EFFICIENCY
HEAT PUMPS
DISTRICT HEATING
NATURAL GAS
HYDROGEN
BIOENERGY
CHP
STORAGE
RENEWABLES
RESISTIVE HEATING

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Future Heat Series
Part 1

Pathways for Heat: Low Carbon Heat for Buildings

A report by
Carbon Connect

Written by Fabrice Leveque and Andrew Robertson

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THIS REPORT CALLS ON THE NEXT GOVERNMENT TO SET HEAT AS A PRIORITY FOR THE COMING DECADE

Jonathan Reynolds MP and Dan Byles MP, Future Heat Series Co-chairs

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FOREWORD

This report calls on the next Government to set heat as a priority for the coming decade. During the 2010-2015 Parliament, the big energy policy priority was progressing power sector decarbonisation by agreeing Electricity Market Reform. Now Electricity Market Reform is legislated and being implemented, it is time for policy-makers to reassess their priorities. We must scale up efforts to prepare for decarbonising heat in buildings by filling the gaps in the evidence that shapes strategy and deploying solutions to develop delivery models and meet targets.

Heat accounts for nearly half of the energy consumed in the UK and a third of carbon emissions. Around 80 per cent of heat is used in homes and other buildings, and gas dominates the fuel mix meeting around 80 per cent of consumers' heating needs. The remaining 20 per cent is mainly industrial process heat, which is also an area in need of more attention from policy makers. Progressively cutting carbon emissions whilst tackling fuel poverty and keeping energy secure will drive a wholesale transformation in the way we heat our homes and buildings. In this inquiry, we have looked at a range of different pathways that the sector could follow to 2050, and two points have become particularly clear. Firstly, we have a range of credible options to decarbonise heat for buildings. Secondly, now is the time to step up our efforts to prepare these and put in place the fundamentals that will deliver more comfortable homes, tackle fuel poverty and decarbonise heat for buildings.

Pathways for Heat takes stock of what we understand today about the challenge of decarbonising heat for buildings by comparing six 2050 pathways from the Department of Energy and Climate Change, the Committee on Climate Change, the Energy Technologies Institute, National Grid, the UK Energy Research Centre and Delta EE. The exercise has been valuable in a number of ways. It has identified common messages and themes across the pathways amongst a high level of uncertainty, as well as areas where the best route is not yet clear. It has also identified the factors which are most influential in shaping the future of heat for buildings, and therefore call for extra attention. Finally, it has brought to the fore gaps in our understanding, what we need to do to address those, and the urgency of action to prepare us for mass deployment of solutions in around a decade's time.

There is no one solution to cutting emissions from building heat. Energy efficiency, gas, electricity and district heat all have something to offer on the journey to a future with warmer, more comfortable and lower carbon homes and buildings. The chapters in this report look at each in turn, comparing results from the pathways and discussing the features that influence differences.

In recent history, energy policy has been dominated by electricity and never more so than over the past few years as Electricity Market Reform was developed, debated and legislated. The important changes taking place in the power sector will continue to attract a lot of attention, but it must not come at the expense of other areas such as heat which now needs more focus. We welcome the *Future Heat Series* for helping to prioritise heat, facilitating a better-informed debate, and building consensus so that more effort can be spent pursuing what are complex challenges and transformative opportunities.

The next part of the Future Heat Series will evaluate the different tools that policy makers have at their disposal to ramp up deployment of low carbon heat and energy efficiency solutions over the next decade and beyond, as this report recommends. It will build upon the findings in this report and we look forward to working on it with Carbon Connect, the expert steering group and everyone contributing evidence.

We would like to thank everyone who participated in this first part of the *Future Heat Series* and contributed evidence, including those whose pathways we have used. We are also extremely grateful to the steering group who contributed their time, knowledge and experience to guide inquiry. Finally, we thank the Institution of Gas Engineers and Managers for their kind sponsorship of the *Future Heat Series*, the Energy and Utilities Alliance whose sponsorship also made this inquiry possible, and Fabrice Leveque and Andrew Robertson at Carbon Connect for researching and writing the report.

Future Heat Series Co-Chairs

Jonathan Reynolds MP

Dan Byles MP

EXECUTIVE SUMMARY

Heat accounts for nearly half of the energy consumed in the UK and a third of carbon emissions. Around 80 per cent of heat is used in homes and other buildings, and gas dominates the fuel mix meeting around 80 per cent of consumers' heating needs. Progressively cutting carbon emissions whilst keeping energy affordable and secure will drive a wholesale transformation in the way we heat our homes and buildings. By comparing six pathways and taking stock of what we understand today, this report identifies areas where more work is needed to shape a robust decarbonisation strategy for the sector. In some cases, work is already underway to build a better evidence base, but more is needed to understand the impact of emerging evidence on pathways.

Prioritising and preparing

Across most pathways, mass deployment of low carbon heat solutions ramps up in the lead-in to 2030. We need to spend the next decade preparing by developing a robust strategy whilst testing and scaling up delivery models. This report calls for the next Government to prioritise these preparations in the same way that preparing for power sector decarbonisation has been the overriding focus of energy policy in the past decade.

Local area pathways

The pathway analyses reviewed in this report provide a framework for understanding how parts of the UK's energy system could be decarbonised. They do this by trying to represent how systems work and interact now and in the future, albeit in a simplified way. The limitations of existing national studies include the low level of detail in which energy networks, the geography of the energy system and characteristics of the building stock are represented. Undertaking local area pathways studies to complement existing national studies would provide a good opportunity to include this extra detail and understand the impact it has on the results.

Meeting peaks

The daily and seasonal peaks in heat demand are significant and today, gas boilers served by the gas networks is the main tool for ensuring these peaks are met. With gas use falling by between 75 and 95 per cent to meet carbon targets, a wider mix of tools is likely to be used in the future. Pathways analyses could be improved with better information about the technical and economic potential of the full range of future options and how they interact with energy networks.

Consumers and supply chains

Existing pathway analyses are primarily concerned with the technical and economic dimensions of how heat for buildings might best be decarbonised. Most analyses give little weight to consumer attitudes, yet they will be critical as heat policies drive changes to how comfort is provided in nearly all homes and buildings across the country. The knowledge and preferences of existing supply chains will also be an important influence on consumer behaviour and heating appliance choice, and will be vital to ramping up the deployment of low carbon heating beyond current niche markets. Both these factors will shape the success of decarbonisation strategies and should be reflected in the pathways work that helps inform them.

Transparency and communication

Pathways are a tool to help consider the solutions, trade-offs and challenges that reducing carbon emissions will entail, and are an important input to both Government and business strategies. They are also valuable for communicating the changes that may lie ahead. They are complex pieces of work and their results must be interpreted carefully in the context of their input assumptions, methodologies and limitations. However, not all pathway results are published alongside key information about their assumptions and methodologies, making interpretation difficult. More transparency and better communication would improve their usefulness.

RECOMMENDATIONS

1. The next Government must scale up and prioritise efforts to prepare for decarbonising heat in buildings. This should involve building a better evidence base to shape a decarbonisation strategy for the sector, as well scaling up deployment of solutions in parallel, so as to develop delivery models and meet carbon budgets.

2. The Government should build on the work of the Smart Grid Forum and improve the representation of energy networks in the national and local area pathways analyses it uses to inform strategy. It should also consider improving transparency and access to network information to facilitate independent assessments.

3. The Government should commission independent studies of pathways for decarbonising heat in buildings within a small number of contrasting local areas. The pilot studies should include detailed geographical, energy network and building stock representation which will enable them to be used to better understand the impact of limitations in existing national energy system models.

4. The Government should commission an independent study to bring together technical and economic assessments of tools for meeting peak heat demand in decarbonisation scenarios with an assessment of how tools interact with energy networks. This should build on work improving Government's understanding of existing energy networks.

5. The Government should improve its understanding of consumer and installer attitudes towards heat solutions to help assess how acceptable different pathways for decarbonising heat in buildings are to consumers from a non-financial perspective. Both will be crucial in determining the success of decarbonisation strategies.

6. Pathways analyses should be presented more transparently and their assumptions and limitations should be communicated more effectively to improve their usefulness. They are complex pieces of work, and there is a risk that the results are misunderstood because there is not enough context to understand their assumptions and limitations.

This report takes stock of what we understand today about the challenge of decarbonising heat for buildings by comparing six pathways to 2050 from the Department of Energy and Climate Change (DECC), the Committee on Climate Change (CCC), the Energy Technologies Institute (ETI), National Grid, the UK Energy Research Centre (UKERC) and Delta EE.

There is no one solution to cutting emissions from building heat. Energy efficiency, gas, electricity and district heat all have something to offer on the journey to a future with warmer, more comfortable and lower carbon homes and buildings. The chapters in this report look at each in turn, comparing results from the pathways and discussing the features that influence differences.

Energy efficiency

The energy efficiency of UK homes and buildings has improved over the past decade, driven by supplier obligation schemes for retrofit energy efficiency measures and tightening energy performance standards for new buildings. Despite this, significant potential remains to improve the energy performance of the UK's existing building stock, which is still amongst the oldest and least thermally efficient in Europe.

Energy saved through retrofitting efficiency measures varies considerably across the pathways, from savings equivalent to around five per cent of heat used in buildings today (ETI) up to around 30 per cent (CCC, UKERC). Lower cost measures such as loft insulation are taken up more consistently across the pathways with most variation around higher cost measures such as solid wall insulation. This variation reflects differences in methodology and in how much detail buildings and measures are represented. For example, in the ETI analysis, efficiency retrofit is represented as three 'bundles' of measures available for homes, whereas others represent individual measures.

There is also an important relationship between investments in energy efficiency and low carbon heating systems. For example, installing energy efficiency measures alongside an electric heat pump can reduce the size of the heat pump needed, saving money on both the upfront and running costs of the heating system. A smaller heat pump can also limit or avoid the need to expand the electricity system, which is often assumed to be expensive in the analyses.

By 2050, it is estimated that around 20 per cent of homes and two thirds of service sector buildings will be newly built, either replacing existing buildings or meeting new demand from a growing population. All the pathways assume that new homes and buildings will be built to high and increasingly stringent energy performance standards, reflecting the lifetime benefits of highly efficient buildings and co-benefits of energy efficiency when deployed alongside low carbon heat systems. However, there is a risk that new regulations, such as Zero Carbon Homes, will not fully correct market failures and deliver buildings to the high standards assumed across the pathways. Although the Government has stated its intention to introduce Zero Carbon Homes regulation in 2016 and similar standards for new non-residential buildings in 2019, current proposals leave a substantial margin of uncertainty as to exactly how energy efficient new homes and buildings will be in practice.

Gas

Gas boilers supply around 80 per cent of heat in buildings today, but across all the pathways the contribution from gas falls by at least three quarters and in some cases much more, to meet carbon targets. Pathways differ on how much gas continues to be used for heating buildings in the long term mainly because of uncertainty over how difficult and expensive it is to make deeper emissions cuts in other parts of the economy, such as the transport and industrial heat sectors, and the most economic ways to meet seasonal peak heat demand. Whilst carbon targets progressively reduce the amount of gas used in heating, hybrid gas/electric heat systems could be a valuable transitional solution that is readily acceptable to consumers, helps limit upgrades needed to the electricity system and cuts emissions.

Some pathways identify a role for gas networks in 2050 as an economic tool to help meet seasonal peak heat demand. This is achieved through the use of hybrid heating systems which combine an electric heat pump with a small gas boiler to provide top-up heat at times of seasonal peak demand, mostly through the winter. Delivering additional heat via gas rather than electricity networks avoids additional reinforcement costs to the latter. However, how much of the gas networks might remain in 2050 and where is poorly understood because little or no geographical information about energy networks is included in existing energy system models.

Biomethane could be used to lower the carbon intensity of using gas to heat buildings, however the economic case for doing so is not clear and there is uncertainty over how much will be available. The Delta EE pathway uses gas which is two-thirds biomethane to heat a sizeable proportion of homes in 2050; however their analysis does not look at competing uses for biomethane in sectors such as industrial heat and transport. Pathway analyses that do cover multiple sectors of the economy indicate that the limited biomethane resource that might be available in 2050 would, for economic reasons, likely be focused on transport or industrial heat, rather than buildings.

Hydrogen could also be an alternative fuel for heating in future, although there are significant uncertainties over its availability and cost. If available at a competitive price, it could be transported through the existing gas distribution networks to provide heat in buildings, but like biomethane there are also competing potential uses in transport and industry. As one of the more innovative potential solutions for the future, hydrogen as an option is generally not well represented in existing analyses and warrants further work.

Although cooking accounts for only six per cent of heat demand in buildings today, it could have a surprisingly significant impact on decarbonisation strategy. This is because there are few options beyond electrification to move away from gas, there is very limited scope to reduce demand and use tends to be at times when demand for space and water heat and electricity are also at their daily peaks.

Electricity

Electricity currently supplies around a tenth of all heat consumed in buildings but has the potential to supply a great deal more in future, as power generation is decarbonised. Electricity can be used to provide heat through a number of heating appliances, from resistive and storage heaters to small or large electric heat pumps drawing on ambient heat in air, water or the ground.

Across all the pathways, electricity provides at least 30 per cent of heat for buildings, and around 75 per cent in several by 2050. This is predominantly through electric heat pumps, which could have a large retrofit potential across the building stock. There is a smaller role for resistive heating, typically in more thermally efficient and newer buildings. Resistive storage heaters could however play a valuable within-day storage role although this is poorly represented within some of the pathways.

The role of heat pumps is most sensitive to the thermal efficiency of the building stock, compatibility with existing heating systems, the carbon intensity of the electricity system and the costs of expanding the electricity network and generation capacity. Thermally inefficient homes are less suitable for heat pump installations as their high heat loss will increase both the capital and running costs of a heat pump. The assumed thermal performance of the housing stock, and anticipated improvements through energy efficiency investments can therefore impact on heat pump deployment. The availability of space in homes for a hot water tank could be a significant further constraint on uptake. Most heat pump systems require a hot water storage tank, but these are currently being removed from homes at a considerable rate. This potential constraint is poorly represented within the pathways and is an area for more work.

Carbon savings from heat pumps and resistive heaters are dependent on a low carbon supply of electricity. There is relatively strong confidence in the availability of low carbon electricity in the future, although relying heavily on power sector decarbonisation means that the downside risk of slower electricity decarbonisation is increased. Recent pathways attempting to better reflect the costs of expanding the capacity of the electricity system to handle the daily and seasonal profile of heat demand suggest that these costs could make deployment of high levels of electric heat an expensive option in the medium-term. Although a variety of solutions to manage these impacts are technically possible, they are poorly represented in the pathways. Furthermore, the costs of these options are currently high but have potential to fall in future.

District heat

District heat networks transport hot water to homes and buildings for space and water heating and supply less than two per cent of heat for buildings today. District heat networks can take heat from a number of sources including waste heat from industry and thermal power stations, large heat pumps and geothermal installations.

District heating is the biggest piece of the jigsaw missing from the puzzle of future heat for buildings, due to the difficulty and complexity of representing them within pathway analyses. In particular, most pathway analyses largely ignore the geography of the energy system which is critical for understanding the potential for district heating. However, analyses that represent the potential for district heating in better detail indicate that where available at competitive cost, it could supply up to 40 per cent of heat used in buildings. Generally, district heating is an alternative in homes and buildings that would otherwise switch to an electric heat pump or hybrid heat system. Therefore, district heat can diversify low carbon heat supply options and reduce the need for back-up electricity generation and electricity network reinforcement.

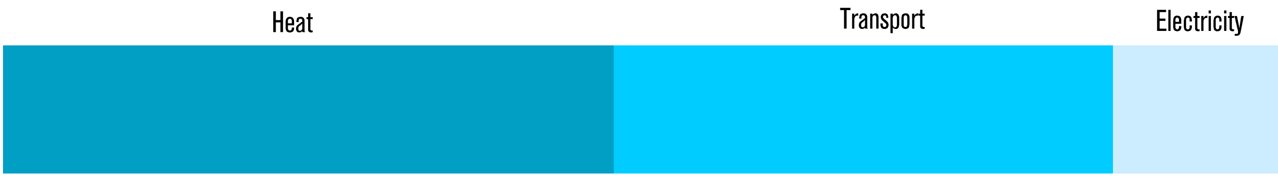
District heat could provide further energy system and consumer benefits but these are poorly captured in current pathways. It is more cost effective and practical to install thermal storage on a district heating scale than in individual buildings, and heat networks are installed with storage to help meet peak demands. Large thermal stores attached to district heat networks are used in some pathways to operate the electricity system more efficiently. From a consumer perspective the heat system unit within the home or other buildings is similar to that of a gas boiler, which may help making district heating readily acceptable to consumers.

The role of district heating within the pathways is particularly sensitive to the assumed availability of low carbon heat sources, with a limited representation of options in current pathways. Gas-fired combined heat and power is a medium term solution for providing heat to district heat networks, but is phased out of the pathways in the long term, unless combined with carbon capture and storage, as carbon constraints tighten. High district heat scenarios rely on waste heat from thermal power stations to provide the majority of low carbon input heat in future, with a limited role for bioenergy and large scale heat pumps. Geothermal and waste heat from commercial and industrial activities could also supply heat networks in future, but have limited representation within the pathways. As a result, the strategic value of district heat networks having the flexibility to use heat from a range of different sources is not well captured.

Despite increasing interest, district heat suffers from limited UK-specific capital cost forecasts, a developed UK supply chain, regulatory frameworks and experience in connecting private consumers to heat networks. As well as depending on the nature of specific projects, heat network construction costs in the UK are highly uncertain, with little construction experience over the past two decades, and none in retrofitting district heat to the existing housing stock. The Government is making welcome progress by setting up the Heat Networks Delivery Unit and supporting feasibility studies for several district heating schemes. These studies and deployment that could follow will help address some of these issues.

INTRODUCTION

Where are we today?



50% of energy is used for **heat**

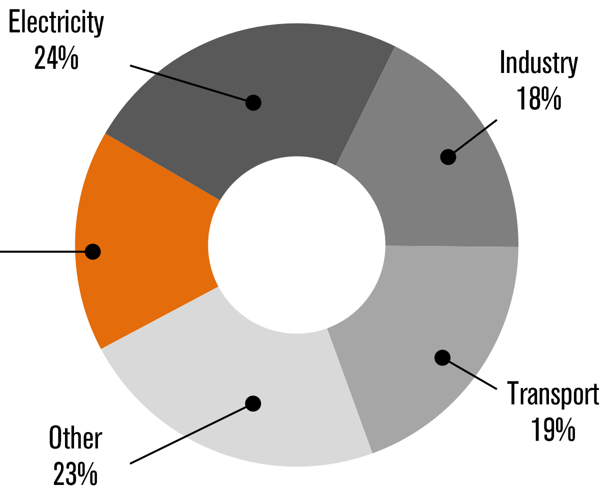
80% is heat for **buildings,** of which...

75% is used in **homes**

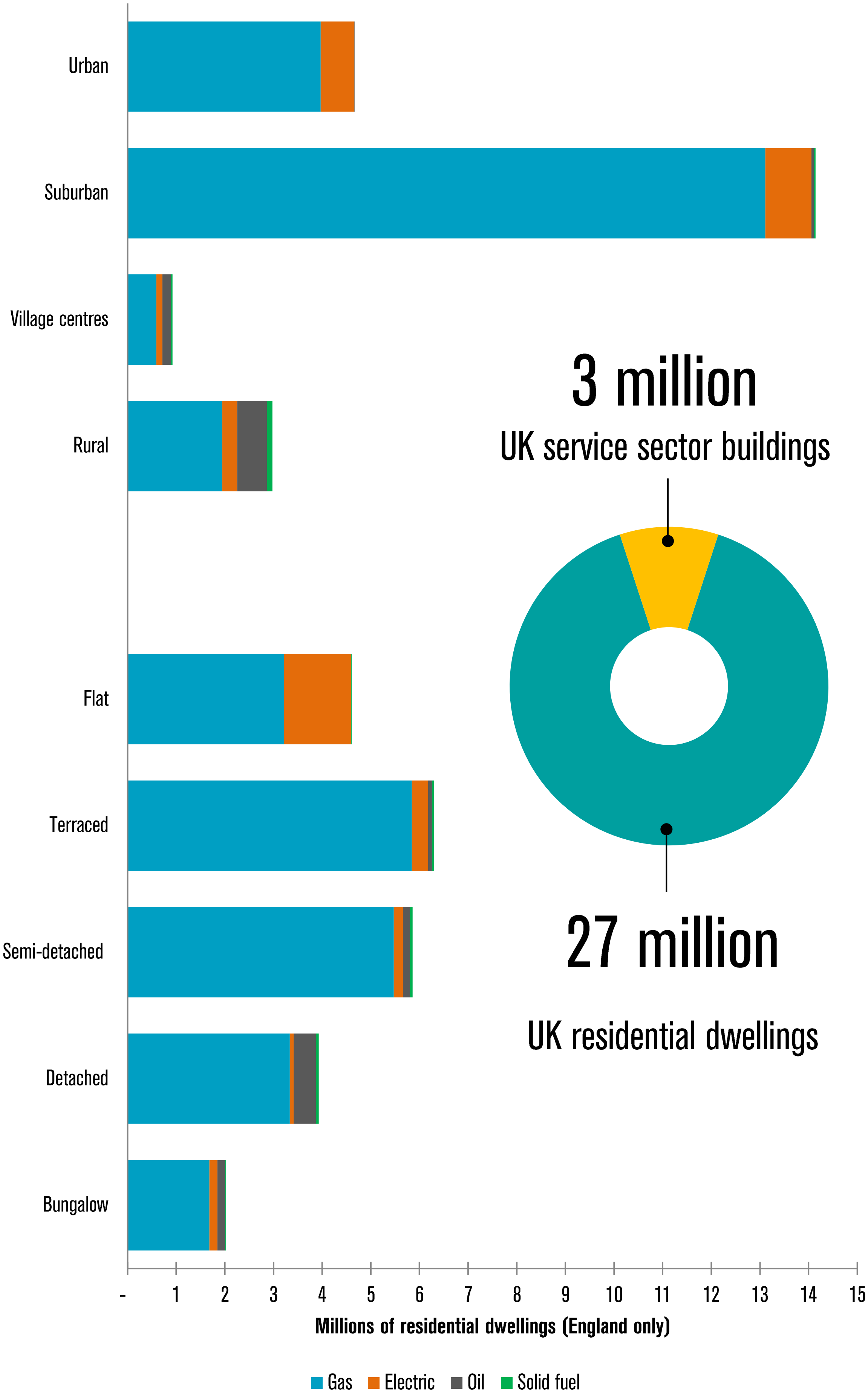
75% is for **space heating**

80% comes from **gas**

16% of **emissions** come from buildings



Heat in buildings



Pathways for heat

This report looks how the way the UK heats homes and buildings could change between now and 2050 as the UK decarbonises. Six pathways for heat to 2050 are compared to draw out common themes, highlight where more work is needed and discuss the factors influencing their differences. All the pathways meet the 2050 carbon target of an 80 per cent reduction on 1990 levels, which requires that economy-wide emissions in 2050 do not exceed 160 million tonnes of carbon dioxide[1].

All except one cover the whole energy system. Consultancy Delta EE has produced a pathway which models residential heating in isolation from the rest of the energy system. It is important to note that because this pathway analysis does not cover the whole economy it does not indicate where alternative carbon savings are made in the latter, or the additional cost of these. Figure 1 gives a background to each of the pathways considered in this report.

Pathway analyses provide a framework for understanding how the UK's energy system could be decarbonised to meet long term carbon reduction targets. The analyses try to show ways in which the energy system, or parts of the system could develop in the future. They do this by trying to represent how systems work and interact now and in the future, albeit in a simplified way. Economic, technological, physical and other information is input into the model and 'runs' of the model under different conditions and constraints produce pathway outputs. The pathways are subject to all the uncertainty of the information input into the analysis and all the simplifications made in trying to represent how systems work and interact. The level of uncertainty can be very high when pathways analyses cover long time periods and complex systems, such as the 2050 energy pathways considered in this report.

Pathways analyses can, however, provide a comprehensive and flexible means to understand future uncertainties and provide useful insights for policy makers. Modelling can show how different sets of solutions could help meet carbon targets, which solutions appear economically optimal and how resilient different decarbonisation strategies are. Pathways aim to provide a guide to the least cost solutions in the long term rather than simulate or predict the future, and their results should interpreted in this way.

Pathway methodologies

The pathways considered here fall broadly into two categories: energy system models, and hybrid approaches which combine the results of detailed sector-specific research. Energy system models, used for the DECC, ETI, UKERC and National Grid (2035 – 2050) pathways, are designed to identify pathways to decarbonise the whole energy system and are most useful in producing insights regarding the appropriate level of heat decarbonisation relative to other sectors and to analyse trade-offs between competing uses of fuels (for example bioenergy) and interactions between different parts of the energy system (such as the power system and electric heating). These models are designed to find the most cost effective energy system design rather than to simulate consumer and investor behaviour or the effect of policies. They also include a temporal resolution to capture short term (daily) and long term (seasonal) fluctuations in energy demand, although the detail with which this is modelled varies. Energy system models provide a systematic way to test outcomes under many different input assumptions, and a range of alternative scenarios, or sensitivities, are generally produced with these models.

A disadvantage of energy system models is that their scope necessarily requires simplification and aggregation of many sectors. For example, they represent the building stock in limited detail and have poor, or non-existent, representation of geographic characteristics. This is

[1] (equivalent) CCC (2010) Fourth Carbon Budget

particularly problematic for heat, given the importance of building properties to thermal demand. Their poor spatial representation is a further limitation, as district heat, electricity and gas network costs are an important factor in assessing future heating solutions.

The other pathways considered in this report (Committee on Climate Change, National grid to 2035 and Delta EE) have been produced using a combination of approaches, drawing on economic models or detailed building stock models. This approach allows more granular detail than an energy system model approach and in some cases (energy efficiency, district heat) more reliable estimates of the economic potential of heating technologies have been produced for these analyses, for example regarding energy efficiency measures or district heat. However, although these pathways reconcile the output from their various input studies to ensure consistency, interactions between sectors will not be modelled dynamically as in energy system models.

'Core' scenarios

The charts and text in this report refer to 'core pathways' from each of the analyses considered (outlined in Figure 1). 'Core' or 'Central' pathways are often used to present a 'central' aggregate result of the pathway work. The most valuable insights from pathway analyses are those that are consistent across many scenario runs, and it is these that are generally presented in the 'core' pathways. Most of the pathway analyses present a range of different scenarios to illustrate the impacts of changing key input assumptions, for example the availability of bioenergy or the cost of key technologies and we refer to alternative scenarios where relevant.

Introductory figures

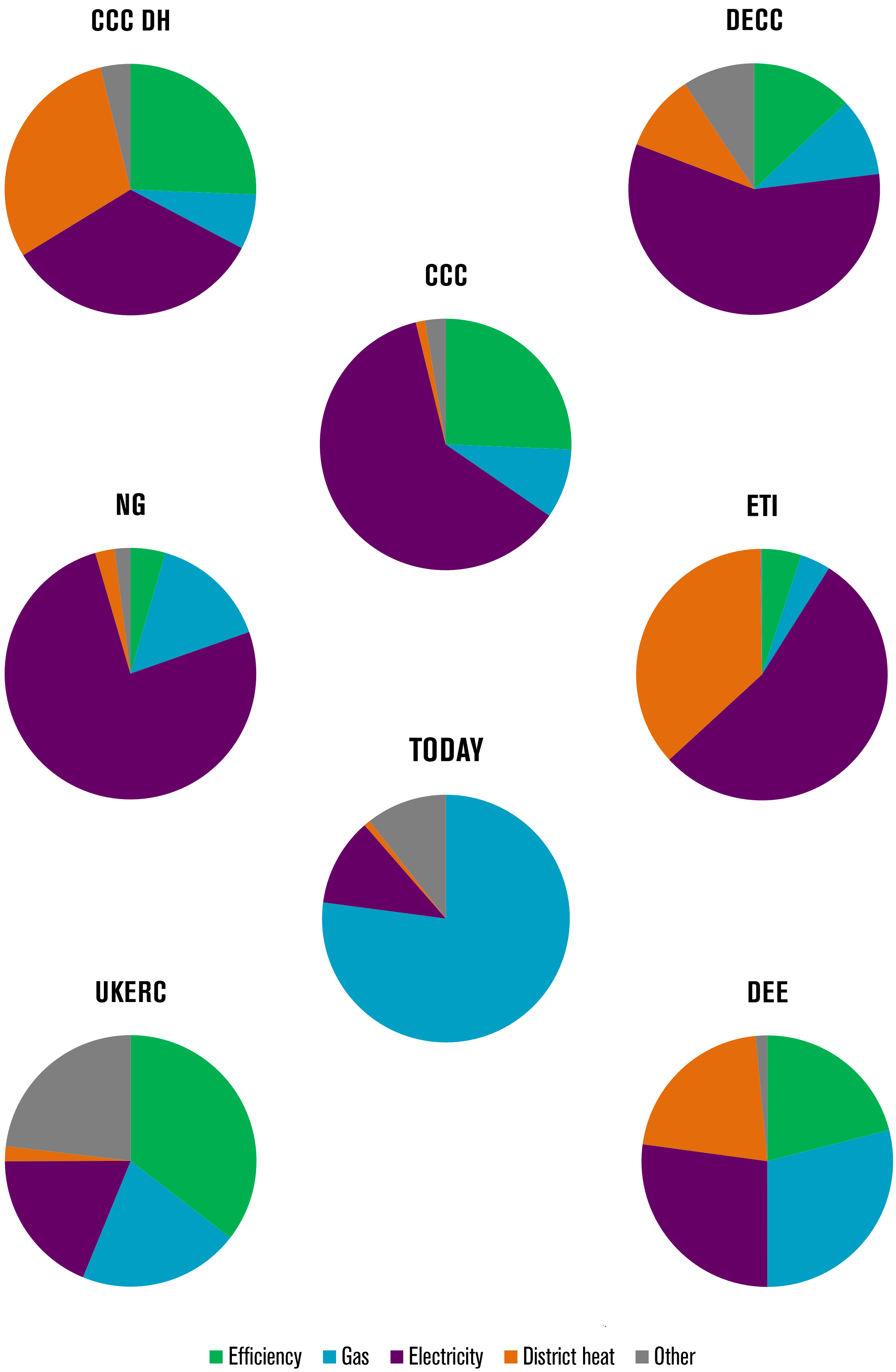
Sources: DECC (2014) Energy Consumption in the UK; CCC (2013) Progress report to Parliament; DCLG (2014) English Housing Survey: Energy Performance; DECC (2013) Heat Strategy Update

Notes: 1) Percentages are rounded to the nearest 5 per cent.

Figure 1: Pathways

	Background	Methodology	Pathway referred to in this report
Department of Energy and Climate Change (DECC)	DECC produced an updated pathway for heat in 2013 using the RESOM partial energy system model developed by consultancy Redpoint-Baringa. The aim of this work was to explore potential pathways to 2050 for decarbonising heat within the context of the wider energy system.	Partial energy system model	Core run
Committee on Climate Change (CCC + CCC DH)	The Committee updated its scenarios for all energy sectors to 2030 (originally produced in 2010) for its review of the Fourth Carbon Budget in 2013. Pathways between 2030 and 2050 were produced for the Committee's advice to Government in 2012, on how to meet the 2050 target with the inclusion of emissions from international aviation and shipping.	Various economic models and underpinning research by several consultancies.	To 2030: Updated medium abatement scenario To 2050: 'Stretch scenario for heat for buildings' (CCC) 'High district heat' variant (CCC DH)
Energy Technologies Institute (ETI)	The ETI uses an energy system model, ESME, also developed by consultancy Redpoint-Baringa. Input technology assumptions are produced in collaboration with the organisations business members.	Energy system model	2013 run
National Grid (NG)	National Grid publishes annual scenarios, the *Future Energy Scenarios*, which cover the heat, power and transport sectors to 2050. A detailed scenario analysis is carried out to 2035. Pathways from 2035 to 2050 are modelled using the energy system model RESOM, also used by DECC (see above). Results from the analysis to 2035 are used as the starting point for the RESOM model to 2050.	Pathways to 2035 are produced using various economic models, engagement with stakeholders and bespoke research. Pathways from 2035 to 2050 are modelled using the RESOM partial energy system model.	'Gone Green' scenario
UK Energy Research Centre (UKERC)	UKERC has produced a number of pathway analyses over the years using the MARKAL energy system model that has been used to inform work by both DECC and the Committee on Climate Change. In 2013 UKERC produced a set of updated pathways exploring the impact of different policy mixes, gas prices, and levels of energy system resilience.	Energy system model	UKERC Phase Two Scenarios: 'Low Carbon'
Delta EE (DEE)	Consultancy Delta EE was commissioned by the Energy Networks Association in 2012 to analyse pathways for residential heat to 2050. This analysis has a particular focus on consumer preference, which is modelled with a higher degree of detail than other analyses.	Economic model	'Balanced transition'

Heat output in 2050 (and output displaced by retrofit energy efficiency)



Biomass and solar thermal

The chapters in this report are structured around the four key solutions to decarbonise heat for buildings in the pathways examined. These are energy efficiency, electricity, gas and district heat. Individual biomass boilers and solar thermal provide further options for providing low carbon heat, but generally play a minor role in these pathways.

Individual biomass boilers

Although individual biomass boilers in buildings play a transitional role to 2030 in some pathways (ETI, CCC, National Grid to 2035) they have a limited role by 2050. This is due to uncertainty regarding the size of sustainable fuel resources in future and the prioritisation of bioenergy to more efficient uses such as larger biomass boilers or combined heat and power plants feeding district heat networks. Sustainable biomass is a flexible and low carbon fuel that can be used in many ways across the energy system. Because of this flexibility, biomass is commonly directed to parts of the energy system that are difficult and expensive to decarbonise, such as industrial process heat and transport. Some pathways suggest there could be a relatively modest long term role for individual biomass boilers in off-gas grid rural homes, operating on local sources of biomass.

Solar thermal

Solar thermal panels are used for hot water in buildings, although larger arrays can be used to provide space heating. They are included as an option in all the pathways except the ETI, although only in the UKERC pathway is there significant deployment where solar thermal provides 39 terawatt hours of heat to residential buildings in 2050.

Their uptake is likely limited by cost and the fact that they do not produce heat when it is most needed, in cold temperatures. On costs, the CCC estimates that solar thermal compares poorly with other heating technologies in 2050, with a capital cost of around £150 per megawatt hour compared with £90 per megawatt hour for heat pumps and £120 per megawatt hour for gas boilers (assuming a carbon price of £200 per tonne of carbon dioxide)[2]. A further limitation is the distribution of energy output throughout the year, with hot water demand only fully met in the summer, while in the winter a supplementary heat source is needed.

An estimate of the maximum heat output from solar thermal is provided in DECC's 2050 calculator, which suggests that by 2050 solar thermal panels could be producing 116 terawatt hours of heat. This assumes that all suitable buildings have 60 per cent of their annual hot water demand met by solar thermal, although this would likely require inter-seasonal heat storage to ensure that excess heat produced in summer is not wasted[3]. Solar thermal could play a small role in highly insulated new buildings or as a top up to heat pumps, however there is limited information about this in the pathways. Large ground based solar thermal arrays could also be used to provide heat to district heat networks in combination with seasonal storage, although space could pose an additional constraint.

[2] CCC (2012) The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping

[3] DECC. 2050 Pathway Calculator: https://www.gov.uk/2050-pathways-analysis

1. ENERGY EFFICIENCY

FINDINGS

1. Energy saved through retrofitting efficiency measures varies considerably across the pathways, particularly for higher cost measures such as solid wall insulation. This reflects significant differences in methodology and how well buildings and efficiency measures are represented.

2. New buildings are assumed to be built to high standards of thermal efficiency across the pathways, reflecting the lifetime benefits of efficient buildings. However, there is a risk that new regulations, such as Zero Carbon Homes, will not fully correct market failures and deliver buildings to the high standards assumed across the pathways.

3. Insulation is particularly valuable in buildings with electric heat pumps because lowering space heat demand not only saves electricity, but it reduces the capital costs of the heat pump and its installation, the need for back-up electricity generation and reinforcements to the electricity network.

4. Smart meters and smart building controls will soon provide the opportunity to gather much better evidence on the effect of efficiency measures in practice. If data is put to good use, it could strengthen the representation of energy efficiency in pathways analyses resulting in more consistent conclusions.

The energy efficiency of UK homes and buildings has improved over the past decade, driven by supplier obligation schemes for retrofit energy efficiency measures and tightening energy performance standards for new buildings. Despite this, significant potential remains to improve the energy performance of the UK's existing building stock, which is still amongst the oldest and least thermally efficient in Europe. According to the Government, if no action is taken to manage heat demand and historic trends continue, demand could rise by up to 50 per cent by 2050, as internal temperatures rise and the number of buildings increases[4].

Heat demand from buildings can be reduced by insulation and by building controls[5] in conjunction with behaviour change, such as turning down the thermostat. These measures can be retrofitted to existing buildings, or included in the design of new buildings. Insulation measures can range from relatively cheap loft insulation to more expensive measures such as solid wall insulation. Building controls range from thermostatic radiator valves to internet-connected smart thermostats.

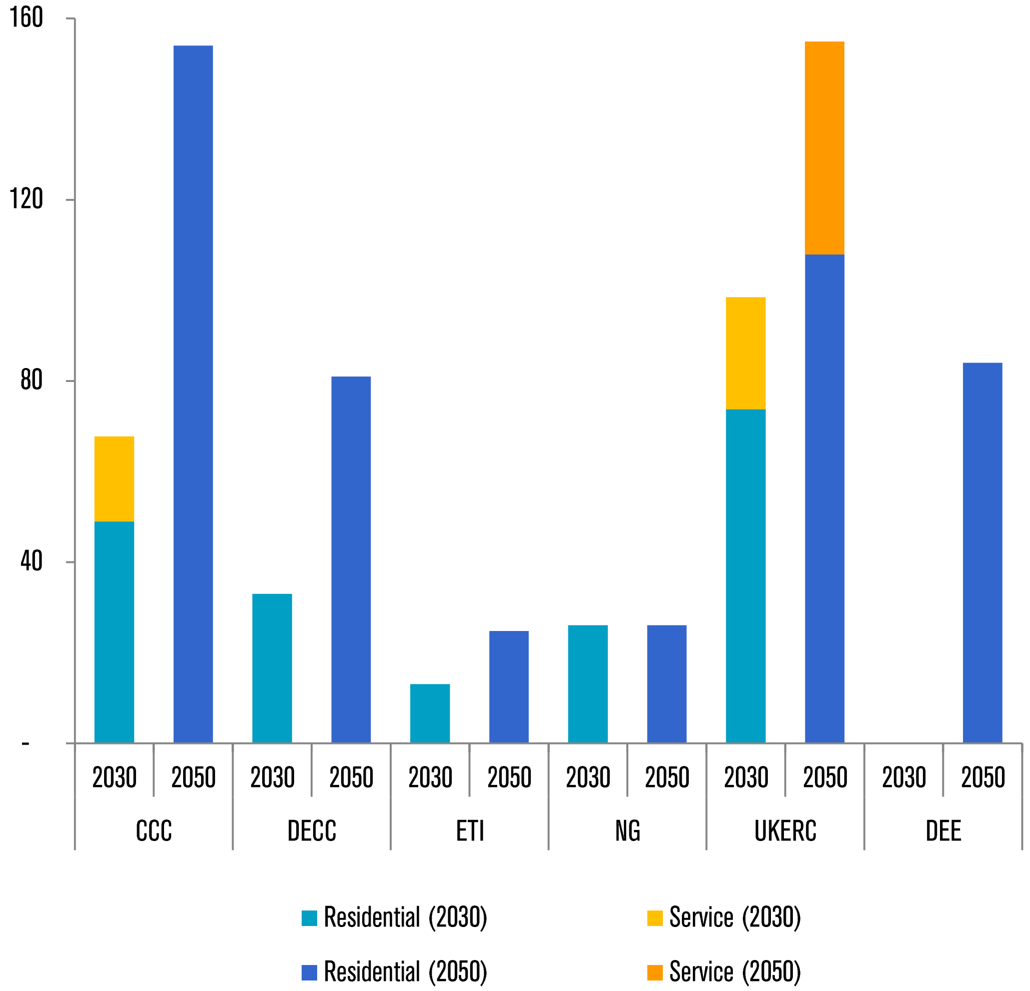
On average, homes last longer than service sector buildings. Homes that exist today are expected to make up around 80 per cent of the housing stock in 2050[6], so retrofitting energy efficiency measures is particularly important to reduce heat demand from the residential sector. In the service sector however, buildings that exist today are expected to make up only

[4] DECC (2011) The Carbon Plan
[5] Building controls, such as thermostats, control the heat system in a building.
[6] CCC (2012) The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping

around a third of the service sector building stock in 2050[7]. Therefore, driving up energy performance standards of new buildings through regulations is particularly important for efficiency in the service sector.

Pathway comparison

Figure 2: Energy efficiency savings from retrofitting measures (TWh)



Source: See appendix
Notes: 1) All data are relative to the pathway start date, approximated here to 'today'
2) Excludes supply-side efficiency savings such as replacement of old boilers with more efficient condensing boilers
3) Compared to today
4) National Grid only savings from loft, cavity and solid wall insulation

[7] Element Energy & AEA (2012) Decarbonising heat in buildings: 2030 – 2050; Report for the CCC

Overview
Figure 2 compares annual (heat) energy saving across the pathways from retrofit energy efficiency improvements in the building stock. The results vary considerably, reflecting differences in the detail with which the building stock and energy conservation measures are modelled. Further savings by 2050 are achieved primarily through the deployment of higher cost measures such as solid wall insulation and improved glazing. Savings from building highly efficient new buildings are generally not shown separately in pathways and are not counted in Figure 2. However, across the pathways new buildings are assumed to be built to high standards of energy efficiency, reflecting the lifetime benefits of highly efficient buildings. Despite improvements from retrofit and new build, total heat demand from buildings in 2050 is expected to remain at similar levels to today due to the effects of a rising population and an increasing number of homes, which increase from 27 million today to around 40 million in 2050 across the pathways.

FINDING 1
Energy saved through retrofitting efficiency measures varies considerably across the pathways, particularly for higher cost measures such as solid wall insulation. This reflects significant differences in methodology and how well buildings and efficiency measures are represented.

Residential buildings

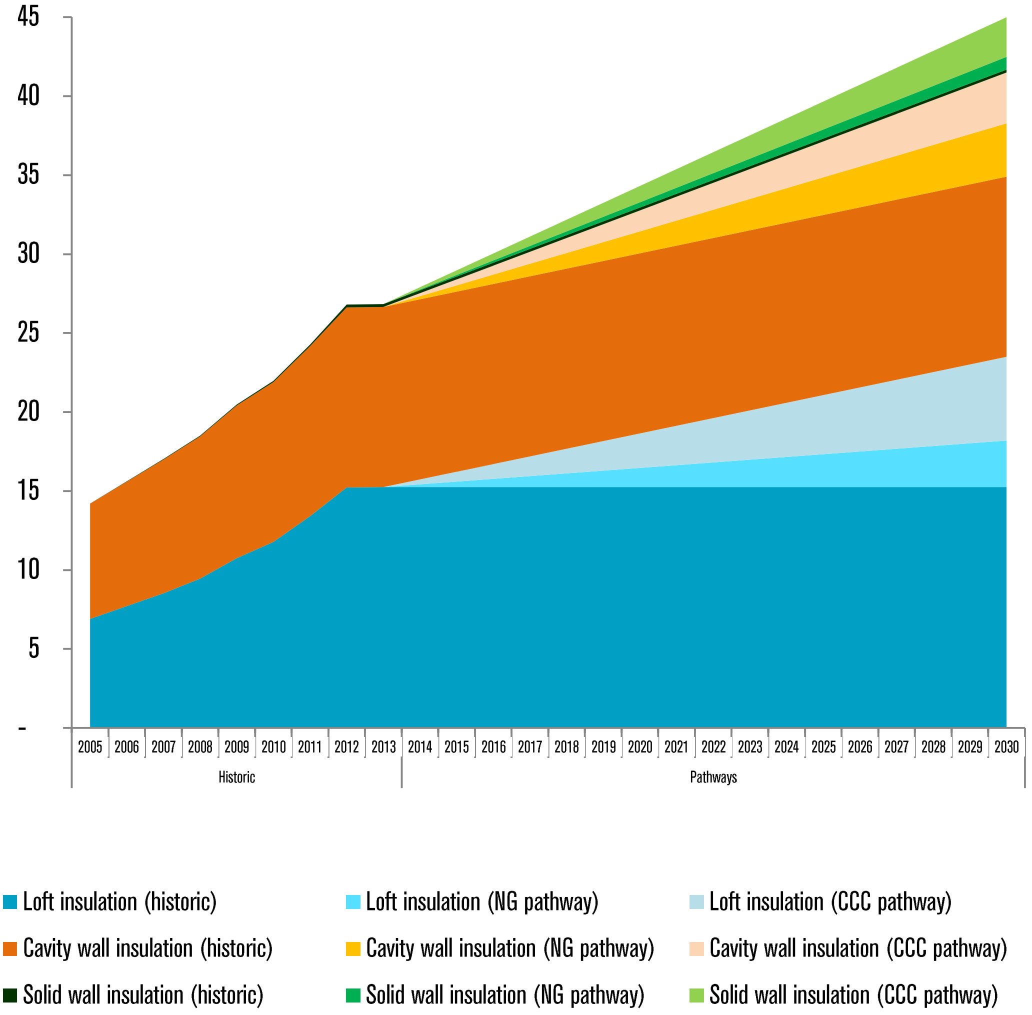
Retrofit energy efficiency across the pathways
The amount of energy saved in 2030 from retrofitting energy efficiency improvements to homes varies considerably between the pathways, ranging from savings equivalent to between 2 and 13 per cent of heat demand today (ETI 13 terawatt hours; UKERC 74 terawatt hours).

Deployment in this time period is focussed on more cost effective measures such as loft and cavity wall insulation. In CCC and National Grid pathways, loft and cavity wall insulation is deployed to between 80 and 96 per cent of their assumed potential in the existing housing stock. Deployment of solid wall insulation varies significantly, with only 0.8 million homes receiving solid wall insulation by 2030 under the National Grid pathway, compared to 3.5 million under the CCC pathway. These differences reflect current uncertainties regarding the costs and energy saving potential of solid wall insulation across the housing stock. Figure 3 compares the deployment of these efficiency measures to 2030 in these two pathways.

Energy saved by energy efficiency measures continues to increase across all pathways between 2030 and 2050, although by very little in some, such as National Grid. By 2050, the level of energy efficiency savings from retrofit measures varies across the pathways by a factor of six (NG 22 terawatt hours; CCC 154 terawatt hours).

Amongst the lowest amount of retrofit efficiency saving is under the ETI pathway, reaching 25 terawatt hours in 2050 with improvements made to only around a quarter of the existing housing stock. Energy efficiency is not modelled dynamically within the Delta EE residential pathway and instead a progressive reduction in thermal demand from homes is imposed, achieving a 17.9 per cent reduction by 2050 (compared with 2012). This is comparable to the moderate level of demand reduction seen in the DECC pathway where retrofit efficiency measures save 81 terawatt hours in the residential sector in 2050. Annual energy saving in homes reaches 108 terawatt hours per year by 2050 in the UKERC pathway, almost fulfilling the assumed potential in the housing stock. Energy efficiency is highest however under the CCC pathway with the majority of additional energy savings come from solid wall insulation which is installed in 6.1 million homes by 2050, followed by high deployment of improved glazing (in 14.6 million existing homes) and draught proofing (16.6 million homes).

Figure 3: Deployment of insulation measures in homes to 2030 (millions of measures)



Sources: DECC (2014) Green Deal and Energy Company Obligation (ECO) statistics; Other data, see Appendix
Notes: 1) 2005-2012 is National Grid data, 2013 is Energy Companies Obligation data

New homes

Savings from building highly efficient new buildings are generally not shown separately in pathways and are not counted in Figure 2. Instead, the energy performance of new buildings, whether replacing old buildings or meeting the needs a growing population, is reflected in the trajectory of future heat demand.

Future heat demand from new buildings is determined by assumptions regarding population increase, changes in occupancy rates (how many people live in a property) and the thermal performance of new homes. Anticipating demographic changes over such a long time period is inherently uncertain, and this accounts for some variation across the pathways. Today there are around 27 million homes, and across the pathways it is estimated that between 9 and 13 million new homes will be constructed by 2050. The effect of changing the rate of population growth is not tested in the pathways, and all assume significant growth to 2050.

Input assumptions for new build homes are listed in Figure 4. Heat demand from new homes is assumed to reduce significantly in comparison to today; the average household consumed 14.8 megawatt hours of gas for space, water and cooking heat in 2013[8]. A single standard is applied to all new homes in the UKERC pathway, whereas National Grid assume a progressive tightening of building regulations such that 'Passivhaus standards' (heat demand of less than 15 kilowatt hours per square meter per year – around 10 per cent of typical demand today) are reached by 2030. New homes account for an additional 29 terawatt hours of heat demand in this pathway by 2035. Additional heat demand is 9 terawatt hours lower by 2035 in this scenario compared with alternatives where less stringent energy efficiency standards are applied to new homes.

Figure 4: Pathway assumptions regarding new build homes

	New homes by 2050 (millions)	Average household heat use (megawatt hours per year)
CCC	11.5	5.5
National Grid	6.0	10.3 (2013) / 3.8 (2033)
UKERC	11.5	7.7

Sources: See appendix
Notes: 1) Includes space and water heat use only

Pathways consistently adopt high energy performance standards for new buildings, reflecting that it is generally cheaper to build high efficiency buildings than to build low efficiency buildings and then retrofit to achieve high efficiency later on. Often, however, the lifetime benefits of investing in high efficiency buildings do not accrue to the person designing and constructing new buildings, and so high efficiency designs are not adopted. The most energy efficient construction standards, such as Passivhaus standard, can reduce space heating demand by 90 per cent compared to existing buildings, although some space heating, hot water and cooking demand remains.

Building regulations have an important role to play in correcting market failures and ensuring that new buildings are highly energy efficient. However, the assumption in most pathways that all new buildings will be built to very high standards of energy efficiency in future does not reflect recent policy developments. Although the Government has stated its intention to introduce Zero Carbon Homes regulations in 2016 and similar regulations for other buildings in 2019, current proposals leave a substantial margin of uncertainty as to exactly how energy efficient new homes will be in practice.

FINDING 2

New buildings are assumed to be built to high standards of thermal efficiency across the pathways, reflecting the lifetime benefits of efficient buildings. However, there is a risk that new regulations, such as Zero Carbon Homes, will not fully correct market failures and deliver buildings to the high standards assumed across the pathways.

[8] DECC (2014) Energy Consumption in the UK - 2014

Service sector buildings

There is significantly more variation in building type and size as well as energy use in service sector buildings, and the representation of this sector within the pathways is very limited compared to residential buildings. Service sector energy efficiency is set exogenously rather than modelled dynamically within the energy system models used by DECC, National Grid (2035–50) and the ETI. The DECC pathway broadly assumes a 20 per cent reduction in heat demand and 10 per cent reduction in hot water demand from each service sector building by 2050.

The CCC undertake a more detailed analysis in which the majority of 'cost effective' energy efficiency potential in the service sector building stock is taken up by 2030, providing savings of 19 terawatt hours per year. This is achieved through the adoption of heating controls and energy management. Although this implies substantial retrofit activity in the sector to 2030, the Committee recently acknowledged that there is little evidence of sustained uptake in the sector[9]. Further energy saving in this pathway beyond 2030 is achieved through the replacement of old buildings with efficient new ones. Supporting analysis for the Committee's scenarios to 2050 estimates that between 62 and 68 per cent of the service sector building stock of 2050 will have been constructed after 2010[10], making building regulations for new build especially important in the service sector.

What affects the role of energy efficiency?

The role of energy efficiency within the pathways is particularly sensitive to input assumptions and the detail with which the building stock and efficiency measures themselves are represented. The impact of efficiency measures in new buildings is determined by assumptions regarding energy performance standards and rates of construction (discussed above). The role of retrofit energy efficiency is governed by assumptions regarding technical potential in the existing housing stock and estimated costs of installation.

Input assumptions and methodology

Representation of the building stock and energy efficiency measures varies across the analyses. Energy system models (DECC, ETI, UKERC) have a necessarily simplistic characterisation of the building stock to reduce their complexity given their wider scope. The building stock is split into residential and service sectors, and further categories such as type (flat, terrace, semi-detached, detached) location (urban, rural, suburban, off-gas grid) and thermal performance, which is often related to the age of a building. The representation of energy efficiency measures is also simplistic within these models. For example, the ETI's pathway represents energy efficiency retrofit as packages rather than as individual measures. However, by modelling more of the energy system, these pathways can provide insights into the trade-off between investment in energy efficiency and low carbon heating, and wider system benefits that may arise from reducing demand.

Sector-specific models, such as those used by the CCC, represent the building stock in more detail, and provide a more robust estimate of the technical potential, and potential take up, of energy efficiency measures. The role of energy efficiency in the CCC's pathways is derived from detailed building stock information which is used to identify the technical potential and the costs of installation for different energy efficiency measures[11,12,13]. Deployment is then prioritised to those measures offering the lowest cost per energy (or carbon) saved. Energy

[9] CCC (2014) 2014 Progress Report to Parliament

[10] Element Energy & AEA (2012) Decarbonising heat in buildings: 2030 – 2050; Report for the CCC

[11] BRE (2008) MAC Curves for the Domestic and Non-Domestic Building Sectors – Technical Documentation

[12] AEA (2008) Review and update of UK abatement cost curves for the industrial, domestic and non-domestic sectors

[13] Element Energy & Energy Saving Trust (2013) Review of potential for carbon savings from residential energy efficiency; Report for the CCC

efficiency is not modelled dynamically within the Delta EE residential pathway and instead a progressive reduction in thermal demand from homes is imposed, achieving a 17.9 per cent reduction by 2050 (compared with 2012).

The range of measures included within studies also varies. National Grid's 2030 analysis is limited to the three types of insulation: loft, cavity wall and solid wall (Figure 3), whereas in contrast the CCC also includes energy saving from improved glazing, draught proofing, floor and hot water tank insulation and installation and use of heating controls. These measures provide a saving of 17 terawatt hours per year by 2030 in the CCC pathway (in addition to 32 terawatt hours of energy saved from loft, cavity and solid wall insulation).

The deployment of energy efficiency is relatively consistent across different variations, or sensitivities, of the pathways that test the effect of different input assumptions. For example, energy saved through retrofit efficiency measures is consistent across six different sensitivities of the DECC pathway that investigate the impact of limited availability of some low carbon technologies (such as new nuclear). Similarly, high deployment of energy efficiency measures is consistent across the sensitivities of UKERC's pathway. This suggests that the variation in energy efficiency between the pathways is due to different input assumptions and methodologies for efficiency measures, rather than the wider decarbonisation strategy adopted.

Policies

Policies to support the take-up of energy efficiency measures are included by UKERC and National Grid's analysis to 2035, but do not feature in the other pathways. National Grid's results for residential energy efficiency to 2035 were developed using a bottom-up method, combining stakeholder views with data on current market trends. This analysis gives more weight to how effective it thinks policies could be in the 'real world' and consequently, its pathway sees a comparatively low take-up of higher cost solid wall insulation to 2030 even with existing levels of Government support. The UKERC pathway mimics the effect of policies such as the Green Deal and ECO by reducing financial barriers to consumer uptake of measures assumed within the model. This has the effect of increasing the adoption of energy efficiency by 50 per cent relative to an alternative pathway with no such policies (and where carbon targets are not met). It should be cautioned that this is a simplistic way to represent policy effects, and in practise there are a number of equally influential non-financial barriers that also act to reduce consumer investment in energy efficiency.

Relationship with low carbon heating

There is also an important relationship between investments in energy efficiency and low carbon heating systems. For example, installing energy efficiency measures alongside an electric heat pump can reduce the size of the heat pump needed, saving money on both the upfront and running costs of the heating system. This could be particularly important in the case where a residential property requires an expensive upgrade to its electricity network connection (from single to three phase) in order to install a larger heat pump. A smaller heat pump can also limit or avoid the need to expand the electricity system, which is often assumed to be expensive in the analyses. The link between energy efficiency measures and heat system is stronger where a larger proportion of the costs of a heat system are variable, such as fuel costs. Insulation is therefore particularly valuable in combination with resistive heating and heat pumps, where the cost of electricity ('fuel') is a relatively high proportion of the lifetime cost for the heat system. For district heating, there is typically a higher proportion of fixed costs, and so insulation gives a comparatively smaller cost saving.

The CCC identifies a particularly important relationship between the deployment of solid wall insulation and achieving maximum levels of electric heat pump deployment. Few of the UK's existing 8 million solid-walled homes are assumed to be suitable for electric heat pumps in its analysis[14]. It suggests that heat pumps would need to be installed in 4.5 million solid walled homes in order to realise its estimate of maximum heat pump deployment by 2050 (supplying 92 per cent of total building heat demand). Solid wall insulation would be required in these homes to make heat pumps economic.

FINDING 3

Insulation is particularly valuable in buildings with electric heat pumps because lowering space heat demand not only saves electricity, but it reduces the capital costs of the heat pump and its installation, the need for back-up electricity generation and reinforcements to the electricity network.

Recent evidence

Estimating potential energy savings from retrofit energy efficiency measures is particularly challenging due to a number of factors that affect their performance and costs. Recent research has revealed that savings may have previously been overestimated, and that the cost of many measures has increased in recent years.

Recent analysis of actual energy use in homes and the level of energy saving from installing efficiency measures has revealed a gap between predicted and recorded energy use and potential energy saving[15]. The Government has subsequently introduced reduction factors to the methodology used to calculate building energy performance and energy savings to reduce the gap between estimated and achieved savings. Recent estimates of energy saving potential have also been adjusted to reflect evidence that a proportion of efficiency gains are often taken back by consumers (a 'rebound' where consumers take some savings to increase temperature and comfort). Research for the Government has also revealed that the installation cost of many measures has increased in recent years[16]. Analysis underpinning the CCC pathway to 2030 concluded that despite lower energy saving and higher costs, the remaining potential for loft and easy to treat cavity wall insulation in the housing stock remains cost effective. The cost effectiveness of solid wall insulation is more uncertain, and the CCC include a lower scenario for deployment by 2030 in 1 million rather than 3.5 million homes, comparable to deployment in the National Grid pathway.

Heating controls

Heating controls could help reduce energy demand by allowing heating systems to be operated more efficiently. Around 800,000 homes currently have no heating controls and over 70 per cent lack the minimum specified by building regulations – a timer, room thermostat and thermostatic radiator valves. Heating controls are included in several pathways. However, there is uncertainty regarding their actual energy saving potential due to the importance of end-user behaviour[17].

Several 'smart' home heating controls have been brought to market in recent years that could potentially improve user interaction and overcome the behavioural factors that limit energy saving from heating controls. These products allow consumers improved control (for example through the use of a smart phone) or automation through 'intelligent' thermostats that record user habits and work to maximise the efficiency of a home heating system. Homes will also be

[14] Frontier Economics & Element Energy (2013) Pathways to high penetration of heat Pumps; Report for the CCC
[15] DECC (2013) National Energy Efficiency Data-Framework
[16] CCC (2013) Fourth Carbon Budget Review – technical report
[17] DECC (2014) Smarter heating controls research program

offered in-home displays as part of the smart-meter roll out, which may encourage further reductions in energy use through the provision of real time information, although actual energy saving resulting from improved information remains uncertain[18]. Data collected by smart controls and devices could soon provide the opportunity to strengthen evidence on the effect of efficiency measures in practice. However, this will depend on who has access to the data and how they are used.

User behaviour may be more successfully addressed in larger service sector buildings where energy use is managed by dedicated staff. The adoption of standards such as EN15232 governing the appropriate use of building controls[19] – at installation and on an on-going basis – would help ensure that systems are operated correctly and that potential energy savings are realised.

FINDING 4

Smart meters and smart building controls will soon provide the opportunity to gather much better evidence on the effect of efficiency measures in practice. If data is put to good use, it could strengthen the representation of energy efficiency in pathways analyses resulting in more consistent conclusions.

[18] House of Commons Energy & Climate Change Select Committee (2013) 'Smart Meter Roll-out'
[19] 'Energy performance of buildings – Impact of Building Automation, Controls and Building Management'

2. GAS

FINDINGS

5. All the pathways agree that the amount of gas used to heat buildings will need to reduce by at least three quarters by 2050 in order to meet carbon targets, and perhaps by as much as 95 per cent.

6. Although the heat demand for cooking is relatively small today, it could have a significant impact on decarbonisation strategy. This is because there are few options beyond electrification to move away from gas, there is very limited scope to reduce demand and use tends to be at times of energy system stress when demand for space and water heat and electricity is also high.

7. Some pathways identify a role for gas networks in 2050 as an economic tool to help meet peak heat demand. However, how much of the gas networks might remain in 2050 and where is poorly understood because little or no geographical information about energy networks is included in existing energy system models.

8. Pathways differ on how much gas continues to be used for heating buildings in the long term mainly because of uncertainty over how difficult and expensive it is to make deeper emissions cuts in other parts of the economy and the cheapest ways to meet peak heat demand.

9. Hybrid gas/electric heat systems could be valuable transitional technologies that are readily acceptable to consumers, help limit upgrades needed to the electricity system and help to progressively lower carbon emissions.

10. Biomethane could technically be used to lower the carbon intensity of gas heating, as in the Delta EE pathway. However, pathway analyses that cover multiple sectors of the economy indicate that the limited biomethane resource that might be available in 2050 would, for economic reasons, likely be focused on transport or industrial heat, rather than buildings.

11. Hydrogen heat technologies are poorly represented in the pathways. If available at a competitive price, it could be transported through the existing gas distribution networks to provide heat in buildings. Significant uncertainties remain however regarding hydrogen's availability and its most economic uses in the energy system.

Natural gas has become the dominant fuel for space and hot water heating and cooking in buildings and process heat for industry since the UK's gas network was converted from town gas to natural gas in the 1960s and 70s. Today, it supplies around 71 per cent of the UK's total heat output, including around 80 per cent of heat output from buildings. Around 80 per cent of UK homes (23 million) are connected to the gas network[20]. Gas is expected to continue to play an important role in heating at least until 2030, during which time the continued

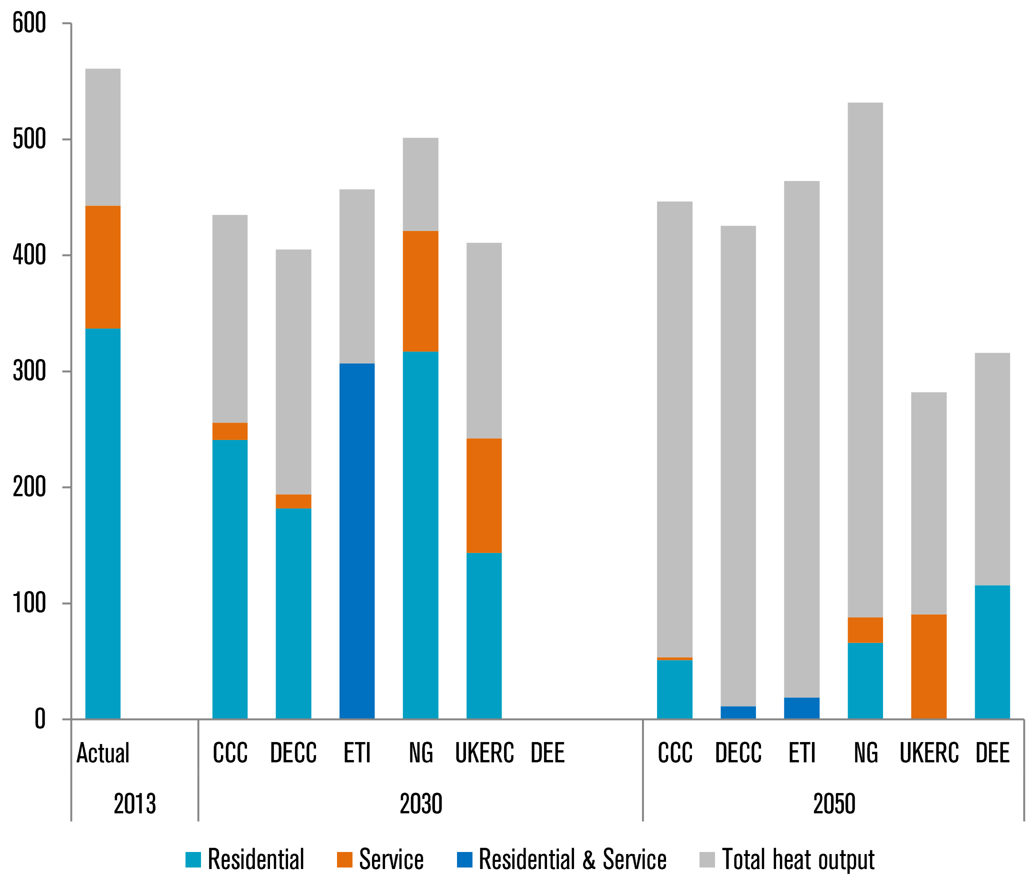
[20] DECC (2013) The Future of Heating: Meeting the Challenge

replacement of older gas boilers by more efficiency condensing boilers will achieve significant energy and carbon savings (31 terawatt hours in 2030 in the National Grid pathway).

Beyond 2030 unabated gas use is primarily constrained by carbon targets, and across the pathways gas used for heating buildings falls by between 75 and 95 per cent by 2050. Switching to transitional gas technologies such as gas heat pumps, gas fired micro combined heat and power and hybrid gas/electric heating systems could enable more efficient and lower carbon gas heating. Injecting biomethane ('green gas') into the gas grid could further reduce emissions from gas heating, although there is uncertainty regarding future production volumes and the most economic uses of biomethane within the energy system. More recent research into the impacts of a large scale roll out of electric heat pumps on the electricity system has also revealed a potential role for gas and the gas grid to provide backup supply mainly during winter. Alternatively, parts of the gas network could be converted to transport hydrogen, although the availability and economics of this fuel are highly uncertain.

Pathway comparison

Figure 5: Heat output from gas (TWh)



Sources: 2013 – DECC (2013) Energy consumption in the UK. For others, see appendix
Notes: 1) Total heat output for space and hot water heating in residential and service sector buildings

Overview

Figure 5 illustrates the heat output of gas heating technologies in 2013, 2030 and 2050. The role of gas diminishes significantly across the pathways, falling by between around 10 and 50 per cent by 2030 and to between around 75 and 95 per cent by 2050. The primary driver is reducing emissions to meet carbon targets. Current emissions from buildings (excluding indirect emissions from electricity) are around 98 million tonnes of carbon dioxide per year (MtCO2/year), the majority of which are from the combustion of natural gas. To meet the 2050 emissions target, annual UK greenhouse gas emissions should not exceed 160 million tonnes of carbon dioxide equivalent. Of this around 40-50 million tonnes of carbon dioxide equivalent are expected to be allocated to international aviation and shipping emissions and around 55 million tonnes to non-carbon dioxide emissions, leaving a residual budget of around 60 million tonnes. Of this 60 million tonnes, around 10-25 million tonnes is used in heating buildings across the pathways.

The role of gas across the pathways

Natural gas remains the dominant supply of heat to buildings to 2030 across all the pathways. Conventional gas boilers are progressively replaced with more efficient condensing boilers, providing significant energy and emissions reductions. It is estimated that around 10.5 million households have installed condensing gas boilers since these were made mandatory for all new boiler sales in 2005, and the installation of more efficient units is thought to have reduced annual heat demand by 55 terawatt hours since the year 2000[21]. Around 12.5 million non-condensing gas boilers remain in the housing stock[22], and their replacement by more efficient units continues in the pathways until most of this potential is exhausted by around 2030. This saves a further 31 terawatt hours per year in National Grid's pathway by 2030.

The share of heating provided by gas boilers begins to decline more steeply beyond 2030 as tightening carbon budgets require further emissions abatement. The use of gas is reduced largely by a major roll out of electric heat pumps and district heat networks, and in some pathways through the deployment of lower carbon gas technologies such as gas heat pumps or micro combined heat and power, or significant injection of low carbon biomethane into the gas grid.

In the DECC pathway, standalone condensing boilers are largely phased out of homes by 2030 and are instead installed alongside electric heat pumps in hybrid heating systems. Gas boilers as part of hybrid heating systems continue to provide a major share of residential heating until around 2040, after which they increasingly play a backup role, providing top-up heat to electric heat pumps during periods of high demand.

Gas appliances are mostly deployed in older detached and semi-detached homes in the Delta EE pathway covering residential buildings only. These dwellings are considered to be the most expensive to switch to low carbon heating due to their high heat demands, greater retrofit barriers or because they are assumed to be beyond the range of district heat networks. Gas also has a role in this pathway as part of hybrid gas/electric heating systems which are present in around 16 per cent of homes in 2050. Gas is assumed to provide 40-50 per cent of heat output from hybrid systems (around 23 terawatt hours per year[23]).

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[21] National Grid (2014) Future Energy Scenarios
[22] HHIC figures, 2014
[23] Carbon Connect estimate based on an average annual heat demand of around 9,000 kWh for dwellings with hybrid heat systems and gas meeting 45 per cent of heat output.

By 2050 the role of gas has declined significantly in the pathways, although in none is it phased out entirely. Gas meets between 3 and 17 cent of space and water heat demand in 2050 across four of the pathways (DECC, CCC, NG, ETI). This is a reduction of between 80 and 96 per cent on gas used in buildings today, and such low levels of gas use raise issues about the feasibility and economics of running and maintaining the gas networks, which is explored later in the chapter.

By 2050 standalone conventional and condensing boilers provide less than ten per cent of total space and water heat across all of the pathways, suggesting continuing replacement of remaining old systems in the 2040s and few, if any, new installations. The majority of remaining gas use in the pathways is with condensing gas boilers (CCC, ETI) or these combined with electric heat pumps in hybrid systems (DECC, National Grid, Delta EE), with small roles for gas heat pumps and gas fired micro combined heat and power in some pathways.

The greatest use of gas occurs in the Delta EE pathway for residential buildings, where gas heating is deployed in around 19 per cent of homes, and hybrid gas/electric heat systems in 16 per cent, providing a total heat output of 116 terawatt hours[24]. This is achieved by injecting high volumes of biomethane into the gas grid, such that 65 per cent of gas supplied to homes is zero carbon biomethane. This has the effect of lowering the carbon intensity of gas heating by two thirds, allowing three times as much use of gas heating within the same carbon budget. In pathways that consider decarbonisation across the energy system, biomethane tends to be diverted to other sectors, such as transport and industry, where there are more limited options to reduce carbon emissions. The role of biomethane is explored in more detail later in this chapter.

FINDING 5

All the pathways agree that the amount of gas used to heat buildings will need to reduce by at least three quarters by 2050 in order to meet carbon targets, and perhaps by as much as 95 per cent.

Cooking

Today the supply of heat for cooking in residential and service sector buildings is split evenly between electricity and gas (48 per cent by gas, 52 per cent electricity[25]). Where gas is retained for cooking in pathways it becomes a significant proportion of gas consumption in buildings because gas used for space and hot water heating reduces considerably. For example, by 2050 cooking is switched entirely to gas in the DECC pathway to avoid adding additional demand to the electricity system at peak times. Gas provides around 50 terawatt hours of cooking heat output in comparison to only 12 terawatt hours for space and water heating, and cooking becomes the primary source of emissions from buildings. Switching all cooking to gas would imply an expansion of the gas network to the approximately 20 per cent of homes that it does not currently serve, or alternative means of distributing gas such as in canisters. Such an extension of the gas networks is unlikely to be feasible given the low volumes of gas that pathways anticipate will be used by 2050.

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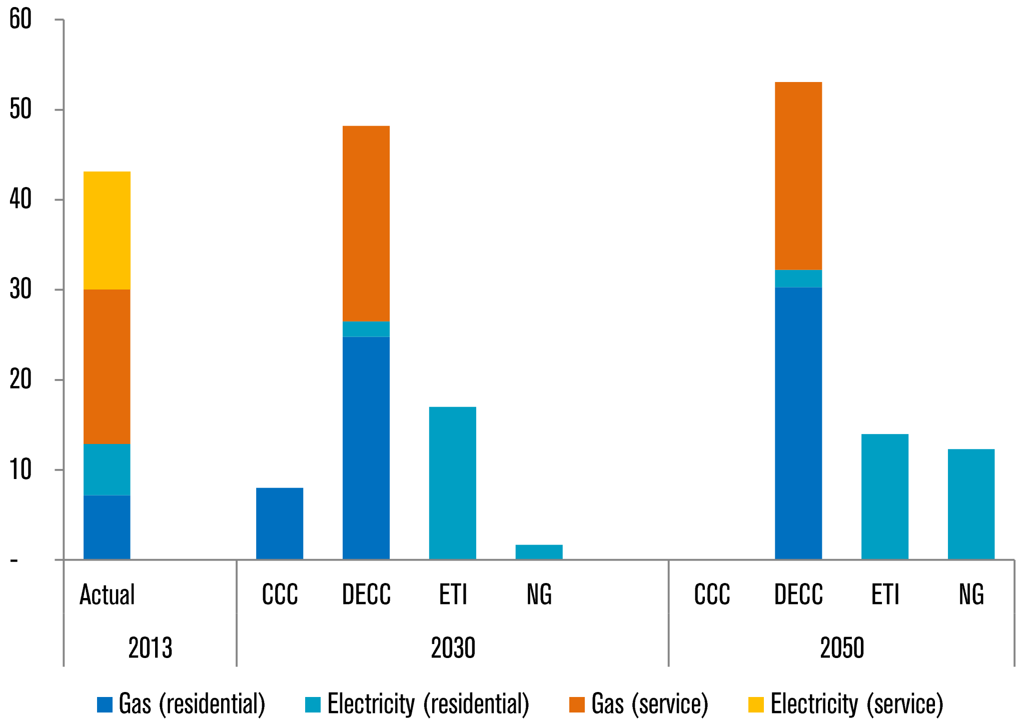
[24] Carbon Connect estimated based upon the following assumptions: 1) The average annual heat demand of a dwelling supplied by a gas boiler is around 14,000 kWh - 55% higher than that of the average dwelling; 2) 55% of heat output from hybrid heating systems comes from an electric heat pump with the balance coming from gas boilers; 3) The annual heat demand of dwellings supplied by hybrid heat systems is assumed to be 'average' at around 9,000 kWh.

[25] DECC (2013) Energy consumption in the UK

Figure 6: Heat output for cooking (TWh)



Sources: See appendix
Notes: 1) No electricity is used for cooking in the service sector in DECC or National Grid pathways
2) All other omissions represent gaps in the available data rather than zero values
3) Cooking is excluded from the Delta EE analysis and not extractable from the UKERC analysis

Despite the potentially significant impact that meeting cooking demand could have upon decarbonisation strategy, there is little detail about how cooking demand is met across the pathways.

FINDING 6

Although the heat demand for cooking is relatively small today, it could have a significant impact on decarbonisation strategy. This is because there are few options beyond electrification to move away from gas, there is very limited scope to reduce demand and use tends to be at times of energy system stress when demand for space and water heat and electricity is also high.

Service sector buildings

Results for service sector buildings are more varied across the pathways in comparison with residential homes, reflecting a more heterogeneous and poorly modelled building stock. Generally, gas heating plays less of a backup role compared to the residential sector, due to assumptions that service sector buildings have a flatter daily heat demand profile and greater potential for building-level energy storage (such as water tanks).

The use of gas reduces significantly by 2050 in all but one pathway (UKERC). Some pathways reduce the use of gas more rapidly in service sector buildings, driven by a faster turnover of the building stock and the improved economics of larger electric heat systems. For example, the share of gas boilers used for space and water heating declines sharply between now and 2025 in the DECC pathway, continuing to decline more slowly and falling to near zero by

2050. In contrast, gas use in non-residential buildings in the National Grid pathway peaks in 2030 at just over 100 terawatt hours and then declines to around 22 terawatt hours in 2050.

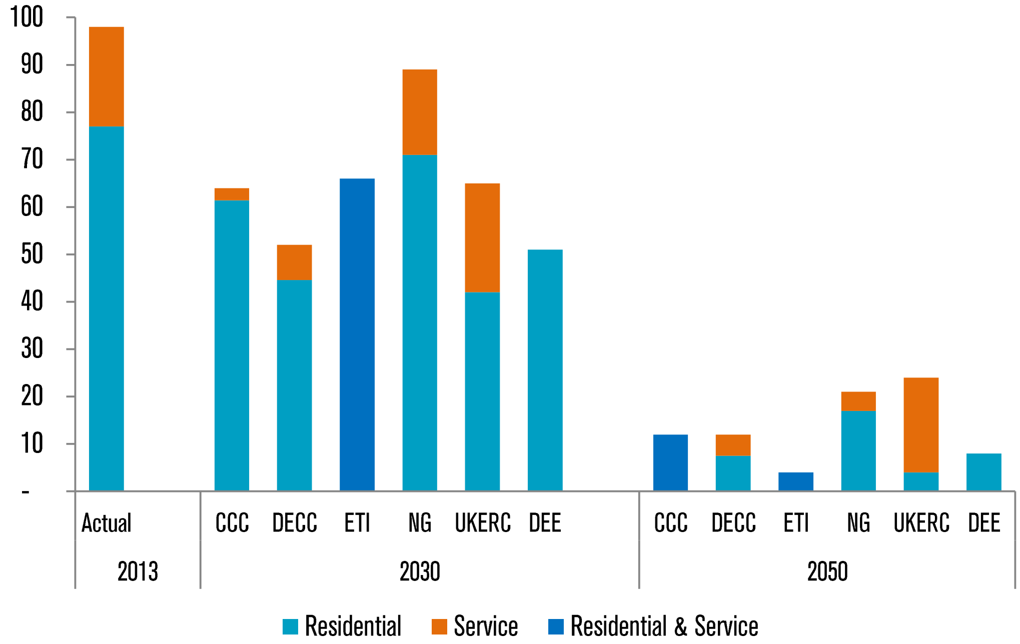
What affects the role of gas?

All the pathways agree that the amount of gas used to heat buildings will need to reduce by at least three quarters in order to meet carbon targets, and perhaps by as much as 95 per cent. The following section explores some of the key assumptions and variables that impact on the role of gas.

Carbon constraint

The use of unabated fossil fuels such as natural gas reduces in all pathways that meet the 2050 carbon target. Figure 7 illustrates emissions arising from heating buildings (all service demands) in 2030 and 2050. Total direct emissions in 2050 vary from 4 to 24 million tonnes of carbon dioxide per year, a reduction between 76 and 96 per cent relative to levels in 2012. Across the pathways building heat uses between 3 and 15 per cent of the greenhouse gas emissions limit for 2050 (160 million tonnes of carbon dioxide equivalent). There is a degree of consistency here, with analyses covering multiple sectors of the economy generally pursuing deep decarbonisation in the power sector and in building heat, and lower levels of decarbonisation in industry and/or transport. For example, in some pathways industry uses up to 54 per cent[26] of the emissions budget and transport up to 72 per cent[27]. This is because deep decarbonisation in industry and transport is generally seen as more expensive or practically challenging than in the building heat sector.

Figure 7: Emissions from buildings (MtCO2)



Sources: 2013 – CCC (2014) Meeting Carbon Budgets – 2014 Progress Report to Parliament. For others, see appendix.

Notes: 1) Includes emissions from cooking

2) National Grid and DECC: domestic and service heat excluding CHP

3) CCC, ETI and UKERC: direct emissions (excluding emissions from generating electricity consumed in buildings) only.

[26] CCC 'Barriers in industry' pathway

[27] DECC 'core' pathway – includes road transport, non-road transport and international aviation and shipping.

The Delta EE pathway is different from others considered here because it focuses solely on residential space and water heating, and does not cover other sectors. The level of decarbonisation in the residential heat sector in this pathway is however consistent with others, such as DECC. The extensive use of biomethane to decarbonise whilst continuing to use a high number of gas heating appliances is however less consistent with multi-sector pathways and is discussed below.

Retaining the gas network

The use of hybrid gas/electric heat systems in several pathways (see below) implies a continued role for the gas networks in 2050. However, there are a number of uncertainties regarding the costs and feasibility of operating and maintaining different parts of the networks for the relatively low volumes of gas that are anticipated to be used by 2050. Although the operating costs of the gas grid will generally not vary with the number of users, costs per individual user will increase given that substantially fewer buildings use gas across the pathways by 2050. Additionally, the poor spatial representation of the pathways means that these do not provide a clear indication of the extent to which parts of the network could be decommissioned, nor how this would affect the economics of the remaining elements. These costs are not therefore fully modelled in the pathways, adding uncertainty to the costs and economic feasibility of using gas in this way. The long term role of the gas networks is a critical issue for the heat sector, with the network companies continuing to invest in maintaining the existing network.

This role for gas networks should be considered alongside alternative means to meet the very large swings in heat demand between days and seasons. As outlined in the electricity chapter, the full costs and impacts of high heat pump deployment on the electricity system and options to mitigate these in future are poorly represented in the pathways. Additional solutions include inter-seasonal storage attached to district heat schemes (although this is not considered economic in the analysis commission by the CCC[28]) or even targeted use of bottled gas, which could be used to provide the very small volumes of gas in select dwellings to top up electric space and water heating (less than 12 terawatt hours in 2050 in the DECC pathway).

FINDING 7

Some pathways identify a role for gas networks in 2050 as an economic tool to help meet peak heat demand. However, how much of the gas networks might remain in 2050 and where is poorly understood because little or no geographical information about energy networks is included in existing energy system models.

FINDING 8

Pathways differ on how much gas continues to be used for heating buildings in the long term mainly because of uncertainty over how difficult and expensive it is to make deeper emissions cuts in other parts of the economy and the cheapest ways to meet peak heat demand.

[28] Element Energy & AEA (2012) Decarbonising heat in buildings: 2030 – 2050; Report for the CCC

Transitional gas technologies

Whilst there is a consistent pattern of reduced gas use by 2050 across the pathways, the mix of gas technologies deployed between 2030 and 2050 is less clear. Some pathways see a role for transitional gas technologies such as gas heat pumps and micro combined heat and power and a continued role for gas boilers as part of hybrid heat system to provide top-up to electric heating mainly during winter.

Gas heat pumps

Gas heat pumps are an established technology in the commercial sector but smaller units for use in homes are still in development. If developed at an economic cost these could operate at efficiencies of up to around 130 per cent[29], providing a greater volume of heat per unit of gas used than condensing boilers, which can be up to 94 per cent efficient. They are not included in several pathways (UKERC, CCC, ETI) and are deployed in significant numbers only in Delta EE's residential sector pathway, where their capital costs are assumed to fall to below those of other low carbon heating technologies (except hybrid gas/electric systems) by the 2040s. They are assumed to have similar retrofit barriers to electric air source heat pumps, those being space for an outside unit and indoor hot water tank.

Micro combined heat and power

Heat and electricity can be generated simultaneously within buildings by using micro combined heat and power units that run on natural gas, biomethane or hydrogen. Units can provide carbon savings relative to separate generation of heat and electricity today, although future carbon savings will depend on the carbon intensity of the electricity that is displaced. By generating electricity at times of peak demand, micro combined heat and power could help reduce the size of peak electricity demand.

Different micro combined heat and power technologies exist at various stages of commercial maturity. Although currently larger than gas boilers, there is potential for units to reduce in size, potentially helping with retrofit barriers and consumer acceptability. Costs are currently high, which is reflected in limited deployment across the pathways. The technology is included in all pathways except the CCC pathway. It plays a small role in the residential sector in the UKERC pathway after 2030 but is phased out again by 2050. A small amount is also deployed in the Delta EE pathway in large hard to heat homes on the gas network. The technology is not deployed in the DECC or ETI core pathways.

Hybrid gas/electric heating systems

Hybrid heat systems, combining condensing gas boilers with electric heat pumps, are included in most analyses and feature prominently in the DECC, Delta EE and National Grid (2035 – 2050) pathways as a potentially cost effective means of deploying electric heat pumps whilst limiting the scale of electricity system investment triggered by electric heat pump loads. Gas boilers are used to top-up output during periods of high heat demand, mainly during the winter. Delivering additional heat output via the gas network reduces the scale of investments required to reinforce electricity networks and build extra grid storage or power generation capacity. Initially, small electric heat pumps run at night to take advantage of lower cost electricity and are installed alongside gas boilers. Later on as the carbon intensity of electricity decreases and carbon budgets tighten, heat pumps play a bigger role such that by 2050 gas boilers are used only to meet peak demand.

[29] Coefficient of performance. For comparison, the COP of air source heat pumps is currently around 2.5 (250 per cent).

All remaining gas boilers in the residential sector beyond 2030 are installed alongside electric heat pumps in the DECC pathway, and hybrid gas/electric heating systems are installed in 16 per cent of homes in the Delta EE pathway by 2050. The take up of hybrid systems in this pathway is facilitated by other potential benefits which include lower capital and installation costs (through greater compatibility with existing heating systems) and greater consumer preference (due to the familiarity with gas boiler technology). Although not selected within the CCC pathway to 2030, the Committee concludes that hybrid systems are a feasible technology and that carbon abatement would still be within the lower range of its estimate for 2030 should all electric heat pumps deployed in its pathway to 2030 be replaced with hybrid systems (where gas boilers provide 25 per cent of heat demand[30]).

FINDING 9

Hybrid gas/electric heat systems could be valuable transitional technologies that are readily acceptable to consumers, help limit upgrades needed to the electricity system and help to progressively lower carbon emissions.

'Green' gas

Biomethane generated by the anaerobic digestion of organic matter such as plants and waste can be injected into the gas grid to lower the carbon intensity of mains gas and, in turn, of gas heating.

The carbon intensity of biomethane depends on the carbon contained within waste and plant matter from which it is produced. Carbon released by organic waste is usually deemed to be neutral, as carbon is likely to have recently been absorbed during the growth of such matter[31]. Biomethane is assumed to be zero carbon in most pathways and injection into the grid therefore reduces the carbon intensity of gas heating.

The Delta EE pathway relies on around two thirds of gas used in 2050 being zero carbon biomethane. This lowers the carbon intensity of a gas boiler from 185 gCO2/kWh in 2015 to 62 gCO2/kWh in 2045. Reducing the carbon intensity of the gas grid by around two thirds allows gas use to remain unusually high in this pathway for the residential sector.

Figure 8 compares the volume of biomethane injected into the gas grid in each pathway. Although the volume of biomethane in the Delta EE pathway is in similar to the ETI pathway, the Delta EE scenario assumes that all this biomethane is used in residential buildings, whereas in the ETI pathway residential buildings use little gas and the majority is used in industry. It is not clear whether further biomethane resources would be used in the service building and industrial heat sectors if the Delta EE pathway were extended to cover more sectors, and, if not, how these sectors would decarbonise.

There are a number of uncertainties regarding the future role of biomethane in the energy system. Injection of biomethane into the gas grid is relatively new to the UK, with a handful of plants currently in operation (although this is expected to increase over the coming years as a result of the Renewable Heat Incentive). The quantities of biomethane that could be produced in future are uncertain and will depend on the availability of waste , investment in the infrastructure to separately collect wastes (such as food waste)[32], and, under current economics, the continuation of financial support currently provided by Government.

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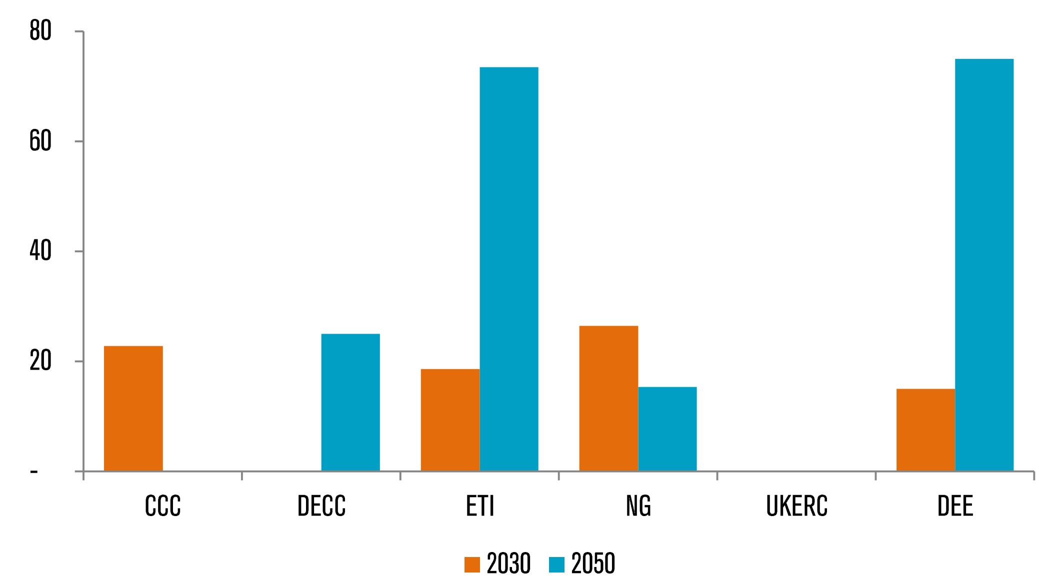
[30] CCC (2013) Fourth Carbon Budget Review – technical report
[31] Defra (2013) Energy from waste; a guide to the debate
[32] CCC (2011) Bioenergy Review

Figure 8: Biomethane injection to gas grid (TWh)



Sources: See appendix
Notes: 1) DEE: Residential buildings only (values are aggregated over the decades 2020 - 2030 and 2040 – 2050).
2) Majority assumed to be injected to gas grid (used by buildings and industry).

FINDING 10

Biomethane could technically be used to lower the carbon intensity of gas heating, as in the Delta EE pathway. However, pathway analyses that cover multiple sectors of the economy indicate that the limited biomethane resource that might be available in 2050 would, for economic reasons, likely be focused on transport or industrial heat, rather than buildings.

Hydrogen

Hydrogen is an alternative gaseous energy vector which is assumed to be low carbon in the pathways analyses, although this depends on how it is produced. It could be used to provide heat to buildings via individual hydrogen boilers, fuel cell micro combined heat and power units and heat pumps in buildings, or in larger combined heat and power units feeding district heat networks. Similar to biomethane, hydrogen could also be injected into the gas grid to lower the carbon intensity of mains gas, although only a small proportion. There are substantial uncertainties regarding the production, cost and delivery of hydrogen as well as its most economic uses in the energy system in the future. Delivery is a critical issue for its use in buildings, and the representation of hydrogen options suffers from the difficulty of representing the spatial element of networks in energy system models.

Production and delivery

There are significant uncertainties regarding potential production volumes and costs of hydrogen in future. It is produced from other fuels (coal, gas, biomass or electricity) and production is therefore contingent on the availability and cost of these inputs and conversion technologies. Many hydrogen production processes would require carbon capture and storage technology to be developed in order to be low carbon, and several production processes (gasification, electrolysis) are at an early stage of commercialisation.

A distribution system is also required to carry hydrogen from its point of production to points of use. Options include building new hydrogen pipelines, transport by road, or converting parts of the existing gas network. If existing gas networks could be converted for use with hydrogen at reasonable cost, this could avoid some of the issues that building new district heat networks or upgrading the electricity system to carry heat demand could entail. There are thought to be significant barriers to the transportation of hydrogen through the gas transmission network, although the distribution networks may be more suitable. Some of this network was originally converted from town gas (which is primarily hydrogen) and parts are currently being converted to plastic pipes, which are more suitable for carrying hydrogen[33]. However at present, understanding of the costs of new infrastructure or conversion remains poor, and as a result these options are inconsistently modelled across the pathways.

Hydrogen in the pathways

Hydrogen is included as a fuel option in all of the pathways examined except Delta EE. The representation of hydrogen heating technologies is less comprehensive, with only the DECC and National Grid (2035 – 50) pathways including hydrogen boilers and fuel cell combined heat and power units as options, and UKERC including only the latter. The option to re-purpose the existing gas network to carry hydrogen is not however considered in the pathway analyses, with a dedicated hydrogen network constructed instead. Around 200 terawatt hours of hydrogen is produced in the UKERC pathway by 2050, the majority of which is allocated to transport and industry. A small amount of hydrogen is also blended with mains gas in the National Grid pathway, capped at three per cent by energy content to avoid the need to modify existing appliances (although this is higher than allowed under current regulations). Similarly, the ETI pathway produces 250 terawatt hours of hydrogen in 2050 but none is used in buildings as the analysis does not include building-level hydrogen technologies nor the option to convert the gas distribution networks to hydrogen.

Recent research has included a more detailed appraisal of the feasibility and costs of using hydrogen to heat buildings. Using an updated version of the MARKAL model (used for the UKERC pathway), this study suggests that fuel cell combined heat and power units running on hydrogen delivered through converted gas networks could provide cost-competitive low-carbon heat for the residential sector[34]. These findings are particularly sensitive to future electricity and hydrogen costs, but do suggest that a more detailed assessment of hydrogen options should be included in future pathways analyses.

FINDING 11

Hydrogen heat technologies are poorly represented in the pathways. If available at a competitive price, it could be transported through the existing gas distribution networks to provide heat in buildings. Significant uncertainties remain however regarding hydrogen's availability and its most economic uses in the energy system.

[33] H2FC (2014) The role of hydrogen and fuel cells in providing affordable, secure low-carbon heat; H2FC SUPERGEN White Paper

[34] H2FC (2014) The role of hydrogen and fuel cells in providing affordable, secure low-carbon heat; H2FC SUPERGEN White Paper

3. ELECTRICITY

FINDINGS

12. Across all the pathways, electricity provides at least 30 per cent of heat for buildings, and around 75 per cent in several. This is predominantly through electric heat pumps, which could have a large retrofit potential across the building stock.

13. Resistive electric heating could play a role with a decarbonised electricity supply in highly efficient buildings. Storage heaters could play a valuable within-day storage role although this is poorly represented within some of the pathways.

14. The role of heat pumps is most sensitive to the thermal efficiency of the building stock, compatibility with existing heating systems, the carbon intensity of the electricity system and the costs of expanding the electricity network and generation capacity.

15. A significant constraint on heat pump deployment could be availability of space in homes for a hot water tank which are currently being removed from homes at a considerable rate. This potential constraint is poorly represented within the pathways and is an area for more research.

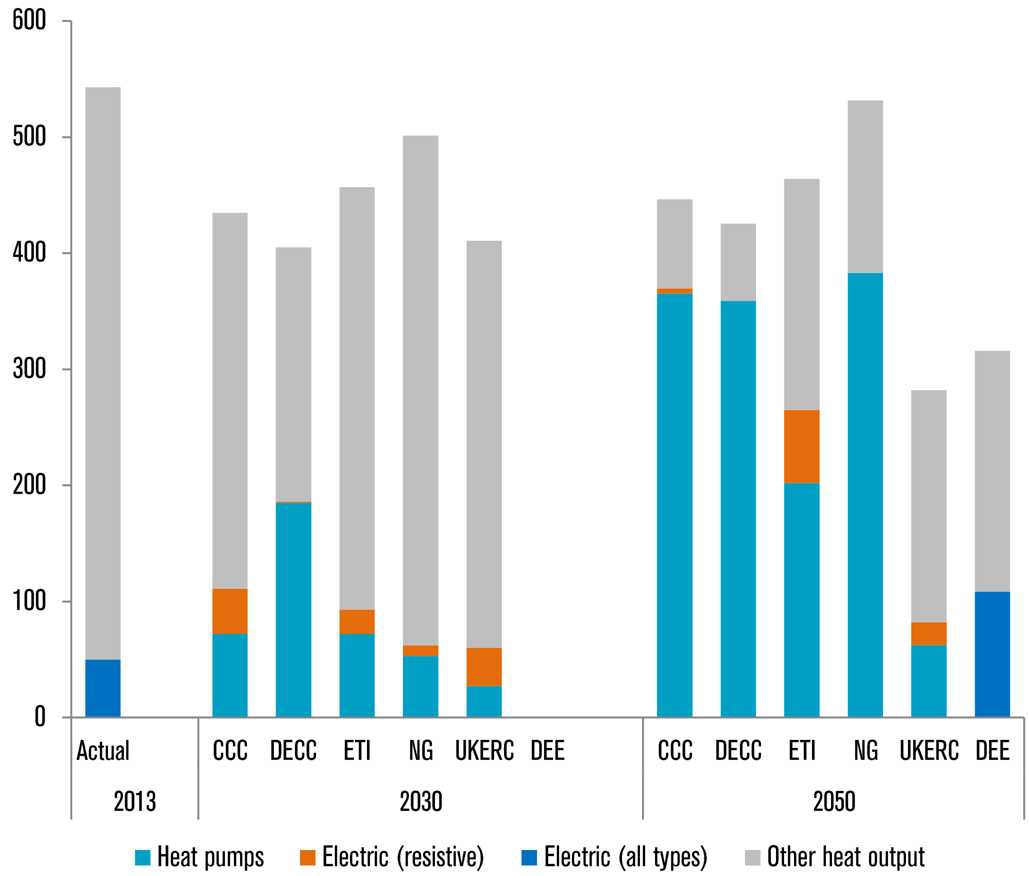
16. Recent pathways attempting to better reflect the costs of expanding the capacity of the electricity system to handle the daily and seasonal profile of heat demand suggest that these costs could make deployment of high levels of electric heat an expensive option. Although a variety of solutions to manage these impacts are technically possible, they are poorly represented in the pathways. The costs of these options are currently high but have potential to fall in future.

Electricity can be used to provide heat through a number of heating appliances, from resistive and storage heaters to small or large electric heat pumps drawing on ambient heat in air, water or the ground. Electricity currently supplies 12 per cent of all heat for space, water and cooking demands in buildings[35]. Electric heat pumps powered with low carbon electricity are one of the front runner options to help reduce emissions from space and hot water heating, thanks to a potentially large retrofit potential across the building stock and the relatively high level of confidence in the availability of low carbon electricity. However, despite being an established technology abroad, there are currently fewer than 200,000 heat pump installations in the UK, due to the historic dominance of gas-fired heating solutions.

[35] DECC (2013) Energy consumption in the UK

Pathways comparison

Figure 9: Heat output from electricity (TWh)



Sources: See appendix

Notes: 1) Space and water heating only, cooking excluded (see Figure 6).
2) Delta EE covers the residential sector only. No data available for 2030.
3) DEE: The heat output for 2050 is based on a Carbon Connect estimate assuming that dwellings heated by resistive electric have an average annual heat demand of around 6,300 kWh, and dwellings with hybrids have an average annual heat demand of around 9,000 kWh. Heat pumps are assumed to provide 55 per cent of heat in hybrid systems.

Overview

Figure 9 illustrates the share of electric heat in total space and water heating across the pathways, split between heat pumps and resistive heating. Electricity supplies at least around a third of space and water heating across the pathways, and more than 70 per cent in half of them (CCC, DECC, National Grid). The proportion of electric heat is lower in the UKERC pathway (29 per cent) primarily due to significant amounts of solid fuel/wood (60 terawatt hours) and solar thermal (41 terawatt hours), and in the Delta EE pathway (34 per cent) where biomethane plays a significant role (75 terawatt hours).

The vast majority of growth in electric heating is from heat pumps rather than resistive heating, primarily because the high efficiency of heat pumps (typically 250 per cent) makes them significantly lower carbon that resistive heating[36]. Although the with-in day storage capabilities of some resistive heaters results in a significant penetration in the ETI pathway where they meet 14 per cent of heat demand for buildings in 2050 (excluding cooking demand).

[36] Until the carbon intensity of electricity is extremely low, when the difference becomes marginal.

In the medium term, heat pumps increase their share of space and hot water heating from near zero today to between 10 and 20 per cent total heat output by 2030 in three of the pathways (NG 11 per cent, ETI 16 per cent, CCC 17 per cent), with slightly lower uptake in the UKERC pathway (7 per cent). The DECC pathway shows more aggressive adoption of electric heat pumps, which provide over 45 per cent of space and water heat output by 2030. Take-up of heat pumps is particularly rapid in the non-residential sector in this pathway, with their contribution increasing from near zero today to 79 per cent of space and hot water demand in 2030 (compared with 34 per cent in residential buildings by 2030). Deployment of heat pumps in the CCC pathway is based on a critical path analysis that is intended to allow time for supply chain expansion, cost reduction and time to keep open the option of very high heat pump deployment by 2050 (up to 91 per cent of building heat demand)[37].

Heat pumps dominate

The vast majority of electric heat in the pathways is supplied by heat pumps in both 2030 and 2050, with a smaller role for resistive heating. In the DECC and CCC pathways around two thirds of these heat pumps are air source, with a smaller role for ground source heat pumps. Air source are generally preferred to ground source heat pumps due to lower capital costs and a greater retrofit potential across the building stock as they do not require outside space for a ground loop or borehole. However, ground source heat pumps operate at higher annual efficiencies and there is also the potential to recoup the higher installation costs of installing ground-loops or boreholes over the long term.

Electric heat pumps are mainly deployed in combination with gas boilers (referred to as hybrid heating systems) in the DECC, National Grid (2035 – 50) and Delta EE pathways. Hybrid heating systems consist of a small electric heat pump installed alongside a gas boiler. The gas boiler is predominantly there to reduce the impacts and costs of adding heat demand to the electricity system at peak times, by topping up the heat pump, mainly during winter. Alternative options for managing peak heat demand through the energy networks are considered in further detail later in the chapter.

Hybrid systems could offer further benefits such as easier integration with existing heating systems, thanks to higher output temperatures from the gas boiler, and could be more readily acceptable to consumers due to the familiarity of the gas appliance and the ability to switch between fuels in a future with flexible energy tariffs. Uptake of these systems in the Delta EE pathway is initially facilitated by this enhanced customer offering. Hybrid gas/electric heating systems are a relatively new addition to pathway analyses as manufacturers are only now bringing products to market.

It should be noted that the CCC pathway to 2050 includes a variant where up to 40 per cent of heat demand is met by district heating at similar costs and emissions as the high heat pump scenario. This relies on current barriers to district heat deployment being resolved (this is explored further in the district heat chapter). In this 'high district heat' scenario, shown in the district heat chapter, heat pumps meet 39 per cent of total heat demand by 2050[38].

FINDING 12

Across all the pathways, electricity provides at least 30 per cent of heat for buildings, and around 75 per cent in several. This is predominantly through electric heat pumps, which could have a large retrofit potential across the building stock.

[37] Frontier Economics & Element Energy (2013) Pathways to high penetration of heat Pumps; Report for the CCC

[38] CCC (2012) The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping

Resistive heating

Heat pumps are generally preferred to resistive heating as the primary means of heating buildings in 2050 due to their higher efficiency, which results in lower carbon emissions and running costs. However, in buildings with very low heat demand, the running costs can be reduced and offset by the much lower capital cost associated with electric storage heaters. In addition the demand side management potential brings additional value. Evidence suggests that energy storage at the distribution level could be particularly useful in reducing future network costs[39], but with pathways lacking detail of the distribution networks these benefits are not currently well reflected.

FINDING 13

Resistive electric heating could play a role with a decarbonised electricity supply in highly efficient buildings. Storage heaters could play a valuable within-day storage role although this is poorly represented within some of the pathways.

Cooking

Today, heat for cooking in residential and service sector buildings is met by roughly even proportions of electricity and gas (48 per cent by gas, 52 per cent electricity[40]). Heat for cooking can be decarbonised using resistive electric or halogen ovens and resistive or induction hobs. The principal reason why some pathways (DECC and National Grid) avoid electrifying cooking demand appears to be to escape further increasing peak electricity demand in early evenings. The implication of this choice in the pathways analyses is that the additional network and capacity costs of meeting increased peak electricity demand outweigh the additional costs of deeper decarbonisation in another area of the economy, such as space, water or process heat, transport or power. In the DECC pathway, heat for cooking is switched entirely to gas for these reasons. In contrast, cooking is entirely electrified by 2050 in the CCC and ETI pathways (see the gas chapter for further detail).

Residential buildings

There is a consistent pattern across the pathways of electric heat deployment in the residential sector, with a high deployment of ground source heat pumps in off-gas grid rural homes. These are a good technological fit due to the larger average size and heat demand of these homes that allows a quicker payback of upfront costs. In the DECC pathway these are combined with hot water storage to allow heat generated overnight on lower electricity tariffs to be stored for later use. Properties off the gas grid are the earliest to adopt electric heat in most of the pathways. This is because heat pumps can compete against oil or all electric heating more readily than against gas boilers due to the higher running costs (fuel) of these technologies currently and the greater scope for emissions reduction (by displacing higher carbon fuels).

Air source heat pumps are deployed in greatest numbers in larger homes (detached and semi-detached), in lower density urban areas both on and off the gas grid. This is primarily driven by their greater retrofit potential as larger buildings are able to accommodate both the outdoor and indoor components (compressor and hot water tank) of air source heat pumps, and assumptions regarding the viability of heat networks which are suited to areas with a higher heat demand density.

[39] Imperial College London & NERA (2012) Understanding the balancing challenge
[40] DECC (2014) Energy consumption in the UK

New build homes

Air source and hybrid heat pumps play a significant role in heating new build homes in the DECC and Delta EE pathways by 2050. According to Delta EE, the proposed 'Zero Carbon Homes' standard is likely to initially be met using a gas boiler combined with solar photovoltaics to offset the carbon emissions. As the grid decarbonises, the volume of solar photovoltaic required to off-set the carbon emissions from a gas boiler will rise, pushing costs higher than those of an air source heat pump, which the analysis assumes become the technology of choice after 2020.

In contrast, analysis underpinning the CCC pathway to 2030[41] sees little take up of heat pumps amongst new builds without additional incentives. The existing subsidy scheme, the Renewable Heat Incentive, currently excludes new homes and is only confirmed until 2020. The Committee recently warned that proposed changes to the Zero Carbon Homes standard, that would allow developers to construct homes that do not fully meet the standard by instead making payments into an energy efficiency fund and an exemption for small developments, would fail to drive the adoption of low carbon heating in the sector[42].

Service sector buildings

Heat pumps also play an important role across most of the pathways in the service sector. There is more variation in the volume of heat output reflecting a more heterogeneous building stock and heat demand and different methods of representing this within the pathways. Heat pumps meet 70 and 90 per cent of space and hot water demand in service sector buildings in the DECC and CCC pathways respectively. There is less consistency regarding the mix of technology, however, with the former suggesting an even split between air and ground source heat pumps, and the latter selecting four fifths of heat pump supply from air source heat pumps.

There is a smaller role in the DECC pathway for hybrid electric/gas heat systems in the service sector due to a less peaky daily and seasonal demand profile and a greater suitability of storage and heat networks for these buildings[43]. Heat pumps play a limited role in the UKERC pathway where gas continues to provide the majority of heating to non-residential buildings. This result is not robust to sensitivity testing which suggests that there is limited confidence in the finding that gas could remain the technology of choice for this sector. Rather, it could be a demonstration of the limitations of some sector-specific results in pathways produced primarily for their system-level results.

What affects the role of electric heat?

The role of electric heat within the pathways is influenced by a number of factors, most important of which are the carbon intensity of grid electricity, suitability of the housing stock, economics, and electricity system impacts. The following section explores the impact of these on the pathways results and to what extent results are uncertain.

Carbon abatement from electric heating

The ability of different technologies to generate low carbon heat is a key factor guiding their selection within the pathways. Electric heating devices can provide very low carbon heat if run on low carbon electricity from sources such as nuclear, renewables or power stations with

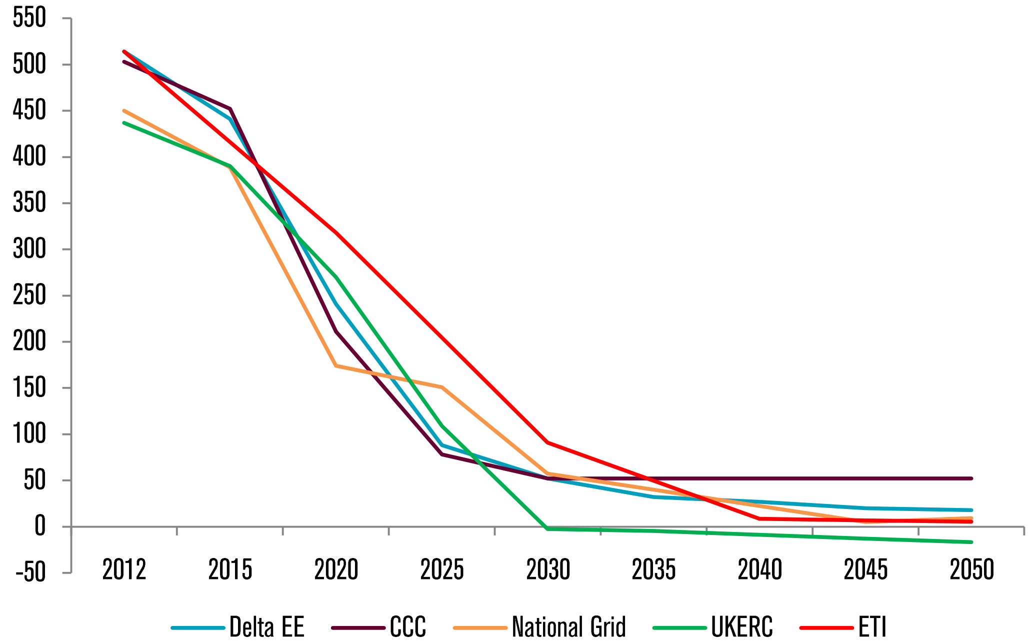
[41] Frontier Economics & Element Energy (2013) Pathways to high penetration of heat Pumps; Report for the CCC
[42] CCC (2014) 2014 Progress Report to Parliament
[43] Redpoint – Baringa (2012) Modelling to support The Future of Heating: Meeting the Challenge

carbon capture and storage. This is particularly true of heat pumps due to their high efficiency. The carbon intensity of electric heat is a function of the carbon intensity of input electricity, grid losses and the efficiency of both the heat appliance and the heating system. When correctly installed a heat pump can create around three units of heat for every unit of power consumed giving an efficiency of around 300 per cent. In comparison, standard resistive heaters are around 100 per cent efficient, resulting in higher emissions per unit of heat generated. The relative difference in carbon emissions between electric heat pumps and electric resistive or storage heating will lessen as the carbon intensity of electricity falls. For example, in the Delta EE pathway the emissions intensity of electric storage heaters broadly matches those of electric heat pumps by the period 2030 – 2040.

Electricity decarbonisation

Figure 10 illustrates the carbon intensity of electricity supply across the pathways. In all pathways the power sector is assumed to be largely decarbonised by around 2030, enabling heat pumps to generate heat at very low carbon intensities. In most pathways, power sector carbon intensity falls to around 50 grams of carbon dioxide per kilowatt hour (gCO2/kWh) or below by 2030, in line with the CCC advice to Government[44]. The average carbon intensity of electricity generation in 2013 was 497 gCO2/kWh[45].

Figure 10: Carbon intensity of electricity supply (gCO2/kWh)



Sources: See appendix
Notes: 1) DECC data not available on a comparable basis

Falling grid carbon intensity and assumed increases in heat pump efficiency in the Delta EE pathway see the carbon intensity of heat pumps fall from around 170 gCO2/kWh today, slightly lower than that of a condensing gas boiler, to around to 30 gCO2/kWh and 10 gCO2/kWh in 2030 and 2050 respectively. There is also a notable effect on emissions from electric storage heaters which are comparable to heat pumps from 2030 onwards.

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[44] CCC (2013) Next Steps on Electricity Market Reform

[45] CCC (2014) Meeting Carbon Budgets; 2014 Progress Report to Parliament

The assumption that the carbon intensity of the electricity system will fall over the next decade is relatively robust given increasing deployment of low carbon renewable and nuclear generation, the development of carbon capture and storage and the likely closure of some old coal power stations. Policy support and cost reduction has helped increase the share of renewables in the electricity supply mix from 4 per cent in 2005 to 15 per cent in 2013[46], and the Government's ambition is to increase this to 30 per cent by 2020 to help meet its obligations under the EU Renewable Energy Directive[47]. This, combined with the closure of old coal power stations, could reduce power sector carbon intensity to around 200 gCO_2/kWh by the end of the decade[48]. The first new nuclear power station is scheduled to come online in 2023, and Government modelling has indicated that its policies could reduce the power sector carbon intensity to between 50 and 200gCO_2/kWh by 2030[49]. However, although there is relatively strong confidence in the availability of low carbon electricity in the future, relying heavily on power sector decarbonisation means that the downside risk of slower decarbonisation in this sector is increased.

Uncertainties

The carbon intensity of grid electricity varies over the course of the day as the mix of power stations supplying the network changes. Indirect carbon emissions from electric heaters could therefore differ to the average annual carbon intensity of the electricity grid according to when they operate. This could have a significant impact on technologies able to defer operation to periods of lower demand and lower prices, which typically correspond to periods of lower grid carbon intensity. This could further lower emissions from electric storage heaters and, to a lesser extent, heat pumps combined with thermal storage. However, benefits of lower night time grid emissions could be offset by lower heat pump operating efficiencies due to colder temperatures at night. Modelling these impacts would require greater granularity than is currently possible in energy system models.

There is additional uncertainty regarding the carbon savings from heat pumps due to their current use of refrigerant fluids with a high global warming potential. These refrigerants can leak to the atmosphere during heat pump operation, system maintenance or in the event of mechanical breakdown. Recent research suggests that leakage from individual appliances tends to be low and does not therefore significantly impact on the carbon savings from heat pumps relative to alternative technologies during the course of their lifetime[50]. New rules restricting the use of Hydro-fluorocarbons (HFCs) and other fluorinated greenhouse gases in appliances in the EU are expected to shift heat pump manufacturers towards more climate-friendly alternatives.

Suitability for retrofit

An important factor affecting the role of all technologies is the degree to which they can be retrofitted in the existing housing stock, particularly in the residential sector where 80 per cent of homes expected to exist in 2050 have already been built.

Thermal efficiency

The thermal performance of a building can affect its suitability to be heated by a heat pump. Buildings with high heat loss are generally assumed to be less well-suited to low temperature heat distribution systems, such as most heat pumps. Poorly insulated buildings need larger

[46] DECC (2013) Energy Trends
[47] Supplying 15 per cent of all UK energy demand with renewables
[48] Carbon Connect (2013) Power from Fossil Fuels
[49] DECC (2013) EMR Delivery Plan
[50] DECC (2014) Impacts of Leakage from Refrigerants in Heat Pumps

heat pumps and possibly an upgraded electricity network connection (from single to three phase) both of which increase costs. Energy efficiency investments therefore not only improve comfort, reduce energy bills and save carbon, but they are an enabler for the concurrent or future deployment of heat pumps. Although higher levels of deployment will be contingent on improvements to the thermal efficiency of the existing housing stock, investment in low-cost efficiency measures is deemed cost effective irrespective of its effect on the uptake of low carbon heating.

Compatibility with heating systems

The cost of retrofitting heat pumps continues to be an area of uncertainty, as heat pumps may require modification or replacement of some existing radiators and the installation of hot water tanks. Heat pumps work best with low temperature distribution systems such as underfloor heating, whereas the radiators present in the majority of the UK housing stock are designed for use with the higher water temperatures achieved by gas boilers. This may be offset to some degree by the effect of subsequent improvements to thermal efficiency which will have left many homes with oversized radiators. However, the results of UK heat pump field trials have indicated the sensitivity of heat pump performance to the design of the heat distribution system and recent analyses have increased the cost of modifications assumed to be required to achieve good system performance[51]. This was one of the principle factors that lead the CCC to halve its 2030 heat pump deployment figure from 143[52] to 72 terawatt hours[53]. The compatibility of heat pumps with existing heating systems could also be improved through technical innovation, with manufacturers now offering high temperature models that could avoid modifications to heating systems, although savings are currently offset by the significantly higher capital cost of these units.

Physical space

Space for equipment is a key issue because heat pumps usually require an outdoor and indoor unit as well as the installation of a hot water tank if this is not already present. Ground source heat pumps require additional space for a ground loop or borehole, and therefore their suitability with the existing housing stock in the pathways tends to be limited to semi-detached and detached homes in suburban and rural areas. Air source heat pumps require much less outdoor space (for a compressor and fan unit), although the availability of adequate space across the housing stock is more complex to quantify and, given the simple categorisation of the building stock in energy-system models, likely to be poorly represented.

A more significant barrier may be the availability of space for a hot water tank. The majority of heat pump systems require an indoor hot water storage tank, which is increasingly an issue in smaller homes due to the trend of replacing hot water tank systems with tankless gas (combi) boilers. These are now present in 48 per cent of all homes in England[54] and account for 76 per cent of annual gas boiler sales[55]. The willingness of homeowners to install a tank and thus lose space is likely to be a further issue affecting the feasibility of high heat pump deployment scenarios. This is captured to some extent in pathways with more detailed consumer preference modelling (CCC to 2030, Delta EE) as a further 'hassle factor' affecting consumer preferences. Technical innovation could resolve this constraint to some extent, with manufacturers beginning to offer tankless hybrid heating systems combining electric heat pumps and gas boilers and potential in future for tankless gas heat pump systems (explored further in the chapter on gas).

[51] Frontier Economics & Element Energy (2013) Pathways to high penetration of heat pumps
[52] CCC (2010) The Fourth Carbon Budget
[53] CCC (2013) Fourth Carbon Budget Review
[54] DCLG (2012) English Housing Survey ; Energy efficiency of English housing
[55] HHIC figures (2014)

FINDING 14

The role of heat pumps is most sensitive to the thermal efficiency of the building stock, compatibility with existing heating systems, the carbon intensity of the electricity system and the costs of expanding the electricity network and generation capacity.

FINDING 15

A significant constraint on heat pump deployment could be availability of space in homes for a hot water tank which are currently being removed from homes at a considerable rate. This potential constraint is poorly represented within the pathways and is an area for more research.

Economics

The key elements of heat system economics are capital and installation costs, variable carbon and fuel costs, and customer attitudes. Customer attitudes are included because where they are reflected in pathways analyses, it is often by adding financial premiums.

Capital and installation costs

Air source heat pumps have lower capital costs than ground source heat pumps due to the costs of ground works (for a ground loop or borehole) required for the latter, although these costs could be recouped over the long term through re-use. There is little expectation across the pathways that heat pump capital costs will reduce significantly in future as heat pumps are a mature technology that already benefit from large overseas markets. Resistive electric heaters have lower capital costs, although their lower efficiency leads to significantly higher running costs, particularly in buildings with moderate to high heat demand. The cost of retrofit installations are currently less certain, and can be impacted by the need for modifications to existing heating systems (outlined above). Deployment of heat pumps in the CCC pathway to 2030 is particularly sensitive to assumptions regarding the cost of modifications required to make heating systems compatible with heat pumps[56].

Carbon and fuel prices

Heat technology running costs in the pathways are determined by fuel and carbon prices. Models adopting DECC's electricity and gas retail price projections, such as the Delta EE analysis, are skewed by significantly more policy costs being added to electricity retail prices than gas retail prices. This inflates the operating cost of electric heating solutions, especially electric storage heaters, relative to gas heating solutions. Carbon costs are increasingly reflected in retail electricity prices, but not gas prices. Similarly, decarbonising electricity supply is primarily funded through a levy on electricity bills, whereas decarbonising heat supply (through the Renewable Heat Incentive) is primarily funded through general taxation.

Assumptions regarding heat pump performance and efficiency are important for both running costs and carbon emissions. Heat pump performance varies according to the temperature difference between the building and the air or ground outside, and is averaged over the course of a year to give a Seasonal Performance Factor (SPF). The SPF of current domestic air source heat pumps is thought to be around 2.0 to 2.5, and ground source heat pumps (without solar recharge) around 4.0[57]. Early field trials of retrofit heat pump installations recorded disappointing performance[58], but learning from these trials has been

[56] Frontier Economics & Element Energy (2013) Pathways to high penetration of heat pumps
[57] Frontier Economics & Element Energy (2013) Pathways to high penetration of heat pumps,
[58] Energy Saving Trust (2010) Getting warmer: a field trial of heat pumps

incorporated into new heat pump installation standards[59] and early evidence from a more recent study suggests improved seasonal performance factors for new installations[60]. Many of the pathways assume that heat pump SPFs improve over the next decades as the supply chain grows and improves, although this will likely require continued training, verification, and monitoring.

Consumer preference

As well as the cost of heating systems, factors such as familiarity with a technology, space requirements and noise of the system also affect decisions. Most pathways do not seek to reflect consumer attitudes, although constraints are applied in all pathways to ensure deployment of emerging technologies does not exceed the likely rate at which supply chains can grow and consumer attitudes change[61]. Where more detailed consumer preference is modelled such as in the Delta EE pathway, uptake of heat pumps is lower. Non-financial factors affecting the selection of technologies are introduced in this pathway to reflect consumer familiarity and preferences. This reduces the deployment of pure heat pumps in favour of hybrid gas/electric heating systems, reflecting assumptions that hybrids will be more appealing to consumers because of their smaller size and the familiarity of the gas boiler element, as well as cheaper to install.

Electricity system impacts

Heat demand varies greatly between seasons and over the course of a day. Peak demand for heat is around five times higher than for electricity, with both peaks typically arising in the evenings of cold winter days. Today most of this energy is delivered through the gas networks that are able to store large volumes of gas, through both compression and dedicated storage. Shifting a large proportion of heat onto the electricity system will require an expansion in power generation and electricity network capacity.

The daily and seasonal profile of heat demand also creates a challenge for power station and network economics. These are sized to meet maximum anticipated demand, and uneven demand over the course of a year would result in some assets being used less frequently, unless more tools, such as storage and demand side response, are deployed to help flatten demand. The electricity system operates at around 60 per cent capacity on average, whilst the gas system is closer to 35 per cent as a result of the peakiness of heat demand. This is less of an economic problem for gas infrastructure as the network itself can be used to store fuel. Electricity storage is more expensive however, and so electricity is generally produced to match demand.

The cost of expanding the electricity system can impact the economic attractiveness of electric heating solutions, leading to different results between the pathways. Heat pumps add between 24 and 46 gigawatts of electricity demand at the peak across the pathways, compared with the current electricity demand peak of around 65 gigawatts. Understanding these impacts has been a particular focus of more recent pathways (National Grid 2035 - 50, DECC) which has resulted in the introduction of hybrid gas/electric heating systems as a solution to limit electricity system expansion. Extending district heat networks can also alleviate electricity system impacts of decarbonising heat for buildings.

[59] MIS 3005
[60] DECC (2014) Preliminary data from the RHPP heat pump metering programme
[61] Redpoint – Baringa (2012) Pathways for decarbonising heat, Report for National Grid

Tools for managing electricity system impacts

There are a variety of tools for managing the impacts of additional electricity demand from electric heating in addition to expanding the power station fleet. A variety of tools are available that can help shift supply and demand and increase the utilisation of both power stations and networks. These include a range of energy storage, demand side response, and demand reduction technologies. Interconnection to neighbouring countries could provide additional electricity supply over longer periods of time, for example cold spells combined with low wind output, although they could also effectively add to demand if market signals see them export during such periods. Inter-seasonal storage, either attached to district heat schemes or of alternative energy vectors such as hydrogen, could store energy over longer periods of time for use at seasonal demand peaks. Distribution network costs can also be reduced through the deployment of 'smart grid' technologies that reduce the need for some physical upgrades through better network management[62].

Although these options are present in most pathways, some of their costs and availability in future are uncertain, and their contribution to electricity system balancing is complex to represent. In particular, some energy storage and demand side response solutions are in the early stages of development and have potential to reduce in cost in future.

As discussed in the gas chapter, some pathways choose to retain a number of gas boilers either as stand-alone or as part of hybrid gas/electric heating systems to assist in limiting the impacts of heat pumps on the electricity system. However, the full costs and practicalities of maintaining parts of the gas network to be operated in this way are poorly understood, and the costs of this solution to meeting peak heat demand are likely to be poorly represented in the pathways. Finally, district heat also provides a way to serve heat demand with more limited impact on the electricity system, providing relatively low cost energy storage that can be used for with-in day balancing of the electricity system.

Spatial information about energy networks is a crucial element currently lacking from the pathways. For example, it is unclear to what extent and where gas networks will be economic in the future. The impacts of heat pump deployment will be focused on distribution networks, and these have little or no representation in the pathways. A potential strategy to reduce costs could be to target deployment of heat pumps in areas with overcapacity on the distribution network, although it is not clear to what extent this information is available currently.

Recent analyses suggest that parts of the gas network continue to play a role in economically balancing the energy system in 2050. However in light of the uncertainties discussed above, it is not yet clear how robust this finding is and what the most cost effective solutions for meeting peak heat demand at the network level may be in future. Pathway analyses have helpfully highlighted potential issues and possible solutions, but a great deal remains to be done to improve our understanding of the challenge and performance of solutions, especially at a local level.

FINDING 16

Recent pathways attempting to better reflect the costs of expanding the capacity of the electricity system to handle the daily and seasonal profile of heat demand suggest that these costs could make deployment of high levels of electric heat an expensive option. Although a variety of solutions to manage these impacts are technically possible, they are poorly represented in the pathways. The costs of these options are currently high but have potential to fall in future.

[62] Element Energy & Imperial College London (2014) Infrastructure in a low carbon energy system to 2030: transmission and distribution, a report for the CCC

4. DISTRICT HEAT

FINDINGS

17. District heating is the biggest piece of the jigsaw missing from the puzzle of future heat for buildings. Most pathway analyses largely ignore the geography of the energy system which is critical for understanding the potential for district heating.

18. Despite increasing interest, district heat suffers from limited UK-specific capital cost forecasts, a developed UK supply chain, regulatory frameworks and experience in connecting private consumers to heat networks.

19. The role of district heating within energy-system pathways is particularly sensitive to the assumed availability of low carbon heat sources, with a limited representation of options in current pathways. As a result, the strategic value of district heat to take heat input from a wide variety of sources is poorly reflected.

20. A large roll out of district heat would provide the opportunity to add large quantities of with-in day energy storage which could contribute to electricity system balancing.

21. Where available at competitive cost, district heat could be used to meet up to 40 per cent of heat output and diversify low carbon heat options, reduce the need for back-up electricity generation and network reinforcement and improve the resilience of decarbonisation strategies.

District heat networks supply heat directly to homes and businesses rather than supplying fuel for the generation of heat on-site. District heat networks can provide individually controlled and metered heat for space and water heating needs (not cooking) and can use a wide variety of sources including waste heat (such as from industry), various types of combined heat and power, large heat pumps (air, water and ground source) and geothermal. Heat networks have been deployed in the UK since the 1950s, driven in particular by the planning system, but schemes have achieved only a low market penetration and today provide less than two per cent of UK heat. In contrast, countries such as Finland and Demark have a long history of district heating with 49 and 60 per cent of their respective heat demand provided in this way[63].

District heat typically caters for a large number of small heat demands using a small number of larger low carbon or energy efficient heat sources such as combined heat and power (CHP), biomass boilers or other renewable heat sources. Heat networks can receive input heat from a number of sources, and therefore provide flexibility in the future. They also offer a big storage potential which could help with two challenges: having lots of low marginal cost power stations such as renewables and nuclear, and inter-seasonal swings in heat demand. The potential role that heat networks could play has gradually increased over time across many pathways, with improved understanding of the costs and benefits.

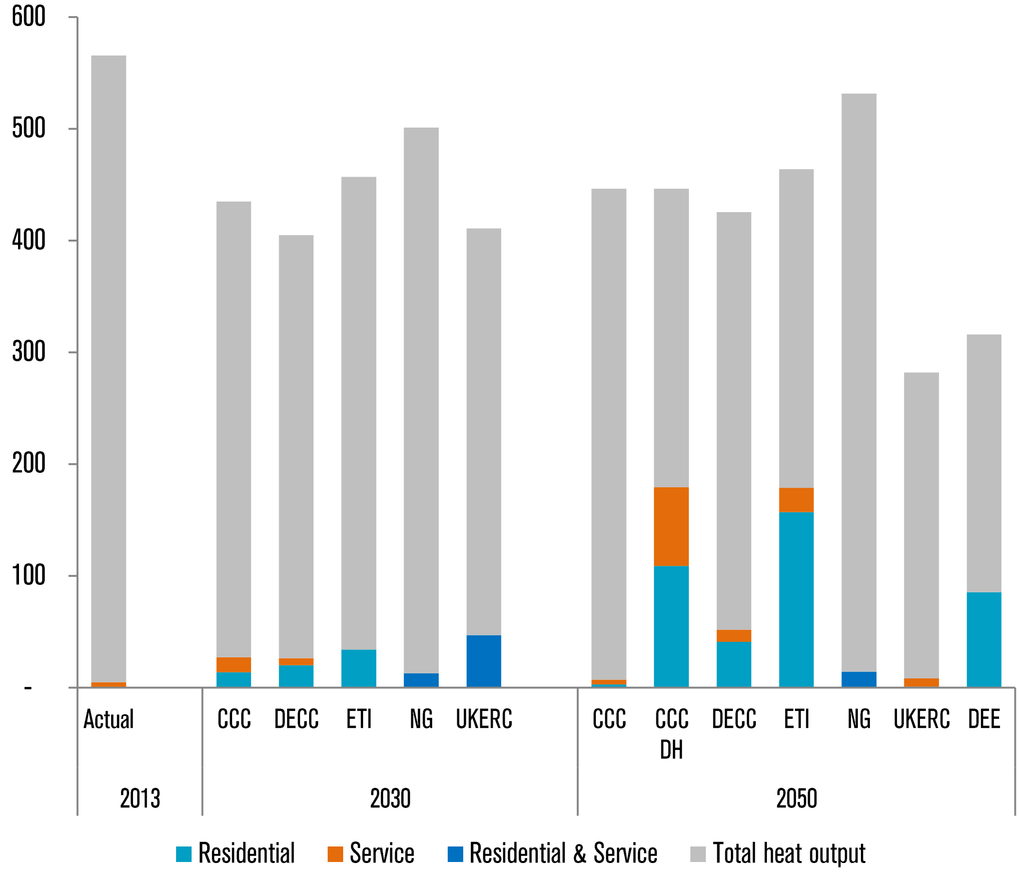
[63] Poyry (2009) The potential and costs of district heating networks

Pathway comparison

Overview

The role of district heating in 2050 varies significantly across the pathways, from just three per cent of heat output in the UKERC pathway to around 40 per cent in the ETI and CCC 'High district heat' pathways (labelled 'CCC DH'). This range reflects a generally limited understanding of district heat and the difficulty in representing it in system models. Figure 11 illustrates the contribution that district heat makes to space and water heat supply (not cooking) in homes and non-residential buildings in 2030 and 2050.

Figure 11: Heat output met by district heat (TWh)



Source: See appendix

Notes:
1)For Delta EE, no pathway data for 2030 and 2050 heat output was estimated assuming homes connected to district heat have an average heat demand of 9,000 kWh per year.
2)CCC DH is the Committee on Climate Change 'High district heat' pathway. The CCC explain that district heat could replace a proportion of heat pumps to provide up to around 40 per cent of total heat output in 2050.
3) In the National Grid pathway, further district heat is deployed for use in industry.
4) Total heat output for space and hot water heating in residential and service sector buildings

District heat across the pathways

District heat meets six per cent of heat output by 2030 in the CCC pathway (30 terawatt hours). The CCC tripled the output of district heat in 2030 compared to an earlier pathway in light of stronger evidence on the role that district heat could play. Looking to 2050, the Committee provides low and high uptake pathways, reflecting uncertainty over the balance of district heat and electric heat pumps in densely built areas. In their low district heat scenario the only source of heat for the networks is locally-sourced bioenergy, such as municipal waste. This is consistent with the findings of their *Bioenergy Review* which found that, given limited potential availability of biomass in future and the preference for its use in other applications such as with carbon capture and the power sector, sustainable bioenergy would have a limited role to play with district heat[64].

The Committee suggests that a higher level of district heat deployment is feasible should current commercial barriers be resolved. In the CCC 'High district heat' pathway, district heat meets 40 per cent of building heat output in 2050 (267 terawatt hours). Heat is primarily sourced from thermal power stations alongside some deployment of large electric heat pumps, including marine source heat pumps (Figure 12). With most district heat potential overlapping with areas that are suitable for heat pumps, a higher level of district heat results in a lower level of heat pump uptake, with similar overall emissions savings and overall cost[65,66].

Similar to the CCC, district heat more than triples in the DECC pathway from less than two per cent to 6 per cent of heat output by 2030 (27 terawatt hours). District heat almost doubles again by 2050 (51 terawatt hours) and avoids extending deployment of electric heat pumps and adding to peak demand on the electricity system. Across six sensitivities of the DECC pathway, the contribution of district heat remains relatively consistent at around 10 per cent of heat output in 2050.

The level of uptake in the CCC high deployment scenario is similar to the ETI pathway, which sees district heat providing 38 per cent of building heat output in 2050 (179 terawatt hours)[67]. Unlike other pathways, deployment is not focused purely in densely built areas, but also stretches into lower density housing with poor thermal efficiency (improvements to building thermal efficiency are only made to around a quarter of homes).

District heat plays a small role in buildings in the National Grid pathway, meeting 13 terawatt hours of heat output by 2030 and 15 terawatt hours by 2050. Beyond 2030 however, heat networks grow in the industrial sector to 37 terawatt hours by 2050, meeting around 10 and 20 per cent of heat output in this sector. In the National Grid analysis, growth is strongly aligned with the development of gas and renewable combined heat and power, and the potential that other pathways see for large scale heat pumps or geothermal is not recognised. In contrast to some other pathways, the majority of district heat schemes are assumed to occur in new build housing, rather than urban centres which are assumed to be less practical and more expensive.

Despite rising to 15 per cent of all building heat output in 2030, district heat is mostly phased out of the UKERC pathway by 2050 and is largely replaced by individual biomass boilers. Although several factors are at play, the tightening emissions constraint appears to be particularly influential in forcing out district heating due to the carbon intensity of input heat which is assumed to be predominantly from gas-fired combine heat and power (a limited

[64] CCC (2011) Bioenergy Review
[65] CCC (2013) Review of the Fourth Carbon Budget
[66] Element Energy & AEA (2013) Decarbonising Heat in Buildings: 2030 – 2050; Summary Report
[67] Excludes space and hot water demand from industrial buildings

range of heat source options is modelled). Further the lifetime of heat networks is assumed to be the same as for the heat sources serving it, although in reality, heat networks can be expected to last around 40 years – twice that of a gas-fired combined heat and power heat source. This is likely to also influence the phasing out of heat networks beyond 2030.

District heat is rolled out to 27 per cent of residential homes in the Delta EE pathway, which we estimate to provide around 85 terawatt hours of heat output[68]. These are mainly new build and higher density city centre homes (flats and terraces). The analysis shows very little reach into semi-detached houses and none to detached houses due to the high assumed cost of pushing heat network infrastructure into less dense areas.

Building stock

As well as significant variation in the level of deployment across the pathways, there are also inconsistencies over which parts of the building stock are best suited to district heat. In some analyses (National Grid 2035-50, DECC) the low density and very good thermal efficiency of new build homes is cited as a reason why heat pumps are the preferred heat supply option. However, in other analyses (National Grid to 2035), new homes are seen as a good fit for district heat because it avoids retrofit costs. There is some evidence to support this, with Government policy targeting housing development on brownfield sites where the density may be sufficient for district heat to be feasible[69].

Similarly, although the CCC DH and ETI pathways see district heat supplying around 40 per cent of heat to buildings in 2050, the CCC sees a much larger proportion of this focus on non-residential buildings (CCC DH 71 terawatt hours, ETI 22 terawatt hours). The CCC explains that non-residential buildings are often well suited to district heat because many have large heat demands which can provide good ‘anchor loads’ to get schemes started. As well as the challenges of representing district heat, data on the non-residential building stock is poor and the stock is heterogeneous. This compounds the challenge of assessing whether and which non-residential buildings are well suited to district heat.

Whilst analyses differ in their treatment of new build homes and non-residential buildings with regards to district heating, there is consistency over the selection of buildings in densely populated areas for district heat. This is mostly, but not exclusively in urban and sub-urban areas.

[68] Assuming the average home connected to district heat has an ‘average’ heat demand (around 9 megawatt hours per annum in 2050).

[69] Frontier Economics & Element Energy (2013) Pathways to the high penetration of heat pumps; Report for the Committee on Climate Change

What affects the role of district heat?

District heat is poorly represented in existing pathways analyses because some of its characteristics are poorly understood and contrast to other heat supply options. The following factors are influential in determining the potential role for district heat:

- **Density of building stock and heat demand** – estimates on the role of district heat networks are a function of heat demands (including from buildings) being located densely enough to make joining them with a heat network economic. Dense heat demands can be found in cities, towns and villages.

- **Costs** – A large proportion of the lifetime costs of district heat is capital construction costs of the network. With limited recent experience of constructing heat networks in the UK and little UK-based manufacturing, the costs of developing heat networks in the UK are particularly uncertain and there are significant commercial barriers which inflate costs.

- **Heat sources** – Not only does the geographical density of heat demands have to be sufficient, but the potential for district heat can be further narrowed by considering the location of existing or new potential heat sources in relation to centres of demand. Increasingly, the carbon intensity of heat sources also become a limiting factor.

- **Benefits –** Some of the benefits of district heat are currently difficult to capture and reflect in pathway analyses. These include its energy storage role and the value of resulting demand management, as well as the option value it provides in being a flexible infrastructure that is compatible with a number of decarbonisation strategies.

- **Maturity and uncertainty –** The district heat market and supply chain in the UK is relatively immature and this means that many of its characteristics of its potential are uncertain. It is difficult to reflect the relative uncertainty of different technologies in pathways analyses.

Density of building stock and heat demand

Estimating the potential scope for district heat is complex and requires information on heat loads (heat demand), heat sources and the ways in which they can be connected. Estimates are based on the number of buildings deemed to be located in close enough proximity to share a heat network cost effectively, and of these, how many are located close enough to existing or new sources of heat.

The maximum feasible penetration of district heating assumed in several pathways is drawn from a study conducted for the Committee on Climate Change. This concluded that up to 80 per cent of UK building heat demand is sufficiently dense to be potentially suitable for cost effective heat networks, with costs escalating rapidly in the last 20 per cent of buildings[70]. This compares to a recent study by the ETI which found that around 54 per cent of UK building heat could be economically connected to district heat schemes, and that assuming an 80 per cent market penetration this could represent 12.4 million homes and 2.9 million non-domestic buildings (43 per cent of the buildings)[71]. Whilst these analyses provide an indication to economic potential, they do not take account of other constrains, explored later in this chapter, such as availability of low carbon and economic heat sources. The

[70] Element Energy & AEA (2012) Decarbonising heat in buildings: 2030 – 2050; Report for the CCC
[71] ETI (2012) ETI Macro Distributed Energy Project

Government is currently developing a stand-alone model to better understand the long-term potential for district heat[72].

Energy system models (RESOM, ESME, MARKAL) have a relatively simple segmentation of building stock and therefore do not provide a useful guide to the total technical potential of district heat exogenously. Segments of the building stock are defined as suitable or not suitable in accordance with the results of more detailed studies (endogenous to the models). The Delta EE analysis also uses a simple segmentation of the housing stock to assess economic penetration of district heat, although this analysis usefully incorporates more detailed information about consumer attitudes, which benefits district heat relative to air source heat pumps up to 2035 for example (discussed later). Heat demand density is used in whole-system pathways to delineate which segments of the building stock may be suitable for district heating.

Although area heat density is in most cases a good indicator of cost effectiveness, this approach may eliminate areas that may in practise be suitable. Linear heat density (heat demand per metre of distribution pipework) is also a key factor in heat network costs. Some areas, such as small villages, may have a low area density but linear density sufficient to support a small heat network[73]. Energy system models do not have sufficient spatial resolution to capture this level of detail for district heat deployment, and may therefore incorrectly rule out some segments of the building stock as unsuitable.

FINDING 17

District heating is the biggest piece of the jigsaw missing from the puzzle of future heat for buildings. Most pathway analyses largely ignore the geography of the energy system which is critical for understanding the potential for district heating.

Cost

The cost of district heat networks is composed of mainly three elements; building connection costs, heat network costs and the cost of the heat supply.

Connection cost

Building connection costs typically comprise the installation of a heat interface unit (looking similar to a boiler unit), heat meter and connection to a nearby heat main. In some cases modifications may need to be made to existing building heat systems, although most existing installations are deemed compatible. Connection costs (excluding connection to a heat main, which may be lower if other ground works are taking place at the same time) will generally be similar for existing and new buildings.

Network costs

The heat network is the largest component, being highly capital intense. This involves heat mains underground, and smaller branches to connect sets of users, such as large buildings or residential roads. This cost of the network is strongly linked to its length which is why the density of heat demand is such an important factor for the economic viability of district heat. Because the capital costs of district heat are so high, the cost of financing district heat infrastructure can often determine its economic viability.

[72] DECC (2012) The Future of Heating: Meeting the challenge; Evidence Annex
[73] Element Energy & AEA (2012) Decarbonising heat in buildings: 2030 – 2050 (Summary Report); Report for the CCC

As well as being very project-specific, heat network construction costs in the UK are highly uncertain, with little construction experience over the past two decades, and none in retrofitting district heat to the existing housing stock. Recent updates to the RESOM model used by DECC and National Grid (2035-2050 only) have revised capital cost estimates downwards (10 per cent) however, contributing to a higher uptake of district heat relative to previous estimates.

There is a significant difference in the estimated cost of building district heats in developed European markets compared to an emerging UK market. This is because the UK does not manufacture district heat pipework, because the low experience here leads to higher finance costs and because heat networks are not regulated in the UK (unlike electricity and gas networks). For example, comparisons between UK and Helsinki prices for heat network piping suggest that pipes could be 50 per cent cheaper if manufactured in the UK rather than being imported[74].

In the MARKAL energy model used for the UKERC pathway, the cost of building water pipes for district heating systems is represented as a transmission cost that is applied to heat technologies (supplying heat networks) as they are built. A significant limitation of this approach is that the lifetime of the pipes is the same as for the heat supply technologies (about 20 years), and they are decommissioned at the same time, whereas in reality network assets may last for 40 to 50 years.

Heat supply cost

The cost of heat supply is low for off-take from industry and thermal power stations because it is primarily utilisation of a by-product, although there are often performance penalties on the primary process (such as power production) and the location of existing heat sources can have a significant influence on network costs. The cost of heat sources can be a more significant cost element if built specifically for the purpose of a heat network, such as a new large marine heat pump or a geothermal scheme.

FINDING 18

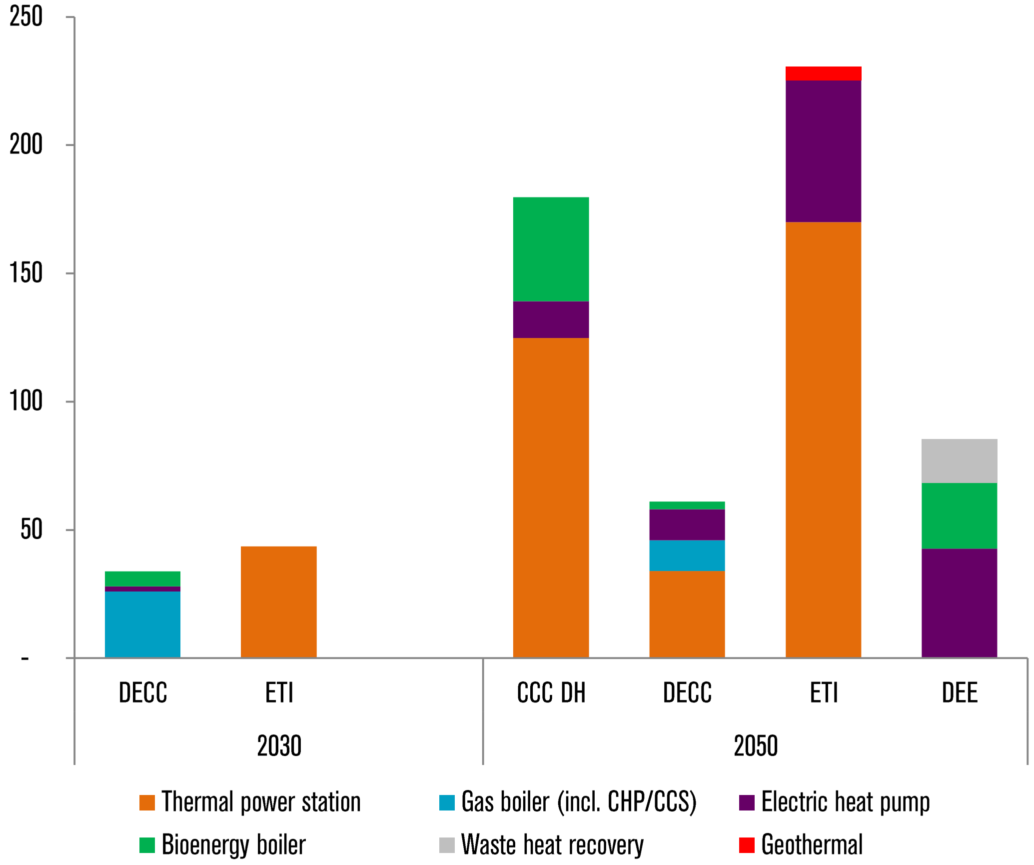
Despite increasing interest, district heat suffers from limited UK-specific capital cost forecasts, a developed UK supply chain, regulatory frameworks and experience in connecting private consumers to heat networks.

Heat sources

Economic availability, carbon intensity and location are the main characteristics of existing and potential heat sources that can constrain the deployment of district heating. Figure 12 illustrates the heat source mix for district heat networks in the pathways with significant deployment. District heat development in the pathways is based around four principle sources of heat: gas-fired combined heat and power (until around 2030, then generally only with carbon capture and storage), off-take heat from thermal power stations, electric heat pumps operating on natural sources of heat, and small amounts of bioenergy. By 2050 the vast majority of heat in most pathways with high deployment is obtained from thermal power stations.

[74] Poyry (2009) The potential and costs of district heating networks

Figure 12: Heat sources for district heat (TWh)



Source: See appendix

Notes: 1) Gas boiler includes gas boilers with and without combined heat and power and carbon capture and storage

2) Electric heat pump includes marine heat pumps

3) CCC DH is the Committee on Climate Change 'High district heat' pathway in which district heat substitutes for a proportion of heat pumps and meets around 40 per cent of heat output.

4) There may be overlap between some categories, such as gas boilers with combined heat and power and thermal power stations.

Economic availability

Although a variety of heat sources could be available in future, their economic availability is uncertain. Bioenergy has many potential uses across the energy system, and full energy system models tend to divert it towards uses in power to generate 'negative' carbon emissions with carbon capture and storage and to areas of industry where there are no or very uncertain cost effective alternatives for decarbonisation. The CCC estimates that district heat limited to local sources of bioenergy could meet only 2 per cent of heat demand in 2050.

Large scale heat pumps running on air, ground or water sources (lakes, rivers and sea) are already used to generate heat for district heat schemes in several Scandinavian countries. Large heat pumps running on water are included in several pathways (ETI 55 terawatt hours; DECC 12 terawatt hours; CCC DH[75] 4 terawatt hours). Large scale air or ground source heat pumps could also be used in combination with heat networks, although these are generally not included in existing pathways.

[75] 'High district heat' scenario

Waste heat from power stations is the main option for sourcing large volumes of heat in the ETI, DECC and CCC DH pathways. This comes mainly from nuclear power stations in the DECC pathway whilst the ETI and CCC do not specify. Alternatives to nuclear are biomass or fossil fuel-fired combined heat and power with carbon capture and storage. As well as commercial uncertainties, this option could be constrained by the location of carbon networks used for carbon capture and storage in the future.

Carbon intensity

The very limited scope for emissions in 2050 means that heat supply to district heat networks must be low carbon. From now to 2030 gas-fired combined heat and power is a cost effective and carbon efficient method of generating heat and power. Beyond 2030 however the carbon intensity of electricity and heat generated from these plants sees them begin to be phased out of the pathways as emissions constraints continue to tighten. The sensitivity of heat supply to the carbon constraint is illustrated by the phasing out of district heat in the UKERC pathway beyond 2030, where an assumed lack of economic alternatives to gas-fired combined heat and power appears to be a contributing factor.

Spatial considerations

The distance between existing and potential heat sources and sufficiently dense heat demands is a further constraint to the deployment of district heat. None of the pathways analyses model this directly, but some do try to reflect the results of separate detailed studies that have analysed this constraint. There is better representation of the location of large power stations, and a link is made in several pathways analyses (ETI, CCC) to the location of these and district heat potential and costs.

Although the analysis commissioned by the CCC identifies that 80 per cent of the building stock may be densely enough situated to make district heat economically viable, the way in which schemes are deployed and linked to heat sources could potentially have a severely limiting effect. Under an optimal scenario, the full 80 per cent penetration is estimated to be achievable, however without significant Government intervention to link district heat schemes to power stations located near to urban centres, penetration is limited to 40 per cent[76].

Other sources of heat

Geothermal and waste heat, such as from industrial processes, are potential sources of heat supply to district heat networks but their coverage in current pathways is patchy or non-existent.

Geothermal energy is energy stored in form of heat below the earth's surface and can be used for both heat and power generation. The UK's geothermal resources are considered to have greater potential for heat-only applications rather than power generation[77]. Geothermal heat supplies a district heat network in Southampton and geothermal has been identified as a heat source for potential heat networks in several cities including Manchester, Newcastle and Stoke. It is only included as an option in the ETI pathway analysis, where it provides only a very small input to district heat networks by 2050 (5 terawatt hours). This appears to be a clear limitation in many existing pathways analyses and reflects the poor data on geothermal potential.

[76] Element Energy & AEA (2012) Decarbonising heat in buildings: 2030 – 2050; Report for the CCC
[77] Atkins (2013) Deep Geothermal Review Study Final Report for DECC

Although our understanding of geothermal potential is particularly poor, work is being done by the British Geological Survey to improve it. A broad national picture was constructed from fewer than 2,000 recorded measurements of water temperature between 100 and 1,000 metres beneath the ground, although the detail and accuracy of the picture is limited by a relatively small and varied dataset[78]. More detailed specific studies are adding to the picture, such as in Glasgow, where it has been estimated that up to 40 per cent of the city's heat could be met by extracting heat from water in dis-used mines using heat pumps[79].

Heat pumps could also be used to upgrade waste heat arising from industrial or commercial activities to supply heat networks. An analysis of secondary heat (waste heat and heat from environmental sources such as rivers) in London concluded heat pumps could theoretically deliver around 71 terawatt hours of heat per year from these sources, which is more than the cities estimated heat demand[80,81]. Technical and economic challenges would need to be overcome before waste heat could be used in this way, and such sources are only likely to be feasible once heat networks are established rather than during their initial development. They represent an uncertain but albeit significant source of heat in future that is currently omitted from the pathways.

FINDING 19

The role of district heating within energy-system pathways is particularly sensitive to the assumed availability of low carbon heat sources, with a limited representation of options in current pathways. As a result, the strategic value of district heat to take heat input from a wide variety of sources is poorly reflected.

Benefits

District heating could provide several benefits including limiting electricity system impacts of decarbonisation, facilitating with-in day energy storage for electricity system balancing, being more acceptable to consumers and providing heat system diversity and flexibility.

Electricity system impacts

District heat tends to be deployed for buildings that would otherwise be electrically heated and therefore helps reduce electricity system (network and generation capacity) impacts associated with high heat pump deployment. This is true in the Delta EE pathway where district heat helps limit the impacts on the electricity network, particularly in densely built urban areas. Even where district heat uses an electrical heat source, such as a large heat pump, the with-in day storage potential of district heating schemes means that heat pumps could be operated in a manner that limited the need for electricity system upgrades.

Energy storage potential

It is more cost effective and practical to install thermal storage on a district heating scale than in individual buildings, and heat networks are installed with with-in storage to help meet peak demands. This may have wider energy system benefits by allowing heat to be generated from heat pumps or resistive boilers using surplus low carbon electricity at times when renewable output is high, helping to manage the electricity grid[82]. District heat level storage is included in the DECC and ETI pathways, but these models may miss the full value of

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[78] Busby, Kingdon, Williams (2011) The measured shallow temperature field in Britain. *Quarterly Journal of Engineering Geology and Hydrogeology*, 44 (3). 373-387

[79] BGS website, accessed October 2014

[80] Estimate for 2010

[81] Buro Happold (2013) London's zero carbon energy resource: Secondary heat. Report for Mayor of London

[82] Element Energy & AEA (2012) Decarbonising heat in buildings: 2030 to 2050; a report for the CCC

storage given that it may provide benefits over shorter timescales than are modelled within the pathways[83].

FINDING 20

A large roll out of district heat would provide the opportunity to add large quantities of within day energy storage which could contribute to electricity system balancing.

Consumer preference

Consumer preference is not modelled in detail within the pathways, but where more detailed analysis has been carried out (Delta EE) results suggest lower likely consumer barriers than most other low carbon heat technologies. This is mainly due to the in-house heat interface unit being similar to that of a gas boiler in size and the limited need for modifications to most heating systems.

Value of pathway flexibility

Heat networks can be used in combination with a wide variety of large-scale heat sources and therefore keep open the possibility for a wide variety of pathways. Given the high degree of complexity and uncertainty over the future of heat in the UK, flexibility could carry substantial value. Emerging low carbon technologies could be retro-fitted, and there are numerous potential new technologies that could emerge over the next two decades. Although future heat supply is a source of uncertainty within the models, there are lots of alternatives that could have good, but currently uncertain potential.

FINDING 21

Where available at competitive cost, district heat could be used to meet up to 40 per cent of heat output and diversify low carbon heat options, reduce the need for back-up electricity generation and network reinforcement and improve the resilience of decarbonisation strategies.

[83] Energy Research Partnership (2012) Delivering flexibility options for the energy system: priorities for innovation

METHODOLOGY AND STEERING GROUP

Carbon Connect carried out this inquiry between April and November 2014. Evidence was gathered by a conference held in Westminster on 29 April 2014, interviews with those working in and around the sector, written submissions, desk-based research and input from our steering group of industry and academic experts. The views in this report are those of Carbon Connect. Whilst they were informed by the steering group and listed contributors, they do not necessarily reflect the opinions of individuals, organisations, steering group members or Carbon Connect members. All mistakes are those of the authors, not the Chairs, Steering Group or contributors.

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APPENDIX

Pathways results, data and analysis obtained from:

Committee on Climate Change

CCC (2013) Fourth Carbon Budget Review
CCC (2013) Fourth Carbon Budget Review – technical report
CCC (2012) The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping
Element Energy & Energy Saving Trust (2013) Review of potential for carbon savings from residential energy efficiency; Report for the CCC
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Energy Technologies Institute

ETI (2014) Modelling Low-Carbon Energy System Designs with the ETI ESME Model
And correspondence

National Grid

National Grid (2014) Future Energy Scenarios
Redpoint-Baringa (2012) Pathways For Decarbonising Heat, a report for National Grid
And correspondence

UK Energy Research Centre

UKERC (2013) The UK energy system in 2050: Comparing Low-Carbon, Resilient Scenarios
And correspondence

ABOUT CARBON CONNECT

Carbon Connect is the independent forum that facilitates discussion and debate between business, government and parliament to bring about a low carbon transformation underpinned by sustainable energy.

In addition to around 40 member organisations, Carbon Connect works with a wide range of parliamentarians, academics, civil servants and business leaders who give their time and expertise to support our work. For our member organisations we provide a varied programme of parliamentary events and policy research. As well as benefitting from our own independent analysis, members engage in a lively dialogue with government, parliament and other leading businesses. Together, we discuss and debate the opportunities and challenges presented by a low carbon transformation underpinned by sustainable energy.

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