can also result in wider environmental impacts beyond greenhouse gas emissions, both positive and negative.

4.49 Through utilising wastes, anaerobic digestion is recognised as playing an important role in reducing the environmental impacts of landfill as we move towards a zero avoidable waste economy.[149] However, not all anaerobic digestion feedstocks have such clear environmental benefits; for example, sub-optimal production of food crops could have negative impacts on soil erosion and water quality. The extent to which best practice is adopted is uncertain.[150] Some farming systems currently in operation seek to demonstrate that crops can be used in anaerobic digestion as part of sustainable farm management.[151]

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147 Energy Technologies Institute (retrieved October 2018) https://www.eti.co.uk/insights/targeting-new-and-cleaner-uses-for-wastes-and-biomass-using-gasification.

148 Main bodies of work include: European Academies Science Advisory Council (2018) https://easac.eu/publications/details/easac-net/ and The Royal Society and the Royal Academy of Engineering (2018) https://royalsociety.org/topics-policy/projects/greenhouse-gas-removal/.

149 Government statements include: Department for Environment, Food and Rural Affairs (2018) Single Departmental Plan https://www.gov.uk/government/publications/department-for-environment-food-and-rural-affairs-single-departmental-plan/department-for-environment-food-and-rural-affairs-single-departmental-plan-may-2018; (2018) Department for Environment, Food and Rural Affairs (2011) Guidance on applying the waste hierarchy https://www.gov.uk/government/publications/guidance-on-applying-the-waste-hierarchy; Welsh Government (retrieved October 2018) Towards Zero Waste https://gov.wales/topics/environmentcountryside/epq/waste_recycling/zerowaste/?lang=en; Scottish Government (retrieved October 2018) Scotland's Zero Waste Plan https://www.gov.scot/Topics/Environment/waste-and-pollution/Waste-1/wastestrategy.

150 Anaerobic Digestion and Bioresources Association (2014) Crop Best Practice Document http://adbioresources.org/library/crop-best-practice-document.

151 Examples include: Ecofys (2018) Assessing the case for sequential cropping to produce low ILUC risk biomethane https://www.ecofys.com/files/files/ecofys-2016-assessing-benefits-sequential-cropping.pdf; Ecotricity (2016) Green Gas: The opportunity for Britain https://www.ecotricity.co.uk/content/download/397/file/green-gas-report.pdf.

4.50 Anaerobic digestion also produces digestate; a by-product which can improve soil quality and replace conventional fertilisers.[152] Digestate can emit more ammonia than the fertilisers it is likely to replace. Ammonia causes significant damage to sensitive habitats and can combine with other chemicals in the atmosphere to form particulate matter which has serious impacts on human health.[153] Digestate currently accounts for around 3% of UK ammonia emissions[154] but could increase as industry expands, even if existing technologies to reduce emissions were implemented.[155]

4.51 Gasification uses a set of dry biomass feedstocks which are very different in scale and reach, particularly in cases where biomass could be imported. The current gasification industry is focused on the use of municipal mixed waste and wood waste, which presents an opportunity to use waste as a valuable resource.[156]

152 Waste Resources Action Programme (2016) Digestate and composte in agriculture (DC-Agri) project reports http://www.wrap.org.uk/content/digestate-and-compost-agriculture-dc-agri-reports.

153 Royal Society (2018) Evidence synthesis https://royalsociety.org/topics-policy/projects/evidence-synthesis/.

154 Ricardo Energy and Environment (2018) UK Informative Inventory Report (1990-2016) https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1803161032_GB_IIR_2018_v1.2.pdf.

155 Department for Environment, Food and Rural Affairs (2018) Air quality: draft Clean Air Strategy 2018 https://consult.defra.gov.uk/environmental-quality/clean-air-strategy-consultation/.

156 Energy Technologies Institute (retrieved October 2018) Targeting new and cleaner uses for wastes and biomass using gasification https://www.eti.co.uk/insights/targeting-new-and-cleaner-uses-for-wastes-and-biomass-using-gasification; Green Investment Group (retrieved October 2018) Investing in the next generation of waste infrastructure http://greeninvestmentgroup.com/investment-sectors/waste-and-bioenergy.

4.52 There has been extensive research into the direct and indirect impacts of increased biomass production. The thrust of this suggests the greatest potential impact is damage or displacement of natural habitats and biodiversity ecosystem services.[157] The EU and UK have implemented the most comprehensive sustainability standards[158] and high compliance rates are reported,[159] however there are concerns about the ability to detect malpractice, especially overseas, and the ability to assess indirect impacts of land-use change.[160] A number of potential improvements to existing sustainability and governance have been made.[161]

4.53 The production of biomass feedstocks, if done in the right way, can also have a net positive environmental impact.[162] For example, the UK Forestry Standard sets out ways in which active management can have a beneficial impact on biodiversity.[163] There is also evidence to suggest that in the right locations, energy crops can be better for biodiversity, water management, soil quality and soil carbon stocks than traditional agricultural crops.[164] However, these positive impacts are generally harder to measure and less well understood.

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157 This site summarises the evidence which led to the European Commissions main findings on the potential risks of biomass production on land use: European Commission (Retrieved October 2018) Biomass https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/sustainability-criteria.

158 Main standards are set out in: Eur-Lex (retrieved October 2018) https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0028; Ofgem (2018) Renewables Obligation: Sustainability Criteria https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-sustainability-criteria; Ofgem (2016) Non-Domestic Renewable Heat Incentive (RHI): Guidance Volume Two: Ongoing Obligations and Payments (Version 7) https://www.ofgem.gov.uk/ofgem-publications/89240/guidancevolume2v7finalmarch2016-pdf.

159 99.96% of biofuels in the UK met the sustainability criteria in 2016–2017: Department for Transport (2018) Renewable Transport Fuel Obligation: annual report 2016-2017 https://www.gov.uk/government/publications/renewable-transport-fuel-obligation-annual-report-2016-to-2017; Ofgem (2018) Renewables Obligation (RO): Annual Report 2016-17 https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-ro-annual-report-2016-17.

160 Examples of issues identified include: World Wide Fund for Nature (2017) EU bioenergy policy http://d2ouvy59p0dg6k.cloudfront.net/downloads/eu_bioenergy_policy___wwf_briefing_paper___final_4.pdf; Biofuelwatch (2016) Why the UK's New Sustainability and Greenhouse Gas Standards for Biomass Cannot Guarantee Sustainability or Low Carbon Impacts http://www.biofuelwatch.org.uk/docs/Biomass-Sustainability-standards-briefing1.pdf; Global CCS Institute (Retrieved October 2018) Impacts of biofuels on food prices https://hub.globalccsinstitute.com/publications/biofuels-markets-targets-and-impacts/6-impacts-biofuels-food-prices.

161 European Commission (retrieved November 2018) Land use change; The International Council on Clean Transportation (2018) Final recast Renewable Energy Directive for 2021–2030 in the European Union https://www.theicct.org/publications/final-recast-renewable-energy-directive-2021-2030-european-union; Committee on Climate Change (2018) Biomass in a low-carbon economy https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/.

162 Energy Technology Institute (2018) The Role for Bioenergy in Decarbonising the UK Energy System: Findings from the ETI Bioenergy Programme https://www.eti.co.uk/insights/the-role-for-bioenergy-in-decarbonising-the-uk-energy-system-findings-from-the-eti-bioenergy-programme.

163 Forestry Commission (2017) The UK Forestry Standard: The government's approach to sustainable forestry https://www.forestry.gov.uk/pdf/FCFC001.pdf/$FILE/FCFC001.pdf.

164 For example: Centre for Ecology and Hydrology (2017) Consensus, uncertainties and challenges for perennial bioenergy crops and land use https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5815384/; The International Council on Clean Transportation (2016) Crops of the Biofrontier: In Search of Opportunities for Sustainable Energy Cropping https://www.theicct.org/sites/default/files/publications/Energy%20Crop%20White%20Paper%20vF.pdf.

Economic costs and benefits

Strategic inferences: economic costs and benefits

- All approaches to decarbonising heat will require very substantial new capital investment in energy production and infrastructure. At the same time, this will provide opportunities to grow the low carbon heating sector.
- Estimates of the costs and benefits of low carbon heating technologies and pathways over the longer term are subject to very significant uncertainties.
- There are now several substantial published studies estimating the costs of a range of alternative pathways for decarbonising heat. On the evidence of these studies there is not a clear basis for determining which approaches are likely to be the most cost-effective overall.
- Gas-based solutions can be expected to involve higher operating costs than electric solutions, primarily due to the lower efficiencies of boilers compared to heat pumps and the reliance on natural gas or biomass feed stocks to produce the required gas, while electric heat pumps can be expected to involve higher consumer appliance costs.
- One key uncertainty is the potential extent to which more flexible energy systems could be deployed and achieve savings. These could substantially reduce the need for additional investments in infrastructure, especially but not exclusively under predominantly electric approaches.
- Continuing innovation and market development will be important in driving down the costs and raising performance efficiencies of different low carbon heating technologies. Even for technologies which are already relatively well established, there remains considerable scope for further cost reductions and performance improvements over time and with scale up. Uncertainty about changes in the wider energy system and markets more broadly will also impact on costs.
- Any future policy framework will need to address the distribution of costs across the energy system and different groups of consumers, for example in terms of affordability for consumers, fairness across society and support and protections for vulnerable users.

4.54 The costs of heating today represent substantial national[165] and household expenditure.[166] As discussed in Chapter 2, major industries support the provision of energy, infrastructure, appliances and services for heating. Shifting our heating to low carbon energy sources and technologies will require major investment in new infrastructure, products and services. The costs and benefits of the transition to low carbon heating will depend both on the efficiency with which these changes occur, and the types of low carbon heating solutions and systems which we adopt.

4.55 The primary economic benefits of transitioning to low carbon economies in the UK and globally will be those which arise from avoiding or minimising costs resulting from the effects of global climate change.[167] Decarbonising heating will make a critical contribution to achieving those benefits, however a discussion of these is beyond the scope of this evidence review. There could also be direct benefits to consumers from the transition to low carbon heating as innovative new business models, technologies and services emerge.

4.56 The Government's Industrial Strategy emphasises the huge opportunities for UK industries, businesses and workers as we and the other major economies around the world decarbonise. Heat decarbonisation represents a major part of the Industrial Strategy opportunities arising from the global drive for clean growth. These opportunities are discussed further in Chapter 2. However, a detailed analysis of the economic opportunities for UK business is again outside the scope of this evidence review.

4.57 The remainder of this section discusses the evidence available on the costs involved in different approaches to decarbonising heat. There is inherently a high degree of uncertainty involved in estimating these costs at the national scale. A wide range of empirical information is available, evidencing the current costs and performance of different low carbon heating technologies, as well as many sources for estimates and analyses of future trends.[168] However, the transition to low carbon heating will involve the development of major new markets and infrastructure change over a period of decades.

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165 The National Infrastructure Commission estimate expenditure on heating as 1.2% of GDP in 2015: National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

166 In 2014, 12% of household expenditure was on gas for fuel: Office for National Statistics (2015) Family Spending A11 https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/compendium/familyspending/2015/familyspending2015referencetables.

167 Nicholas Stern, London School of Economics (2006) Stern Review: The Economics of Climate Change http://www.lse.ac.uk/GranthamInstitute/publication/the-economics-of-climate-change-the-stern-review/.

168 Although not intended to be comprehensive, the bibliography lists a wide range of sources, including research commissioned by BEIS in preparing this report.

4.58 Over this period and scale of change there is potentially significant scope for innovation and efficiencies to lower costs and improve performance, as well as the potential for unanticipated challenges and costs. Even for low carbon heating technologies that are already widely deployed around the world and extensively studied, such as electric heat pumps, we can anticipate that their cost will be substantially lower in the future, with greatly increasing scale driving efficiencies and innovations. In addition, the extent of building energy efficiency measures installed will also impact overall costs in all scenarios to varying extents.[169]

4.59 Numerous studies and reports estimate the overall costs of decarbonising heating; some within an overall assessment of the costs of decarbonising the economy, and others more or less limited to heat decarbonisation pathways. All such studies acknowledge the large range of uncertainties involved in estimating future costs, and some present estimates within ranges.

4.60 The results of such studies are not generally directly comparable, due to differences in scope, for example some include industrial heating while others are limited to buildings. Importantly, studies vary in terms of the level of carbon savings assumed from heating. Sensitivity analysis on targeted buildings and industry decarbonisation levels by Imperial College for the Committee on Climate Change also suggest that the lower the greenhouse gas emissions target for heat, the higher the likely pathway costs.[170] Estimates of costs vary, reflecting these factors and the substantial uncertainties involved.

4.61 However, such studies invariably estimate that the costs of low carbon heating will be higher than the costs of fossil fuel-based heating today. For example, a report prepared for the National Infrastructure Commission earlier this year concluded that the amount households spend annually on heat could increase by £100–£300 by 2050.[171] This report also notes that, while costs will be higher in the future, with these estimates we would be spending a lower proportion of our GDP (in nominal terms) on heating in 2050 than we do today.

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169 Recent examples of studies estimating costs of decarbonising heating include: National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/; Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

170 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

171 National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

4.62 Our evidence review indicates there is a fairly high degree of alignment between the majority of such studies in terms of the relative costs of different decarbonisation pathways. There are exceptions to this broad picture. The report, *2050 Energy Scenarios: The UK gas networks role in the 2050 whole energy system* for example, estimates significantly higher costs under an electrification scenario than under alternative scenarios.[172] In most studies, however, the estimated cost differences between the various scenarios assessed appear relatively small compared to the very large uncertainties to which all such estimates are subject.

4.63 There are clearly substantial differences in where the main costs arise between different approaches to decarbonising heating. These differences may have significant implications, for example when costs might be incurred, the level of risk or opportunity in relation to future costs, and for how costs might be distributed between different types of consumer (subject to any policy interventions as is discussed further in Chapter 5).

4.64 Any heating system will involve costs in the production of fuel, the transport and storage of energy and the manufacture and installation of heating appliances. In the following paragraphs we summarise our understanding of the current evidence on the main cost drivers relating to use of electricity, hydrogen and bioenergy.

Electrification

4.65 The largest categories of cost relating to electric heating are the capital costs of the energy system infrastructure, including the necessary electricity generation capacity, and the appliances required to deliver it.[173]

4.66 The highly capital-intensive nature of electrification places significance on how costs are distributed and on policies or market-led developments to reduce upfront costs.[174] In particular, consumer appliance costs will be one of the largest drivers of costs.[175] This includes the cost of the heating appliance itself, changes to the building and wider heating system (such as insulation, larger emitters, or hot water storage) and the cost of installation. Air source heat pumps, including their installation, currently cost around £6,000 to £11,500 for the average UK household, and ground source heat pumps cost between £9,000 and £20,000+ depending on size, complexity of install and, for ground source heat pumps, the groundworks required.[176]

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

173 For example: National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/; Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

174 National Energy Action (2017) Heat Decarbonisation: Potential impacts on social equity and fuel poverty http://www.nea.org.uk/wp-content/uploads/2017/09/Heat-Decarbonisation-Report-2017.pdf

175 For example: National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/; Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

176 Delta-ee (2016) The potential for a novel fuel cell – heat pump heating system https://www.delta-ee.com/downloads/783-the-potential-for-a-novel-fuel-cell-heat-pump-heating-system.html

4.67 The costs of deploying heat pumps are currently spread broadly across the appliance, installation and overheads. Studies emphasise the uncertainty around the potential for cost reduction, with suggestions that despite heat pumps' relative maturity as a low carbon heating technology significant cost reductions may be possible in the UK market.[177] This could draw upon innovation in global markets, given that many countries do not have an extensive reliance on natural gas at present and will therefore need to use low carbon electricity to decarbonise their heating. A study by Delta-ee for the then Department of Energy and Climate Change found that installation costs fall significantly as the volume of sales increases and that this could drive a fall in overall costs of approximately 20%.[178] Additionally, the heat Technology Innovation Needs Assessment suggests that innovation and deployment could reduce heat pump technology costs by 50% by 2050.[179] Recent experience in the Solar PV and Offshore Wind sectors show that rapid deployment of technologies at scale can drive down costs quickly.

4.68 With performance at around SPF 2.5,[180] heat pumps should have roughly similar running costs for fuel as current gas systems (at current prices).[181]

4.69 Some studies suggest the use of hybrid systems could potentially reduce installation costs through the avoidance of radiator replacements, fabric efficiency improvements, hot water tank installation and changes to cooking equipment.[182] One study estimates that a hybrid system can be 25% cheaper than a stand-alone heat pump, although exact costs would depend on the system design.[183]

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177 For example: National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/; Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

178 Delta-ee (2016) Potential Cost Reductions for Air Source Heat Pumps https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/498962/150113_Delta-ee_Final_ASHP_report_DECC.pdf. Current data and future scenarios reflect expert opinion informed by primary research as part of this project (27 phone interviews with industry stakeholders, i.e. product manufacturers, installers, distributors, industry groups), as well as the project team's several years of heat pump market research through Delta-ee's Heat Pump Research Service and consultancy work into the heating market globally, and through Chris Dale's experiences managing the UK business of one of Europe's major heat pump manufacturers.

179 Low Carbon Innovation Coordination Group (2012) Technology Innovation Needs Assessment (TINA): Heat Summary Report https://www.carbontrust.com/media/190042/tina-heat-summary-report.pdf.

180 UCL Energy Institute (2017) Final report on the analysis of heat pump data from the renewable heat premium payment (RHPP) scheme https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/606818/DECC_RHPP_161214_Final_Report_v1-13.pdf.

181 Department for Business, Energy and Industrial Strategy (2018) Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal.

182 For example: Element Energy (2017) Hybrid Heat Pumps Study https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf; The Carbon Trust and Rawlings Support Services (2016) Evidence gathering – Low Carbon Heating Technologies: Domestic High Temperature, Hybrid and Gas Driven Heat Pumps https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/565248/Heat_Pumps_Combined_Summary_report_-_FINAL.pdf; Imperial College London (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

183 Element Energy (2017) Hybrid Heat Pumps study https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf. Values presented by Element Energy are broadly consisted with figures reported in other literature, for example: The Carbon Trust and Rawlings Support Services (2016) Evidence gathering – Low Carbon Heating Technologies: Domestic High Temperature, Hybrid and Gas Driven Heat Pumps https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/565248/Heat_Pumps_Combined_Summary_report_-_FINAL.pdf; The Committee on Climate Change (2013) Fourth Carbon Budget Review – technical report https://www.theccc.org.uk/wp-content/uploads/2013/12/1785b-CCC_TechRep_Singles_Book_1.pdf.

4.70 Direct electric heating systems such as storage heaters are typically much less expensive to buy and install than heat pumps. However, they consume considerably more electricity, with potential impacts on peak electricity demand as referred to in the *Energy system impacts* section of this chapter.

4.71 The costs of generating capacity to meet additional electricity demand is another large category of costs identified in relevant studies.[184] However, the scale of additional costs will be highly dependent on a range of factors, in particular: the performance efficiencies of heating appliances installed, the mix of heating appliances as well as the mix of appliances across the entire electricity network, the size of the peaks in electricity demand, and the extent to which greater system flexibility, such as energy storage, demand side response and interconnection can minimise the requirement for generating capacity. Among the studies examining these issues there is considerable variation in cost estimates, with those at the lower end assuming high levels of system flexibility.

4.72 A further significant area of difference between recent studies, relevant to generation costs, is the variation in demand patterns which we might expect to see from large numbers of heat pump installations. Analysis by University College London indicates that as heat pump deployment increases a "diversity benefit" is created that means peak demand does not increase proportionately at the national level.[185] However, the relatively small number of heat pumps installed in the UK limits the evidence base from which assumptions can be drawn.

4.73 Studies suggest the use of hybrid heat pumps could also reduce overall electricity generation costs, though this is highly dependent on the extent to which they are deployed.[186] There are, however, additional costs associated with continued gas use in a hybrid system, including the cost of continued operation and maintenance of the gas grid.[187]

184 For example: National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/; Imperial College London (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

185 University College London (2017) The addition of heat pump electricity load profiles to GB electricity demand: evidence from a heat pump field trial http://discovery.ucl.ac.uk/1566603/1/heat%20pump%20load%20profiles%20paper.pdf.

186 For example: Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

187 There remains some uncertainty around the economic viability of operating the gas grid with significantly lower volumes of gas. The National Infrastructure Commission (Element Energy & E4tech for the National Infrastructure Commission, 2018, Cost analysis of future heat infrastructure options, p. 9 – 10) highlight this as the main drawback, in cost terms, of a hybrid scenario. Imperial College state that the feasibility of operating distribution gas networks with low utilisation has been demonstrated in the Freedom project (Imperial College London (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/; Wales & West Utilities (2018) Freedom Project: Final Report https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf).

4.74 Like generation capacity costs, electricity network reinforcement cost estimates are dependent on estimates of peak demand. A range of studies have sought to estimate network reinforcement costs primarily driven by work on the distribution network.[188] Studies suggest there is potentially scope for reducing cost and disruption through careful planning, for example through the clustering of heat pump deployment, as this would limit distribution network upgrades in these areas.[189] Innovations, promoted by Ofgem's Network Innovation Competition,[190] and BEIS's Smart Systems Plan,[191] could contribute to driving down costs substantially through avoiding conventional reinforcements and mitigating disruption.

4.75 Through switching to operate on gas when electricity demand is high, hybrid heat pumps reduce the peak capacity required in the electricity system, which is likely to reduce the amount of electricity grid reinforcement needed (as well as costs and disruption associated with it). The extent of potential cost reductions is uncertain but could be significant.[192]

4.76 Conversely, direct electric heating technologies typically consume significantly more electricity than heat pumps, which is likely to result in need for further network reinforcement and expansion in generation requirements. Work on this by the National Infrastructure Commission estimated that peak electricity demand could be ~30GW higher when using direct electric heating technologies as compared to heat pumps.[193]

4.77 The future of the gas grid in a full-scale electrification scenario may also have an impact on costs. To date there is been limited published analysis in this area. However, a report by Frontier Economics concurs with the National Grid's estimate that if the distribution grid were to be totally decommissioned, costs – while materially uncertain – could be up to £8bn.[194]

188 Element Energy for the National Infrastructure Commission (2018) Cost analysis of future heat infrastructure options https://www.nic.org.uk/supporting-documents/cost-analysis-of-future-heat-infrastructure-options/.

189 Imperial College London for the Committee on Climate Change (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

190 Ofgem (retrieved October 2018) Ofgem announces winners of Network Innovation Competitions https://www.ofgem.gov.uk/publications-and-updates/ofgem-announces-winners-network-innovation-competitions.

191 In the Smart Systems Plan, BEIS announced smart innovation funding of up to £70m to 2021. Since January 2017 BEIS have launched competitions in the following areas: Energy Storage cost reduction, and feasibility studies; Domestic and Non-Domestic Demand Side Response trials; Flexibility Markets Feasibility Studies; Vehicle to Grid (V2G) Pilots.

192 Element Energy (2017) Multi Vector Integration Study (Assessment of Local Cases) https://www.eti.co.uk/index.php/actions/digitalDownload/download?u=a3a1c471751fef6bf4804cff9dc34224; Wales & West Utilities (2018) Freedom Project: Final Report https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf.

193 Element Energy for the National Infrastructure Commission (2018) Cost Analysis of Future Heat Infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

194 Frontier Economics (2018) Future Regulation of the UK Gas Grid https://www.theccc.org.uk/publication/future-regulation-of-the-gas-grid/.

Hydrogen conversion

4.78 A number of studies have sought to estimate the costs of converting significant parts, or all, of the gas system from natural gas to hydrogen. In 2013 a study by University College London made an assessment of the net public benefit resulting from scenarios involving switching to hydrogen or electricity.[195] More recently, the *H21 Leeds Citygate and North of England* reports have described roadmaps for hydrogen conversions of Leeds and the North of England, including estimating the costs involved. Other studies have made estimates of the costs of a hydrogen conversion across the wider network.[196] BEIS recently published a report by Element Energy on the current evidence for costs across the hydrogen supply chain.[197] These studies identify the main elements of cost involved in a heating system where the gas grid is converted to hydrogen. These include the production of hydrogen, the transportation and storage of carbon dioxide, the conversion works required across the gas network and the replacement of consumer heating appliances.

4.79 All the main hydrogen scenario studies assume hydrogen is produced primarily through methane reformation, coupled with carbon capture, usage and storage (MR-CCUS), as the most cost-effective means of production at the scale required.[198] In addition to the costs of the methane reformation plants and associated carbon transport and storage infrastructure, modelling carried out by Imperial College for the Committee on Climate Change indicates that a major component of the costs of producing hydrogen via MR-CCUS is the cost of the natural gas inputs, which are sensitive to the price of natural gas, and the cost of a large-scale transition to hydrogen. Future natural gas prices are inherently challenging to predict over the longer term.[199] This modelling also finds that substantial investment in inter-seasonal hydrogen storage via salt caverns would be cost-optimal as it reduces the investment in methane reformation plants required.

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195 Dodds & McDowall (2013) The future of the UK gas networks https://www.sciencedirect.com/science/article/pii/S0301421513003625.

196 For example, Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/; National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/; KPMG for Energy Networks Association (2016) 2050 Energy Scenarios http://www.energynetworks.org/gas/futures/the-uk-gas-networks-role-in-a-2050-whole-energy-system.html.

197 Element Energy for the Department for Business, Energy and Industrial Strategy (2018) Hydrogen supply chain evidence base https://www.gov.uk/government/publications/hydrogen-supply-chain-evidence-base.

198 For example, Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/; National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/; KPMG for Energy Networks Association (2016) 2050 Energy Scenarios http://www.energynetworks.org/gas/futures/the-uk-gas-networks-role-in-a-2050-whole-energy-system.html.

199 Imperial College London for the Committee on Climate Change (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

4.80 A number of studies consider the potential cost-effectiveness of electrolysis as a means of producing hydrogen on the scale required to meet a large part of our heat demand and conclude that it would be considerably more expensive.[200] One report, by the Sustainable Gas Institute, estimates that electrolysis could be at least twice as expensive as MR-CCUS. Studies by Element Energy[201] and the Sustainable Gas Institute[202] suggest significant potential for a reduction in electrolyser capital costs of between a half to over two thirds. However, studies identify the largest driver of electrolysis costs as the price of the input electricity (followed by the capital cost and load factor of the electrolyser).[203] In the UK, surplus renewable electricity generation capacity could be used to support low-cost electrolysis but, as noted in the *Emissions Reduction Potential* section, the scale of heat demand is a major challenge.

4.81 Some commentators have indicated the potential for cheap hydrogen production abroad which might enable cost-effective hydrogen imports. In its report for the Committee on Climate Change,Imperial College suggest that after low financing costs, if low-cost hydrogen imports become available they could provide the second greatest potential for cost reductions in a full-scale hydrogen transition.[204] In addition to production costs, importation would incur transportation costs such as the costs of liquifying or transforming and shipping hydrogen. However, as far as we are aware, there is little evidence or analysis currently available to help assess such production and transport possibilities. The Committee on Climate Change have concluded that given uncertainties over the availability and price of future hydrogen imports, strategic decisions about decarbonising heat should not be made in the near term that rely on them.[205]

200 For example: Imperial College London (2018) HYPERLINK “https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/” Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/ ; Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/ ; Sustainable Gas Institute (2017) Greening the Gas Grid: What are the Options? https://www.sustainablegasinstitute.org/wp-content/uploads/2017/06/SGI-A-greener-gas-grid-what-are-the-options-WP3.pdf?noredirect=1

201 Element Energy for the Department for Business, Energy and Industrial Strategy (2018) Hydrogen supply chain evidence base https://www.gov.uk/government/publications/hydrogen-supply-chain-evidence-base.

202 Sustainable Gas Institute (2017) Greening the Gas Grid: What are the Options? https://www.sustainablegasinstitute.org/wp-content/uploads/2017/06/SGI-A-greener-gas-grid-what-are-the-options-WP3.pdf?noredirect=1

203 For example: Sustainable Gas Institute (2017) Greening the Gas Grid: What are the Options? https://www.sustainablegasinstitute.org/wp-content/uploads/2017/06/SGI-A-greener-gas-grid-what-are-the-options-WP3.pdf?noredirect=1; Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/..

204 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

205 Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.

4.82 In their report *Greening the Gas Grid*, the Sustainable Gas Institute also make an assessment of the potential cost effectiveness of both biomass and coal gasification for hydrogen production, estimating that both could be cost-effective compared to MR-CCUS.[206] However they note that the price of the input fuel is a major cost driver and that the constrained nature of biomass availability may lead to future increases in traded biomass prices.

4.83 Another major cost component of a full-scale transition to hydrogen would be the investment required in hydrogen appliances and household conversion costs.[207] Work by Element Energy indicates that there is substantial uncertainty in the extent and cost of within-home conversion work required.[208] Work by Imperial College suggests that the overall costs of hydrogen conversion are sensitive to appliance cost assumptions.[209] Hydrogen appliance costs are uncertain as they are not currently commercially available; gas boiler manufacturers estimate that the cost of hydrogen boilers may be around 20% more expensive than current costs of natural gas boilers in the first years of a hydrogen conversion, and could reach close to current boiler prices once supply chains are established.[210] The Government's £25m hydrogen innovation programme, Hy4Heat,is carrying out further work, including funding demonstration of products, to better understand the costs of hydrogen appliances and in-home conversion requirements.[211]

4.84 Much of the analysis to date has focused on the use of hydrogen boilers in buildings. However, other possible hydrogen driven heating technology choices exist, such as fuel cells, combined heat and power and gas driven heat pumps, which could have quite different impacts on both overall system and consumer cost.

4.85 Significant investment would also be required in the repurposing of the distribution grid, the construction of new hydrogen transmission pipelines and new natural gas import facilities. However, both the H21 report and work by Imperial College for the Committee on Climate Change estimate that the works needed on the gas network would be a relatively small component of the overall costs of a large scale transition to hydrogen. However considerable uncertainties remain, which require further investigation.

206 Sustainable Gas Institute (2017) Greening the Gas Grid: What are the Options? https://www.sustainablegasinstitute.org/wp-content/uploads/2017/06/SGI-A-greener-gas-grid-what-are-the-options-WP3.pdf?noredirect=1.

207 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

208 Element Energy for the Department for Business, Energy and Industrial Strategy (2018) Hydrogen supply chain evidence base https://www.gov.uk/government/publications/hydrogen-supply-chain-evidence-base.

209 Imperial College London (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

210 Kiwa for the Department of Energy and Climate Change (2016) Hydrogen Appliances: Desk study on the development of the supply chain for 100% hydrogen-fired domestic and commercial appliances https://www.gov.uk/government/publications/hydrogen-appliances-desk-study-on-the-development-of-the-supply-chain-for-100-hydrogen-fired-domestic-and-commercial-appliances.

211 Hy4Heat (retrieved November 2018) https://www.hy4heat.info/.

Bioenergy

4.86 The principal costs of decarbonising heat with biogas result from production, including the costs of producing and transporting the feedstock, and the costs of generating biogas from the feedstock.

4.87 The costs of biogas production are mainly dependent on the choice of biomass type, gas production technology and scale of production.[212] Government data gathering exercises[213] and responses to incentive schemes[214] provide a good indication of recent biogas production costs, which, for biomethane, are based on anaerobic digestion. This data shows that biomethane is more expensive than current natural gas prices. Supplying biomethane into the grid currently requires a support level of between 2.53 and 5.60p/kWh above the wholesale gas price.[215] Cost reductions are possible by improving performance and increasing the value of by-products, but may ultimately be limited by the scale at which anaerobic digestion is feasible, as well as wider market factors such as the price construction materials like steel,[216] and the marketability of co-products such as digestate.[217]

4.88 The costs of biogas production from technologies other than anaerobic digestion, such as gasification, are a lot less certain because they are not commercially available in the UK. Information gathered by the Go Green Gas demonstration plant[218] and other cost estimates indicate that the gasification of biomass, though initially more expensive than anaerobic digestion, could achieve significant cost reductions through increased commercialisation, scale up and innovations, which reduce costs and improve performance.[219] One review suggested, for example, that capital costs could reduce by 30% and operating costs by 19%.[220]

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212 Sustainable Gas Institute (2017) A Greener Gas Grid: What are the Options? https://www.sustainablegasinstitute.org/wp-content/uploads/2017/06/SGI-A-greener-gas-grid-what-are-the-options-WP3.pdf?noredirect=1.

213 For example, Department of Energy and Climate Change (2014) RHI biomethane injection to grid tariff review https://www.gov.uk/government/consultations/rhi-biomethane-injection-to-grid-tariff-review; Department for Business, Energy and Industrial Strategy (2017) Review of support for Anaerobic Digestion and micro-Combined Heat and Power under the Feed-in Tariffs scheme https://www.gov.uk/government/consultations/review-of-support-for-anaerobic-digestion-and-micro-combined-heat-and-power-under-the-feed-in-tariffs-scheme; Arup (2016): Review of Renewable Electricity Generation Cost and Technical Assumptions https://www.gov.uk/government/publications/arup-2016-review-of-renewable-electricity-generation-cost-and-technical-assumptions.

214 Renewable Heat Incentive Statistics show the change in deployment patterns following major changes in tariffs. See: Department for Business, Energy and Industrial Strategy (retrieved October 2018) RHI mechanism for budget management: estimated commitments https://www.gov.uk/government/publications/rhi-mechanism-for-budget-management-estimated-commitments; Department for Business, Energy and Industrial Strategy (retrieved October 2018) RHI deployment data: June 2018 https://www.gov.uk/government/statistics/rhi-deployment-data-june-2018.

215 Ofgem (retrieved October 2018) Tariffs and payments: Non-Domestic RHI https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi/contacts-guidance-and-resources/tariffs-and-payments-non-domestic-rhi.

216 Deloitte (2018) Overview of steel and iron market - 2018 https://www2.deloitte.com/content/dam/Deloitte/ru/Documents/research-center/Iron_and_steel_industry_report_2018_en.pdf.

217 Summarising activity on marketing digestate see: Waste and Resources Action Programme (retrieved October 2018) Introduction to Driving Innovation in AD http://www.wrap.org.uk/node/16671; Waste and Resources Action Programme (retrieved October 2018) http://www.wrap.org.uk/collections-and-reprocessing/organic-waste/anaerobic-digestion/guidance/new-markets-digestate.

218 Go Green Gas (2015) BioSNG Demonstration Plant: Project Close-Down Report http://gogreengas.com/wp-content/uploads/2015/11/BioSNG-170223-1-Project-Close-Out-Report.pdf.

219 See evidence reviews undertaken on behalf of BEIS here: Ecofys for Department for Business, Energy and Industrial Strategy (2018) Bioenergy heat pathways to 2050: rapid evidence assessment https://www.gov.uk/government/publications/bioenergy-heat-pathways-to-2050-rapid-evidence-assessment; Ecofys and E4Tech (2018) Innovation needs assessment for biomass heat https://www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat.

220 Ecofys and E4Tech (2018) Innovation needs assessment for biomass heat https://www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat.

4.89 The price of biomass feedstocks strongly influence the cost of producing biomethane. As is well documented, there are huge variations in the price of different feedstocks depending on the cost of producing them and market forces, such as high demand from other potential users. At the more expensive end are imported feedstocks, such as wood pellets, which may be required if large scale biogas production was necessary, with the price reflecting higher production and transport costs.[221] Lower cost sources, such as by-products, which include residues from agriculture and forestry, may be harder to access in substantial quantities. Some waste feedstocks can generate revenue; for example, some biogas producers are paid to process UK wastes.[222]

4.90 It is widely recognised that there is potential to expand the sustainable global supply of biomass feedstocks, but future prices of these feedstocks are uncertain. Prices could reduce if there is an increase in investment and innovation, or an increase under competition for resources from other countries or with other sectors of the economy. For energy crops, one study estimates innovations could help to overcome cost barriers by reducing costs by up to 34% and increasing productivity by up to 67%.[223]

221 IEA Bioenergy (2017) Global Wood Pellet Industry and Trade Study 2017 https://www.ieabioenergy.com/publications/global-wood-pellet-industry-and-trade-study-2017/.

222 Waste and Resources Action Programme (retrieved October 2018) Gate Fees Report 2018: comparing the costs of waste treatment options http://www.wrap.org.uk/content/gate-fees-report-2018-comparing-costs-waste-treatment-options.

223 Ecofys and E4Tech (2018) Innovation Needs Assessment for Biomass Heat: Final report https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/699669/BE2_Innovation_Needs_Final_report_Jan18.pdf.

Consumer experience

Strategic inferences: summary of consumer experience

- The transition to low carbon heating will result in significant change for consumers, but the nature and scale can vary significantly depending on the low carbon technologies used and how the change is managed.
- Switching to electric heating is likely to result in the most obvious changes for the consumer. All gas appliances would need to be replaced by electric alternatives and in most cases, heat pumps in place of boilers. In many homes this will also mean additional insulation, hot water storage and larger radiators are required, each of which presents considerable up-front costs. On the other hand, consumers may have more flexibility over the timing of their conversion to electric heating than under a hydrogen conversion process.
- Heat pumps also provide a different heating experience, with a more sustained ambient heat replacing the quick response of hot radiators. Evidence to date suggests that although consumer awareness is low, consumers tend to be satisfied with heat pumps once installed.
- Hybrid heat pumps may offer the ability for consumers to reduce changes to their homes and retain the quick heating response provided by boilers, but there is still relatively little experience of hybrid deployment in the UK.
- Converting the gas grid to hydrogen would also require replacement of all appliances. While these are not yet either commercially available nor proven for safe use, it is probable that they will be very similar products with broadly similar costs to existing gas appliances.
- The main disruption to the consumer in this approach is likely to be during the process of converting to hydrogen, which may require multiple home visits and new gas pipework within the home.
- Biogas blended into the gas grid can achieve carbon reductions without disruption in the home, but its potential is limited by the availability of supplies.
- All of the approaches to low carbon heating are likely to have cost implications for consumers, although the timing and distribution of these costs will in part depend on policy design and energy service models available on the market.

4.91 This section considers the potential changes and adaptations required of consumers, and how these may vary depending on the low carbon heat solutions they adopt. The discussion focuses on the changes as experienced in domestic buildings, where the majority of studies to date have drawn their evidence. However, all options for decarbonising heat will have consequences for the majority of consumers, whether using heat in homes, workplaces or industrial sites.

4.92 The consumer experience of these changes will reflect how the costs of different low-carbon heat solutions are distributed across society, how advancements in technologies and market offerings alter the low-carbon heat proposition for consumers, and how public policies are implemented.

4.93 Any future policy framework for heat decarbonisation will need to carefully consider the impacts of these changes on different consumer groups across domestic, non-domestic and industrial sites. It will also need to take into account the broad diversity of the ways in which heat is used within households, and recognise that achieving a given ambient room temperature is only one dimension, as recent reports by the Energy Technologies Institute discuss.[224]

4.94 Across all of the approaches discussed, technological innovation could improve the consumer proposition. For example, heat networks could at least partly mitigate disruption to consumers from changing fuel since the consumer is separated from the actual heat production. The BEIS Heat Network Consumer Survey showed that heat network consumers were just as satisfied overall with their heating systems as non-heat network consumers (74% of heat networks consumers and 72% of non-heat networks consumers were "very satisfied" or "satisfied").[225] In addition, smart appliances could help consumers to better understand their energy use and identify opportunities to reduce fuel consumption, and ultimately, bills.

Electrification

4.95 Converting to electric heating requires replacing natural gas boilers with electric heating systems. The conversion to electric heating may result in changes to the heating unit, but also, depending on the low carbon heating system and building characteristics, to the fabric of the building, radiators and hot water storage, in order to ensure the system works effectively.

4.96 Heat pumps typically transport heat through a lower temperature distribution system than gas fired systems. They may therefore require larger emitters (such as radiators or underfloor heating), and good levels of insulation, to operate efficiently and provide adequate thermal comfort. They may also involve a number of other practical requirements, for example space for the outdoor and indoor unit, and hot water storage.[226] Ground source heat pumps require a suitable area of ground to either dig trenches or drill a borehole (between 15 and 100 meters deep).[227]

224 Energy Technologies Institute (2018) How can people get the heat they want at home, without the carbon? https://www.eti.co.uk/insights/how-can-people-get-the-heat-they-want-without-the-carbon. See also: Energy Technologies Institute (2015) Smart Systems and Heat: Consumer challenges for low carbon heat https://d2umxnkyjne36n.cloudfront.net/insightReports/Consumer-challenges-for-low-carbon-heat.pdf?mtime=20161110163229.

225 Heat Network Consumer Survey (2017) Heat Networks Consumer Survey https://www.gov.uk/government/publications/heat-networks-consumer-survey-consumer-experiences-on-heat-networks-and-other-heating-systems.

226 National Energy Action (2017) Heat Decarbonisation: Potential impacts on social equity and fuel poverty https://www.nea.org.uk/resources/publications-and-resources/heat-decarbonisation-potential-impacts-social-equity-fuel-poverty/.

227 Which? (retrieved October 2018) Ground source heat pumps explained: Installing a ground source heat pump https://www.which.co.uk/reviews/ground-and-air-source-heat-pumps/article/ground-source-heat-pumps-explained/installing-a-ground-source-heat-pump.

4.97 Whilst these measures and requirements are broadly understood, there is relatively limited evidence to support estimates of the number of UK households that are already 'heat pump ready', or the number that are suitable but would require some retrofitting or ancillary works. As the UK Energy Research Centre states, "the performance and acceptability of heat pumps in a wide range of UK homes remains unproven".[228]

4.98 A report by the Committee on Climate Change estimates that heat pumps are currently suitable in around ten million properties on the gas grid, and a further ten million or more could be made suitable through insulation and other heating system upgrades. The report notes that whilst such improvements can be disruptive, this disruption can be reduced by upgrading heating systems at 'trigger points', such as building retrofits, renovations or boiler replacements.[229] The Energy Technologies Institute emphasises the opportunity for this, reporting that renovations are being planned in 35% of properties at any time, and that 70% of plans take over a year to finalise.[230] Energy efficiency improvements can also deliver added benefits.[231]

4.99 Similarly, relatively little is known about the need for hot water storage in UK households. The number of homes without hot water tanks has risen substantially with the introduction of combi-boilers. In 1996 12% of households were without hot water tanks, rising to 54% in 2016.[232] In its report, Heat Decarbonisation: Potential impacts on social equity and fuel poverty, National Energy Action suggest the internal space requirements of hot water tanks may make heat pumps an unsuitable solution for many low-income customers.[233]

4.100 The Greater Manchester Smart Community Demonstration Project also highlighted the unsuitability of heat pumps for heating "hard-to-treat" properties. For example, the demonstration project found that where properties lacked the space for installation works, or were poorly insulated, they could not install heat pumps, as was the case for 19.5% of the properties in the project.[234] In these cases, other electric heating systems such as high-temperature heat pumps, hybrid heat pumps or storage heaters may deliver the heating service required whilst avoiding potentially disruptive or difficult ancillary works.[235]

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228 The UK Energy Research Centre (2014) UK Energy Strategies Under Uncertainty: Uncertainties in Energy Demand in Residential Heating http://www.ukerc.ac.uk/publications/uk-energy-strategies-under-uncertainty-uncertainties-in-energy-demand-in-residential-heating.html.

229 Committee on Climate Change (2016) Next steps for UK heat policy https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/.

230 Energy Technologies Institute (2015) Smart Systems and Heat: Consumer challenges for low carbon heat https://www.eti.co.uk/library/smart-systems-and-heat-consumer-challenges-for-low-carbon-heat.

231 The Department for Business, Energy and Industrial Strategy (2017) Clean Growth Strategy https://www.gov.uk/government/publications/clean-growth-strategy.

232 MHCLG (2016) English Housing Survey 2016: Energy Efficiency https://www.gov.uk/government/statistics/english-housing-survey-2016-energy-efficiency.

233 National Energy Action (2017) Heat Decarbonisation: Potential impacts on social equity and fuel poverty https://www.nea.org.uk/resources/publications-and-resources/heat-decarbonisation-potential-impacts-social-equity-fuel-poverty/.

234 Greater Manchester Smart Energy (2017) Greater Manchester Smart Community Demonstration Project http://media.ontheplatform.org.uk/sites/default/files/GMCA%20NEDO%20Smart%20Communities%20Exec%20Report%20FINAL.pdf.

235 The Carbon Trust and Rawlings Support Services (2016) Evidence gathering – Low Carbon Heating Technologies: Domestic High Temperature, Hybrid and Gas Driven Heat Pumps https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/565248/Heat_Pumps_Combined_Summary_report_-_FINAL.pdf.

4.101 Hybrid appliances may offer the possibility for reducing the disruption consumers may face upon transitioning to a heat pump. The retention of a gas boiler, which can provide higher temperatures when required, can alleviate the need for installing low-temperature heat emitters or making fabric efficiency improvements.[236] The space requirements may differ as well, as the outdoor heat pump unit can be smaller[237] and a separate hot water tank may not be required.[238]

4.102 Our understanding of the UK consumer experience of low carbon heating systems, once installed, is limited by the relatively low uptake of these systems so far. What evidence is available is often derived from a limited range of consumers, usually early adopters, and in the case of the Renewable Heat Incentive, often wealthier households with access to capital.[239] There is also a range of evidence to draw on from other countries' experience of heat pump deployment, although not all of this will be directly applicable to the UK context.

4.103 Various studies have looked at the significant differences between the consumer experience of lower-temperature electric heating (e.g. with heat pumps) and gas heating. For example:

- heat pumps release heat slowly through the day, rather than heating quickly at very hot temperatures. This can require consumers to adapt to a different experience of heat; for example, although temperatures may be more even throughout the day they may no longer be able to rapidly boost heating to feel an immediate effect;[240,241]

- unlimited hot water may not be possible if switching to a storage tank solution for water heating; and

236 For example: The Carbon Trust and Rawlings Support Services (2016) Evidence gathering – Low Carbon Heating Technologies: Domestic High Temperature, Hybrid and Gas Driven Heat Pumps https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/565248/Heat_Pumps_Combined_Summary_report_-_FINAL.pdf. Element Energy (2017) Hybrid Heat Pumps https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf.

237 Element Energy & E4tech (2018) Cost analysis of future heat infrastructure options https://www.nic.org.uk/wp-content/uploads/Element-Energy-and-E4techCost-analysis-of-future-heat-infrastructure-Final.pdf.

238 The Carbon Trust and Rawlings Support Services (2016) Evidence gathering – Low Carbon Heating Technologies: Domestic High Temperature, Hybrid and Gas Driven Heat Pumps https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/565248/Heat_Pumps_Combined_Summary_report_-_FINAL.pdf.

239 Department of Energy and Climate Change (2016) The Renewable Heat Incentive: A reformed and refocused scheme https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/505972/The_Renewable_Heat_Incentive_-_A_reformed_and_refocussed_scheme.pdf.

240 National Energy Action (2017) Heat Decarbonisation: Potential impacts on social equity and fuel poverty https://www.nea.org.uk/resources/publications-and-resources/heat-decarbonisation-potential-impacts-social-equity-fuel-poverty/.

241 Some consumers may be able to adapt more easily, for example the constant heat provided by a heat pump may be more suitable for someone at home for extended periods.

- electrification will also involve consumers with gas cookers and fires replacing them with electric alternatives. Research has found that consumers may be reluctant to opt for electric heating, if it means they have to use electric hobs, but where they currently use gas ovens, they may welcome the change to an electric oven.[242]

4.104 Despite these differences, the Government's evaluation of Renewable Heat Incentive and Renewable Heat Premium Payment installations, has found users to be very satisfied with their heat pump systems (~80% for both ground source and air source heat pumps), especially once they had time to adapt.[243] These evaluations found that satisfaction levels could be enhanced as the supply chain matures to address issues around the reliability of installation work, unpredictable levels of disruption, and better identification of preparatory work.[244] However, as argued by , amongst others, Policy Exchange there is a significant education challenge that must be overcome before this knowledge is transferred into the wider market.[245]

4.105 Element Energy and NERA Consulting's report for the Committee on Climate Change has raised concerns about the cumulative noise impact of heat pumps in densely populated areas.[246] However, there is potential to reduce these noise impacts. Innovation has already made some progress in this regard, with some products already much quieter than previous ones.[247]

4.106 Hybrid systems have the potential to limit the level of change in heating experience as a result of moving from gas to electric heating, as consumers can retain access to gas heating, cooking and hot water without the use of a cylinder. Results from the Freedom Project found 60% of respondents felt that hybrid systems met their expectations (although opinions differed on the individual characteristics of systems with 74% of respondents satisfied with their ease of use, compared to only 42% with aesthetics).[248]

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242 Research has found that consumers show a preference for using gas hobs over electric alternatives, because of the temperature control gas offers, and Which? highlight this in their advice to consumers. Accordingly, DEFRA (2009) found that 55% of the population use gas hobs, and they projected this to increase to 60% by 2020. However, the opposite trend has been found in oven cooking, as consumers have found electric ovens to cook more evenly. In 2009, DEFRA projected that the number of gas ovens would decline from 36% to around 30% by 2020. Which? (retrieved August 2018) Gas cookers vs electric cookers https://www.which.co.uk/reviews/freestanding-cookers/article/gas-cookers-vs-electric-cookers; Department for Environment, Food and Rural Affairs (2009) Saving Energy Through Better Products and Appliances. A consultation on analysis, aims and indicative standards for energy efficient products 2009 – 2030 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69219/pb13559-energy-products-101124.pdf.

243 Department for Business, Energy and Industrial Strategy (2017) RHI evaluation synthesis https://www.gov.uk/government/publications/rhi-evaluation-synthesis-report.

244 Department of Energy and Climate Change (2016) Qualitative Research with domestic RHI owner occupier applicants https://www.gov.uk/government/collections/renewable-heat-incentive-evaluation#domestic-rhi-evaluation-reports.

245 Policy Exchange (2016) Too Hot to Handle https://policyexchange.org.uk/publication/too-hot-to-handle/.

246 Element Energy and NERA Economic Consulting (2011) Achieving deployment of renewable heat https://www.theccc.org.uk/archive/aws/Renewables%20Review/CCC%20Renewable%20Heat%20-%20final%20report_06.05.11.pdf.

247 Mitsubishi Electric and Ecodan (2018), state that new models such as Mitsubishi's 'Ultra Quiet Ecodan' are three times quieter than equivalent models, operating at 1m of 45dB, virtually eliminating planning restrictions. http://library.mitsubishielectric.co.uk/pdf/book/Ultra_Quiet_Ecodan.

248 Wales and West Utilities (2018) Freedom Project: Final Report https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf.

4.107 However, concerns have been raised, including by Element Energy and E4Tech in their work for the National Infrastructure Commission, about the complexity of running a hybrid system in an 'optimal' way to ensure the "share of the heat demand met by the gas boiler is not larger than necessary", given potentially limited supplies of low carbon gas.[249] As explored by the Freedom Project, there is potential for advanced control and remote operation platforms to automatically manage 'optimal' fuel switching for the consumer in a "convenient and intuitive" way.[250]

4.108 Studies have shown that even when consumers are generally satisfied with a heat pump system, there are aspects which could be changed to increase their level of acceptability. For example, 79% of Renewable Heat Incentive occupants were very or fairly satisfied with the heat pump installation's noise, and 76% with the appearance, however only 65% were satisfied with their understanding of system controls, and 67% with ease of adjusting controls.[251] A 2015 report by the Energy Technologies Institute also suggested that improved, more advanced control systems could help improve consumer satisfaction with and uptake of heat pumps.[252]

Hydrogen conversion

4.109 To ensure they function correctly, gas appliances are designed for the particular gas specification they will use.[253] As hydrogen has a different specification to natural gas, using hydrogen for heating will likely require replacing the existing stock of natural gas appliances, including boilers, cookers and fires. Hydrogen appliances are not currently commercially available, and the safety of using them in domestic settings is yet to be proven. However, it is considered technically feasible for hydrogen appliances to be developed with similar performance characteristics to current natural gas equivalents, and even to develop 'hydrogen ready' appliances which can switch from burning natural gas to hydrogen, following adaptation by a trained professional.[254] Hy4Heat, the Government's £25m hydrogen innovation programme, is in part focused on overcoming the challenge of developing new appliances to burn hydrogen rather than natural gas with the aim of delivering prototype appliances in the early 2020s.

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249 The Carbon Trust and Rawlings Support Services (2016) Evidence gathering – Low Carbon Heating Technologies: Domestic High Temperature, Hybrid and Gas Driven Heat Pumps https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/565248/Heat_Pumps_Combined_Summary_report_-_FINAL.pdf; and Element Energy & E4tech (2018) Cost analysis of future heat infrastructure options https://www.nic.org.uk/wp-content/uploads/Element-Energy-and-E4techCost-analysis-of-future-heat-infrastructure-Final.pdf.

250 Wales and West Utilities (2018) Freedom Project: Final Report https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf.

251 Department for Business, Energy and Industrial Strategy (2017) Census of Owner-Occupier Applicants to the Domestic RHI https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/642097/Domestic_Census_waves_1-24.pdf.

252 Energy Technologies Institute (2015) Smart Systems and Heat: Consumer challenges for low carbon heat https://www.eti.co.uk/library/smart-systems-and-heat-consumer-challenges-for-low-carbon-heat.

253 Kiwa for the Department of Energy and Climate Change (2016) Hydrogen Appliances: Desk study on the development of the supply chain for 100% hydrogen-fired domestic and commercial appliances https://www.gov.uk/government/publications/hydrogen-appliances-desk-study-on-the-development-of-the-supply-chain-for-100-hydrogen-fired-domestic-and-commercial-appliances.

254 Frazer-Nash (2018) Appraisal of Domestic Hydrogen Appliances https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/699685/Hydrogen_Appliances-For_Publication-14-02-2018-PDF.pdf.

4.110 Without prior installation of "hydrogen-ready" appliances, the timing of appliance replacement would be dictated by the timetable for the conversion of the local gas distribution network to hydrogen. This would mean limited potential for individual consumer choice or influence on timing, and could increase costs as otherwise-functional appliances would need to be replaced prematurely. As suggested by H21, the conversion of consumers to hydrogen could take place incrementally across zones (H21 suggests these could consist of approximately 2,500 homes each).[255] At the point of conversion, all consumers in that zone would be disconnected from natural gas. Hereafter, consumers would be unable to continue using existing natural gas appliances and would need to replace them with either hydrogen equivalents, or an alternative low carbon system, such as electric heating.

4.111 More work is needed to fully understand the consumer experience of a transition to hydrogen. However, the H21 Leeds City Gate report, alongside work commissioned by BEIS from Frazer-Nash, provide insights on the level and length of disruption consumers may experience during a conversion. They suggest this will involve multiple home visits (Frazer-Nash suggest three on average) entailing disruption for consumers as they are required to give access to their homes for survey and conversion work.[256] Disruption will also be caused by the length of time consumers are disconnected from the gas supply. H21 suggest this could be between 1 and 5 days depending on the size of the workforce carrying out the conversion.[257]

4.112 The extent of gas pipework in homes which would require replacement is currently uncertain. If required, as identified by Frazer-Nash, this could entail significant work and disruption within the home, especially if the pipework is inaccessible, e.g. in floors and ceilings.

4.113 The report by Frazer-Nash indicates that, if developed, the presence of "hydrogen-ready" boilers could reduce the time taken on the day of conversion to around an hour per appliance and could reduce the extent of asset stranding.[258] Pre-conversion work would still be required, but this could be done at a time of the consumer's choice, or as a natural gas appliance reaches the end of its life.[259]

4.114 Various technical studies provide evidence which indicates that hydrogen appliances are likely to be able to offer consumers a very similar heating experience to natural gas. For example, Kiwa, in their 2016 review of the development of hydrogen appliances concluded that a hydrogen combi boiler is expected to look like and operate very similarly to an existing natural gas combi boiler.[260] Testing and demonstration of the look and feel, and safety of hydrogen appliances is being carried out as part of the Government's £25m Hy4Heat innovation programme.

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255 H21 Leeds City Gate Report (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf.

256 Frazer Nash for the Department for Business, Energy and Industrial Strategy (2018) Logistics of domestic hydrogen conversion https://www.gov.uk/government/publications/logistics-of-domestic-hydrogen-conversion.

257 H21 Leeds City Gate Report (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf.

258 Frazer-Nash (2018) Appraisal of Domestic Hydrogen Appliances https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/699685/Hydrogen_Appliances-For_Publication-14-02-2018-PDF.pdf.

259 Frazer Nash for the Department for Business, Energy and Industrial Strategy (2018) Logistics of domestic hydrogen conversion https://www.gov.uk/government/publications/logistics-of-domestic-hydrogen-conversion.

260 Kiwa for the Department of Energy and Climate Change (2016) Hydrogen Appliances: Desk study on the development of the supply chain for 100% hydrogen-fired domestic and commercial appliances https://www.gov.uk/government/publications/hydrogen-appliances-desk-study-on-the-development-of-the-supply-chain-for-100-hydrogen-fired-domestic-and-commercial-appliances.

Bioenergy

4.115 Once converted into biogas and blended into the gas grid, bioenergy can be used to reduce carbon emissions with no perceived change to the consumer. It is widely accepted that biomethane could be substituted into the gas grid without the need to change existing gas appliances and heat emitters (e.g. radiators), nor would it be necessary to install additional hot water storage. Consumers would not need to adapt to a new heating system and would avoid disruption in the home. However, as discussed later in this Chapter, no studies have suggested that biogas could fully replace the role of natural gas at its current levels of use.

Energy system impacts

Strategic inferences: energy system impacts

- Given the size of heat as a proportion of UK energy demand, and the far-reaching role of the current UK gas grid, the decarbonisation of heat is likely to have broad impacts across the whole energy system. These need to be understood in order to ensure the necessary changes are practically deliverable and acceptable and that key parameters of security and resilience are maintained throughout and beyond transition.

- Electrification of heat would greatly increase electricity system requirements – substantially increasing the total and peak demand for electricity. This will present challenges in supplying the total required low carbon generation capacity and in reinforcing the distribution and transmission network. Meeting peak generation requirements would require greatly increased and sustained levels of deployment of low carbon electricity.

- The level of peak demand will depend on the type of heat systems installed and how they are used. It will be important to better understand the cumulative electricity demands of large numbers of heat pump systems installed in the UK building stock.

- The use of hybrid heat pumps may provide an additional way of reducing peak demand, as consumers could switch demand from electricity to gas in response to capacity constraints at a national or local level. This localised ability might provide a means of reducing the potential disruption reinforcement could cause to distribution networks – although the disruption involved under different demands is poorly understood.

- Hydrogen conversion would require significant new infrastructure, including a new hydrogen transmission system alongside hydrogen production and storage facilities and carbon capture, usage and storage (CCUS) infrastructure. The scale and sequencing of growth in capacity of these assets represents a significant challenge and would require systems level planning. Hydrogen conversion through methane reformation raises new issues in terms of security of supply due to the significant increase in natural gas demand and declining indigenous production.

- The role of biogas is likely to be influenced by total potential and security of supply of bioenergy, and where that potential is prioritised across the energy system. It is not considered a stand-alone solution for heat decarbonisation for these reasons. However, given its like-for-like replacement potential with natural gas, biomethane could help minimise energy system impacts.

4.116 Changing the way we heat our homes and businesses will have wide-ranging impacts on the rest of the UK energy system. Switching away from natural gas towards other means of heating will put new demands on our energy infrastructure – meaning changes to the methods and scales of producing, storing and transporting the energy required.

4.117 The security and resilience of energy supply that has been provided through natural gas in the gas system will need to be maintained during and following the transition to low carbon heating. In particular, the gas system has been designed to provide flexibility with multiple gas supply flexibility sources, such as interconnectors, storage, and LNG amongst others, which can be very quickly ramped up and ramped down as needed. This is particularly well suited to the very seasonal demand presented by heating, but is also helpful in absorbing any potential energy shocks and servicing the power sector in meeting peak electricity demand (using combined cycle gas turbine plants).

Electrification

4.118 Moving from using gas or fossil fuels to using electricity for heating on a large scale will cause a major increase in the amount of electricity demand. As discussed in Chapter 2, the scale and variability of heating demand greatly exceeds that of historical electricity demand. As the level of demand for electricity increases, supply will need to keep pace, meaning more electricity being generated and transported through the transmission and distribution networks to homes, businesses and industry.

4.119 While both total and peak demand will increase, it is peak demand that principally dictates the level of capacity required in the generation, transmission and distribution elements of the electricity system.

4.120 Figure 2.8 in Chapter 2 shows the estimated current peak demand for heating on a normal winter workday. Unlike traditional electricity demand, and with certain exceptions such as hot water and process heating, demand is highly concentrated in winter and is very sensitive to changing outdoor temperatures. However, understanding demand for heat is only part of the picture in understanding resultant peak demand for electricity.

4.121 Estimates of peak demand resulting from electrification of heat vary between published studies and are influenced by a number of key factors and assumptions with uncertainty driven by both a lack of high-quality empirical evidence and a wide variety of potential choices and behaviours. Estimates indicate peak demand could be around two times today's peak electricity demand.[261]

4.122 The evidence suggests that the choice of electric heating system used has fundamental impact on peak demand:

261 Studies include: National Grid (2018) Future Energy Scenarios fes.nationalgrid.com; Element Energy for the National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

(a) Direct electric resistive heating tends to operate at nearly 100% efficiency and is used much like a gas boiler (operated when heat is desired). This would result in very high peak electricity demand, adding up to 82GW to existing peak demands, compared with 49GW for heat pumps.[262]

(b) Storage heaters work at similar efficiency, though storing heat can shift some demand away from peak times to times to when demand is low. However, it is uncertain if this would be possible during an extended cold snap or with a larger deployment of storage heaters.

(c) Heat pumps, meanwhile, provide high efficiency heating, achieving performance of [around SPF 2.5[263] – insert link to RHPP field trial data] and use low flow temperatures and large emitters[264] to spread heating out across the day, meaning peak demand would be much lower.[265]

(d) Hybrid heat pumps could potentially reduce peak demand further, by augmenting the heat pump with gas boilers. At times of peak demand, they can switch away from electricity to gas.[266]

(e) Heat networks that are powered by heat pumps typically have higher coefficients of performance and some studies indicate they can reduce the peak demand for electricity.[267]

4.123 The characteristics and geographies of electrified buildings are another important consideration. Research conducted for Electricity North West shows significant variation in heat pump performance dependent on house type, how the appliance is controlled and outside air temperature.[268] Given the UK's unique building stock and climate, there are limitations on how far we can understand these impacts through deployment in other countries alone.

4.124 The potential impact of measures to reduce or smooth electricity for heat demand can also have a direct bearing on the resulting level of peak demand. Through the insulation of buildings and the addition of heat storage, consumers can decrease their total and/or peak demand. The introduction of smarter grids and appliances could allow consumers to actively "shift" demand away from peak times. The Government is working closely with Ofgem and industry partners to support the transition to a smarter, more flexible energy system which could bring

262 Element Energy for the National Infrastructure Commission (2018) Cost analysis of future heat infrastructure options https://www.nic.org.uk/supporting-documents/cost-analysis-of-future-heat-infrastructure-options/.

263 UCL Energy Institute (2017) Final report on the analysis of heat pump data from the renewable heat premium payment (RHPP) scheme https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/606818/DECC_RHPP_161214_Final_Report_v1-13.pdf.

264 Delta-ee (2011) Heat Pumps in the UK: How Hot Can They Get? http://www.green-alliance.org.uk/resources/01.01.11%20Delta%20-%20Heat%20Pumps%20in%20the%20UK%20How%20Hot%20Can%20They%20Get.pdf.

265 National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/.

266 For example: Element Energy (2017) Multi Vector Integration Study (Assessment of Local Cases) https://www.eti.co.uk/programmes/energy-storage-distribution/multi-vector-integration; Element Energy & E4tech for National Infrastructure Commission (2018) Cost analysis of future heat infrastructure options https://www.nic.org.uk/wp-content/uploads/Element-Energy-and-E4techCost-analysis-of-future-heat-infrastructure-Final.pdf; Wales and West Utilities (2018) Freedom Project: Final Report https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf.

267 Imperial College London (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

268 Delta-ee (2016) Managing the future network impact of electrification of heat https://www.delta-ee.com/downloads/30-consultancy-downloads/873-managing-the-future-network-impact-of-electrification-of-heat.html#form-content.

significant benefits to consumers and the economy. Research by Imperial College and the Carbon Trust estimates system-wide savings in Great Britain of £17–40bn to 2050.[269] The Smart Systems & Flexibility Plan outlines the underlying principles of the approach the Government and Ofgem are taking to enable the transition to a smart and flexible system.[270]

4.125 Perhaps least well understood, is the impact of "diversity" of demand across populations and different locations. Recent studies have shown that as heat pump deployment increases, peak demand rises proportionally less, providing a "diversity benefit" in peak demand at the national level.[271] This can result from a number of causes such as variations in consumer behaviour, regional weather or technical operation of equipment.

4.126 However, it is also understood that both efficiency (for heat pumps) and "diversity" will diminish as the outside temperature drops, when demand for heat is highest, such as during extended cold weather events[272] The National Infrastructure Commission, amongst others, suggest that some of these uncertainties could be further understood through electrification demonstration projects of increasing scale.[273]

4.127 The generation capacity required to meet service peak demand will depend on the nature of generation technologies employed and the level of system flexibility that can be achieved. Numerous modelling studies suggest that a mix of low carbon generation technologies is likely to be needed and significant deployment of smart systems and flexibility technologies will be necessary to minimise system costs.

4.128 Modelling supports the concern that a more variable demand (a far greater difference between average and peak demand) could result in reduced utilisation of generation capacity and high redundancy costs, as plants required to meet winter peaks are not required during the rest of the year.[274] Intermittent generation meanwhile, such as wind and solar, cannot respond to demand fluctuations as well as some conventional plants (eg combined cycle gas turbines). For example, Aurora Energy have expressed concern over the coincidence of cold weather and prolonged periods of low wind.[275]

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269 Imperial College London and the Carbon Trust (2016) An analysis of electricity system flexibility for Great Britain https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf.

270 The Department for Business, Energy and Industrial Strategy and Ofgem (2017) Upgrading our energy system, Smart systems and flexibility plan https://www.gov.uk/government/publications/upgrading-our-energy-system-smart-systems-and-flexibility-plan.

271 University College London (2017) The addition of heat pump electricity load profiles to GB electricity demand: evidence from a heat pump field trial http://discovery.ucl.ac.uk/1566603/1/heat%20pump%20load%20profiles%20paper.pdf.

272 UCL Energy Institute (2017) Final report on the analysis of heat pump data from the renewable heat premium payment (RHPP) scheme https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/606818/DECC_RHPP_161214_Final_Report_v1-13.pdf

273 National Infrastructure Commission (2018) National Infrastructure Assessment https://www.nic.org.uk/assessment/national-infrastructure-assessment/low-cost-low-carbon/.

274 Imperial College London for the Committee on Climate Change (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

275 Aurora Energy Research (2018) Are "kalte Dunkelflauten" killing the electrification of the heating sector? https://www.energie-experten.org/uploads/media/Kurzinfo_Aurora-Studie_Waermepumpen-Dunkelflaute.pdf; Thornton et al (2017) The relationship between wind power, electricity demand and winter weather patterns in Great Britain http://centaur.reading.ac.uk/71293/1/Thornton_2017_Environ._Res._Lett._12_064017.pdf.

4.129 Several studies have examined the role of flexibility technologies in mitigating these challenges, such as storage and interconnection, and vehicle to grid technologies.[276] Innovation and development of inter-seasonal solutions will be important to significantly reduce capacity needs.[277,278] Some modelling highlights the potential value of a continued role for (relatively inexpensive) unabated gas in meeting peaks.[279]

4.130 Numerous studies have considered the impacts of electric heating on the electricity transmission and distributions systems. As the Energy Technologies Institute has summarised, electricity demand from electrified heating and vehicles will bring peak demand "significantly above the design limits adopted when the existing electricity distribution networks were installed".[280] Ofgem reflect the view of many commentators, that the increased peak demand associated with widespread installation of heat pumps is likely to require significant network reinforcement.[281]

4.131 As the Committee on Climate Change, amongst others, highlight, network reinforcement could cause significant disruption. A study by Imperial College examines how heat electrification could drive "extensive" reinforcement of the low voltage and 11kV networks, as well as upgrading substations, including some major road excavation works.[282]

4.132 Work by TNEI for BEIS suggests the scale of investment needed in the network is sensitive to a range of variables, including heat pump deployment pattern and demand profiles; flexibility of the generation mix; and deployment of electric vehicles and distributed generation. It also suggests that impacts are also likely to be highly local in nature, due to different demand profiles and the variation in regional networks.

4.133 A study undertaken by UK Power Networks highlights the importance of such studies being based on empirical data.[283] The report found that the move from assumptions to real-world data resulted in a much flatter load profile and relatively minor, though not insignificant, modelled impact on their network, highlighting the need to update this work with further modelling and trials from across the country.

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276 Carbon Trust and Imperial College London (2016) An analysis of electricity system flexibility for Great Britain https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf; Aurora Energy Research (2018) Power sector modelling: system cost impact of renewables https://www.nic.org.uk/wp-content/uploads/Power-sector-modelling-final-report-1-Aurora-Energy-Research.pdf.

277 Energy Technologies Institute (2015) Smart Systems and Heat: Decarbonising Heat for UK Homes http://www.eti.co.uk/wp-content/uploads/2015/03/Smart-Systems-and-Heat-Decarbonising-Heat-for-UK-Homes-1.pdf.

278 Energy Research Partnership (2017) The transition to low carbon heat http://erpuk.org/wp-content/uploads/2017/10/ERP_heat_transition-Oct-2017.pdf.

279 Imperial College London for the Committee on Climate Change (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/

280 Energy Technologies Institute (2015) Smart Systems and Heat: Decarbonising Heat for UK Homes http://www.eti.co.uk/wp-content/uploads/2015/03/Smart-Systems-and-Heat-Decarbonising-Heat-for-UK-Homes-1.pdf.

281 Ofgem (2018) Future Insight Series: Implications of the transition to Electric Vehicles https://www.ofgem.gov.uk/ofgem-publications/136142.

282 Imperial College London for the Committee on Climate Change (2018) Analysis of alternative UK heat decarbonisation pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

283 UK Power Networks (2014) Impact of Electric Vehicle and Heat Pump loads on network demand profiles https://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-(LCL)/Project-Documents/LCL%20Learning%20Report%20-%20B2%20-%20Impact%20of%20Electric%20Vehicles%20and%20Heat%20Pump%20loads%20on%20network%20demand%20profiles.pdf.

4.134 The scale of disruption and cost is also likely to be affected by the level of cost-effectiveness and potential of innovative approaches in conjunction with traditional network investment.[284] The industry-led Customer Led Network Revolution is one such innovation project, which sets out to demonstrate the benefits of a "smart grid" approach and the potential role of innovative solutions in reducing the need for network investment.[285]

4.135 Findings from the Freedom project[286] and National Infrastructure Commission's work[287] suggest hybrid heat pumps, could have the potential to reduce peak electricity demand compared with stand-alone heat pumps, and thus lower the extent of generation capacity and reduce network reinforcement required.[288]

4.136 Some commentators argue that electrification of heating may offer some energy security benefits to the UK, as the required electricity production portfolio is likely to be formed of a diverse mix of domestic sources and may reduce our reliance on natural gas imports.[289] However, it will be important in ensuring resilience during transition that generation and network capacity increase "in-step" with increased demand.

4.137 Hybrid heat pumps could provide an alternative approach to the challenge of balancing supply and demand by allowing switching from electricity to gas during periods of high electricity demand.[290] Work carried out by Imperial College indicates that the flexibility offered by the fuel switching capabilities of hybrid heat pumps could enable reductions in the capacity of the electricity network required for maintaining a secure and resilient supply.[291]

Hydrogen conversion

4.138 Transitioning from natural gas to hydrogen for heat would not involve the same major increases in electricity demand and flexibility as an energy vector means it could play a complementary and enabling role in the decarbonisation of industry (both as a fuel and feedstock), transport (particularly heavy transport) and power. However, conversion of all or large parts of the gas grid to hydrogen would still represent a huge transformation in the context of the energy system overall, with major implications for the overall balance of fuel demand and the infrastructures required for energy production, storage and distribution.

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284 Energy Networks Association (2011) Developing Networks for Low Carbon: The Building Blocks for Britain's Smart Grids https://www.ofgem.gov.uk/ofgem-publications/56828/smart-grid-forum-workstream-3-report-071011-master.pdf.

285 Consumer-Led Network Revolution (2015) Project Closedown Report http://www.networkrevolution.co.uk/project-library/project-closedown-report-2/.

286 Wales and West Utilities (2018) Project Freedom: Final Report https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf.

287 Element Energy for the National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/wp-content/uploads/Element-Energy-and-E4techCost-analysis-of-future-heat-infrastructure-Final.pdf.

288 For example: Element Energy for the Energy Technologies Institute (2017) Multi Vector Integration Study (Assessment of Local Cases) https://www.eti.co.uk/programmes/energy-storage-distribution/multi-vector-integration Wales and West Utilities (2018) Project Freedom: Final Report https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf.

289 Element Energy and E4Tech (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/wp-content/uploads/Element-Energy-and-E4techCost-analysis-of-future-heat-infrastructure-Final.pdf.

290 Imperial College London (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

291 Imperial College London (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

4.139 The nature of the implications for the energy system will depend on the ways in which hydrogen is produced. As discussed earlier in this chapter, methane reformation is the leading technology option for production of hydrogen in the volumes required for a full-scale hydrogen conversion. This would involve a hugely expanded hydrogen production industry and capacity, together with the necessary supporting carbon capture, usage and storage (CCUS) infrastructure.[292] Widespread use of hydrogen for heating therefore implies a heavy reliance on CCUS and a large scale-up of the industry to achieve the levels of capture which would be required in 2050.

4.140 The Committee on Climate Change question whether the necessary deployment levels could be achieved.[293] Work undertaken by Element Energy estimated that to convert the existing gas grid to hydrogen, 120GW of new low carbon hydrogen generation capacity would be required by 2050 indicating a growth rate of around 6GW per year between 2030 and 2050. This is comparable with the period of rapid expansion of gas fired power generation in the 1990s when new gas generation capacity was added at maximum rate of 5GW per year, albeit over a shorter period.

4.141 This scale of hydrogen production from methane reformation would also involve continuing and potentially increasing reliance on natural gas supplies for heating to the long term. For example, the Sustainable Gas Institute suggests that production efficiencies could be between 60 and 90%, entailing an increase in the natural gas supply needed of between 15% and 66% to satisfy the same heat demand with hydrogen.[294]

4.142 Historically the UK has had access to secure indigenous sources of natural gas, but North Sea gas made up 48% of UK demand in 2016 and is expected to decline to approximately 24% of demand by 2035.[295] Liquified natural gas (LNG) is expected to play an increasing role in the UK supply mix, with CEPA analysis for BEIS (2017) estimating it has the potential to contribute up to 60% of demand by 2035.[296] Globally there are currently significant reserves of unexploited natural gas and IEA figures suggest that, at a global level, natural gas resources will last well beyond 2040, with some estimates ranging as high as 200 years at current production levels.[297] Other options for accessing natural gas, for example domestic unconventional sources, may also become available, and are currently under development.

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292 Imperial College London for the Committee on Climate Change (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/; H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf; Energy Research Partnership (2017) The transition to low carbon heat http://erpuk.org/project/low-carbon-heat/.

293 Committee on Climate Change (2018) Hydrogen in a low carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.

294 Sustainable Gas Institute (2017) A Greener Gas Grid: What are the Options? https://www.sustainablegasinstitute.org/wp-content/uploads/2017/06/SGI-A-greener-gas-grid-what-are-the-options-WP3.pdf?noredirect=1.

295 UK Oil and Gas Production and Expenditure Projections (Feb 2018) Oil and Gas Authority https://www.ogauthority.co.uk/data-centre/data-downloads-and-publications/production-projections/; Department for Business, Energy and Industrial Strategy (2017) Gas security of supply: strategic assessment and review https://www.gov.uk/government/publications/gas-security-of-supply-strategic-assessment-and-review.

296 Gas security of supply: strategic assessment and review, CEPA/BEIS (Assumptions not based on hydrogen pathway projections): https://www.gov.uk/government/publications/gas-security-of-supply-strategic-assessment-and-review; https://www.gov.uk/government/publications/gas-security-of-supply-strategic-assessment-and-review.

297 Holz et al., '*A global perspective on the future of natural gas: resources, trade and climate constraints*', 2015.

4.143 Reliance on natural gas could be reduced through a more diverse production mix, either through producing hydrogen in the UK from a more diverse mix of input fuels or by importing it. However, we are not aware of any published analysis of the energy security implications of a more diverse mix.

4.144 Hydrogen production for electrolysis is an energy intense process[298] due to the efficiencies of producing hydrogen via electrolysis (70–90%)[299] and then burning it in a boiler (80–95%).[300] One estimate, from the Energy Research Partnership, suggests that the UK would need to increase its nuclear capacity seven-fold to meet heat demand through electrolysis.[301] A report by Imperial College takes the view that fully meeting heat demand in 2050 through electrolysis in the UK is not feasible.

4.145 The role that hydrogen from biomass could play is also limited by the availability of sustainable feedstocks as detailed in paragraph 4.155 onwards of this chapter. There are many other ways in which hydrogen could be produced but these are currently pre-commercial and there is no available evidence on their potential to rapidly scale-up supply from novel sources. Some commentators remark on the possible role for low carbon hydrogen imports over the longer-term as a steady demand pulls through supply that can take advantage of low-cost production abroad.[302] Moreover, the international hydrogen market does not currently operate at a scale which would enable full conversion to hydrogen for heat – 95% of global hydrogen production is produced and consumed at the same location.[303]

4.146 Various commentators have discussed the energy system advantages which a hydrogen network could be expected to provide through its storage potential, responsiveness to demand and physical robustness.[304] These are important advantages of the gas system today. However, there would also be important differences between a hydrogen system and today's gas system, as well as key challenges in any conversion process.

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298 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf; Imperial College London for the Committee on Climate Change (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

299 Element Energy (2018) Hydrogen supply chain evidence base https://www.gov.uk/government/publications/hydrogen-supply-chain-evidence-base.

300 Frazer Nash for the Department for Business, Energy and Industrial Strategy (2018) Logistics of domestic hydrogen conversion https://www.gov.uk/government/publications/logistics-of-domestic-hydrogen-conversion.

301 Energy Research Partnership (retrieved November 2018) http://erpuk.org/project/hydrogen/.

302 See for example: Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.

303 E4tech for Committee on Climate Change (2015) Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target https://www.theccc.org.uk/wp-content/uploads/2015/11/E4tech-for-CCC-Scenarios-for-deployment-of-hydrogen-in-contributing-to-meeting-carbon-budgets.pdf.

304 Sustainable Gas Institute (2017) A Greener Gas Grid: What are the Options? https://www.sustainablegasinstitute.org/wp-content/uploads/2017/06/SGI-A-greener-gas-grid-what-are-the-options-WP3.pdf?noredirect=1;
KPMG (2016) 2050 Energy Scenarios https://www.energynetworks.org/assets/files/gas/futures/KPMG%20Future%20of%20Gas%20Main%20report%20plus%20appendices%20FINAL.pdf;
Energy Research Partnership (2016) Role of Hydrogen in UK energy system http://erpuk.org/project/hydrogen/.

4.147 Currently there is limited evidence on how a hydrogen system could be balanced in practice, including the sizing and location of hydrogen storage. Several studies consider there could be reductions in the storage potential of the gas grid in transitioning from natural gas to hydrogen and modelling carried out by Imperial College for the Committee on Climate Change suggests the use of above ground pressurised tanks as a suitable option for balancing supply and demand in the short-term, e.g. within days.[305]

4.148 Various studies indicate an important role for salt caverns storage in providing inter-seasonal hydrogen storage.[306] This storage reduces the capacity of hydrogen generation required, substantially reducing whole system costs while adding a buffer to supplies. The location of this storage would be important to ensure sufficient local hydrogen supply capacity.

4.149 To transport hydrogen from the sites of production and storage to the distribution network, relevant studies indicate that an entirely new high-pressure hydrogen transmission pipeline network would need to be built.[307] The existing natural gas transmission system is likely to be required, at least in part, to transport natural gas to methane reformation facilities. It is also made from steel thought to be unsuitable for hydrogen due to embrittlement issues.[308]

4.150 In order to transport hydrogen across the distribution network, the existing natural gas distribution grid would need to be made suitable for hydrogen and then converted.[309] The H21 study explored the engineering feasibility of converting the distribution grid in the Leeds area to hydrogen, and suggested that once polyethylene pipes have been installed under the Iron Mains Replacement Programme, relatively minor additional pipework modifications would be required. The report describes an approach of sequentially isolating sections of the distribution grid, removing the natural gas before replacing or converting any components not suitable for hydrogen, like any remaining iron pipes, some other network components, such as district governor, and gas-using appliances.

4.151 A programme of physical testing and trialling will be required to confirm safety and feasibility, with the H21 report itself setting out a proposed programme of work. Northern Gas Networks are currently undertaking work to provide quantified safety-based evidence on the suitability of the gas distribution network to transport 100% hydrogen.[310]

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305 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf; Imperial College London for the Committee on Climate Change (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

306 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf; Imperial College London for the Committee on Climate Change (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.

307 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf.

308 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf.

309 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf.

310 Northern Gas Networks (2017) Gas NIC submission: Northern Gas Networks – H21 https://www.ofgem.gov.uk/publications-and-updates/gas-nic-submission-northern-gas-networks-h21.

4.152 Currently, there is limited evidence on the practicalities of delivering a hydrogen transition in practice. Frazer-Nash investigated the logistical requirements of transitioning domestic properties from natural gas to 100% hydrogen (see *Consumer Experience* section). It also considered how a hydrogen appliance installer workforce could be built, building on existing knowledge of Gas Safe engineers, and utilising existing training centres to upskill the workforce through a hydrogen changeover qualification focused on the fundamental differences between hydrogen and natural gas.[311] Further work will be required to fully understand the practical implications of a hydrogen transition across the whole hydrogen supply chain.

4.153 Converting the gas grid to hydrogen would introduce new elements to the network, such as hydrogen production plants and a hydrogen transmission grid, which would constitute additional potential points of failure. The most significant resilience challenges could arise during conversion of sections of the network. Currently the N-1 standard is used to assess gas system resilience and consideration would need to be given to how to apply this to a hydrogen system, especially during the conversion.[312] The initial sections to be converted will not benefit from being connected to the wider network so additional redundancy may need to be built to achieve appropriate resilience levels. As each section of the network is repurposed, hydrogen would need to be injected and natural gas appliances replaced, indicating the need for a highly organised and coordinated transition programme.[313]

311 Frazer Nash for the Department for Business, Energy and Industrial Strategy (2018) Logistics of domestic hydrogen conversion https://www.gov.uk/government/publications/logistics-of-domestic-hydrogen-conversion.

312 BEIS (2016) UK risk assessment on security of gas supply 2016 https://www.gov.uk/government/publications/uk-risk-assessment-on-security-of-gas-supply-2016. The UK's N-1 calculation (whether peak demand could still be met if the single largest piece of infrastructure fails) exceeds the target of 100% with a score of 120%, meaning that UK has 20% more infrastructure than is required to meet demand on the coldest day in 20 winters even if the single largest piece of infrastructure fails.

313 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf.

Bioenergy

4.154 The use of biomass in energy production has the potential to diversify energy sources available to the UK, whether it is used in heat, industry, electricity generation, or transport.[314] Currently, the UK consumes 160TWh of bioenergy per year accounting for 8% of primary energy supply.[315]

4.155 The gas grid supplies a large amount of heat and power in the UK. 873TWh of gas was used in the UK in 2017, with 297TWh of this used for domestic heating.[316] Many energy systems models, such as that of the National Infrastructure Commission or Imperial College London's whole energy systems model shows that the continued use of gas would help to reduce costs and mitigate impacts of full electric heating.[317] A low carbon gas could potentially be used to reduce the overall need for electric heating, offer fuel switching away from electricity in times of peak demand, or provide a rapid supply of electricity to meet peak demand. In their 2016 report, Policy Exchange's scenario analysis suggests an important role for low carbon gas in 2050, requiring 30-40TWH of green gas to heat 20 million homes with efficient gas appliances and hybrid heating systems.[318]

4.156 As already noted, the ability of low carbon gas from biomass to deliver benefits across the heat and power networks is a major uncertainty. Although no studies suggest that biomethane could fully replace the role of natural gas at its current levels of use, a number indicate that it is feasible to deliver much higher quantities compared to current levels of supply. The Committee on Climate Change consider the delivery of 20TWh of biomethane from waste as a low-regrets option. Other studies have suggested a broader range of potential roles for biomethane or hydrogen from biomass to be part of a regional mix, or for industrial fuel switching.[319]

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314 International Energy Agency (2007) Contribution of Renewables to Energy Security https://www.iea.org/publications/freepublications/publication/so_contribution.pdf.
315 Digest of UK Energy Statistics for Department for Business, Energy and Industrial Strategy (2018) Collection: Digest of UK Energy Statistics (DUKES) https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes.
316 Digest of UK Energy Statistics for Department for Business, Energy and Industrial Strategy (2018) Digest of UK Energy Statistics (DUKES): natural gas https://www.gov.uk/government/statistics/natural-gas-chapter-4-digest-of-united-kingdom-energy-statistics-dukes.
317 See National Infrastructure Commission (2018) Cost analysis of future heat infrastructure https://www.nic.org.uk/publications/cost-analysis-of-future-heat-infrastructure/ and Imperial College London for the Committee on Climate Change (2018) Analysis of Alternative UK Heat Decarbonisation Pathways https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/.
318 Policy Exchange (2016) Too Hot to Handle? https://policyexchange.org.uk/publication/too-hot-to-handle/.
319 Examples include: Department of Energy and Climate Change and Department for Business, Innovation and Skills (2015) Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050: Cross-sector Summary https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/419912/Cross_Sector_Summary_Report.pdf; McKinsey & Company (2018) How industry can more toward a low-carbon future https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/how-industry-can-move-toward-a-low-carbon-future; E4Tech for Committee on Climate Change (2015) Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target: Final Report https://www.theccc.org.uk/wp-content/uploads/2015/11/E4tech-for-CCC-Scenarios-for-deployment-of-hydrogen-in-contributing-to-meeting-carbon-budgets.pdf.

4.157 A key determinant of the role of biogas is likely to be influenced by total potential and security of supply of bioenergy[320] and where that potential is prioritised across the energy system.[321] The delivery challenges of deployment of anaerobic digestion and gasification are not the same because they operate at different scales and use different sources of biomass.

4.158 Anaerobic digestion typically uses wet feedstocks such as food wastes, farm wastes and residues and potentially some crops such as maize. As outlined in Chapter 3, estimates of potential range from 20TWh[322] to to 67TWh,[323] (which is equivalent to ~6% of current natural gas demand [324]) of biogas through anaerobic digestion using a wider range of UK feedstocks. To reach the higher end of that range, supply-side barriers such as access to wastes (e.g. household food waste), would need to be overcome[325] and innovation to access feedstocks which are not commonly used, such as agricultural residues, energy crops or algae,[326] may be required.

4.159 Developing gasification technologies can use a wide range of dry feedstocks such as wood residues, energy crops or residual wastes. The National Infrastructure Commission estimate sources from UK feedstocks could provide a maximum of 67TWh,[327] whereas a study produced by Cadent estimates 108TWh.[328] However, this would require commercialisation and scale-up of gasification technology[329] as well as a significant expansion in energy crop production, which has to date fallen short of expectations, mainly due to uncertain

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320 UK Pellet Council (2018) Wood Pellet Shortages http://www.pelletcouncil.org.uk/
321 Some examples of energy system models which indicate priorities based on carbon savings: Energy Technologies Institute (2018) The Role for Bioenergy in Decarbonising the UK Energy System: Findings from the ETI Bioenergy Programme https://www.eti.co.uk/insights/the-role-for-bioenergy-in-decarbonising-the-uk-energy-system-findings-from-the-eti-bioenergy-programme; Committee on Climate Change (2018) Biomass in a low-carbon economy https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/; The International Council on Clean Transportation (2018) Bioenergy can solve some of our climate change problems, but not all of them at once https://www.theicct.org/blog/staff/bioenergy-solve-some-climate-problems-not-all-once.
322 Department for Business, Energy and Industrial Strategy (2017) UK and Global Bioenergy Resource Model https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model.
323 Element Energy & E4tech for the National Infrastructure Commission (2018) Cost analysis of future heat infrastructure options https://www.nic.org.uk/supporting-documents/cost-analysis-of-future-heat-infrastructure-options/.
324 Based on primary energy demand for natural gas, from the Digest of UK Energy Statistics for Department for Business, Energy and Industrial Strategy (2018) Digest of UK Energy Statistics https://data.gov.uk/dataset/894d91a9-5d13-4220-b9a2-e124e6436304/digest-of-united-kingdom-energy-statistics.
325 Wrap (2016) The Food Waste Recycling Plan http://www.wrap.org.uk/content/food-waste-recycling-action-plan.
326 Seagas (retrieved October 2018) http://seagas.co.uk/; Anaerobic Digestion and Bioresources Association (retrieved October 2018) http://adbioresources.org/news/heat-decarbonisation-and-the-role-of-new-ad-feedstocks.
327 Element Energy & E4tech for National Infrastructure Commission (2018) Cost analysis of future heat infrastructure options https://www.nic.org.uk/supporting-documents/cost-analysis-of-future-heat-infrastructure-options/.
328 Anthesis and E4Tech (2017) https://cadentgas.com/about-us/the-future-role-of-gas/renewable-gas-potential. Central estimate of renewable gas potential of 108TWH (range 68-183TWh) in 2050.
329 as plants could be built at the scale of a small power station (100MW+) and could utilise a range of feedstocks that are more plentiful and available in bulk such as dry wastes (e.g. mixed municipal waste and waste wood), residues (e.g. straw and forest residues) and woody or grassy crops (energy crops).

demand,[330] high establishment costs and delayed returns in investment.[331]

4.160 Supply of biogas or biomass feedstocks could be available through imports. The Government and the Committee on Climate Change set out estimates of sustainable biomass potential including estimates of the UK's "fair share" of imports – total sustainable potential lay between 200 and 550TWh of biomass.[332] Absolute estimates of global biomass supply are far higher, but are highly uncertain due to the relative immaturity of the global energy crop market and assumptions about the quantity of suitable land.[333] Even if such supply developed, it would likely come with significant risk; the infrastructure required to integrate it into UK supply chains, the impacts of weather on prices and production and international competition for resource could make supply and prices volatile.[334] Because of the bulky nature of the feedstocks, imports of anaerobic digestion waste feedstocks are unlikely. Although an international trade in biomethane made through anaerobic digestion abroad is technically possible,[335] the scale of a potential global market has not been estimated.

4.161 Beyond potential size and security of supply, conversion of gas supply to biomethane would also require some infrastructure changes. Currently natural gas is supplied from offshore to a few key locations to flow from high pressure to lower pressure networks.[336] Biogas is more likely to be produced in multiple UK locations; most in closer proximity to the distribution grid, necessitating changes to the way in which gas is stored and transported in the gas grid.

4.162 Greater use of domestically produced biomethane is likely to result in gas injection at multiple points,[337] and gas supply which cannot easily ramp up and down according to changes in gas demand. As a result, a greater focus on network integrity and storage may be required as supply becomes more highly distributed, more UK focused and less flexible.

330 Piterou, A., Shackley, S. & Upham, P. (2008) Project ARBRE: lessons for bio-energy developers and policy makers https://www.researchgate.net/publication/223720605_Project_ARBRE_Lessons_for_bio-energy_developers_and_policy-makers; National Farmers Union (retrieved October 2018) NFU moves to reassure Drax miscanthus growers https://www.nfuonline.com/cross-sector/farm-business/energy-and-renewables/energy-and-renewables-news/nfu-moves-to-reassure-drax-miscanthus-growers/; Farmers Weekly (retrieved October 2018) Drax ends miscanthus contracts and review straw supply https://www.fwi.co.uk/business/drax-ends-miscanthus-contracts-reviews-straw-supply.
331 Energy Technologies Institute (2016) Bioenergy crops in the UK: Case studies on successful whole farm integration evidence pack https://www.eti.co.uk/library/bioenergy-crops-in-the-uk-case-studies-on-successful-whole-farm-integration-evidence-pack.
332 See Digest of UK Energy Statistics for Department for Business, Energy and Industrial Strategy (2018) Digest of UK Energy Statistics (DUKES): natural gas https://www.gov.uk/government/statistics/natural-gas-chapter-4-digest-of-united-kingdom-energy-statistics-dukes and Committee on Climate Change (2018) Biomass in a low-carbon economy https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/.
333 Global market status for energy crops summarised in: Ecofys and E4Tech (2017) https://www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat.
334 UK Pellet Council (2018) Wood Pellet Shortages http://www.pelletcouncil.org.uk/news/wood-pellet-shortages.
335 Ends (2017) UK sends first biomethane directly to Europe https://www.endswasteandbioenergy.com/article/1429136/uk-sends-first-biomethane-directly-europe; Green Gas Certification Scheme (retrieved October 2018) https://www.greengas.org.uk/; Green Gas Trading (retrieved October 2018) http://greengastrading.co.uk/.
336 Digest of UK Energy Statistics for Department for Business, Energy and Industrial Strategy (2018) Digest of UK Energy Statistics (DUKES): natural gas https://www.gov.uk/government/statistics/natural-gas-chapter-4-digest-of-united-kingdom-energy-statistics-dukes.
337 Biogas map (retrieved October 2018) http://www.biogas-info.co.uk/resources/biogas-map/.

Industrial heating

Strategic inferences: Industrial Heat

- There are a range of technologies which have the potential to make important contributions to the transition to low carbon industrial heating. The use of heat in industrial processes is much more varied than for heat in buildings, depending on factors such as the fuels and processes used and the temperature required. Partly because of the diversity of heat use in industry, the evidence base on effective decarbonisation options is less well-developed than for heat in buildings.
- A combination of technologies is likely to be required to achieve deep decarbonisation in various industrial sectors cost-effectively, and energy efficiency and carbon capture are likely to have a wide role to play alongside various fuel switching options.
- While the best technology choices for reducing carbon emissions from various industries are unlikely to be limited to those approaches taken to decarbonise space heating in buildings, certain industry choices may be affected by future decisions relating to the gas grid.
- There are a range of barriers to the deployment of technologies that can decarbonise industry. Many of these flow from the lack of sufficient incentive at present for private investment in industrial decarbonisation and from questions over the commercial readiness of certain technologies for specific processes. Resolving these technical and economic uncertainties, including through further exploration of the role that clustering can play in improving efficiencies, will be crucial to bringing forward deployment of industrial decarbonisation.

4.163 As set out in Chapter 2, industry relies on a range of energy sources for heating with needs determined by process-sensitive factors including the temperature required. As such, not all low carbon fuels will be suitable for decarbonising all industrial processes. A combination of solutions is likely to be required.[338]

4.164 Given this diversity of industrial heat demand and use, the potential costs of changing heating processes or fuels, the related commercial investment decisions involved, and the varying levels of commercial readiness of technologies for doing so, industry is recognised as a difficult area to fully decarbonise, with a range of distinct technological and economic barriers

338 Department of Energy and Climate Change and Department for Business, Innovation and Skills (2015) Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050.

4.165 Illustrating this challenge, even the "maximum technology" pathway[339] of the Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 studies prepared for the Government in 2015 (the "2050 Roadmaps") estimated an annual industrial emissions reduction of 73% by 2050.[340] However, this set of studies did not take into account the potential of hydrogen as a fuel in its analysis, as noted below.

4.166 Various studies for BEIS in recent years have also noted that the heat requirements of some industrial processes mean that certain low carbon technologies are unlikely to be suitable. Across industry, a combination of solutions is likely to be required.[341] There is thus a potential role for a range of lower carbon technologies and fuels to contribute to the decarbonisation of industry, including the electrification of certain processes and the use of biomass and hydrogen fuels for others.

4.167 For example, analysis in the 2050 Roadmaps, which assessed the technical potential for reducing emissions in the eight most heat-intensive industrial sectors, suggested that under certain scenarios biomass could play a potentially major role in decarbonising the cement, paper and pulp, and chemicals industries, while the electrification of presently combustive processes could potentially play a significant role in both high and lower temperature processes, including in ceramics, glass, food and drink, and paper and pulp.[342]

4.168 The same studies note that energy efficiency measures and CCUS, potentially aided by greater geographic clustering of certain industries, are likely to have an important role to play under any scenario and across many industrial processes. Figure 4.1 helps to illustrate this, showing the technical potential contribution to industrial emissions reductions of a range of factors and process changes, under the 2050 Roadmaps' "maximum technology" scenario.

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339 Where it was assumed that technology was deployed to the greatest extent possible, setting aside cost-optimisation considerations

340 Department of Energy and Climate Change and Department for Business, Innovation and Skills (2015) "2050 Roadmaps" Cross-Sector Summary https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050

341 For example: Department of Energy and Climate Change and Department for Business, Innovation and Skills (2015) Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050 ; Department for Business, Energy and Industrial Strategy (2018) Industrial Fuel Switching Market Engagement https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf

342 Department of Energy and Climate Change and Department for Business, Innovation and Skills (2015) Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050. Note that technical potential here does not take into account cost, and that Figure 4.2 below from the same study does not represent cost-optimised estimates of the role of different technologies.

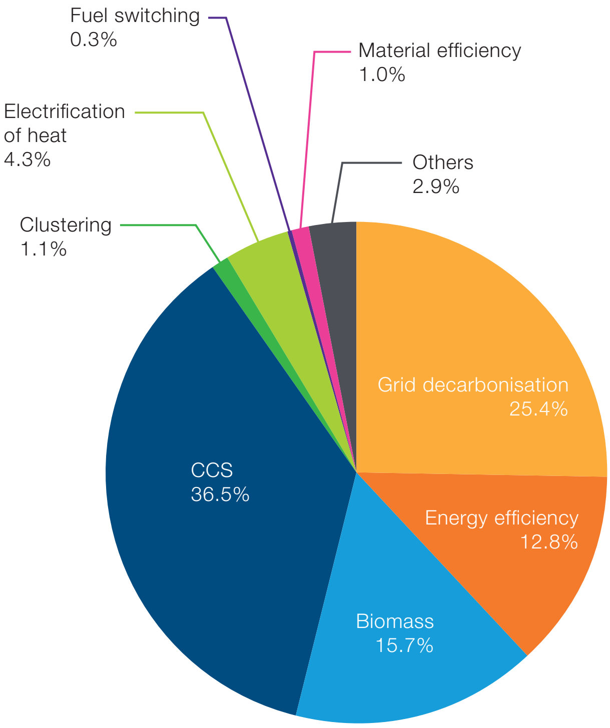

Figure 4.1 2015 analysis on the technical potential for emissions reduction in 8 most heat-intensive industrial sectors Source: BEIS, 2015.

4.169 However, the 2050 Roadmaps did not examine all technologies which have the potential to decarbonise industry, such as hydrogen. More recent analysis has taken a broader scope, including to examine the role which hydrogen might play in reducing emissions from industry.[343]

4.170 In their report, the Committee on Climate Change conclude that hydrogen could play a larger role than previously assessed, and is likely to be particularly valuable in industrial processes (e.g. furnaces and kilns) where the flame and combustion gases need to come into direct contact with the material or product, and where there are more distributed sources of carbon emissions (e.g. in the food and drink sector) which it would be impractical or costly to capture. Their modelling (see Figure 4.3) suggests that hydrogen enables cost-effective industrial decarbonisation to be deeper, with an extra 9Mt abated (of the 25-35Mt emissions from manufacturing industry in 2050 previously projected in a 2016 study by the Committee).[344]

343 Including: The Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/; Department for Business, Energy and Industrial Strategy (2018) Industrial Fuel Switching Market Engagement https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf; Energy Transitions Commission (2018) Mission Possible: Reaching Net-Zero Carbon Emissions From Harder-to-Abate Sectors by Mid-Century http://www.energy-transitions.org/mission-possible

344 The Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/

Costs and potential of fuel switching options in industry (excludes CCS)

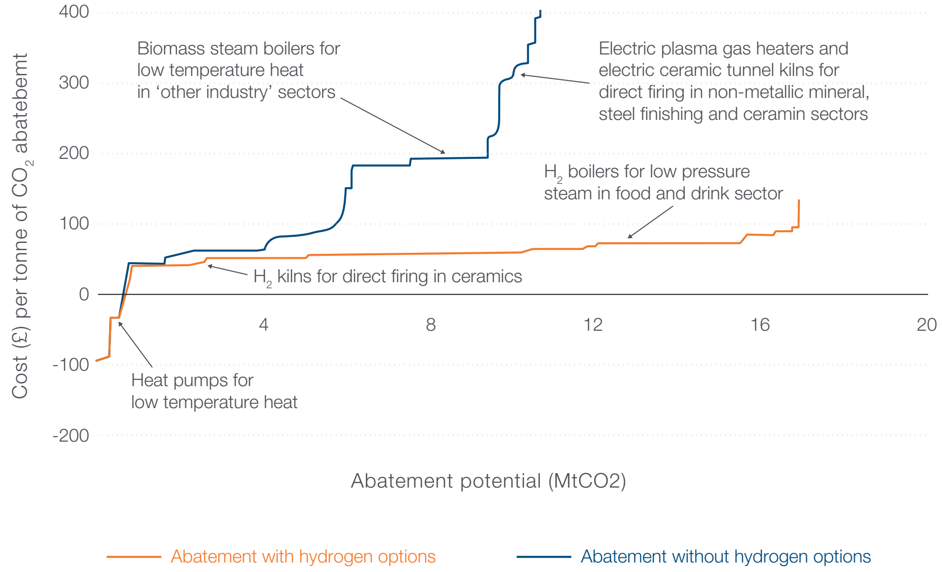

Figure 4.2 Marginal abatement cost curve showing hydrogen's potential role in industrial decarbonisation.[345]

4.171 Element Energy's report for BEIS on *Industrial Fuel Switching* also suggested that hydrogen could have a significant role to play in industrial decarbonisation. Their analysis showed that across various indirect and direct industrial heating processes, available fuel switching options differed (see Table 4.1 below), with the estimated overall technical potential of hydrogen the highest (94TWh of replaced heat demand) followed by biomass (54TWh) and electricity (48TWh) when only one alternative fuel type was considered across all applications.[346]

345 ibid.

346 Department for Business, Energy and Industrial Strategy (2018) Industrial Fuel Switching Market Engagement https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf.

Table 4.1 Suitability of fuel-switching options for key industrial processes

Processes driven by	Process type*	Suitable fuel-switching options	Key sectors relying on these processes
Indirect heating	Low temperature	Biomass boilers, hydrogen boilers, electric boilers, electric heaters, heat pumps (up to 25% substitution), microwave heaters	Vehicles, other industry
	High temperature	Electric heaters, hydrogen heaters	Refining, Ethylene & Ammonia
	Steam	Biomass boilers, hydrogen boilers, electric boilers, heat pumps in limited applications (up to 25% substitution)	Food & Drink, Paper, Chemicals, other industry
Direct heating	Low temperature	Electric heaters, hydrogen heaters	Vehicles, other industry
	High temperature	Biomass and waste combustion (cement sector – up to 80% substitution), hydrogen heaters, electric kilns / furnaces, radio frequency heating, electric plasma gas heaters (up to 25% substitution)	Glass, Ceramics, Cement, other non-metallic minerals
	Reduction processes	Direct reduction of biomass/waste materials (up to 25% substitution) or hydrogen (up to 25% substitution)†, electric plasma gas heaters (up to 25% substitution)	Iron production

* "Low temperature" corresponds to processes requiring temperatures of 30-80°C for indirect heating, and 80-240°C for direct heating. High temperature corresponds to processes requiring temperatures of up to 600°C for indirect heating, and up to 2,000°C for direct heating. Steam at different pressures can meet indirect heating requirements in the 80-240°C range.

† Note that this does not refer to DRI (direct reduced iron) but to substitution of alternative fuels within the baseline UK primary iron production route (either blast furnace or, in the future, HISarna)

4.172 The Energy Technologies Institute's report: *The role for bioenergy in decarbonising the UK energy system, provides a different perspective to the Element Energy Industrial Fuel Switching* report on the role that bioenergy in industry could play. The former focused on technical potential in industry whereas the latter took a system-wide view on where bioenergy can be used to maximise its value. The report recommended that the value of bioenergy would be "greatest when combined with CCUS to deliver negative emissions", and that "in the absence of CCUS its value would be greatest when producing gaseous or liquid fuels for use in sectors which are otherwise difficult to decarbonise", including industry.[347]

4.173 Either way, the ultimate potential for biomass in contributing to industrial decarbonisation, as across heat decarbonisation more broadly, will be constrained by economy-wide considerations on the best use for a limited national and international supply of biomass for the energy system overall, as noted earlier in this chapter and as the *Industrial Fuel Switching* study also underlines.

4.174 As all studies note, however, there are a range of barriers to the implementation of each of the technologies discussed above. For instance, a report for BEIS on industrial carbon capture business models highlighted 13 key barriers to the deployment of industrial carbon capture (see Table 4.2), including technical, economic, political and cross-chain (integration of capture and transport and storage) issues.[348]

4.175 Many of the technical, economic and political barriers that Element Energy highlight in this report for industrial carbon capture are also likely to apply to other approaches to decarbonising industrial heat. Other challenges include the fact that many of the relevant technologies for particular sectors or uses of heat are not yet commercially available, that in most cases carbon capture technologies will still result in some level of residual emissions, and that the very long lives of some industrial assets may either delay the deployment of new technologies or require the scrapping of existing plant before the end of its useful life.

4.176 Addressing similar themes, the recent *Industrial Fuel Switching* report for BEIS emphasises the importance of considering the technical challenges and system costs for each industry group individually, noting that even where some technologies are already commercially viable for certain processes, significant further design work may be required before they will reach readiness for application in other industries, with effects on costs and deployment timelines.[349]

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347 Energy Technologies Institute (2018) The role for Bioenergy in Decarbonising the UK Energy System: Findings from the ETI Bioenergy Programme https://www.eti.co.uk/insights/the-role-for-bioenergy-in-decarbonising-the-uk-energy-system-findings-from-the-eti-bioenergy-programme

348 Department for Business, Energy and Industrial Strategy (2018) Industrial carbon capture business models https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/759286/BEIS_CCS_business_models.pdf

349 Department for Business, Energy and Industrial Strategy (2018) Industrial Fuel Switching Market Engagement https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf. The 2050 Roadmaps studies make a similar point about industry-specific technological readiness: Department of Energy and Climate Change and Department for Business, Innovation and Skills (2015) Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050

4.177 In addition, the costs of the different decarbonisation technologies can vary significantly depending on industrial process or geographic location. For instance, the study on industrial carbon capture highlights that the cost of carbon capture from hydrogen production (mainly in the fertiliser and oil refining sectors) can be significantly cheaper than in other sectors due to the purity and pressure of carbon that is produced. [350]

4.178 In a similar vein, the *Industrial Fuel Switching* report observes that where industry is co-located in clusters with isolated energy networks, leading to integrated sites with greater efficiency, it may be more straightforward to overcome some of these technical and economic barriers by taking advantage of the opportunities to share infrastructure and resources, including but not only for carbon capture, usage and storage.[351] Depending on the proportion of UK industry that is located in clusters this could offer a significant opportunity to drive down the costs of action whilst also delivering an agglomeration of benefits.

Table 4.2 Summary of key industrial carbon capture barriers

Category		Risks, challenges & market failures
Technical & operational	1	Technology performance
	2	Plant integration risks
Economic & market	3	Capital cost uncertainty
	4	Poor finance terms due to perceived high risks
	5	Insufficient value proposition and lack of revenue model
	6	Industry instability and product demand uncertainty
	7	Competitiveness and carbon leakage
	8	Opex uncertainty including fuel prices
Political	9	Policy uncertainty
	10	CO2 price uncertainty
Cross-chain	11	Cross-chain integration
	12	Transport and storage fee uncertainty
	13	Transport and storage availability and performance

350 Department for Business, Energy and Industrial Strategy (2018) Industrial carbon capture business models https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/759286/BEIS_CCS_business_models.pdf

351 Department for Business, Energy and Industrial Strategy (2018) Industrial Fuel Switching Market Engagement https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf

Questions

4.179 We welcome your views on the above discussion, in particular:

(a) Does this overview of the strategically important issues, as identified in the course of our review of the evidence, highlight the key issues? Are there important issues missing?

(b) Are there any important pieces of evidence that require further consideration?

(c) Do you agree with the set of strategic inferences we have drawn out?

Discussion of the Evidence Base: Achieving Change

5. Discussion of the Evidence Base: Achieving Change

Introduction

5.1 Like the transition to low carbon electricity generation, the transition to low carbon heating will require major changes in our energy production industries and distribution systems. However, the changes in our electricity generation industries require little if any adaptation by the consumer. In heating, the shift to low carbon will affect us directly and require adaptations to the vast majority of our buildings and industrial sites.

5.2 This chapter focuses on what the available evidence and analysis can tell us about:

- the readiness of consumers to accept and switch to low carbon heating options, and how public engagement with and participation in the transition might be enhanced;
- the extent to which policy co-ordination and direction might be needed to enable different options or improve outcomes for consumers – for example by optimising systems, enabling markets to play a role in shaping outcomes, enabling efficient provision of infrastructure – as well as to ensure social fairness and protection for vulnerable consumers; and,
- the potential for local government and other local organisations to play an increasing part in delivering heat decarbonisation, through public engagement and support, or the co-ordination and direction of energy policies and plans.

5.3 While few public policy change programmes involve a similar breadth and depth of change as transitioning to low carbon heating, we must look to learn the lessons of relevant parallels wherever we can find them. Some examples include the transition from town gas to natural gas in the 1960s and 70s, the rollout of broadband, the current efforts to support the transition to low carbon vehicles, and the example of the small number of countries which have already made major progress in decarbonising heating. However, there are few such countries, and none so far have tried to implement a shift away from natural gas for heating.

5.4 As in Chapter 4, we seek to provide an overview of strategically significant issues discussed in the research and analytical studies available; and then to highlight strategic inferences which might inform development of a future policy framework. Again, we seek to give fair coverage across the range of issues addressed in the studies available, while recognising that no reasonably concise summary can be comprehensive.

Strategic inferences: Heat decarbonisation outcomes and approaches

- Public awareness of the need to transition to low carbon heating and the technologies available remains low. This will need to change to enable a more informed debate about our long term options and choices for decarbonising heat. Markets could play a role in driving public engagement on these issues, not least by improving the consumer proposition.
- A comprehensive policy framework will need to be developed to address the range of barriers to the take up of low carbon heating and provide consumers with appropriate incentives, support and protections.
- How costs are distributed across society and the economy will also be a key question in developing any future policy framework.
- All approaches to achieving deep decarbonisation of heat would involve far-reaching changes for our energy infrastructures. Extensive planning and co-ordination will be required to enable these changes to be funded and delivered as cost-effectively as possible, and with minimum disruption to consumers, businesses and the wider public.
- Conversion of large parts or the whole of the gas distribution system to hydrogen would require the most comprehensive planning and co-ordination, continuing over a period of decades, encompassing all parts of the supply chain for hydrogen, including carbon capture and storage provision, product development, and the full range of consumers affected. On the other hand, large-scale adoption of electric heating could require more extensive infrastructure developments within communities and therefore require greater localised planning.
- Any policy framework should also effectively leverage market dynamics in developing technologies and enabling as much consumer choice as possible. Markets also play a role in determining the most cost-effective routes to decarbonisation, although the evidence around this is uncertain and debated. At the same time, some degree of strategic direction is likely to be required to enable efficient planning and co-ordination and drive major investments.
- Any future long term policy framework is likely to need to be sufficiently flexible to adapt effectively to different local circumstances and requirements as they develop over time. Local leadership could play an important role in achieving this, while recognising the need in some instances for more centralised planning and coordination.

Consumer engagement

5.5 Studies routinely identify key barriers to more rapid consumer take up of low carbon heating, including: low levels of awareness and familiarity of low carbon alternatives; the hassle and disruption involved in switching; and the relatively high costs compared to natural gas heating.[352] Any successful framework for the long-term decarbonisation of heat will need to address each of these factors.

5.6 Low public awareness of the case for change and the options available remains a key strategic challenge.[353] Current Government support for low carbon heating is targeted at a small subset of consumers – mainly those in buildings off the gas grid – and many consumers do not think about their heating until they need to replace it. In this context, the BEIS Public Attitudes Tracker indicates that 92% of the public are unfamiliar with renewable heating technologies, having never heard of them, knowing little about them, or not understanding the technologies involved.[354]

5.7 Research also suggests the current low desirability and low uptake of low carbon heating systems may be due to poor awareness, not an inherent bias against the possibility of change.[355] One recent study found that while awareness of the case for a switch to low carbon heating was generally low, when asked a significant majority of survey respondents were open to the idea in principle (in line with levels of support for action to reduce carbon emissions generally), albeit in a context of very limited awareness of the options or implications in achieving a heating transition.[356]

352 For example, Madano and Element Energy for the Committee on Climate Change (2018) Public acceptability of hydrogen in the home https://www.theccc.org.uk/publication/public-acceptability-of-hydrogen-in-the-home-madano-and-element-energy/

353 Committee on Climate Change (2018) 'Hydrogen in a low-carbon economy': https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.

354 Department for Business, Energy and Industrial Strategy (2018) Public Attitudes Tracker: Wave 26 https://www.gov.uk/government/statistics/beis-public-attitudes-tracker-wave-26.

355 Chaudry, M et al (2015). Uncertainties in decarbonising heat in the UK https://orca.cf.ac.uk/75558/7/OA-20152016-43.pdf.

356 Madano and Element Energy for the Committee on Climate Change (2018),"Public acceptability of hydrogen in the home https://www.theccc.org.uk/publication/public-acceptability-of-hydrogen-in-the-home-madano-and-element-energy/.

5.8 Other research suggests that the more information people have about renewable and low carbon technologies, the more acceptable they become.[357] And while not representative of the population at large, among the customers who have installed renewable heating technologies under government incentives like the Renewable Heat Premium Payment and the Renewable Heat Incentive, satisfaction is high once the technologies are in place (over 90% satisfaction under the Renewable Heat Premium Payment scheme).[358] International evidence suggests favourable consumer perception of and confidence in technologies to be an important factor for driving the uptake of low carbon heating, often underpinned by quality standards, as seen in countries such as Germany and Sweden.[359]

5.9 As the evidence indicates that UK consumers are generally very satisfied with their existing heating systems, it will likely take a strong consumer proposition to increase public readiness to accept a transition to low carbon heating. Research in 2013 found that for 90% of people, a gas boiler would be their preference for a future heating option[360] and 70% of the public would not change their existing system until their current one fails.[361] Evidence suggests that improvements in the attractiveness of low carbon products relative to predominant heating technologies could drive their widespread adoption.[362] The Energy Technologies Institute point out that the adoption of central heating rose from 25% in 1970 to 90% in 2006, despite the disruption caused by its installation, because it offered an improved consumer experience.[363]

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357 Energy Technologies Institute (2017) An ETI Perspective – Public Perceptions of Bioenergy https://www.eti.co.uk/library/an-eti-perspective-public-perceptions-of-bioenergy.

358 Department for Business, Energy and Industrial Strategy (2018) Public Attitudes Tracker: Wave 26 https://www.gov.uk/government/statistics/beis-public-attitudes-tracker-wave-26.

359 Vivid Economics for Department for Business, Energy and Industrial Strategy (2018) International Comparisons of Heating, Cooling and Heat Decarbonisation Policies https://www.gov.uk/government/publications/international-comparisons-of-heating-cooling-and-heat-decarbonisation-policies; See also: UK Energy Research Centre for the Committee on Climate Change (2016) Best Practice in Heat Decarbonisation Policy https://www.theccc.org.uk/publication/ukerc-best-practice-in-heat-decarbonisation-policy/.

360 Department of Energy and Climate Change (2013) Homeowners' Willingness to Take Up More Efficient Heating Systems https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/191541/More_efficient_heating_report_2204.pdf.

361 Department for Business, Energy and Industrial Strategy (2018) Public Attitudes Tracker: Wave 26 https://www.gov.uk/government/statistics/beis-public-attitudes-tracker-wave-26.

362 Energy Technologies Institute (2016) Smart Systems and Heat: Consumer challenges for low carbon heat https://www.eti.co.uk/library/smart-systems-and-heat-consumer-challenges-for-low-carbon-heat.

363 Energy Technologies Institute (2016) Smart Systems and Heat: Consumer challenges for low carbon heat https://www.eti.co.uk/library/smart-systems-and-heat-consumer-challenges-for-low-carbon-heat.

5.10 The Committee on Climate Change among others recognise the need for greater public engagement on heat decarbonisation.[364] However, there is very little academic literature on strategic approaches to developing public engagement on this specific issue, and only a limited amount on comparable transitions overall, particularly regarding the early stages of raising awareness and building support. The range of the studies that do exist on the topic, however, demonstrates the breadth of avenues for and dimensions of engagement and actors involved, including for information and awareness-raising, deliberation, and consumer action. Current work by the UK Energy Research Centre is seeking to map this breadth of engagement.[365]

5.11 While there is a growing literature on historical energy transitions, work in this area tends to emphasise the unique and particular circumstances and complexities of different transitions.[366] Nevertheless, the broader literature focussing on technological and environmental issues suggests that effective public engagement strategies can be built from certain core principles, arguing, for example, that public engagement is most effective when it helps enable debate and reflection.[367]

5.12 There is some evidence to suggest the public may view the Government as a more trustworthy leader for an energy transition than industry,[368] and that the Government should take more responsibility than industry to ensure the necessary changes to our energy system.[369] To translate this into committed public support, long-term strategies need to seek to explore public expectations and concerns regarding the decision-making behind projects and the relative roles of different trusted authorities.[370]

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364 Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.

365 UK Energy Research Centre (2017) Public Engagement with Energy: broadening evidence, policy and practice http://www.ukerc.ac.uk/publications/public-engagement-with-energy.html.

366 Arapostathis, S. et al. (2013) Governing transitions: Cases and insights from two periods in the history of the UK gas industry https://www.sciencedirect.com/science/article/pii/S0301421512006957.

367 Stirling, A. for Department of International Development (2005) Opening Up or Closing Down?: Analysis, Participation and Power in the Social Appraisal of Technology https://www.gov.uk/dfid-research-outputs/opening-up-or-closing-down-analysis-participation-and-power-in-the-social-appraisal-of-technology; Leach, M. et al. for Department of International Development (2005) Science, Citizenship and Globalization. https://assets.publishing.service.gov.uk/media/57a08c8e40f0b649740012bc/intro1.pdf; Corner and Clarke (2017) Talking Climate: From Research to Practice in Public Engagement https://www.palgrave.com/gb/book/9783319467436; Stirling, A. for the Social, Technological and Environmental Pathways to Sustainability Centre (2015) Towards innovation democracy? Participation, responsibility and precaution in the politics of science and technology https://steps-centre.org/wp-content/uploads/Innovation-Democracy.pdf; Chilvers, J. and Kearnes, M. (2015) Remaking Participation: Science, Environment and Emergent Publics. https://www.routledge.com/Remaking-Participation-Science-Environment-and-Emergent-Publics/Chilvers-Kearnes/p/book/9780415857406; Armeni, C. (2016) Participation in Environmental Decision-making: Reflecting on Planning and Community Benefits for Major Wind Farms https://academic.oup.com/jel/article-pdf/28/3/415/9370794/eqw021.pdf.

368 Demski, C. et al. (2017) Public prioritisation of energy affordability in the UK https://www.sciencedirect.com/science/article/pii/S0301421513011063?via%3Dihub.

369 UK Energy Research Council (2013) Transforming the UK Energy System: Public Values, Attitudes and Acceptability – Deliberating Energy System Transitions in the UK http://www.ukerc.ac.uk/publications/transforming-the-uk-energy-system-public-values-attitudes-and-acceptability-deliberating-energy-system-transitions-in-the-uk.html.

370 Upham, P. (2012). Don't lock me in: Public opinion on the prospective use of waste process heat for district heating https://research.ncl.ac.uk/pro-tem/components/pdfs/SusTEM2010_Track1_2_Paul_Upham.pdf.

5.13 A recent report by UKERC on incumbency in the UK heat sector highlighted the importance of smaller industry players, such as appliance installers, in influencing consumer decision-making.[371] The role of heating engineers and their capacity to influence customers, it is argued, makes them a group that should be the focus of further research and consideration when designing policy.[372]

5.14 On the consumer side, commentators have noted growing opportunities presented by innovative technologies for consumers to engage with energy in new ways and to play an increasingly influential role in shaping the energy system. It is argued that the growth of home generation and the increasing uptake of electric vehicles, coupled with far greater access to data, have created real potential for consumers to take control of their energy production and more actively interact with the wider market.[373] In turn it is argued that, given the right signals or enabling technologies, consumers will become more responsive to the costs of energy in much the same way industrial or business users are today and more proactive regarding when or how they consume energy.[374] A more engaged consumer base could potentially drive the uptake of new low carbon heating products.

5.15 As homes become more connected there could also be new opportunities for innovative business models that enable consumers to buy heat or energy as a service rather than simply purchasing units of fuels. This could provide important opportunities for supporting the uptake of low carbon heating – enabling energy providers to better understand customer needs and design better low carbon heating solutions and help overcome barriers including high up-front costs.[375] The Smart Systems and Heat project led by the Energy Systems Catapult is developing and testing innovative consumer propositions in this regard.[376] Similarly, among the objectives of the Freedom project was to use hybrid heat pumps combined with sophisticated controls to make demand smarter, providing heating to consumers with lower bills, while at the same time providing more flexibility to gas and electricity suppliers.[377]

Markets, co-ordination and planning

5.16 Studies into heat decarbonisation generally assume, explicitly or implicitly, that new frameworks of law and governance will be required to overcome barriers to change and to manage effectively the risks and complexities involved.[378]

371 UKERC (2018), Incumbency in the UK heat sector and the implications for transformation towards low-carbon heating, http://www.ukerc.ac.uk/asset/71244478-75C6-497A-BD33737EDDACFA0B/.

372 UKERC (2018), Incumbency in the UK heat sector and the implications for transformation towards low-carbon heating, http://www.ukerc.ac.uk/asset/71244478-75C6-497A-BD33737EDDACFA0B/.

373 For example: KPMG (July 2016) 2050 Energy Scenarios: The UK gas networks role in the 2050 whole energy system http://www.energynetworks.org/gas/futures/the-uk-gas-networks-role-in-a-2050-whole-energy-system.html; or Energy Technologies Institute (2018) How Can People Get the Heat They Want at Home, Without the Carbon? https://d2umxnkyjne36n.cloudfront.net/insightReports/FINAL-How-can-people-get-the-heat-they-want-at-home-without-the-carbon.pdf?mtime=20180209112725.

374 Leal-Arcas, R. et al. (2018) Prosumers as New Energy Actors https://link.springer.com/chapter/10.1007/978-3-319-93438-9_12.

375 Energy Systems Catapult (2018) Using the connected home to deliver low carbon energy services that people value https://es.catapult.org.uk/news/the-fight-against-carbon-how-technology-can-help-us-heat-our-homes-the-cleaner-way/.

376 Energy Systems Catapult (last accessed November 2018) Smart Systems and Heat https://es.catapult.org.uk/projects/smart-systems-and-heat-ssh/.

377 Wales and West Utilities (2018) Freedom Project: Final Report (2018) https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf.

378 For example: Carbon Connect (2015) Policy for Heat: Transforming the System http://www.policyconnect.org.uk/cc/sites/site_cc/files/policy_for_heat_-_transforming_the_system_online.pdf; Imperial College London (2016) Managing Heat System Decarbonisation: Comparing the impacts and costs of transitions in heat infrastructure https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf.

5.17 Relatively few published studies focus primarily on broad policy architecture and co-ordination. Studies that do comment on this vary in the emphasis they place on the role of markets and the role of centralised decision-making in achieving a low carbon transition. For example, Policy Exchange have discussed the importance of carbon pricing in incentivising the deployment of low carbon technologies. They advocate that government avoids choosing between technologies and instead enables the market to determine the most cost-effective path to heat decarbonisation while maximising consumer choice.[379] In a similar vein, an independent review commissioned by the Department for Business, Energy and Industrial Strategy on reducing energy costs in the long-term also recommends that the most cost-effective means of achieving the Government's decarbonisation commitment is to apply carbon pricing across the whole economy, including emissions from buildings.[380] On the other hand, several commentators focus on the potential for centralised action. For example, the Committee on Climate Change has called for a heat strategy and for the Government to make strategic decisions about how buildings connected to the gas grid should be decarbonised.[381]

5.18 More widely considered, in varying degrees of depth, are more specific policy requirements and options, including:

- interventions to address differentials in costs between low carbon and fossil fuelled heating,[382] including subsidies for the former and carbon taxes on the latter, and interventions to address the problem of high up-front costs;[383]
- how to reduce the risk of disproportionate impacts on consumers on low incomes;[384] and,
- new regulation, particularly in the areas of product standards and of building or planning controls, to incentivise or require low carbon solutions in specified circumstances.[385]

5.19 There is partial evidence in each of these areas from the application of policies in the UK. For example, the operation of the Renewable Heat Incentive has provided a wide range of evidence which can inform future policy.[386] There is evidence that building regulations and local planning guidance are increasingly incentivising district heating and electric heating in new developments in urban areas, although there is no systematic study available to evidence and assess such effects. However, the design of policy to support low carbon heating has a relatively short history compared with other areas.

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379 Policy Exchange (2016) Too Hot to Handle? https://policyexchange.org.uk/publication/too-hot-to-handle/.
380 Dieter Helm (2017) Cost of Energy: Independent Review https://www.gov.uk/government/publications/cost-of-energy-independent-review.
381 Committee on Climate Change (2018) Hydrogen in a low-carbon economy https://www.theccc.org.uk/publication/hydrogen-in-a-low-carbon-economy/.
382 Policy Exchange (2016) Too Hot to Handle? https://policyexchange.org.uk/publication/too-hot-to-handle/.
383 National Energy Action (2017) Heat Decarbonisation: Potential impacts on social equity and fuel poverty https://www.nea.org.uk/resources/publications-and-resources/heat-decarbonisation-potential-impacts-social-equity-fuel-poverty/.
384 National Energy Action (2017) Heat Decarbonisation: Potential impacts on social equity and fuel poverty https://www.nea.org.uk/resources/publications-and-resources/heat-decarbonisation-potential-impacts-social-equity-fuel-poverty/; Friends of the Earth (2018) Delivering on the Paris Climate Agreement – the future of home heating https://cdn.friendsoftheearth.uk/sites/default/files/downloads/Future%20of%20Heating_August_2018.pdf.
385 Aldersgate Group (2016) Briefing: Decarbonising Heat in Buildings http://www.aldersgategroup.org.uk/asset/551.
386 For example: Department for Business, Energy and Industrial Strategy (last accessed November 2018) Renewable Heat Incentive Evaluation https://www.gov.uk/government/collections/renewable-heat-incentive-evaluation.

5.20 Research into policy frameworks adopted in other OECD countries reveals a wide range of interventions including all those mentioned above.[387] A report prepared by Vivid Economics for BEIS observes that: "effective transitions (to low carbon heating) have been supported by a package of policies which span regulation, information, standards, research and development and long term targets."[388]

5.21 Various studies focus on delivery challenges in relation to one or more parts of our energy distribution infrastructure. For example, the report *Managing Heat Decarbonisation* compares the different delivery challenges associated with reinforcing the electricity network, repurposing the gas grid for hydrogen, and expanding the reach of district heat networks,[389] while various studies have examined each of these questions separately in varying degrees of depth.[390] Commentators point out that new levels of energy system planning and co-ordination will be required across the energy system under any transition to low carbon heating.[391]

5.22 A number of studies specifically assess the impacts on the public of the change programmes required to extend, convert or reinforce the energy infrastructure. This is a specific point of focus in the report Managing Heat Decarbonisation, which considers, for example, the street works and other disruption associated with reinforcing electricity cables and substations, and similar disruption involved in laying new pipes for district heating. This implies a need for careful infrastructure planning and local and consumer engagement.

387 UKERC (2016) Technology and Policy Assessment: Best Practice in heat decarbonisation policy https://www.theccc.org.uk/wp-content/uploads/2017/01/UKERC-for-the-CCC-Best-practice-in-heat-decarbonisation-policy.pdf

388 Vivid Economics for Department for Business, Energy and Industrial Strategy (2018) International Comparisons of Heating, Cooling and Heat Decarbonisation Policies https://www.gov.uk/government/publications/international-comparisons-of-heating-cooling-and-heat-decarbonisation-policies.

389 Imperial College London (2016) Managing Heat System Decarbonisation: Comparing the impacts and costs of transitions in heat infrastructure https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf

390 For example: H21 North of England (2018) https://www.northerngasnetworks.co.uk/h21-noe/H21-NoE-26Nov18-v1.0.pdf; Element Energy and Imperial College London for the Committee on Climate Change (2015) Infrastructure in a low-carbon energy system to 2030 https://www.theccc.org.uk/wp-content/uploads/2013/12/CCC-Infrastructure_TD-Report_22-04-2014.pdf; or Element Energy and Imperial College London for the Committee on Climate Change (2015) Research on district heating and local approaches to heat decarbonisation https://www.theccc.org.uk/wp-content/uploads/2015/11/Element-Energy-for-CCC-Research-on-district-heating-and-local-approaches-to-heat-decarbonisation.pdf.

391 Imperial College London (2016) Managing Heat System Decarbonisation: Comparing the impacts and costs of transitions in heat infrastructure https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf.

5.23 Relatively less disruption to the public and the consumer during the transition is said to be a key advantage of hydrogen conversion over electric or district heating.[392] A growing number of studies consider the works which will be needed in practice and the options, such as making available "hydrogen ready" appliances, which might smooth the process.[393] However, there are key uncertainties surrounding the likely level of disruption, such as the extent of in-home pipework replacement required,[394] and real-world testing and trialling will be required to confirm the extent of works that might be needed.

5.24 The conversion of significant parts or all of the gas grid to hydrogen would require an extremely high degree of planning and co-ordination across many sections of society including the energy infrastructure operators, industry supply chains, product markets, government and regulators and the public. It is often suggested that the town to natural gas transition between 1966 and 1977 provides a good model for this process.[395] There are clearly important parallels and there is much to be learnt from the natural gas conversion. For example, the earlier conversion programme involved numbers of people on a broadly similar scale, with 14 million customers and 40 million appliances converted on a rapid timescale. On the other hand, the industry structure was very different; the market during this period was less fragmented making it easier to exercise central control. Some have questioned whether the co-ordination required for a conversion to hydrogen would be compatible with what is now a liberalised market and fragmented supply chain.[396]

392 For example: Imperial College London (2016) Managing Heat System Decarbonisation: Comparing the impacts and costs of transitions in heat infrastructure https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf; or H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf.

393 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf; Frazer-Nash (2018) Appraisal of Domestic Hydrogen Appliances https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/699685/Hydrogen_Appliances-For_Publication-14-02-2018-PDF.pdf.

394 Frazer Nash for the Department for Business, Energy and Industrial Strategy (2018) Logistics of domestic hydrogen conversion.

395 H21 Leeds City Gate (2016) H21 Report https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf.

396 Policy Exchange (2018) Fuelling the Future https://policyexchange.org.uk/publication/fuelling-the-future/.

5.25 In addition, in any hydrogen conversion, consumers would be switched as and when their part of the grid is converted and though they may be able to take preparatory actions to limit the costs and disruption incurred such as purchasing hydrogen-ready appliances, they would not determine the timing of the changeover. Switching to electric heating allows individual consumers greater autonomy over the timing of any change, although some coordination may be needed, for example, to enable the required reinforcement of local distribution networks to take place.

5.26 The report *Managing Heat System Decarbonisation* points out that some key delivery activities in achieving heat decarbonisation relate to energy networks and will need to be carried out by regulated monopolies where there is no 'market' to make the decisions. It argues that in these instances decisions should instead be made by the appropriate governance institutions, in order to allow private sector network operators to deliver timely investment in the measures needed to support heat users and producers.[397]

5.27 Regarding the electricity system in particular, the Institute of Engineering and Technology's report *Future Power System Architecture* suggests that for the electricity system to be capable of managing the multiple new functionalities that will arise from decentralisation and greater consumer participation, a central architect is needed to coordinate change.[398] In a heat-focused context, a report by Imperial College recommended the Institute of Engineering and Technology's proposal be extended to cover the whole energy system to balance considerations between gas and electricity networks. Arguably, taking this approach would ensure the characteristics of local and national energy systems are properly valued and the most cost-effective solutions are introduced.[399]

5.28 A report for BEIS by Frontier Economics into the type of market and regulatory frameworks that could support a low-carbon gas network highlighted the importance of coordination frameworks for ensuring consistent and efficient decisions across energy vectors and geographic areas.[400] In discussing a scenario where a more diverse range of end-use technologies are deployed, the report indicated that greater coordination across gas and electricity sectors may be desirable to manage patterns of demand and ensure more efficient system operation.[401]

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397 Imperial College London (2016) Managing Heat System Decarbonisation: Comparing the impacts and costs of transitions in heat infrastructure https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf.

398 The Institution of Energy and Technology for Department of Energy and Climate Change (2016) Future Power System Architecture https://www.theiet.org/sectors/energy/resources/modelling-reports/fpsa-main-report.cfm?type=pdf.

399 Imperial College London (2016) Managing Heat System Decarbonisation: Comparing the impacts and costs of transitions in heat infrastructure https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf.

400 Frontier Economics for Department for Business, Energy and Industrial Strategy (2018) Market and Regulatory Frameworks for a Low-Carbon Gas System https://www.gov.uk/government/publications/market-and-regulatory-frameworks-for-a-low-carbon-gas-system.

401 Frontier Economics for Department for Business, Energy and Industrial Strategy (2018) Market and Regulatory Frameworks for a Low-Carbon Gas System https://www.gov.uk/government/publications/market-and-regulatory-frameworks-for-a-low-carbon-gas-system.

5.29 Studies discussing the deployment of low carbon heating technologies implicitly assume the development of the relevant markets, including the necessary supply chains and skilled labour. However, at least in a UK context, there is limited analysis discussing how this can be achieved. Carbon Connect argue that investors require long-term policy certainty to have the confidence to grow supply chains and offers examples of how this could be achieved, such as setting minimum deployment levels of low carbon technologies and setting a long-term policy framework.[402] In this vein, the Carbon Trust suggest that greater certainty over the existence and extent of future support schemes could have enhanced the growth of the relevant supply chains and skills for heat networks.[403] A study focussing on the bioenergy sector suggests that greater coordination between the different parts of the supply chain could aid its development.[404]

5.30 Ensuring equality of costs and service provision are also a key challenge in planning for the delivery of low carbon heat. A report by National Energy Action (NEA) into the impacts of decarbonising heat at a national level found that average heating costs per household could rise between £250-£800 per annum.[405] If these costs were spread evenly across all households and recovered through consumer bills over a 20-year period, the report states, the difference in up-front capital and ongoing fuel costs paid by the first customers to transition to the last could be between £5,000 and £16,000.[406] NEA's analysis highlights important risks for considering the policy frameworks or delivery methods with potential to facilitate the transition to low carbon heat. These challenges may be particularly acute if technology deployment and infrastructure availability varies between areas and there are uncertainties about how equitable such outcomes may be.

402 Carbon Connect (2015) Policy for Heat: Transforming the system http://www.policyconnect.org.uk/cc/sites/site_cc/files/policy_for_heat_-_transforming_the_system_online.pdf.
403 Hawkey, D. J. C. (2012) District heating in the UK: A Technological Innovation Systems analysis http://isiarticles.com/bundles/Article/pre/pdf/28105.pdf.
404 Low Carbon Innovation Coordination Group (2012)Technology Innovation Needs Assessment (TINA): Bioenergy Summary report https://www.carbontrust.com/media/190038/tina-bioenergy-summary-report.pdf.
405 National Energy Action (2017) Heat Decarbonisation: Potential impacts on social equity and fuel poverty http://www.nea.org.uk/wp-content/uploads/2017/09/Heat-Decarbonisation-Report-2017.pdf
406 National Energy Action (2017) Heat Decarbonisation: Potential impacts on social equity and fuel poverty http://www.nea.org.uk/wp-content/uploads/2017/09/Heat-Decarbonisation-Report-2017.pdf

Local leadership and action

5.31 Numerous studies and commentaries have argued local government and other local organisations can provide important leadership in the effort to decarbonise heat. For example, the Carbon Connect report *Policy for Heat* argues in one of its key findings for more involvement for Local Authorities in the provision of low carbon heat and energy efficiency programmes.[407] The Imperial College report *Managing Heat System Decarbonisation* recommends that service requirements and delivery methods for heat should be established and decided locally, rather than seeking a single national level approach. Friends of the Earth advocate for an area-by-area transformation of heating with Local Authorities at the heart of it on the basis of their recognition and trust among local communities.[408] Work by Energy Capital,[409] the UK Energy Research Centre[410] and UK100,[411] amongst others, has highlighted the potential benefits of a decentralised approach to heat decarbonisation and the role for local leaders in identifying unique local opportunities for projects. Studies by the Energy Technologies Institute consider a 'Patchwork' scenario in which informal networks of local energy strategies drive decarbonisation with these local networks being incorporated into a national approach over time.[412]

5.32 Advocates of greater local leadership in energy and heat planning point to the progress in decarbonisation driven by municipalities in the other countries, for example Sweden and Denmark.[413] In the UK, many local authorities have historically been and will continue to be instrumental in developing district heating in their areas. More recently there has been increasing interest in exploring the potential for Local Government, Enterprise Partnerships and other local organisations to shape heating strategies in other ways.

407 Carbon Connect (2015) Policy for Heat: Transforming the system https://www.policyconnect.org.uk/cc/research/report-future-heat-series-part-2-policy-heat.

408 Friends of the Earth (2018) Delivering on the Paris Climate Agreement – the future of home heating https://cdn.friendsoftheearth.uk/sites/default/files/downloads/Future%20of%20Heating_August_2018.pdf.

409 Energy Capital (2018), Powering West Midlands Growth: A regional approach to clean energy innovation, https://www.energycapital.org.uk/wp-content/uploads/2018/03/powering-west-midlands-growth-regional-energy-policy-commission-report-2018.pdf.

410 Webb et al (2017), What we know about Local Authority engagement in UK energy systems, http://www.ukerc.ac.uk/asset/CF38B43E-23AA-433B-A3BE79CC11270E20/.

411 UK100 (2017), http://www.uk100.org/wp-content/uploads/2017/09/UK100_Report_SEP04_Final.pdf.

412 Energy Technologies Institute (2015), Options, Choices, Actions: UK Scenarios for a Low-Carbon Energy System Transition, https://www.eti.co.uk/insights/options-choices-actions-uk-scenarios-for-a-low-carbon-energy-system. See also Energy Technologies Institute (2018) Local Area Energy Planning: Supporting clean growth and low carbon transition https://es.catapult.org.uk/wp-content/uploads/2018/12/Local-Area-Energy-Planning-Supporting-clean-growth-and-low-carbon-transition.pdf.

413 Vivid Economics for Department for Business, Energy and Industrial Strategy (2018) International Comparisons of Heating, Cooling and Heat Decarbonisation Policies https://www.gov.uk/government/publications/international-comparisons-of-heating-cooling-and-heat-decarbonisation-policies.

5.33 Local organisations may be better able to generate public support for projects and overcome consumer barriers during the transition to low carbon heat.[414,415] They may be well placed to understand specific local requirements and opportunities, tackle local delivery challenges and integrate decarbonisation, energy efficiency and fuel poverty programmes on the ground.[416]

5.34 The findings of such studies are supported by work to develop capability in local areas to identify potential solutions for decarbonising through local energy plans and strategies.[417] For example, the Government is supporting the development of local energy strategies and the Energy System Catapult's recent Local Area Energy Planning report advocate the development of energy plans for all local areas to inform future UK heat policy decisions.[418 419]

5.35 However, this clearly needs to be balanced against the potential role for central planning and coordination in delivering the transition to low carbon heating, as discussed above in this chapter. There may be a need for regional or national policy frameworks to enable local leadership to be focused in the areas in which it is most effective. In addition, there may be the potential for inefficiencies and missed opportunities if strategies at local level become detached from wider energy system policy and planning. Therefore, consideration is needed as to the full extent of the role played by local actors in shaping the transition to low carbon heating.

Questions

5.36 We welcome your views on the above discussion, in particular:

(a) Does this overview of the strategically important issues, as identified in the course of our review of the evidence, highlight the key issues?

(b) Are there any important pieces of evidence that require further consideration?

(c) Do you agree with the set of strategic inferences we have drawn out?

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414 Energy Capital (2018), Powering West Midlands Growth: A regional approach to clean energy innovation, https://www.energycapital.org.uk/wp-content/uploads/2018/03/powering-west-midlands-growth-regional-energy-policy-commission-report-2018.pdf.

415 Fudge, S., Peters, M., & Wade, J. (2012), Locating the agency and influence of local authorities in UK energy governance https://www.surrey.ac.uk/ces/files/pdf/01-12_Paper_Fudge_Peters_Wade.pdf.

416 Carbon Connect (2015) Policy for Heat: Transforming the System http://www.policyconnect.org.uk/cc/sites/site_cc/files/policy_for_heat_-_transforming_the_system_online.pdf; Energy Technologies Institute (2018) Local Area Energy Planning: Supporting clean growth and low carbon transition https://es.catapult.org.uk/wp-content/uploads/2018/12/Local-Area-Energy-Planning-Supporting-clean-growth-and-low-carbon-transition.pdf

417 See for example: South East Local Enterprise Partnership (last accessed November 2018) Energy South2East https://www.southeastlep.com/our-strategy/energy-south2east/.

418 Energy Systems Catapult (2018), Local Area Energy Planning: supporting clean growth and the low-carbon transition, https://es.catapult.org.uk/publications/local-area-energy-planning-supporting-clean-growth-and-low-carbon-transition/.

419 Energy Systems Catapult (last accessed November 2018) Smart Systems and Heat https://es.catapult.org.uk/projects/smart-systems-and-heat-ssh/.

Developing a New Policy Framework

6. Developing a New Policy Framework

Introduction

6.1 The Government is in no doubt about the central importance of decarbonising heat to achieve our Industrial Strategy and clean growth goals, as we transition to a low carbon economy. Equally, we recognise that heat decarbonisation is a complex policy challenge, requiring a combination of approaches contributing to complementary goals, that will require a long term policy framework to incentivise and support the national transition required.

6.2 The Government's approach to decarbonising heat includes a range of programmes and initiatives which together aim to achieve:

- a reduction in heat demand;
- substantial growth of low carbon heating in the shorter term; and,
- a new long term policy framework for heat to enable decisions in the first half of the 2020s ahead of the national-scale transition required.

6.3 This approach is underpinned by further **innovation** and "**learning by doing**" to develop and prove both existing and newer technologies, and to better understand how our energy systems and infrastructure will need to adapt as many more people shift to low carbon heating systems.

6.4 In this chapter we focus on the key steps we are taking now to increase take-up of low carbon heating in the short term, and the priority actions we believe necessary to lay the groundwork for a new long-term policy framework.

6.5 This chapter is not intended to be an exhaustive list of the action we are taking, or that will need to be undertaken, to support the transition to low carbon heat. However, it represents a very substantial and wide-ranging programme which reflects the more immediate key priorities for the activity required across government, industry, academia and the wider public sector.

6.6 **We will build on these actions, taking into account the views we receive in response to this report, and the outcomes of the next Spending Review, to develop a new roadmap for policy on heat decarbonisation. We aim to publish this roadmap within eighteen months**.

The Government's approach to decarbonising heat now and in the 2020s

Reducing heat demand

6.7 Whilst reducing demand for heat will not be enough on its own to meet our ambitious emissions reduction commitments, robust action will need to be taken to promote energy efficiency. This means enhancing the energy efficiency of new and existing buildings and industrial processes. Although action to reduce energy demand is not the focus of this document, **the Government is driving forward ambitious action to improve energy efficiency of buildings and industrial processes**, including through:

- upgrading as many homes as possible to Energy Performance Certificate band C by 2030 where practical, cost-effective and affordable; and,
- improving the way businesses use energy, to support delivery of our ambition to reduce business energy use by 20% by 2030.

Policies to expand low carbon heating

6.8 The heat sector must make a full contribution towards meeting our carbon budgets during the 2020s and lay the foundations for the scale and depth of change required to deliver the transition to low carbon heat. To enable this, low carbon heating technologies, and supply chains will need to be further developed and scaled up through the 2020s. The Government is delivering a range of programmes and policy initiatives in order to support this.

6.9 The Renewable Heat Incentive is a major programme providing financial support for deployment of low carbon heat technologies in homes and businesses, including heat pumps, biomethane injection into the grid and biomass boilers. The Renewable Heat Incentive is primarily intended to contribute to the UK's renewable energy target and reduce carbon emissions, but it is also designed to encourage learning by doing, improve consumer confidence in low carbon heat technologies and foster the supply chains we will rely on to expand these technologies in the future. The Government has recently introduced reforms to improve the cost-effectiveness of the scheme and sharpen its focus on technologies which are most likely to be strategically important in the longer term, including heat pumps and biomethane.

6.10 After 10 years of support for renewable and low carbon heat provided under the Renewable Heat Incentive, the Government is now considering how to transition support for these technologies away from direct subsidy. Developing a clear framework for supporting low carbon heating technologies beyond 2021 will be important to ensure continuity in supply chains and provide long term confidence to industry.

Action: We will consider how future support for low carbon heating technologies may be best targeted as part of the next Spending Review.

6.11 The Government also recently published A Future Framework for Heat in Buildings, which set out our plans to support decarbonisation of heating in properties which are off the gas grid. Both the Government and industry have important roles to play in this transition.

Action: In 2019, we plan to consult on a package of measures to drive change in the off gas grid heating market. This includes consulting on options for a regulatory framework and the Government's role in skills and training in low-carbon heat technologies.

6.12 Part L of the Building Regulations is existing legislation which sets minimum energy performance requirements for new and existing buildings. Consequently, it influences choices that developers make, such as the choice of heating system. The Government has committed to review Part L of the Building Regulations for England, and we intend to use this exercise to consult on the most practical, safe and cost-effective ways to adapt building regulations to discourage the use of high carbon fuels in new buildings.

Action: We will consult on Part L of the Building Regulations in relation to England in 2019, covering energy performance of buildings.

6.13 In May this year, as a part of the Industrial Strategy Clean Growth Grand Challenge, the Government launched a Buildings Mission which aims to at least halve the energy use of new buildings by 2030. Achieving this aim will include making sure new buildings are more efficient and use clean heating and giving consumers more control over how they use energy. The mission is backed by £170m of public money through the Transforming Construction Industrial Strategy Challenge Fund. The Government expects this will be matched by £250m of private sector investment, meaning over

£400m will be invested in new construction products, technologies and techniques.

6.14 In its Buildings Mission, the Government also aims to halve the cost of renovating existing buildings to the standard of new builds, while increasing quality and safety. Six local supply chain demonstration projects have been launched across the country. These will focus on reducing the cost for retrofit and building supply chain capacity whilst also addressing the non-financial barriers to deeper retrofit, such as supply chain fragmentation.

Action: We will take forward the Buildings Mission, including by consulting on tighter Building Regulations, launching a design competition for the Home of the Future in 2019, and publishing a Call for Evidence.

6.15 The UK's heat networks market needs to grow rapidly from a relatively small base if it is to deliver the contribution required to meet our carbon reduction commitments.

6.16 The Heat Networks Investment Project (HNIP) will invest £320m of capital funding in heat network projects through grants and loans. This is provided as 'gap funding' to lever in significant private and other capital, and grow the UK heat networks market, overcoming the barriers it currently faces.

Action: The successful applicants from the first Heat Networks Investment Project funding round will be announced in Spring 2019.

6.17 In addition, the Government provides advisory support through the Heat Networks Delivery Unit (HNDU) which has provided expertise and over £17m in grants to local authorities on a pipeline of projects across England and Wales since it was launched in 2013.

Action: Also by Spring 2019, successful applicants for HNDU's Round 8 funding will be announced.

6.18 Beyond the HNIP, developing the heat networks market will require a market framework to ensure heat network customers are adequately protected and that the sector continues to attract investment and decarbonises cost-effectively.

Action: Subject to further consultation in 2019, we will develop a market framework that will ensure consumers receive sufficient protection; build investment in the sector; and maximise the potential decarbonisation benefits of heat networks.

Promoting innovation in low carbon heating

6.19 Innovation will be particularly important over the next 5–10 years, to reduce key risks and uncertainties with different technologies and reduce the barriers to increasing consumer take up. Some of this innovation and learning can only come from growth in the demand and supply of low carbon heating solutions. Other important innovations might require R&D projects supported by the private and/or public sectors. Learning from innovations and experience internationally is likely to be just as important as progress within the UK. BEIS engages with a large number of international research and innovation fora. These include many of the International Energy Agency's Technology Collaboration Programmes, such as those on heat pump technology and on hydrogen, and Mission Innovation, where the UK co-leads the innovation challenges on Affordable Heating and Cooling, and Carbon Capture, and is involved in the Renewable Clean Hydrogen Challenge.

Action: We will step up our innovation work on low carbon heating, in partnership with the industry, academia and other partners.

6.20 Our policies to support early market growth and deployment of low carbon heating facilitate learning by doing, including innovation by technology producers, installers and other service providers. Alongside these initiatives, central government and other public bodies support a wide range of innovation projects including those focusing on strategically important uncertainties, opportunities and barriers. These include:

- **Practical testing and demonstration**. For example, the £38m of work supported by Ofgem and BEIS to prove the feasibility of repurposing the gas grid for hydrogen. BEIS is also exploring options for a new project to demonstrate modern electric heating solutions across a range of building types and consumers.
- **The acceleration of emerging technologies.** BEIS, Ofgem and UKRI are all investing in projects to advance state-of-the-art technologies, products and processes in areas including energy efficiency, power and low carbon gas generation, thermal and electrical storage and end-use technologies. Such investments have been made through programmes such as the BEIS Energy Entrepreneurs Fund, the first six phases of which awarded £50.7m in grants,[420] and the BEIS Thermal Energy Efficiency and Low Carbon Heating Innovation funds[421] which awarded a further £15m. In addition, the Smart Systems and Heat Programme, led by the Energy Systems Catapult, is a collaborative project exploring, among other topics, how to use new technology to increase the uptake of low carbon heating solutions in to UK homes.
- **First of a kind development and demonstration.** BEIS is currently inviting bids for Phase 2 of its up to £20m Industrial Fuel Switching Programme[422] to develop low carbon alternatives for industrial processes. In September, the Government launched its £20m Hydrogen Supply Programme which aims to accelerate the development of low carbon bulk hydrogen supply solutions for heat, transport, industry and power, with a focus on novel hydrogen production methods.

6.21 The Government is keen to see development of innovative technologies and solutions of all kinds, recognising that today's most promising emerging technologies might be overtaken by new ones in the future. The Government is also keen to encourage future research and development projects which contribute to our strategy development, by addressing the most significant uncertainties, barriers and opportunities involved in different approaches to low carbon heating.

Action: We invite views on priorities for further development and testing of emerging technologies, and we will increase efforts to promote a common agenda for research and development across the public sector, academia and industry on heat decarbonisation.

420 Department for Business, Energy and Industrial Strategy (2018) The Energy Entrepreneurs Fund: Phase 7 Guidance Notes https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/722140/FINAL_EEF_7_Guidance_Document.pdf.

421 Department for Business, Energy and Industrial Strategy (2017) Low Carbon Heating Technology Innovation Fund https://www.gov.uk/guidance/innovations-in-the-built-environment.

422 Department for Business, Energy and Industrial Strategy (2017) Funding for low carbon industry https://www.gov.uk/guidance/funding-for-low-carbon-industry#industrial-fuel-switching-to-low-carbon-alternatives.

The need for a new long-term policy framework

6.22 In the UK, in common with most other industrialised economies, it will take longer to achieve deep decarbonisation in heating than in the power sector. To some extent this reflects the strategic need to achieve deep decarbonisation of the power sector as a foundation for decarbonising other energy intensive sectors. The most mature low carbon heating technologies depend on clean electricity to deliver their full carbon benefits. But it also fundamentally reflects the barriers to shifting to low carbon heat systems. The scale of change involved for consumers, alongside change to our energy system and infrastructure, means that heating is arguably the most difficult of the major energy-consuming sectors of the economy to decarbonise.

6.23 For these reasons most projections for decarbonising our economy, including the illustrative scenarios developed for the Government's Clean Growth Strategy, see the large majority of carbon savings from heating being achieved in the 2030s and 40s. At the same time, ambitious action on low carbon heating will be needed during the 2020s to ensure that our legally-binding carbon budgets are met and to put us on the right trajectory to achieve our 2050 commitments.

6.24 In addition, the scale and depth of the changes involved also means that:

- lead times are long for many of the conditions needed to enable cost-effective change on a much larger scale, including: changes to our energy infrastructure, which need careful planning; much higher levels of consumer awareness of and confidence in new ways of heating; and new and strengthened supply chains; and,

- to some extent at least, a new policy framework and strategic direction will be needed to facilitate these conditions, ensuring appropriate incentives and support for change, and enabling the most cost-effective transition across the energy system.

6.25 We have a key opportunity over the next few years to develop this new long term policy framework. It is an open question as to what form this might take – the range of issues it should address and its specific purpose. This should be an important aspect of the debate about future heat policy.

6.26 For example, it is not yet clear the extent to which any new policy framework might be needed to determine or influence the range of technology choices available in the future. Any policy framework should leverage market forces in the development of technical solutions and facilitate consumer choice between them. At the same time, the production of heat relies on the provision of adequate energy infrastructure and other major investments. It is likely that some degree of policy direction will be required to enable efficient incentives for major investments. For example, it seems very unlikely any significant part of the gas distribution network could be repurposed for hydrogen without there being specific public policy decisions to that effect.

6.27 In addition, the framing of any new long-term policy framework must be informed by a robust understanding of potentially important technology options. This includes their costs and benefits for individuals, their impacts on the energy system and wider public interests if adopted at scale, and the barriers to the large scale adoption of these technologies. Who pays, how and when, will also be a key question for consideration in the development of any future policy framework.

6.28 It is unlikely that any one low carbon heating technology will be the most appropriate for all users in all circumstances, given the diversity in heat demand across buildings and industry. Any future policy framework will need to take this into account, building on a deeper understanding of the ways in which this varies across different consumer groups.

6.29 As our review of the current evidence has confirmed, there remain important areas where further work is needed to develop our knowledge and confidence. The following sections seek to highlight priority areas where we believe further development work is necessary. As this work develops, we will continue to explore and evaluate available evidence from third parties, recognising the increasing commercial significance of policy decisions and therefore the evolving landscape of stakeholder interests and the impact this may have on the quality of evidence.

6.30 The actions set out in this chapter are by no means an exhaustive list of the work required to develop the evidence base on low carbon heating and inform out future policy framework. They are intended to help establish a clearer common agenda for attention across industry, academia and the public sector, to help ensure that effort and resources are efficiently aligned and applied to the most important and urgent issues.

6.31 We therefore invite views on the priority issues identified, on any important omissions, on the parties who may be best placed to deliver in these areas, and on opportunities for enhancing co-ordination.

Electric heating

6.32 Widescale electrification of heating would represent a fundamental shift in our energy demand, with major implications for our energy systems. These potential implications – and how the electricity system in particular might best respond to them – need to be better understood than they are today.

6.33 There is only limited knowledge at present of how the installation of heat pumps at scale will affect aggregate demand patterns and therefore the peak loads which the energy networks, generating capacity and flexibility mechanisms will need to manage.

6.34 Further evidence of how demand patterns might be modified by the use of hybrid heating systems will be important in this context, building on the existing evidence, including from the Freedom project[423] and Element Energy's study for BEIS on the potential role of hybrid heating systems in heat decarbonisation.[424]

6.35 For the electricity distribution network, additional capacity will be needed to meet demand – however it is not sufficiently clear when or where this requirement might materialise during a transition, nor how best to respond to it.

6.36 The Government is keen to improve understanding of the potential for flexibility mechanisms to moderate the requirement for additional generation and network capacity, including the potential for inter-seasonal storage, smart systems, demand-side response (DSR) and interconnection to avoid the huge costs of meeting peak demand.

423 Freedom project, final report (2018) Wales & West Utilities (2018) Freedom Project: Final Report https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf.

424 Element Energy for Department for Business, Energy and Industrial Strategy (2017) Hybrid Heat Pumps: Final report https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/700572/Hybrid_heat_pumps_Final_report-.pdf.

6.37 We are interested in exploring with stakeholders the value and feasibility of further localised studies to improve the understanding of the level of and disruption that would result from needing to reinforce electricity networks under a range of demand scenarios. We are also interested to explore the potential for innovation projects to develop smart solutions for network reinforcement that avoid conventional reinforcements, or on reducing the disruption where reinforcement is needed. The disruption associated with ensuring the electricity networks can reliably accommodate large-scale deployment of electric heating could present a major barrier if met through scaled-up conventional approaches to investment and operation.

Action: We will work with colleagues from across industry and academia to:

- **improve understanding of potential future requirements for electricity generation and network reinforcement under different circumstances, and how these might be most cost-effectively and practicably met**; and
- **explore the potential for more sophisticated systems modelling work, informed by broader demonstration and trialling work, to improve understanding of the potential of flexibility systems**.

6.38 From the consumer's perspective, the changes involved in shifting to electric heat pumps can represent a significant barrier. The installation of lower temperature, higher efficiency heat pumps often requires changes to the home, for example the installation of larger radiators or underfloor heating. There may also be changes to consumers' experience such as the availability of large quantities of hot water or quick-response space heating. The actions summarised earlier in this chapter, and detailed in the Government's *Future Framework* for Heat in Buildings, sets out a range of actions with industry that can help to address such challenges.

6.39 The relatively high appliance and installation costs represent a particular barrier for all forms of electric heat pumps. The Government received a range of views about the potential to reduce the costs of heat pumps in response to our Call for Evidence earlier this year.[425] These are discussed in more detail in the Government's response, the Future Framework for Heat in Buildings. Understanding the scope for substantial cost reductions should be a key objective of our future work.

6.40 While there is a wealth of evidence on electric heat pumps, both from the UK and internationally, the accessibility of this information to the wider public is limited. We believe a carefully planned demonstration project at this stage could have important benefits in terms of public engagement, as well as providing important learnings about what works best for consumers in different circumstances.

425 Department for Business, Energy and Industrial Strategy (2018) A Future Framework for Heat in Buildings: Call for Evidence https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/691546/Future_framework_for_heat_in_buildings_call_for_evidence.pdf.

Action: We will develop plans for a substantial new project to demonstrate modern electric heating solutions across a range of building types and consumers.

Hydrogen

6.41 Each of the options for making greater use of hydrogen in relation to heating – including through blending relatively small proportions of hydrogen with natural gas in the grid, to the use of hydrogen in specific roles such as in industrial heating processes, as well as the potential for fully replacing natural gas with hydrogen in all or parts of the grid - would involve changes which need to be much better understood. All require rigorous technical investigation, development and testing alongside improving understanding of how they could be delivered in practice and the impacts, costs and barriers.

6.42 At this stage we need to work with industry to progress work to test and demonstrate the use of hydrogen as a full replacement for natural gas in the gas network. This is likely to include testing the costs, practical delivery challenges and public perception and experience of these technologies and the conversion process.

6.43 BEIS is managing a £25m hydrogen innovation programme, Hy4Heat, which will test and demonstrate some aspects of the work required including:

- the use of hydrogen appliances (boilers, cookers, and gas fires) and meters;
- an assessment of the safety of using hydrogen in properties;
- demonstration of using hydrogen in unoccupied buildings; and,
- undertaking scoping for a potential occupied community trial using hydrogen

6.44 A separate project is being delivered by the Gas Distribution Network Operators to demonstrate the feasibility and safety of the transportation of hydrogen through the distribution system. A comprehensive programme of further work, taken forward across government and industry will be necessary to prove all relevant parts of the supply chain.

6.45 A further key issue is the process efficiency and carbon emissions associated with hydrogen production in the future. Hydrogen production from methane reformation is a proven technology used around the world, and there are strong commercial pressures to drive efficiencies. Nevertheless, there is a need to gain greater assurance of the costs, efficiencies and carbon capture rates which could be achieved in practice and deepen our understanding of the potential for innovation to deliver higher efficiencies and improved carbon capture rates in the future. It will also be important to improve understanding of approaches which could support achieving net zero emissions over the longer term. BEIS is currently running a £20m Hydrogen Supply Competition to identify and test approaches to supplying bulk low carbon hydrogen; either to the gas grid, industry, power, transport, or import terminals.

6.46 There have been a number of valuable studies considering the role of hydrogen storage, both within the gas grid and in storage facilities.[426] However, the storage potential of hydrogen is a key strategic consideration and further work will be important in this area.

426 Studies include: The Energy Technology Institute's work on salt caverns storage (2015), the Leeds City Gate report by H21 (2016); and, the work of Imperial College London for the Committee on Climate Change on alternative heat decarbonisation pathways (2018).

6.47 There is also a need for further evidence and analysis of the options, costs and physical constraints for long distance hydrogen transit (e.g. ammonia, liquefied hydrogen, organic hydrides), and the potential for imports.

6.48 Further evidence gathering including primary research is needed to improve our understanding of the potential for hydrogen in industry applications, to identify the current range of industrial fuel uses and the impacts of switching these to hydrogen. BEIS is currently running a three phase Industrial Fuel Switching competition, which will allocate up to £20m to stimulate early investment in fuel switching processes and technologies.[427] Phase 1 of this work sought to understand the potential for industry to operate on low carbon fuels and the innovation required to enable this to happen, the supporting report has recently been published.[428] Phase 2 will fund feasibility studies looking into developing technologies to enable the use of a low carbon fuel for a particular industrial process or across an entire site. Applications for Phase 2 are due in by 4th February 2019. Phase 3 will seek to bring forward demonstration of a process or technology that enables industry in the UK to switch to low carbon fuel sources. This will open in summer 2019.

6.49 There is also a wide range of light industry, non-domestic and other end-uses of natural gas that depend on the gas grid, where a better understanding of the different end-use types and the technical potential for using hydrogen is also required. The Hy4Heat programme will investigate the variety of industry and commercial appliances and the issues which may need to be addressed in a potential conversion to hydrogen.

6.50 We are also keen to further explore the potential role of alternative hydrogen heating appliances such as fuel cells and, while not yet commercially available for hydrogen, gas driven heat pumps, which could provide a credible, more efficient, alternative to hydrogen boilers. BEIS is currently supporting two projects with £3m of grant funding to develop a gas driven heat pump optimised for the UK market, and a system involving a fuel cell driving a heat pump that could meet a home's entire heat and power needs.[429]

6.51 A deeper understanding of the practical delivery requirements and impacts of a potential conversion to hydrogen is required, including of the end to end conversion process, the work which will be required in homes, the impact on consumers and how critical dependencies, such as with CCUS could be managed. BEIS recently published a study exploring the logistical challenges associated with transitioning UK domestic properties from natural gas to hydrogen.[430]

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427 Department for Business, Energy and Industrial Strategy (2017) Funding for low carbon industry https://www.gov.uk/guidance/funding-for-low-carbon-industry#industrial-fuel-switching-to-low-carbon-alternatives

428 Department for Business, Energy and Industrial Strategy (2018) Industrial Fuel Switching Market Engagement https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/764058/industrial-fuel-switching.pdf

429 Department for Business, Energy and Industrial Strategy (2017) Low Carbon Heating Technology Innovation Fund https://www.gov.uk/guidance/innovations-in-the-built-environment.

430 Frazer-Nash for the Department for Business, Energy and Industrial Strategy (2018) Logistics of Domestic Hydrogen Conversion https://www.gov.uk/government/publications/logistics-of-domestic-hydrogen-conversion.

Action: We will work in partnership with industry, academia and other key stakeholders to build up a comprehensive programme of work to demonstrate the technical and practical feasibility of using hydrogen in place of natural gas for heating and to gain greater assurance of the costs, benefits and impacts, including on the wider energy system, and the practical delivery implications, to enable a more informed debate on the potential of using hydrogen for heat. Key immediate priorities for investigation and testing under this programme for us to progress, include:

- **continuing to progress testing and demonstrating the safety of hydrogen in buildings through the Hy4Heat programme**;
- **improving understanding and accelerating the development of low carbon hydrogen production methods through our Hydrogen Supply Competition;**[431] and,
- **exploring the potential for hydrogen in industrial processes as part of our Industrial Fuel Switching programme.**[432]

6.52 The case for continuing and progressively expanding this programme will be kept under review in response to the results of the work as it progresses.

6.53 The Committee on Climate Change suggest that blending could be one route for helping to bring forward hydrogen production technologies and might also have benefits for delivering short-term emissions savings.[433] The current gas regulatory regime prohibits the blending of hydrogen, except at extremely small proportions, however work is ongoing, primarily through HyDeploy, to prove the safety of transporting blends of up to 20% hydrogen with methane in the gas distribution network.[434] UK firms are also actively trialling hydrogen blending in European markets.

Action: As set out in the *UK Carbon Capture Usage and Storage Action Plan*, we will consider, in association with the Health and Safety Executive (HSE) and other interested parties, and subject to the satisfactory demonstration of safety, the inclusion of a percentage of low carbon hydrogen in gas networks, within the context of strategic decisions for the long term decarbonisation of heat for buildings and industry, and the potential for an emerging hydrogen economy.

431 Department for Business, Energy and Industrial Strategy (2018) Hydrogen Supply Programme https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/738344/Hydrogen_Supply_Competition_-_ITT_and_Guidance_Notes.pdf.

432 Department for Business, Energy and Industrial Strategy (2017) Funding for low carbon industry https://www.gov.uk/guidance/funding-for-low-carbon-industry#industrial-fuel-switching-to-low-carbon-alternatives.

433 The Committee on Climate Change (2018) Hydrogen in a low carbon economy https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf.

434 HyDeploy (accessed November 2018) https://hydeploy.co.uk/about/.

Bioenergy

6.54 The most critical questions over the potential for biogases to make a strategic contribution to the national scale decarbonisation of heating are the scope for substantially and securely increased volumes of biogas becoming available for heating purposes over the longer term. These questions centre on the potential for expanding feedstocks in ways which are sustainable and affordable, and on the competition for limited bioenergy resources in the future including in the context of the Government's wider strategies for decarbonisation in transport, power and industry.

6.55 The Committee on Climate Change has recently published a review of bioenergy, which sets out their view of the different strategic uses for biomass across the economy and are likely to make further recommendations on bioenergy following their anticipated advice on the implications of "Global Warming of 1.5ºC" report published by the IPCC earlier this year.[435]

6.56 There are a range of new and emerging technologies which could have strategic implications in terms of the availability of sustainable and affordable biogas in the future. One key area is the potential for new and emerging production technologies to use a wider range of feedstocks cost-effectively. In order to unlock broader contributions in UK biogas supply, gasification technologies are likely to be required. Such technology can create biogas from solid fuels such as woody biomass, energy crops and residual waste, greatly increasing technical potential and potentially reduce unit costs.

6.57 A second category of technical issues concerns the scope for innovation in the production of biomass in ways which reduce costs and minimise pressure on the environment and natural resources.[436]

Action: We will consider the Committee on Climate Change's recommendations on bioenergy as we develop our Heat Policy Roadmap.

Action: We will continue to consider how innovation could play a role in encouraging technologies which enable more efficient production, deeper emission reductions and use a wider range of feedstocks cost-effectively.

Industrial heating processes

6.58 We committed in the Clean Growth Strategy to develop, over the course of this Parliament a framework to support the decarbonisation of heavy industry and recent action announced will contribute to the delivery of this framework.

6.59 In October 2018, we announced an Industrial Energy Transformation Fund backed by up to £315m of investment to help businesses with high energy use transform the way that they use energy, helping to cut their bills and transition UK industry to a low carbon future. The detailed design of this scheme will be determined subject to consultation, but we envisage that it could include support for technologies like fuel switching and carbon capture, which can enable low-carbon industrial process heat.

Action: We will consult on the Industrial Energy Transformation Fund during 2019.

435 Intergovernmental Panel on Climate Change (2018) Global Warming of 1.5ºC http://www.ipcc.ch/report/sr15/.
436 Ecofys and E4tech for Department for Business, Energy and Industrial Strategy (2018) Innovationn needs assessment for biomass heat https://www.gov.uk/government/publications/innovation-needs-assessment-for-biomass-heat.

6.60 At the Accelerating Carbon Capture, Usage and Storage (CCUS) global conference, co-hosted by the UK Government and the International Energy Agency, we published our CCUS Action Plan, setting out how the Government and industry can work in partnership to achieve the Government's ambition to have the option to deploy CCUS at scale from the 2030s, subject to costs coming down.

6.61 CCUS is one of the technologies that can enable low carbon heat in industrial processes and delivering the commitments set out in the Action Plan are a key part of our framework to support the decarbonisation of heavy industry.

Action: We will progress the commitments set out in the CCUS Action Plan.

6.62 We announced on the 13th December, at COP24 our latest Clean Growth Grand Challenge Mission:[437]

"We will establish the world's first net-zero carbon industrial cluster by 2040 and at least one low carbon cluster by 2030".

6.63 This mission seeks to maximise the advantages of cluster-based action on industrial decarbonisation, magnifying economic benefits and driving down costs, and could see significant decarbonisation of industrial heat in multiple clusters, helping us learn lessons that can be applied to the rest of industry, and heat more broadly.

Action: We will provide further details of our delivery plan for the Mission, which will be developed including through extensive stakeholder engagement, in the new year.

Developing a policy framework for low carbon heating

6.64 The scale and complexity of the transformation required means there will need to be further thinking about the long-term policy framework for heat. Under any strategy for decarbonising heating a combination of policy approaches will be required. It will be important to learn from relevant experience in the UK and internationally. We will need to think broadly about fundamental aspects of the future policy framework, for example where the framework should facilitate the market to determine outcomes and conversely, where policy or regulatory intervention might have to be more prescriptive to ensure efficient or fair outcomes. Further thinking will also be important on the question of where relevant policy-making powers and other relevant responsibilities are best exercised.

Action: We will build on these actions, taking into account the views we receive in response to this report, and the outcomes of the next Spending Review, to develop a new roadmap for policy on heat decarbonisation. We aim to publish this roadmap within eighteen months.

6.65 There is potential for future Government policies to heavily influence a wide range of outcomes, including the new heating choices available to consumers in the future, the costs and benefits involved and how different groups of consumers are affected by these, the roles and responsibilities of a wide range of organisations and the extent to which the wider UK economy is able to seize the opportunities available. Such policies will therefore need to be informed by wide engagement. Over recent years there has been extensive discussion of the options for decarbonising heating among experts and those with a particular interest from industry, academia, Government and

437 UNFCCC Conference of the Parties 24, Katowice, Poland.

Parliament and elsewhere. However, wider public awareness of low carbon heating, and its importance for our wider climate commitments, remains low.

Action: We will commission research to improve our understanding of current public awareness, attitudes and preferences for different approaches to decarbonising heat, and explore options for engaging stakeholders and the wider public in the development of heat policy.

6.66 For any new long-term policy framework to command support, there will need to be confidence that the costs of transitioning to low carbon heating options will be affordable. Improving confidence about the scale of future costs is therefore a fundamental issue in relation to all the main cost drivers for all low carbon heating options throughout the supply chain. The most effective contributions to confidence about future costs will clearly be evidence of real-world cost reductions, for example through technical innovations, economies of scale, new business models and increasing competition. How these costs are distributed across the economy and society is also a key question.

Action: We will take into account the impact of innovation, demonstration and future support, on the costs of transitioning to low carbon heating, in the development of our new roadmap for policy on heat decarbonisation.

6.67 In our review of the evidence the Government has benefited greatly from advice and information provided by many people with relevant expertise and experience from across industry, academia and the public sector.

Action: As we develop our approach in the future we will find ways to facilitate greater exchange and testing of stakeholders' views and analysis, with a view to promoting transparency and building confidence in the discussion and deliberation of key issues and challenges. *We would welcome suggestions on how this might practicably be organised.*

Questions

6.68 We welcome your views on the above next steps, in particular:

(a) Do you agree that we have identified the most important issues to be addressed as we develop our thinking? Do you consider that there are important omissions?

(b) Do you have any comments on the types of actions identified to meet these challenges? Do you have other suggestions?

(c) Do you have views on which parties are best placed to deliver actions to address the key issues?

(d) Do you have any views on priorities for further development and proving of emerging technologies with clear potential to provide strategically important options and benefits in relation to decarbonising heating? Please provide supporting argument for your views.

(e) Do you have views on how co-ordination and prioritisation of relevant initiatives across industry, academia and the public sector could be improved?

(f) Do you have views on ways in which the Government, and other actors, could seek to engage stakeholders and stimulate a wider public debate?

(g) Are there practicable ways in which we could facilitate greater transparency in the exchange of views and analysis on relevant issues?

Initial next steps

Action		Indicative timing
Polices to expand low carbon heating		
1.1	We will consider how future support for low carbon heating technologies may be best targeted.	As part of the next Spending Review
1.2	We plan to consult on a package of measures to drive change in the off gas grid heating market. This includes consulting on options for a regulatory framework and the government's role in skills and training in low-carbon heat technologies.	During 2019
1.3	We will consult on Part L of the Building Regulations in relation to England, covering energy performance of buildings.	During 2019
1.4	We will take forward the Buildings Mission including consulting on tighter Building Regulations, launching a design competition for the Home of the Future in 2019, and publishing a Call for Evidence.	During 2019
1.5	We will announce the successful applicants from the first funding round of the Heat Networks Investment Project.	Spring 2019
1.6	We will announce successful applicants for round 8 of the Heat Networks Delivery Unit funding.	Spring 2019
1.7	We will develop a market framework that will ensure consumers receive sufficient protection; build investment in the sector; and, maximise the potential decarbonisation benefits of heat networks.	Consultation in 2019
Promoting innovation in low carbon heating		
2.1	We will step up our innovation work on low carbon heating, in partnership with the industry, academia and other partners.	During 2019
2.2	We invite views on priorities for further development and proving of emerging technologies, and we will increase efforts to promote a common agenda for research and development across the public sector, academia and industry on heat decarbonisation.	During 2019
Preparing the ground for a new long term heat policy framework		
4.1	**Electric heating** – we will work with colleagues from across industry and academia to: • improve understanding of potential future requirements for electricity generation and network reinforcement under different circumstances, and how these might be most cost-effectively and practicably met; and, • explore the potential for more sophisticated systems modelling work, informed by broader demonstration and trialling work, to improve understanding of the potential of flexibility systems.	During 2019
4.2	**Electric heating** – we will develop plans for a substantial new project to demonstrate modern electric heating solutions across a range of building types and consumers.	During 2019

4.3	**Hydrogen** – we will work in partnership with industry, academia and other key stakeholders to progressively build up a comprehensive programme of work to demonstrate the technical and practical feasibility of using hydrogen in place of natural gas for heating and to gain greater assurance of the costs benefits and impacts, including on the wider energy system, and the practical delivery implications, to enable a more informed debate on the potential of using hydrogen for heat. Key immediate priorities for investigation and testing under this programme for us to progress, include: • continuing to progress testing and demonstrating the safety of hydrogen in buildings through the Hy4Heat programme; • improving understanding and accelerating the development of low carbon hydrogen production methods through our Hydrogen Supply Competition; and, • exploring the potential for hydrogen in industrial processes as part of our Industrial Fuel Switching programme.	Ongoing Hy4Heat to complete in 2021
4.4	**Hydrogen** – we will consider, in association with the Health and Safety Executive (HSE) and other interested parties, and subject to the satisfactory demonstration of safety, the inclusion of a percentage of low carbon hydrogen in gas networks, within the context of strategic decisions for the long term decarbonisation of heat for buildings and industry, and the potential for an emerging hydrogen economy.	During 2019
4.5	**Bioenergy** – we will consider the Committee on Climate Change's recommendations on bioenergy as we develop our Heat Policy Roadmap.	During 2019
4.6	**Bioenergy** – we will continue to consider how innovation could play a role in encouraging technologies which enable more efficient production, deeper emission reductions and use a wider range of feedstocks cost-effectively.	During 2019
4.7	**Industrial heating** – we will consult on the Industrial Energy Transformation Fund.	During 2019
4.8	**Industrial heating** – We will progress the commitments set out in the CCUS Action Plan.	Ongoing
4.9	**Industrial heating** – We will provide further details of our delivery plan for the Clean Growth Grand Challenge Mission to establish the world's first net zero carbon industrial cluster by 2040 and at lease one low carbon cluster by 2030.	Early 2019
4.10	**Policy development** – taking into account the views we receive in response to this report, and the outcomes of the next Spending Review, we will develop a new roadmap for policy on heat decarbonisation.	To be published within the next eighteen months
4.11	**Policy development** - we will commission research to improve our understanding of current public awareness, attitudes and preferences for different approaches to decarbonising heat, and explore options for engaging stakeholders and the wider public in the development of heat policy.	Research contract to be awarded early 2019
4.12	**Policy development** – we will take into account the impact of innovation, demonstration and future support, on the costs of transitioning to low carbon heating, in the development of our new roadmap for policy on heat decarbonisation.	During 2019
4.13	**Policy development** - as we develop our approach in the future, we will find ways to facilitate greater exchange and testing of stakeholders' views and analysis, to promote transparency in the discussion of key issues and challenges	Ongoing

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