Department of Energy & Climate Change

The Future of Heating: Meeting the challenge

Evidence Annex

March 2013

The Future of Heating: Meeting the challenge

Evidence Annex

March 2013

For further information on this document contact:
Heat Strategy Team
Department of Energy and Climate Change
3 Whitehall Place
London SW1A 2AW
Telephone: 0300 068 4000

Email: heatstrategy@decc.gsi.gov.uk

This publication can be found on the Government's website:
www.gov.uk/decc

Published by the Department of Energy and Climate Change.

Contents

Evidence Annex

Introduction

This annex sets out in greater depth some of the new evidence that underpins the analysis and conclusions in *The Future of Heating: Meeting the challenge*. The annex is divided into nine sections, each describing a separate evidence source. It includes new evidence commissioned for this policy document (sections 2, 4 and 6), summaries of other relevant DECC research (sections 5 and 8), as well as initial research to inform thinking about the next steps (sections 3, 7 and 9).

Section 1 describes a range of lower carbon heating technologies, and their characteristics. This includes existing technologies, as well as descriptions of technologies still in development or not yet used in the UK.

Section 2 describes the modelling DECC has commissioned to understand the possible pathways to decarbonising heating out to 2050.

Section 3 describes the early stage development of DECC's Heat Networks modelling, which is intended to complement the Department's National Household Model.

Section 4 reports the findings of a qualitative research project commissioned to look at the barriers to the development of heat networks.

Section 5 reports the key findings from qualitative and quantitative research into energy use in the domestic sector.

Section 6 summarises qualitative and quantitative research into homeowners' willingness to take up more efficient heating systems.

Section 7 sets out the economic modelling of potential support options for gas (CHP).

Section 8 presents interim findings from analysis of customer data from phase one of the Renewable Heat Premium Payments (RHPP1) scheme.

Section 9 is a series of data sheets on heat-intensive industrial sub-sectors.

1. Summary of heating technologies

Biomass boilers supply space heating and hot water using biomass such as wood pellets as a fuel source. Biomass boilers are considered a low or zero carbon technology; this is because whilst the amount of carbon dioxide released in biomass combustion is roughly the same as that released by burning fossil fuel, that carbon dioxide was taken out of the atmosphere during the growth of the bio-material.

Central heating systems provide warmth to the whole interior of a building (or portion of a building) from one point (a central boiler or energy centre) to many rooms via pipes and (usually) radiators in each room.

Combined Heat and Power (CHP) is the simultaneous generation of heat and electricity in the same process. A domestic CHP plant is typically referred to as a 'micro-CHP', due to its small size when compared to the more familiar industrial-scale CHP. In a domestic application, heat will be used within the dwelling to provide space heating and hot water; electricity generated will be used locally and any excess may be exported to the grid. Micro-CHP is normally fuelled by natural gas and uses either a Stirling engine, gas reciprocating engine, or a fuel cell.

Condensing gas boilers supply space heating and hot water to a dwelling. Condensing boilers are around 10% to 20% more efficient than conventional boilers because they extract further heat from the unit's exhaust gases to offset heat normally provided by burning fuel. 'Condensing' refers to water vapour in the exhaust gases that is condensed (and subsequently drained) in the process of extracting heat. Domestic condensing boilers typically use natural gas as a fuel. In homes not connected to the gas grid, oil is often used. combination boilers (a boiler that heats water for both central heating and domestic hot water, removing the need for a separate hot water cylinder) can also be a condensing boiler. In this instance it may be referred to as a 'condensing combination boiler'.

Heat networks (also referred to as 'district heating') is a system where heat for more than one building or an area is produced at a central location and distributed through a network of insulated pipes. Sources of heat for heat networks can be single or multiple and often include gas or biomass boilers, gas or biomass CHP, heat from waste incineration and potentially from surplus industrial heat or large scale heat pumps.

Electric heating can take a range of forms such as storage heaters, radiative heaters or convection heaters. Storage heaters heat a storage medium, (typically clay bricks), usually overnight to take advantage of off peak electricity tariffs (Economy 7 or Economy 10). The clay bricks then release heat during the day when required. Radiative or convection heaters are usually used to supplement another form of heating.

Heating controls, such as programmable timers and room thermostats, allow users to control when and how their building is heated. Fuel savings as well as greater comfort levels are normally experienced when heating controls are applied.

Heat pumps transfer thermal energy from one location (or source) for use in another by utilising a cycle that takes advantages of changes in state and pressure. The working fluids used within the cycle are referred to as refrigerants. The cycle has the following four stages:

a. *Evaporation* The refrigerant passes through a heat exchanger where it absorbs heat from the surroundings (the source); within this device the refrigerant evaporates, changing from the liquid phase to vapour and absorbing heat in the process.

b. *Compression* The vaporous refrigerant containing heat recently absorbed during evaporation is compressed to higher pressure. An electrically driven compressor is typically used; however other devices that are driven by heat energy can be used.

c. *Condensation* The compressed refrigerant passes through another heat exchanger located in the space to be heated; at this point the refrigerant condenses, changing state from vapour back to liquid and rejects heat in the process. This rejected heat can then be used for space heating and/or hot water needs.

d. *Expansion* Liquid refrigerant passes through an expansion device, reducing in pressure prior to returning to the evaporator.

A heat pump operates in a similar fashion to a domestic refrigerator, albeit in reverse; rather than cooling a space and rejecting the heat to the surroundings, heat is absorbed from the surroundings and used to heat a space.

Air Source Heat Pumps (ASHP) use the ambient air as the heat source for the evaporator. The unit uses an electric compressor and will typically have a fan that blows air across a finned heat exchanger to improve heat transfer.

Ground Source Heat Pumps (GSHP) use nearby ground as the heat source for the evaporator. The temperature in the ground between six and 15 metres below the surface is roughly constant throughout the year and is almost always greater than that of the ambient air during the winter months. The unit uses an electric compressor and will typically have a water/glycol closed-loop system buried below ground for extracting heat.

Gas Absorption Heat Pumps (GAHP) use the same operating principles as for other heat pumps, but the electrically driven compressor is replaced by a separate device, powered by heat from gas combustion. Ammonia and water are typically used in a GAHP; ammonia is referred to as the refrigerant and water the 'absorbent'. Within the compression device, vaporous ammonia from the evaporator mixes with water in a device referred to as an 'absorber' and is 'absorbed' into a water-ammonia solution. This solution is then pumped, increasing in pressure, to a device heated by a gas burner referred to as a 'generator'. Within the generator the ammonia boils and flows on in a vaporous state to the condenser; the water returns to the absorber.

Hybrid systems contain two heating technologies, typically a heat pump and a gas boiler. Under normal operation the system should react to changing temperatures and automatically uses the more efficient of the two heating technologies.

Solar thermal heating systems use heat from the sun to provide heating to a building. Water passes through an outside heat exchanger (known as a 'solar collector') positioned to catch the sun. Unless considerable thermal storage is applied, a solar thermal system typically requires a back-up source of heating for night time heat demands or days with little sunshine. Often solar thermal will be used for hot water heating, to complement a space heating system.

2. Modelling pathways to 2050

A.1 This section provides further details on the cost-optimisation modelling undertaken to understand the pathways to decarbonise heat by 2050 in line with the UK's statutory target.[1] The analysis to support the Carbon Plan showed that in order for the UK to meet its 2050 climate change targets, domestic heat would need to be almost entirely decarbonised, and industry would need to make up to a 70% reduction in emissions.

A.2 Building on last year's document *The Future of Heating: A strategic framework for low carbon heat in the UK* (henceforth the Strategic Framework), DECC commissioned further cost-optimisation modelling to understand in greater detail the need for reductions in emissions from heat, and the mix of technologies that this might imply. Cost-optimisation models represent the whole UK energy system and therefore look at the trade-offs between heat and other sectors. DECC has used the Redpoint Energy System Optimisation Model (RESOM[2]) as it has a detailed representation of domestic heat demand, heat technologies and networks, which allows exploration of the implications for heat in detail. DECC has also used the Energy Technology Institute's Energy System Modelling Environment (ESME) to look at sensitivities, and to compare results with RESOM. This has allowed DECC to understand how sensitive the results are to

Box A1: Background on the RESOM and ESME models

RESOM has been developed by Redpoint building on an earlier project for DECC and the Committee on Climate Change on the Appropriate Uses of Bioenergy (AUB). RESOM aims to minimise the total energy system costs (capital, operating, resource, etc.) to 2050. The model decides what technologies to build and how to operate them to meet future energy service demands, whilst ensuring all other constraints (such as the Greenhouse Gas target) are satisfied. The optimisation effectively allows all trade-offs in technologies and energy vectors, in all periods on the pathway to 2050 to be resolved simultaneously.

RESOM models in five-year steps to 2050, and within each year considers five characteristic days which are modelled to account primarily for the swing in seasonal heat demand (winter, spring, summer, autumn and a 1-in-20 peak day representing an extreme winter). Each characteristic day is divided into four-hour blocks, to capture the variation and interaction between supply and demand for both electricity and heat.

Decisions about how much energy storage to build and how it should be operated are included. Storage is divided into seasonal storage (for both gas and hydrogen storage), and diurnal storage whereby storage operation is determined on a within day cycle. Electricity and heat storage options are included, the latter at both building level as well as larger scale attached to heat networks (to help decouple supply of heat from time of use).

1 The Climate Change Act 2008 sets a 2050 target of an 80% cut in greenhouse gas emissions from 1990 levels for the UK. Available at http://www.legislation.gov.uk/ukpga/2008/27/contents, accessed 15th March 2013

2 RESOM was developed in conjunction with National Grid to look specifically at the challenges to decarbonise heat. Further background, including details of the disaggregation of the building stock see reference. See Redpoint, 2012, *Pathways for decarbonising heat – report for National Grid*, http://www.baringa.com/files/documents/NG-003_-_Redpoint-Baringa_-_Heat_Economics_Study-_Final_-_v20120924-1_1.pdf, accessed 15th Match 2013

RESOM splits heat demand into separate space heat, hot water and cooking demands. Within year profiles have been added for all heat demands for each segment, and for each type of service demand. The domestic sector draws on studies from National Grid, desegregating the buildings into ten types, with an additional disaggregation by location. The combination of sector, location and building type leads to approximately 40 heat segments in total, with some of these segments (e.g. domestic buildings) having a number of heat service demands. The heat-related technologies in the model, such as ASHPs or building heat storage are characterised separately for each heat segment so that RESOM makes a decision to build and operate the technology in the optimum way for that individual segment, whilst also considering the impact on the wider system.

RESOM represents heat used in industry based on the temperature required, with high and low temperature process heat demand, and space heating modelled separately. These energy service demands are consistent with the Department's modelling for the *Bioenergy Strategy.*[3]

ESME covers fossil fuel combustion, international aviation and shipping; it does not cover non-CO_2 greenhouse gases and land use, land use change and forestry. Like RESOM, ESME is a cost-optimisation model, and focuses on the engineering system design for pathways to 2050, characterising optimal outcomes at the energy system, sector and individual technology levels.

The model can be constrained in various ways to show optimal pathways under different conditions. Constraints can encompass variables ranging from technological choices to build rates. ESME is also able to test these pathways against a range of factors that affect energy security. It does not model specific government policies, and learning rates are exogenously set. Similarly, demand for energy services is prescribed by input scenarios and is not responsive to prices.

ESME's representation of industry is less detailed than its buildings sector. Energy service demands are based on the ETI's data and are not consistent with the Bioenergy Strategy. Energy technologies (e.g. CHP) are not specifically included but the ability to switch between fuels is (e.g. from gas to electricity). Energy consumed by industry is an input which is a combination of efficiency and energy service demands. Therefore the ESME results represent the fuel needed by industry to meet its energy demand, which decreases out to 2050 due to a combination of increased efficiency in processes and changes to activity levels.

The model represents uncertainty of technology costs and other key assumptions by probability distributions. Perfect foresight is assumed in each run, with the costs being drawn from these probability distributions. A key change since the Carbon Plan is improved resolution of seasonal and in-day heat demand.

3 DECC, 2012, *UK Bioenergy Strategy*: https://www.gov.uk/government/publications/uk-bioenergy-strategy, accessed on 20 March 2013

changes in assumptions, such as the cost or availability of technologies or fuels.

A.3 DECC has updated the assumptions in both models to ensure they are consistent with other DECC modelling. Changes made to the heat technology assumptions are set out in Table A1.

A.4 As optimisation models they show the least cost mix of technologies to allow the UK to reach the 2050 emissions target, based on assumptions about cost, performance and the various constraints placed on build rates. In general they assume perfect markets and information, and therefore do not attempt to capture the effects of consumer preferences for different technologies.

A.5 RESOM and ESME do not attempt to model the policies that would be required to deliver these emissions reductions, and are not designed to provide the detailed forecasts needed for policy appraisal. Rather they provide insights to optimal pathways for the long term. As these models lack detail in some regards (e.g. geographic constraints on certain technologies), care is required in interpreting the results.

Findings

A.6 The Government has developed a core run for the RESOM model, to provide a benchmark for comparison with other sensitivities, and with the ESME modelling. This has been aligned as far as possible to Government assumptions on the cost of technologies, the availability of biomass and future fossil fuel prices.

A.7 A number of sensitivities have been run through both of the models to assess how sensitive the pathway is to changes in response to the input assumptions. A number of 'stress

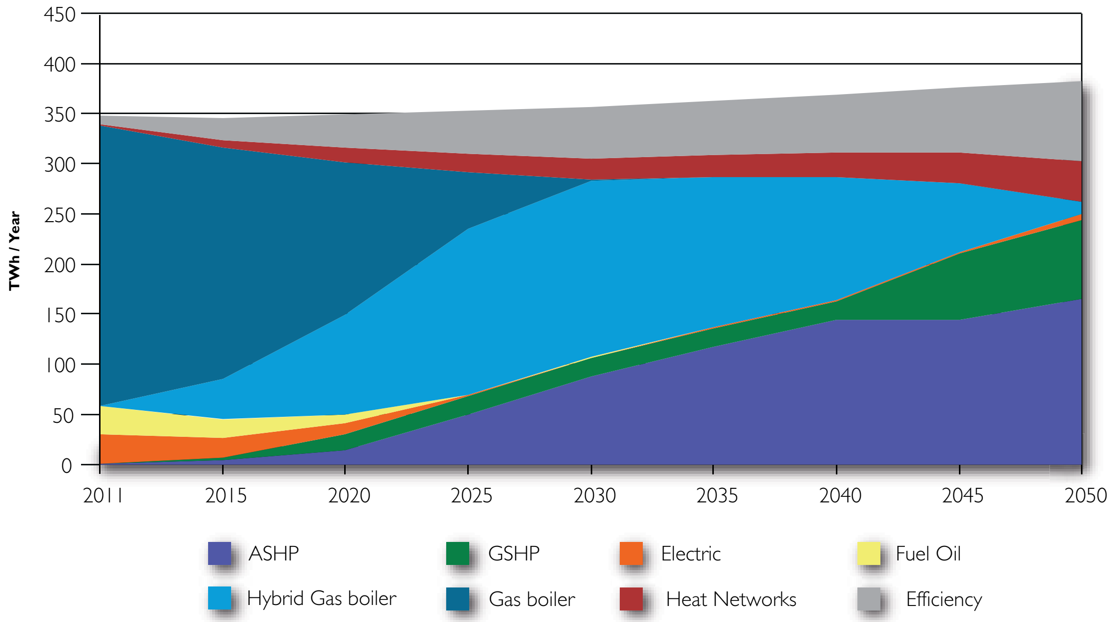
Table A1: Key assumptions updated for this modelling.

Assumptions	Comments
Suitability for heat networks	Adjusted constraints on the suitability of heat networks in urban and suburban areas to allow heat networks to supply up to 80% of buildings. Heat networks not considered suitable for buildings in low density areas.
Storage for heat networks	In day storage options for heat network systems. No seasonal storage modelled.
Costs of heat networks	Revised network costs and cost of connection to buildings. Additional sources of heat included – large scale heat pumps, either ground source or riverine/marine included with a maximum output of 12 TWh/year[4] in 2050.
New Building level technologies	Hybrid systems combining a gas boiler and an air or ground source heat pump, and gas absorption heat pumps included for domestic and non-domestic buildings. Micro-CHP fuel cells and hydrogen boilers included as option for domestic buildings. Diurnal heat storage for buildings
Industrial use of hydrogen	Inclusion of industrial hydrogen, through boilers and direct fired applications
Availability of biomass Imports	Consistent with the 'lower core' scenario in DECC's UK Bioenergy Strategy.[5]

4 Consistent with CCC analysis on decarbonisation of heat from 2030 to 2050. CCC, 2012, *Decarbonising heat in buildings: 2030–2050* http://hmccc.s3. amazonaws.com/IA&S/Element%20Energy%20-%20Decarbonising%20heat%20to%202050%20-%20Report.pdf, accessed 15th March 2013

5 DECC, 2012, *UK Bioenergy Strategy*, https://www.gov.uk/government/publications/uk-bioenergy-strategy, accessed 15th March 2013

Chart A1: Domestic space heat and hot water output by technology[6]



Source: RESOM core run

testing' scenarios were run to understand how the results for buildings might change in response to removing or changing assumptions about key technologies such as the deployment of nuclear, use of bioenergy or the use of Carbon Capture and Storage (CCS) or the internal temperatures of domestic buildings. Such scenarios are not intended to represent possible future states of the world, but are used here to test how sensitive the findings from the core run are to significant changes to the mix of technologies.

Domestic buildings – core run

A.8 The RESOM core run (Chart A1 above) shows a similar overall picture for 2050 as presented in the Carbon Plan, with natural gas remaining the main fuel used in domestic buildings until the 2030s, but reducing thereafter. The model suggests a role for hybrid systems where gas boilers are used in conjunction with heat pumps. These are adopted relatively quickly, with stand-alone condensing gas boilers being completely replaced by 2030.

A.9 At first hybrid systems generate most of their heat from the gas boiler, supplemented by a small heat pump running at night to take advantage of off peak electricity. Heat pumps are used throughout the year to provide heating and hot water. Storage tanks allow the heat to be used during the day. By 2050 gas is used to meet peak heat demands only, with heat pumps providing the "base load" heat.

A.10 Properties on the gas grid are predicted to mainly use hybrid systems consisting of a gas boiler and an air source heat pump. The model predicts that by 2050 rural properties off the gas grid will mainly be using ground source heat pumps incorporating storage, with a small amount of electric heating to provide peak top up on certain days.

A.11 The core run suggests that domestic cooking will not decarbonise, and in fact completely switches to gas where available. Although cooking could be electrified (and in practice often is), the peaks in demand for cooking coincide with the peaks for appliances

6 Note that the heat generated by an ASHP and GSHP used as part of a hybrid systems is not identified separately in the chart.

and heating, which suggests that continuing to use gas for cooking would be lower cost than electrification and reinforcement of the local electricity grid. The model shows around 8 $MtCO_2$ of emissions from gas used in domestic buildings in 2050, with the majority from cooking. All gas used for heating in 2050 is through hybrid systems, accounting for 2.2 $MtCO_2$.

A.12 There is a substantial role for heat networks by 2050, with the heat supplied from a range of technologies. Heat networks are predicted to be taken up in higher density, older buildings. Heat networks are predicted to grow rapidly to 2030, with the majority of heat being supplied by gas sources through large scale CHP, but complemented with around a quarter of heat from biomass. From 2030 gas use declines and the remaining gas used by 2050 will be with CCS. Large scale heat pumps and heat from nuclear power stations will make up the majority of heat supplied to heat networks by 2050.

Non-domestic buildings – core run

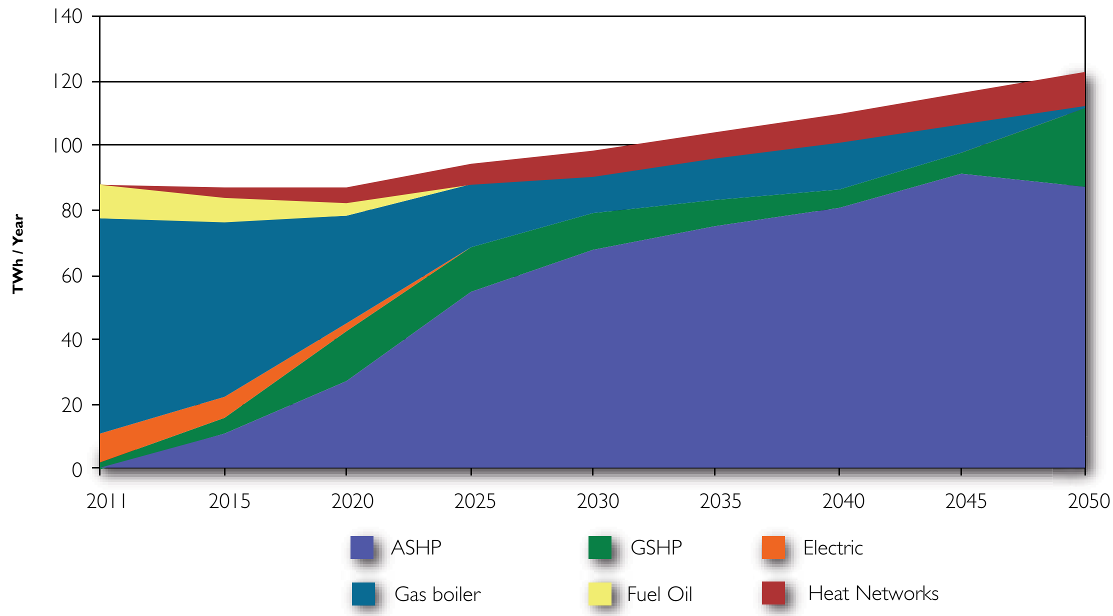
A.13 The results for non-domestic buildings (Chart A2 below) show a similar pattern to domestic buildings, with the majority of heat coming from heat pumps by 2050. ASHPs replace gas boilers in many buildings, with virtually no gas used in non-domestic buildings by 2050. Electricity for direct resistive heating and cooking is shown to be phased out almost entirely by 2025, with cooking being entirely by gas in 2050. Heat networks grow to provide 7% of non-domestic heat by 2030 and 9% by 2050.

Building results – comparison with ESME

A.14 The ESME core run (Chart A3 opposite) suggests gas will be the main fuel used to provide space heat up until the 2040s, but that by 2050 gas will mainly be used in GAHPs. The results however suggest there may be a role for gas boilers to provide back-up capacity for a one in twenty cold winter. GAHPs also provide the majority of the hot water demand until the late 2040s, but ASHPs and hydrogen boilers start to be used more to provide hot water by 2050.

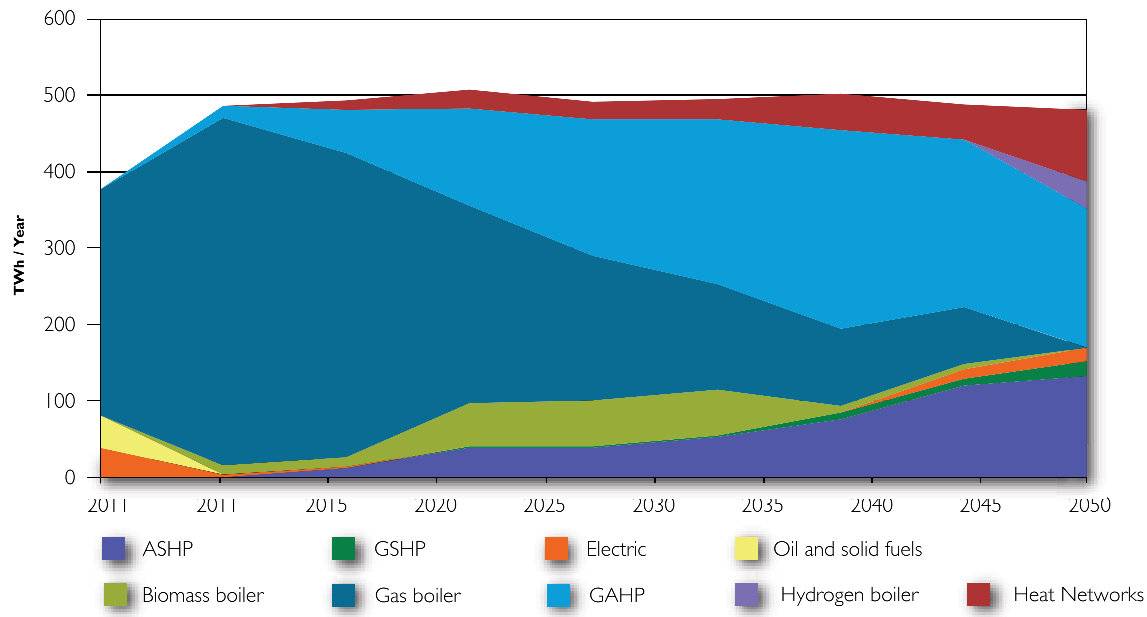
A.15 The ESME results suggest a role for heat networks, with heat supplied from a range of sources including large scale heat pumps. The inclusion of heat network storage in the model means it can more easily meet the peak demand for heat and therefore displace electric resistive heating.

Chart A2: Non-domestic space heat output by technology



Source: RESOM core run

Chart A3: Domestic and non-domestic buildings heat output by technology



Source: ESME core run

A.16 The ESME core run suggests there may be a role for biomass boilers as a transition technology, but by 2050 biomass in buildings has been replaced by other technologies. There may also be a role for hydrogen used in buildings, with around 37 TWh of heat provided by hydrogen boilers in 2050, modelled in ESME as a separate network rather than blended with natural gas. However, as the costs of a hydrogen grid are currently only approximate this result may misrepresent the potential for hydrogen. Further work is required to better understand the costs of using hydrogen in buildings.

A.17 The Monte Carlo function in ESME[7] has allowed DECC to explore the sensitivity of the results to a number of changes to the input assumptions. This shows that gas boilers on their own play next to no role in providing space heat or hot water by 2050. Domestic use of GAHPs shows a greater degree of uncertainty, with a contribution to the heat supply ranging between zero and 140 TWh per year. The Monte Carlo results also show that the role for hydrogen boilers is also uncertain, with 14% of the runs showing no role for hydrogen.

Sensitivities

A.18 DECC has also looked at a range of scenarios to test the robustness of the core run to different assumptions in the heat sector and major system changes:

a. *no bioenergy*: where there is no biomass used as an energy source;

b. *no new nuclear* power generation;

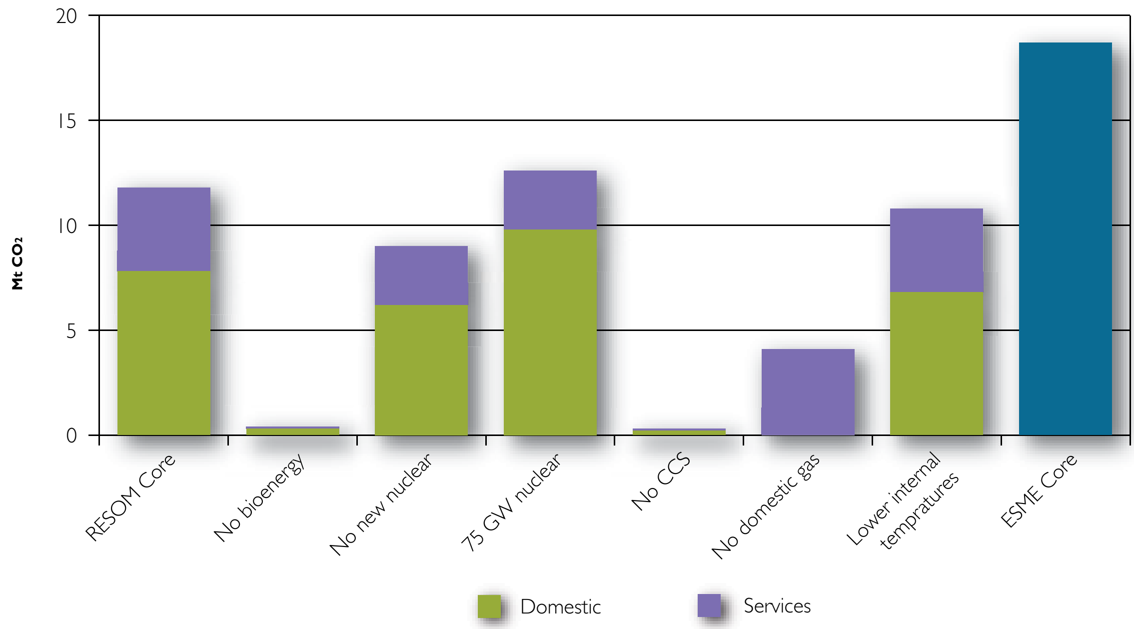
c. higher levels of nuclear power generation: where the model limits new capacity to 75 GW rather than the 39 GW in the core run;

d. *no CCS*: where there is no CCS in any sector of the UK energy system;

e. *no domestic gas*: looks at the impact of removing gas technologies as an option for domestic buildings; and

7 This function runs the model one hundred times to test the sensitivity of the results to the assumptions

Chart A4: Emissions from buildings by RESOM sensitivity scenario



Source: DECC calculations

f. *lower internal temperatures*: looks at scenarios where domestic heat demand is lower as a result of changes to internal temperatures to 16°C.

A.19 Detailed results for these runs are not included in this annex, but Chart A4 (above) summarises the emissions from buildings for each of these sensitivity scenarios.

A.20 As an example, the no new nuclear power generation scenario shows little impact on the mix of technologies used to provide heating. RESOM shows a slight reduction in the amount of gas used in buildings in 2050, as it is now more difficult to decarbonise the power sector. The amount of heat supplied from heat networks is also lower with no new nuclear, as there is no low temperature heat from these plants to feed into heat networks.

Industry – core run

A.21 The picture for high temperature applications (Chart A5 opposite), suggests a continued role for gas out to 2050, and with hydrogen replacing coal and coke where very high temperatures are required.

A.22 For lower temperature processes (Chart A6 opposite), the RESOM core run suggests switching away from gas and electricity towards industrial heat networks supplied by predominantly[8] gas CHP. However, by 2050 as the electricity grid decarbonises, and given the assumed constraints on deployment of CHP with CCS, the emissions savings from gas CHP disappear, a proportion of industry reverts to using high efficiency gas boilers.

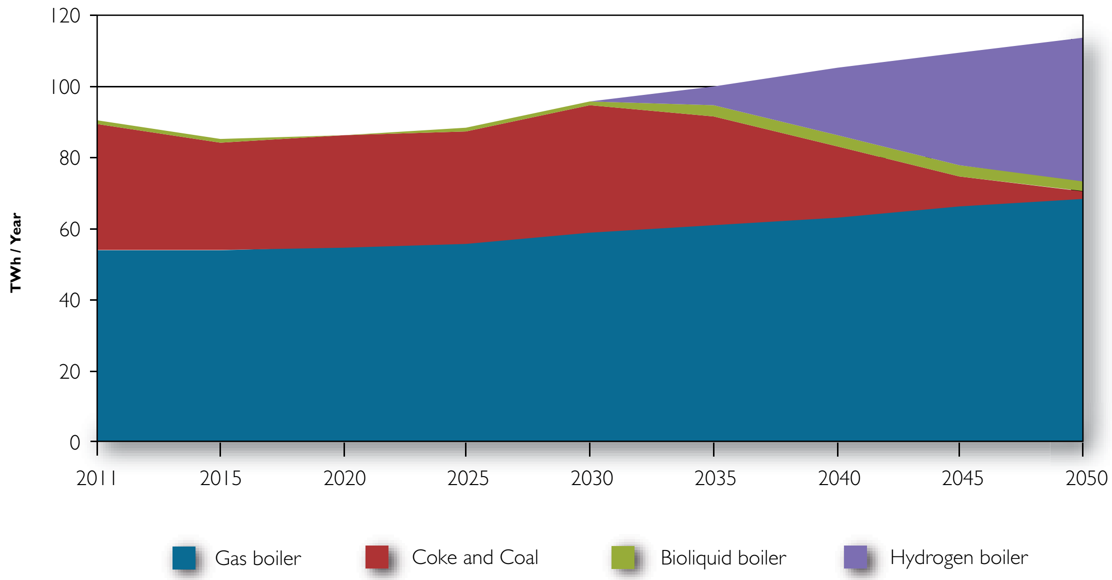
A.23 For industrial space heating demand, gas boilers are replaced with a combination of air and ground source heat pumps. Total emissions from industrial combustion (excluding CHP) are 26 $MtCO_2$ per year in 2050.

Industry – ESME comparison

A.24 The ESME results (Chart A7) suggest that there are limited opportunities for fuel switching at the aggregate level, but that fuel switching may be more important in some sectors. From

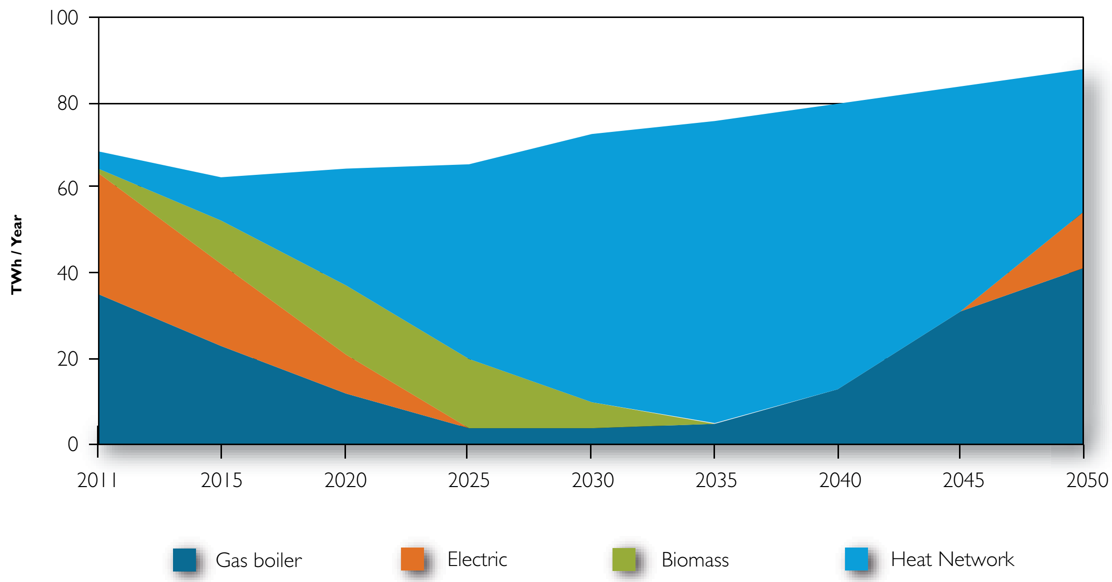
8 The core run includes some biosyngas CHP and a small amount of waste heat from large bio-SNG plant. All of these are used with CCS by 2050.

Chart A5: Technologies used to supply high temperature process heat for industry



Source: RESOM core run

Chart A6: Technologies used to supply low temperature process heat

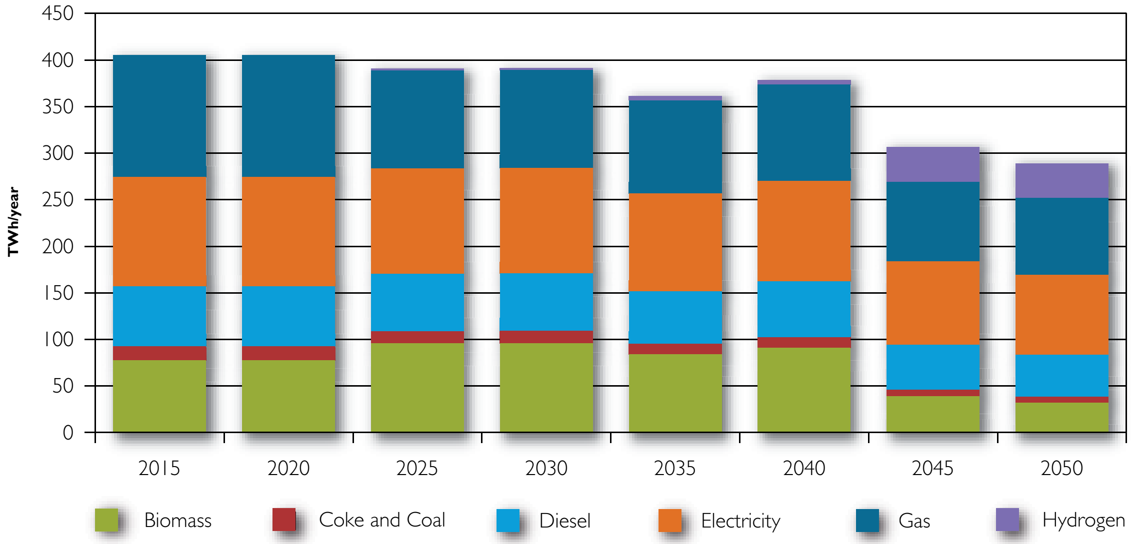


Source: RESOM core run

the 2040s there could be a role for hydrogen to provide some heat to industry. Along with fuel switching, the model predicts the take up of CCS in industry, with 20% of industrial energy related emissions being sequestered by 2050.

A.25 The RESOM core run shows emissions reductions of 65% compared with 1990 levels will be required in order to meet the UK's 2050 climate change targets. This is a similar level of decarbonisation suggested by ESME, although direct comparison between the models is difficult as ESME explicitly allows for industrial CCS of emissions from fuel combustion by industry within the model, while industrial CCS is incorporated within RESOM's input

Chart A7: Industrial fuel consumption



Source: ESME core run

assumptions by adjusting to the overall UK emissions target.[9]

A.26 Both ESME and RESOM suggest a role for hydrogen in industry from 2040 and also highlight the continued role for gas out to 2050. Some differences in results can be explained by the different structures of the models; for example, ESME does not include the option of industrial heat networks. The industrial 2050 roadmaps work (discussed in chapter 1) may provide better evidence on the potential for fuel switching that could inform the Department's modelling.

Conclusions

A.27 Overall the updated modelling confirms and increases confidence in the pathways to 2050 that were set out by Government in the Carbon Plan, suggesting that the most cost-effective pathways to 2050 will require a very radical decarbonisation of heat for buildings, and a 60-70% reduction in emissions for industry in the coming decades.

A.28 The more detailed representation of the profile of heat demand within day and across seasons, and the inclusion of additional technologies has provided a more detailed understanding the pathways for heat to 2050. The modelling suggests that heat pumps and heat networks will be needed to achieve the UK's overall emissions reduction target. However, the results suggest that there may be a role for gas in 2050, either in more efficient appliances (e.g. GAHPs), or used in conjunction with heat pumps in hybrid systems.

A.29 The modelling also highlights the potential role for hydrogen to provide heat, both in industry and domestic buildings. It is important to stress that the modelling relies on only approximate estimates of future grid and infrastructure costs at this stage. Representation of both hydrogen and gas networks is relatively underdeveloped in the models. Further work is needed to understand the technical and economic constraints of both using hydrogen in buildings and the potential to repurpose or decommission parts of the local gas distribution grids.

9 This is discussed in detail in the UK Bioenergy Strategy

3. Developing DECC's heat network model

A.30 As part of the wider development of the National Household Model, DECC is developing a stand-alone model to understand the long-term potential for heat networks. The Heat Networks Model will be able to estimate the potential for take up of heat networks under a number of assumptions. This section sets out the data and assumptions used in the model, and provides a high level overview of the approach DECC has taken. As the model is currently under development the results reported from the model in this document are only provisional.

A.31 The model compares heat networks using different heating sources with individual building level technologies to understand the key drivers of cost and performance. The model segments the national housing stock based on a number of criteria set out in Table A2, below. The heat demand for each of the segments is estimated out to 2030.

A.32 For each segment, the model assesses the suitability of a handful of mature technologies. Not all the technologies are considered suitable for all housing segments with suitability restrictions imposed (Table A3). These assumptions will be refined at a later stage as the model develops.

A.33 Heat networks are assumed to be suitable for areas of high heat density. In the modelling these are taken to be the urban areas which account for around 20% of the domestic heat demand.[10] A heat density of 3000 kW/km^2 or above is considered suitable for district heating.[11] Based on analysis of the data from the

Table A2: Segmentation of the housing stock in the model

Segments	Description
Location	Urban, suburb or rural
Off gas grid	Yes/no
Type	Flats, detached and semi-detached/terrace
Age	Pre-1990, 1990-2010, post 2010
Insulation	Yes/no, in addition solid or cavity walls for pre-1990 builds
Number of bedrooms	1,2,3,4 or more than 4
Tenancy	Council/housing association, owner occupied or privately rented

Table A3: Suitability criteria applied to the house types

Technology	Restriction/suitability
Electric resistive heating	No restriction
Gas boilers	Dwellings need to be on the gas grid
Oil/coal boilers	Restricted to off grid dwellings in rural areas
Biomass boilers	Restricted to dwellings in rural areas with more than three bedrooms[12]
Air source heat pumps	Not suitable for flats
Ground source heat pumps	Restricted to dwellings with more than three bedrooms
Heat networks	Restricted to urban areas

10 Heat networks may also be a solution in isolated rural communities but, for simplicity, this is not modelled
11 Poyry et al, 2009, *The Potential and Costs of District Heating Networks*, http://webarchive.nationalarchives.gov.uk/20121205174605/http://decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/distributed%20energy%20heat/1467-potential-costs-district-heating-network.pdf, accessed 15th March 2013
12 The number of bedrooms has been used as a proxy for dwelling size

National Heat Map[13] around 40% of domestic demand in the UK is estimated to be in these areas. For each technology, information is drawn from performance and cost data from DECC commissioned reports of technical information on renewable heat technologies[14] and from the Poyry report.

A.34 Heat networks are assumed to be able to use a range of technologies to generate heat including: gas or biomass boilers, large scale heat pumps, and CHP using either gas, biomass, anaerobic digestion or waste incineration.

A.35 Table A5 below sets out the main costs considered in the modelling. In addition to the heating source, the external elements of the heat network are considered, such as the pipe infrastructure, energy centres and thermal stores as well as internal pipes, hydraulic interface units and heat meters.

Table A4: The technology assumptions used for the heat network source

Assumption	Comments
Lifetime of the heat source	This is the expected life of the heat source and is used as the payback period for individual dwelling heating technologies.
Efficiency of the heat source	This is the efficiency of the heat source and is used to calculate the amount of fuel consumed. In the case of heat pumps, the coefficient of performance is used.
Load factor	This is a factor to size the technology to meet heat demand of the dwelling.
Carbon intensity of the fuel	The amount of CO_2 emitted per heat energy output (kg/kWh)

Table A5: Costs used in the model

Costs considered	Comments
Capital cost	Annualised and spread across the life-time of the installation or payback period in the case of heat networks at different discount rate. In the case of heat networks, the pipe infrastructure if correctly maintained is likely to last more than 30 years. The payback period is taken to be a number less than the life-time. The capital cost is given as the cost of buying and installing the heating system. In the case of district heating this includes equipment and installations that are not part of the dwelling. Capital costs vary substantially for different installations and depend on such factors such as size, the density of heat demand, the discount rate used to estimate the payback and the payback period.
Operational and maintenance cost	The operational and maintenance costs for heat networks are dominated by those for its heating source. The infrastructure itself would need to be maintained but the assumption is that the infrastructure could last longer than 30 years. This gives the opportunity to connect different heating sources when the current heating source come to the end of its life.
Fuel cost	The fuel price in the model is based on DECC forecasts.[15] The fuel consumption is how much fuel is used to meet the heat demand, which depends on how efficiently the fuel is used.
Carbon savings	Consistent with Government IAG values.

13 DECC, 2012, *The National Heat Map*: http://ceo.decc.gov.uk/nationalheatmap/, accessed 15th March 2013
14 AEA, 2012, *RHI Phase II – Technology Assumptions Key Technical Assumptions for Selected Technologies*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66165/RHI_Phase_II_-_technology_assumptions.pdf, accessed 15th March 2013
15 DECC, 2012, https://www.gov.uk/government/organisations/department-of-energy-climate-change/about/statistics, accessed on 15th March 2013

A.36 For each technology the total cost for each segment is estimated as the sum of the capital, operating and maintenance, fuel, and carbon costs, net of any incentives. The model is able to rank the most economical heating solutions based on assumptions on costs and performance. A heat network is considered financially viable if the heat supplier is able to sell the heat at a price lower than that pegged to the average price for heating the home using gas. For simplicity, the model assumes networks spread into suburbs of sufficient heat density once established in urban centres.

A.37 The modelling is still in the early stages of development, but provisional results indicate that heat networks could play a large role in domestic heating. Discount rates and payback periods are the key drivers of take up. Over a 30 year payback and with a discount rate of 3.5%, heat networks using gas CHP appear to be the least cost heating solution in the majority of areas where suitable.

A.38 DECC is currently developing a National Household Model, and additional research is planned to examine the costs of heat networks and the heat density of urban areas. More research is also being considered to look at the impact of thermal storage on cost and performance.

4. Results from heat networks barriers research

A.39 DECC commissioned research by the Buildings Research Establishment (BRE) to obtain a better understanding of the full range of barriers at each stage in the development of a heat network project.[16] The research also looked at whether the same barriers were faced by both private sector and local authority schemes, and whether there were local barriers. The report reflects the experiences of those directly involved in developing heat networks and as such has highlighted the key barriers faced by project teams involved in recently developed networks.

A.40 The researchers identified a sample of 40 project teams involved in developing heat networks over the past 10 years. The researchers sampled on the basis on the size of scheme, whether local authority, university or property developer led and location. The heat network developers were interviewed face to face, with participants completing an online survey to establish quantitative details on the schemes they were involved with e.g. heat output and fuel type. The main barriers mentioned by the project teams are given below.

- **Difficulties with funding** – Obtaining internal funding and resource for the development phase are considered the most important factors for local authorities in deciding whether to proceed with a project. For developers the main difficulty was absorbing the costs in the price of the housing, which was harder in parts of the country with lower housing costs.

- **Uncertainty of customer heat demand** – In order to make the costs for a new scheme add up, the scheme commissioners were required to secure agreement from potential customers to long-term contracts. There were difficulties in getting private sector customers to sign up to contracts of more than five years. For new build, this risk could be mitigated to some extent through agreements between the scheme providers and the housing developers to not install mains gas on the development. With local authority led schemes, the local authority itself often had to commit its own buildings to long contracts to be able to make a scheme work.

- **Uncertainty with heat sources** – Some respondents expressed concern that government policy would mean that support for gas CHP (the primary heat source for most heat networks) would reduce. Also there was little appreciation of the carbon savings that could be made from gas CHP and for its role as an interim heat source. Some respondents pointed out that large scale biomass was only cost effective once a certain size of scheme had been reached, and concerns were raised about sourcing biomass in the future. A number of respondents thought there was potential for using waste heat.

- **Lack of regulation and transparency of pricing** – A few of the project developers thought that lack of regulation was a barrier to greater take-up of heat networks. Property developers had faced difficulties in reassuring customers about security of supply and pricing. Some property developers wanted to see regulation on the supply of heat. The lack of a standard methodology for calculating the price of heat for customers was considered a barrier since it could cause confusion and lack of trust.

- **Lack of standard contract mechanisms** – Several interviewees thought the lack of standardised commercial and contractual documentation was a barrier. The procurement process was a major barrier for some local authorities. There was also a

16 BRE, University of Edinburgh and the Centre for Sustainable Energy, March 2013, *Research into barriers to deployment of district heating networks*

concern raised by some of the interviewees that there was not a genuine transfer of risk in local authority commissioned schemes, partly due to a lack of expertise in drafting contracts in this area.

- **Lack of established role for local authorities** – While many local authorities understood how they could help, those in areas with no or little experience of heat networks were viewed as needing education and support. Some energy service providers thought that local authorities needed to understand better where schemes were likely to be viable. For local authority commissioned schemes, early political commitment was viewed as essential along with working level champions. Local authorities also had an important role to play in encouraging heat networks through the planning process for new building developments, several felt that planning frameworks could be strengthened (through planning guidance) to encourage heat networks.

- **Skills and knowledge gap** – Access to the necessary skills and knowledge needed at each stage of development was identified as critical to optimum scheme development. Many project developers felt reliant on advice from consultants. Some local authority respondees stated they were not aware of existing best practice guidance or how to tender and evaluate for the best consultants for a project. Similarly, that they lacked experience in procuring 25-year contracts (for heat) and therefore did not always give enough weight to life-cycle costs and benefits. Separately, a number of consultants mentioned the lack of suitably qualified engineers. While there were some very experienced engineers and installers they felt the pool was limited and there were few training and development opportunities in this area.

- **Statutory powers for network providers** – Access to land was highlighted as a barrier by some energy service providers. As non-statutory undertakers they were required to negotiate with private landowners direct for each heat network development. This could lead to delays in the projects and meant they had to pay financial penalties to the landowners.

A.41 The interviewees were also asked to provide details on how they overcame those barriers and for their thoughts on what other factors would have enabled them to progress their project with greater ease.

- **Customer charter or code of conduct** – Several project teams supported the idea of a customer code of conduct but there were some concerns about the prospect of a statutory code being put in place.

- **Provision of an independent advisory service** – Most interviewees, who expressed an opinion, supported the establishment of an independent advisory service on heat networks. Some respondents stressed the need for any unit to be staffed by people with experience of delivering actual heat network projects and who were genuine experts in this area. Those that expressed a view thought the services should be provided for free because project commissioners could already source consultants for a fee.

- **Contract frameworks** – Some scheme developers thought that the availability of standard contracts would help while some identified a need for there to be some flexibility to allow for different scheme types. However, almost all respondents thought that some further guidance, including examples of contracts, would be helpful.

- **Technical standards** – Most interviewees, who expressed a view, consider that developing generic technical standards would be helpful. While the majority of energy service providers thought standards would help, some raised concerns that this might stifle innovation.

- **Risk underwriting** Most interviewees, who mentioned it, felt that the government should help to underwrite the risk of heat network projects. To reduce the risk of projects, some energy service providers suggested that public buildings should be mandated to connect to heat network schemes and some local authorities identified zoning cities, whereby all new developments in a zone were required to connect to heat networks (in the same way as Denmark) as a way of reducing the risk of projects.
- **Assessing the potential for district heating** Most respondents thought that local authorities should be required to consider the potential for heat networks and that guidance should be provided to local authorities to help them with this process.

Conclusions

A.42 For local authority respondents the most prevalent barriers were: identifying internal resources to instigate a scheme and overcome a lack of knowledge (cited by most respondents); identifying and selecting suitably qualified consultants (cited by half the respondents) and paying the upfront capital cost (cited by some respondents).

A.43 For property developer led schemes the most citations from respondents were: persuading building occupants to accept communal heat (cited by some respondents); selecting suitably qualified consultants (cited by some respondents); and a lack of generally accepted contract mechanisms (cited by some respondents).

Table A6: Barriers identified by the research[17]

	Local Authority Led	Property Developer Led
Objective setting and mobilisation	Identifying internal resources to instigate a scheme and overcome lack of knowledge (**) Customer scepticism of technology (*)	Persuading building occupants to accept communal heat (mandated by the planning authority) (*)
Technical Feasibility and Financial Viability	Obtaining funding for feasibility/viability work (***) Selecting suitably qualified consultants (**) Uncertainty regarding longevity and reliability of heat demand (*) Uncertainty regarding reliability of heat sources (*) Correctly interpreting reports prepared by consultants (*)	Selecting suitably qualified consultants (**) Uncertainty regarding longevity and reliability of heat demand e.g. lack of heat demand in new buildings (*) Uncertainty regarding reliability of heat sources (*)
Implementation and Operation	Obtaining capital funding (***) Obtaining funding for independent legal advice (***) Lack of generally accepted contract mechanisms (**) Inconsistent pricing of heat (**) Upskilling LA procurement team on DH (*)	Concluding agreement with energy services provider including obtaining capital funding contribution (**) Lack of generally accepted contract mechanisms (**) Inconsistent pricing of heat (**)

17 Star ratings reflect the severity of the challenge posed by the barriers with one star being the least problematic to three stars being the most

5. Recent research findings: energy use in the domestic sector

A.44 Several policies are focused on encouraging people to install energy efficient home improvements. While there is a reasonable understanding of barriers and triggers for such 'one-off' decisions, less well understood is how everyday behaviours affect energy consumption, and what can reduce this. DECC has recently conducted a number of studies which look at these issues, the findings from which are summarised below.

Study 1: Which interventions change energy behaviour in the home?[18]

A.45 DECC commissioned a rapid evidence assessment to understand *"what works"* in changing energy-using behaviours in the home, with a focus on international evidence. The aim was to establish the extent of the evidence base to identify gaps. It included recommendations for improving evaluation of future behaviour change programmes. The search identified 48 behaviour change programme studies, through applying several selection criteria; studies were required to:

- measure behaviour change in a real-world setting;
- involve comparison between groups or across time periods; and
- go beyond direct feedback on past energy use and pricing strategies.

A.46 The literature provided evidence that some behaviour change programmes can be effective in encouraging people to use less energy at home, and some (not all) lead to durable energy reductions. Programmes tended to yield higher savings when including tailored advice or comparative feedback. Evidence supported the effectiveness of enhanced billing (sometimes called 'Home Energy Reports') which inform households how their consumption compares with other households as well as providing advice. Sustained savings from this were around 1-3%.

A.47 Community-based approaches, using peer support (and influence) were effective in reducing consumption, and showed higher short-term savings than home energy reports (the evidence includes cases where energy savings were around 8-10%). However, these findings may be difficult to replicate in a roll out: the participants (or community) may have been more motivated than average, and providing such highly tailored instructions or coaching may be difficult at a larger scale. 'Competition' approaches tended to yield high-savings, not maintained over the longer term. There was some evidence to suggest that education programmes provided at the point of adoption of new technology and one-off modifications can act as a stimulus for changing routine behaviours.

Study 2: How much energy could be saved by changing everyday behaviours?[19]

A.48 DECC commissioned a study to estimate potential energy savings if households made small changes to everyday energy-using behaviours. A list of 45 behaviours was developed; some described a change in the way

18 DECC, 2012, *What works in changing energy use behaviours in the home? A rapid evidence assessment*, https://www.gov.uk/government/publications/what-works-in-changing-energy-using-behaviours-in-the-home-a-rapid-evidence-assessment, accessed 15th March 2013

19 DECC, 2012, *How much energy could be saved by making small changes to everyday household behaviours?* https://www.gov.uk/government/publications/how-much-energy-could-be-saved-by-making-small-changes-to-everyday-household-behaviours, accessed 15th March 2013

people use energy (e.g. 'turn the thermostat down'), while others described a technical upgrade (e.g. 'insulate hot water tank'), and a small number described both. A tiered approach to calculating the savings at a household level was used; methodologies were ranked according to their robustness and reliability.

- Tier 1: Where possible, use the Cambridge Housing Model[20].
- Tier 2: Use robust data from Cambridge Architectural Research's (CAR) library of published reports and papers about energy behaviours.
- Tier 3: Use published data in combination with expert judgement.
- Tier 4: Use expert judgement, experiments, and CAR's experience in working on household energy behaviours to formulate an estimate.

A.49 This analysis was designed to estimate the potential for behaviour changes to reduce consumption at household and national level. As such, it was not intended to give precise estimates of energy savings, or reflect how people actually use energy in their homes. The research had to oversimplify behaviours, in order to develop assumptions. 'High', 'low', and 'most likely' estimates of the energy saving were drawn up from adopting narrowly-defined behaviours, but there is at least as much uncertainty about the number of households that could be persuaded to adopt the behaviours, and how they would do so. Additionally, the cumulative savings of combining more than one behaviour change cannot be inferred.

A.50 A simple ranking of the savings from behaviour change if they were adopted across the whole housing stock of Great Britain was compiled. This indicated that the total saving (over one year) from changing a single behaviour could be from 49 TWh to zero (no saving) across the stock. These estimates give an indication of potential, as opposed to realistic levels of savings. The top five energy-saving behaviours (across Great Britain) to emerge from this work were:

1. turning the thermostat down by two degrees from 20°C to 18°C (49 TWh/year);
2. turning the thermostat down by one degree from 19°C to 18°C (24 TWh/year);
3. delaying the start of heating from October to November (11 TWh/year);
4. wearing a thick jumper at home in the heating season (6 TWh/year);
5. replacing standard shower head with a water efficient shower head and using it twice every day (5 TWh/year).

Study 3: What drives large variations in household gas consumption?[21]

A.51 This qualitative research was commissioned to better understand how and why people use gas at home. Gas consumption can vary considerably between households: evidence suggests that the highest 10% of gas users consume around four times as much as the lowest 10%. Quantitative modelling, based mainly on the physical characteristics of houses (but also others such as tenure and income), has so far been able to account for less than

20 The Model is described in more detail in Hughes, 2011, *A Guide to The Cambridge Housing Model. Cambridge: CAR/DECC*, www.tinyurl.com/HousingFactFile, accessed 15th March 2013

21 DECC, 2012, *Why do comparable homes use different amounts of energy?* https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65599/6919-domestic-energy-use-study.pdf, accessed 15th March 2013

40% of this variation.[22] To begin to explore the remainder of variation, research was undertaken with 70 households.[23] Half were identified at the study outset as being 'High' gas users and half as 'Low' users, (the top or bottom decile), which were later re-classified based on actual data. Semi-structured interviews were undertaken alongside house-tours and exercises designed to explore every day life in each home. This was followed by an eight week diary exercise; unobtrusive temperature monitoring in some homes; and follow-up interviews.

A.52 The study noted that despite sharing the same overall characteristics, properties differed widely, with alterations such as open-plan arrangements, garage conversions, conservatories or carpets. These one-off decisions to undertake small renovations altered the thermal characteristics of the property. The research also revealed wide variations in routine behaviours with consequences for gas consumption. 'High' and 'Low' users did not demonstrate particular behaviours that made them straightforward to identify. It appears, instead that a range of quite commonplace behaviours culminate in particularly high or low levels of gas use.

A.53 The household composition influenced how heat was used. The presence of young children led to people taking steps to manage temperature. Occupants with health concerns often used heat or hot water to alleviate aches and pains. Those who said they particularly 'felt the cold' (or who had visitors who did so) preferred higher temperatures. 'High' households tended to be empty less often than 'Low' households. Showering and bathing habits also varied considerably between households, with implications for gas consumption.

A.54 Very few participants fully understood their heating systems; they controlled their heating systems in varied ways to make their homes feel comfortable. Participants were generally not aware of how much gas they used, in absolute or relative terms. Most estimated their use was 'about average'. Paying by direct debit, fluctuating energy prices, variations in winter temperatures and changing household circumstances appeared to cloud people's understanding of this. Energy efficiency was almost unanimously seen as a good idea, but few people seemed to be attempting to reduce gas consumption and were far more focused on electricity.

A.55 The amount of energy used by space heating, relative to other energy uses, was underestimated by most. The research suggested that every household, even the lowest gas users, had the potential to reduce their use of gas without reducing their comfort.

22 DECC, 2012, *National Energy Efficiency Data Framework. Annex E*, Table A 3.1 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65974/6869-need-report-annex-e.pdf, accessed 15th March 2013

23 All living in 3-bed semi-detached owner-occupied, gas-centrally heated properties

6. Understanding homeowners' willingness to take up more efficient heating systems

Purpose of research and methods

A.56 DECC commissioned qualitative and quantitative research to explore Great Britain homeowners' preferences and willingness to take up more efficient heating systems.[24] The research explored homeowners' attitudes towards their current heating system, the triggers prompting replacement, their decision-making process when replacing their heating system, and their preferences based upon heating system type, upfront and ongoing costs and whether an incentive was available. The research included three initial qualitative workshops, a large-scale survey and choice experiment (2900 homeowners representative of GB), and follow-up interviews with 18 survey respondents.

Attitudes towards current heating systems

A.57 The most common heating system used by homeowners was a gas boiler (80%). Initial workshops found that combination gas boilers were best regarded by homeowners, and were the preferred future means of heating. Off-gas grid workshop participants were less satisfied with their current heating system than on-gas grid homeowners.[25] Survey respondents said that purchase and running costs were the most important criteria for their heating systems, but analysis of trade-offs made in the survey choice experiment found that technology type was the key determinant, with running costs a less decisive influence.

Triggers to replace heating systems

A.58 System breakdown was the most common reason respondents had replaced their heating system in the past (30% gave this as the main reason). 'Non-emergency' situations where their system was still working but was coming towards the end of its life were also commonly cited as the main reason – 14% had replaced as they were told it would not last much longer, 14% because it needed frequent repairs, and 3% because they were told the parts would no longer be available in the future (3%). The most common reason to replace a system *other than* actual/anticipated breakdown was as part of a wider property renovation (13% gave this as the main reason).

A.59 Over half (58%) expected to replace their heating system at least every fifteen years, although one in five (19%) anticipated waiting more than 20 years. The follow-up interviews found that often there was no clear sequence of events in terms of installation of heating systems or insulation, although most agreed with the principle of installing insulation prior to replacing a heating system.

Decision-making processes

A.60 Among homeowners who had replaced the heating system in their current property, some (42%) had consulted their boiler technician, while 24% had consulted a friend, 14% had consulted their energy supplier and 14% a builder. These were all trusted sources of advice – but more so for energy companies if it was delivered face-to-face via a technician. Two in five (39%) had replaced their heating system within three months of deciding to do so, two thirds (67%) within one year, and one in five (18%) waited one year or more.

A.61 Gas boilers were the clear favourite for future installation. When asked spontaneously

24 Ipsos MORI and the Energy Saving Trust, 2013, *Homeowners' Willingness To Take Up More Efficient Heating Systems*, DECC. The study considered the following technologies: gas condensing boilers, micro-CHP, air and ground source heat pumps, biomass boilers, heat networks; and also separately explored preferences relating to solar thermal

25 On-gas grid homeowners were those in properties currently connected to the mains gas grid. Off-gas grid homeowners were those not currently connected

which system they would consider installing in the future, 90% of on-gas grid respondents said a gas boiler (with 71% specifically saying a combination boiler). The most commonly mentioned system by off-gas grid homeowners was an oil boiler (40%, with 25% specifically mentioning a combination boiler).

A.62 Few mentioned any other type of heating system. This likely related in part to lower awareness of other such systems. While claimed awareness was highest for gas condensing boilers (86%) and solar thermal (83%), just under half had heard of a ground source heat pump and biomass boiler (both 47%), 32% for air source heat pumps, 31% for heat networks and 27% for micro-CHP.

Preferences for more efficient heating systems

A.63 Based on basic information on heating systems (not including cost information), the most appealing technology for on-gas grid homeowners was a gas condensing boiler (80% positive and only 5% negative), followed by micro-CHP (46% positive). Two in five (38%) of those with private outside space were positive about ground source heat pumps, with off-grid homeowners the most positive (53%). A third (34%) of homeowners were positive about heat networks, however, more homeowners felt negatively than positively towards air source heat pumps and biomass boilers.

A.64 Homeowners were asked to make a series of trade-offs between different more efficient heating systems in a non-emergency scenario, where they were considering replacing their heating system because it was coming towards the end of its life or for another reason. In this non-emergency scenario, the majority (81% at current costs with no financial incentives) would not make a replacement. The choice experiment found that there were considerable barrier costs to homeowners replacing their current heating system with a more efficient system in a non-emergency situation. Barrier costs represent the economic value homeowners would need to be compensated by to address their concerns about the new technology.

A.65 Among on-grid homeowners who would make a non-emergency replacement, the most popular option would be a gas condensing boiler, followed by similar interest in heat networks and micro-CHP. Even if gas prices increased by 40% and other fuel prices stayed at 2012 levels, this would still be installed by the majority of those making a replacement.

A.66 Among off-grid homeowners who would make a non-emergency replacement, the most popular more efficient heating option was a heat network, followed by similar proportions choosing a biomass boiler, ground and air source heat pump.

A.67 In an emergency situation, when their system had broken down, the majority of on-grid homeowners would only consider installing a gas condensing boiler, with off-gas homeowners equally likely to be willing to install a heat network or ground source heat pump, with slightly fewer choosing an air source heat pump or biomass boiler.

A.68 The key determinant of choices in a non-emergency influencing 54% of decisions in the choice experiment, was the technology itself rather than installation or ongoing costs or whether a financial incentive is available – illustrating that technology appeal and familiarity are vital. The up-front grant was next most influential in affecting homeowners' choices, driving 13% of choices, compared to 9% for each of the incentive tariff length and amount, 8% for installation cost, and 7% for annual fuel bill.

A.69 The research shows that financial incentives can help encourage uptake of low carbon heating technologies, but that even where high levels of incentive are offered (such as an up-front grant to cover 100% of installation costs) homeowners retain a strong preference for gas heating and the majority will still choose to retain their current heating system in a non-emergency scenario.

A.70 The majority of homeowners would also be unlikely to install a solar thermal system alongside their current heating system, even though more felt positively (45%) than negatively (32%) about this technology.[26] Provision of a grant or tariff-based financial incentive, however, could encourage uptake.

A.71 Many homeowners would opt to pay for a new heating system through their savings (47%), although a significant proportion did not have savings (14%) and so would need to rely on alternative sources of finance to cover the up-front cost. Workshops and follow-up interviews revealed that most of these homeowners would only do so as a last resort if they were in an emergency situation.

A.72 With regard to heat networks, the majority liked the idea that they would not be responsible for the maintenance of the heating system (63%). The majority (55%) would also be more interested in joining a heat network that charged them for the amount of heat used, although a fifth (23%) disagreed. However, disruption was a potential concern: homeowners appeared more willing to connect to a heat network in a new rather than their existing home.

26 Respondents were asked how positive or negative they felt about solar thermal having seen factual and cost information, whereas the other heating systems were rated positively or negatively based only on factual information

7. Modelling options to support natural gas CHP

A.73 This section of the Annex describes DECC's updated CHP model, the results of baseline projections in CHP capacity under existing policies and the modelling of scenarios for further support for natural gas-fired CHP.

The DECC CHP model

A.74 The DECC CHP model is designed to project CHP capacity out to 2030 using data from the CHPQA database, information from industry, economic growth projections and other data as recommended by the Interdepartmental Analysts Group (IAG). The model uses a Monte Carlo technique to model the uncertainty in the returns from installing CHP. This reduces the expected uptake of CHP. Over-estimates were the primary criticism of previous models.

A.75 The model consists of two parts, a bottom-up projection of technical potential produced by Ricardo-AEA and the Monte Carlo model, recently taken in-house in DECC. The bottom-up model is based on information on UK industrial heat and power demands, supplemented by data from Office for National Statistics, EU ETS and the National Allocation Plan. From this and cost data Ricardo-AEA project CHP potential in six size/technology bands for each sector. The bottom-up model includes some basic economic filtering, but excludes elements of risk, uncertainty and commercial hurdle rates that can stop projects progressing. This is the function of the Monte Carlo model.

A.76 Using the bottom-up estimates, the Monte Carlo model accounts for existing policies and the range of possible future fuel prices to produce a distribution of outcomes for the Internal Rate of Return (IRR) for a CHP project. This distribution is used, together with an investment probability curve, to estimate the capacity that will be built. Where a site is suitable for both renewable and fossil fuel technologies, the model estimates how much of each is built. The CHP capacity and fuel type projections allow calculation of emissions, emissions savings and costs. In the following modelling of additional hypothetical support options, social net present value of additional capacity brought forward has been calculated including the following elements:

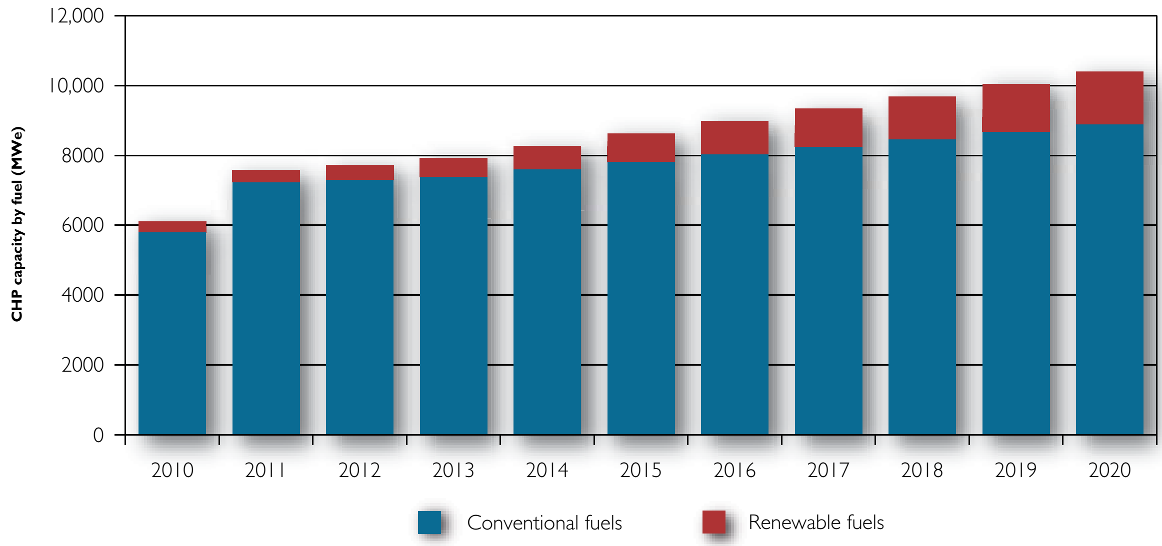
- capital expenditure;
- finance costs over a 10 year debt lifetime;
- operating expenditure;
- fuel cost;
- carbon savings;
- electrical output; and
- heat output.

A.77 Carbon savings have been calculated against a counterfactual of grid electricity and heat from gas boilers. Two assumptions for grid electricity carbon intensity were used. These were a natural gas-fired Combined Cycle gas Turbine (CCGT) emissions factor of 374 $kgCO_2/MWh$ and the October 2012[27] IAG grid marginal emissions factors, which implicitly assume a mix of generating capacity with an increasing proportion of low carbon generation technologies over time. Results using both sets of assumptions are presented.

A.78 The models do not cover all sectors, excluding sectors where there are few sites or the modelling methodology is not appropriate. Capacity in non-modelled sectors (energy industries, non-ferrous metals, non-metallic minerals, other, sewage and iron and steel), is added to the modelled output, based on existing capacity and projected growth based on market intelligence.

27 DECC/HMT, 2012, *Valuation of energy use and greenhouse gas (GHG) emissions*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/68947/supplementary.docx, accessed 15 March 2013

Chart A8: Projected growth in CHP capacity to 2020

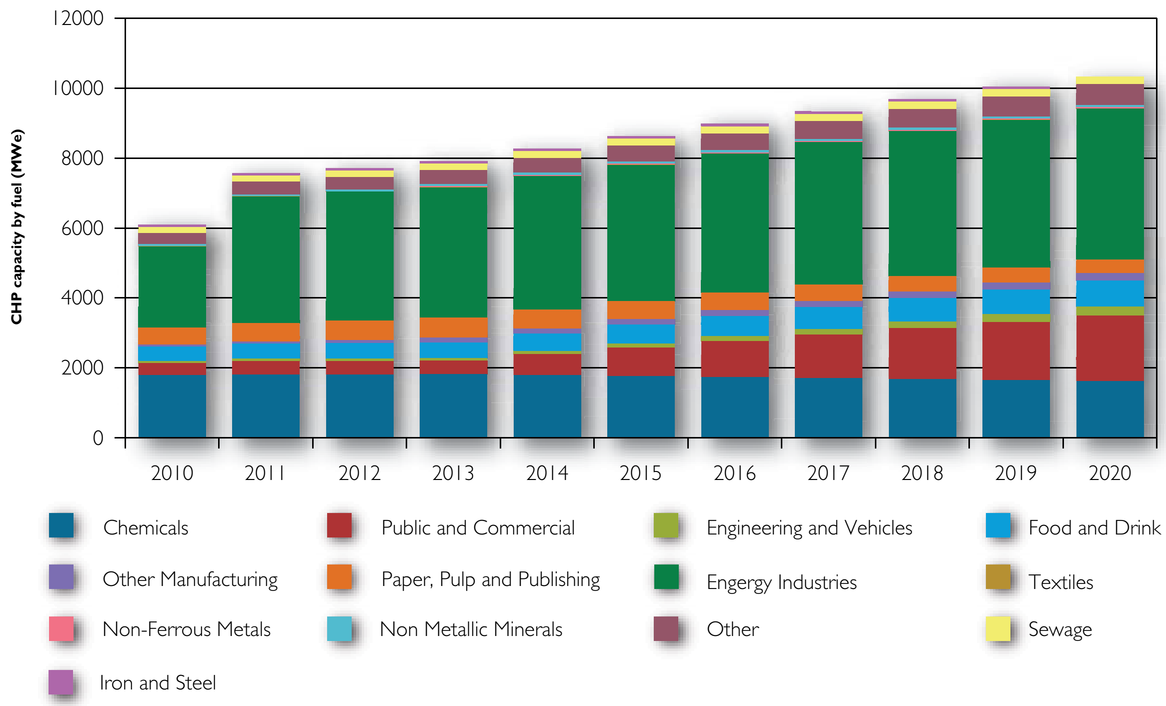


CHP baseline projection results

A.79 Projected growth in CHP capacity to 2020 under existing policies and projected energy prices is shown in Chart A8 above.

A.80 Renewable CHP capacity is projected to grow from 0.4 GW electrical (GWe) currrently to 1.5 GWe by 2020. Conventional (i.e. non-renewable) CHP capacity is projected to grow from 7.4 GWe currently to 8.9 GWe by 2020. This compares with 18 GWe potential estimated by the bottom-up model. Growth is primarily small CHP in public and commercial buildings. This is driven in particular by electrical output displacing electricity purchased from the grid at retail prices and exemption from Carbon Price Support costs for CHP schemes below 2 MWe. The sectoral breakdown of this capacity is shown in Chart A9.

Chart A9: Projected growth in CHP capacity by sector



A.81 Although significant growth in the public and commercial sector is projected, the majority of capacity remains in industrial sectors due to their large, high density heat loads. Baseline modelling projects steady growth in renewable CHP due to Renewables Obligation and proposed Renewable Heat Incentive support. However, growth in natural gas CHP capacity is projected to be proportionally slow under existing policy.

Natural gas CHP support scenarios

A.82 The following hypothetical options for additional support for natural gas CHP have been modelled. A number of different levels of support have been considered in some cases.

- "Soft" loans for capital investment in new CHP to reduce project hurdle rates to the level of power-only projects (assumed to be 8%);
- Feed in Tariffs providing average support of £1-10/MWh of electricity exported to the grid (but no support for on-site consumption); and
- Capacity Market payments for CHP in the range £10-40/kW.

A.83 The modelling suggests that an additional 3.4 GWe CHP capacity, over the 2020 baseline, could be brought forward by soft loans, 0.6 GWe by a £10/MWh FiT and 1.5 GWe by Capacity payments of £40/kW. The levels of support modelled are those considered plausible for each mechanism and do not represent equivalent levels of support. It is therefore more useful to compare the results in terms of support cost per unit of capacity brought forward (Chart A10) and social net present value (excluding monetised carbon savings) per unit carbon saving (Chart A11).

A.84 One important point to note is that CHP is not homogenous and this is reflected in the modelling. Capacity brought forward under each scenario differs in average capital cost, operating cost, heat to power ratio, etc depending on how each scenario impacts on each sector and size of plant.

A.85 Another point to note is that using the IAG marginal emissions factors suggests additional natural gas CHP capacity would increase carbon emissions over the assessment period (2013-2035). This is because these emissions factors assume rapid decarbonisation of marginal grid electricity generation. If the CCGT emissions factor is used, as would be appropriate if carbon pricing within electricity market prices ensures that natural gas CHP only runs at times when it would be economic for gas CCGT to run, additional CHP capacity delivers significant carbon savings.

Chart A10: Cost of support per unit of additional capacity brought forward

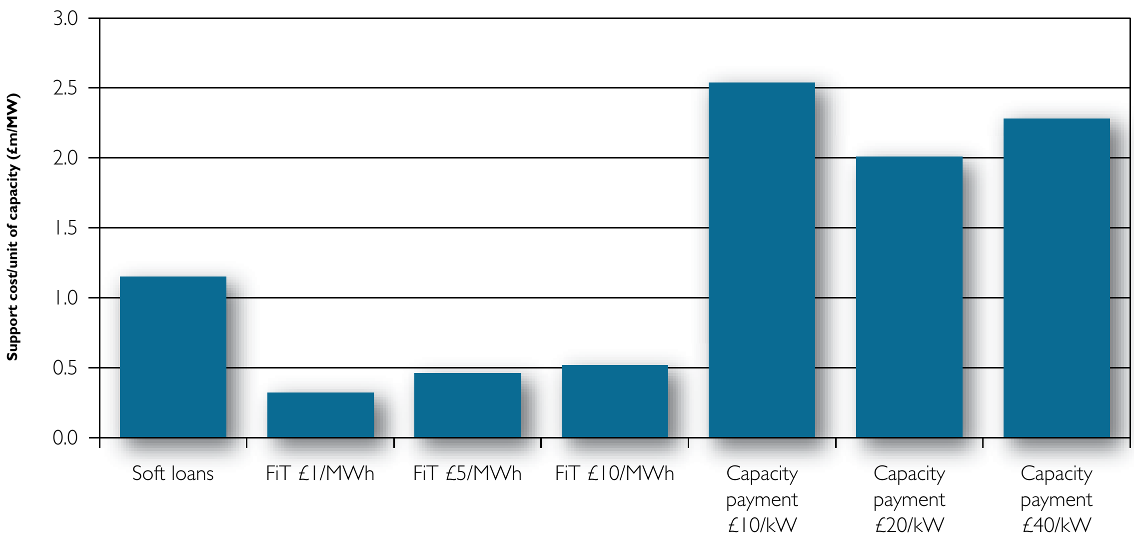
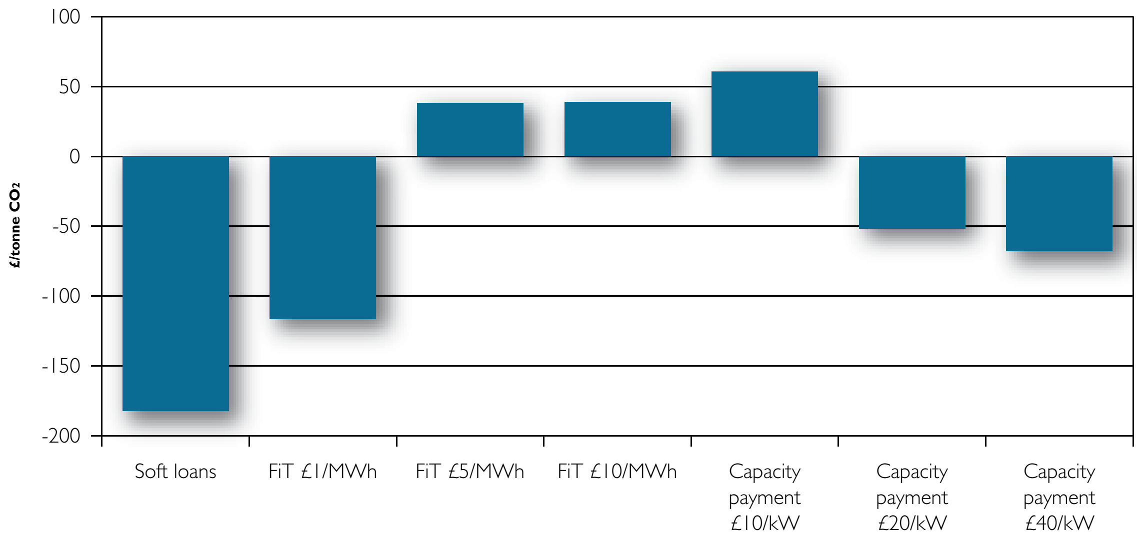


Chart A11: Social cost of additional capacity per tonne of CO_2 saved



Next steps

A.86 DECC will continue to refine the CHP model to improve its capability to model policy interventions. A report documenting the model's assumptions and methodologies in more detail is being published alongside this publication to enable peer review.

8. Analysis of customer data from phase one of the renewable heat premium payments (RHPP) scheme: interim findings

A.87 The Renewable Heat Premium Payment Scheme Phase 1 (RHPP1) was a voucher scheme which paid a grant to householders installing certain renewable heating technologies.[28] In addition to supporting the deployment of renewable heating technologies, the scheme also provided Government with an opportunity to learn more about the performance of these technologies and the customer experience.

A.88 Following the installation of renewable heat technology, all RHPP1 customers were asked to complete an on-line questionnaire. In total 5230 questionnaires were distributed to RHPP1 customers and 3988 responses were received, giving a response rate of 76%. The interim findings in this annex are based solely on the analysis of the post-installation questionnaire responses.[29] Customers were also asked to complete a follow up questionnaire after they had used their system over winter and some customers had a meter installed alongside their heat pump so that meter readings can be analysed. Findings from both surveys and the metering data will be published in summer 2013 and will form part of a wider evaluation into the RHPP1 scheme.

Who were RHPP1 customers?

A.89 RHPP1 customers were predominately aged 45 or older (74%) and tended to have higher incomes than the national average. Two fifths had an income of over £52,000 (39%) and nearly a quarter (23%) had an income over £72,000.

In what types of properties were installations made under RHPP1?

A.90 The majority of installations under RHPP1 took place in relatively large[30] (66%), detached (82%) properties built prior to 1990 (66%).

A.91 Almost three quarters of properties (74%) were located in rural areas. This was expected given the scheme eligibility criteria and the greater proportion of homes off the gas grid in rural areas.

A.92 Participation in RHPP1 was particularly high among those who had not yet or only recently moved into their home. Just under half (47%) of customers had lived in their home for two years or less. In fact, around one in five of respondents stated that they had installed renewable heating because they were building a new home (20%) or refurbishing (19%).

What was installed under RHPP1?

A.93 Air source heat pumps and solar thermal panels were the most popular type of renewable heat technology installed under RHPP1. Around a third of the sample had installed an air source heat pump (35%) and/or solar thermal panels (32%). Significant minorities installed a ground or water source heat pump (19%) and/or a biomass boiler (14%).

A.94 61% of installations cost less than £12,000. About a quarter (27%) spent less than £6000 on their installation (mainly solar thermal panels) and a third (34%) spent between £6,000 and £11,999. About one in eight (12%) spent more than £20,000.

28 The eligible technologies were solar thermal panels, heat pumps and biomass boilers. For heat pumps and biomass boilers, only homes off the mains gas grid were eligible
29 This analysis has been undertaken by Aecom, commissioned by DECC.
30 Defined as having four or more bedrooms

A.95 To some extent, the technology installed varied by the type of property and situation. Ground or water source heat pumps were more likely to be installed by customers who were renovating or building their own properties (63% compared to 48% overall). Solar thermal panels were more likely to be installed at properties with longer-term residents (42% had lived in their homes more than 10 years compared to 30% overall). Biomass boilers were more likely to be installed in the oldest properties (pre-1900) than other types of renewable heat technology (47% compared to 28% overall).

What were the attitudes and motivations of RHPP1 customers?

A.96 Almost all RHPP1 customers (99%) said they were concerned about fuel prices, while four in five (88%) said they were concerned about the impact of carbon emissions and a similar proportion (84%) agreed that they like to be green. These factors were key motivators for RHPP1 customers with four out of five (79%) saying that they decided to install their new technology because it helped the environment or because of the rising price of fossil fuels (79%), while seven in ten (72%) said they wanted to reduce their dependence on fossil fuels.

A.97 Costs now and in the future was also a key motivation for installing under RHPP1. The vast majority of customers (92%) stated that 'saving money' was an important consideration in deciding to install renewable heat technology, whilst four in five (82%) perceived that their new renewable heating system will save them money 'in the long run'.

A.98 Nearly half (45%) stated that their previous system was working well when they decided to install a renewable heating system and one in five (21%) that it broke down occasionally, suggesting that in the majority of cases customers were changing their heating system out of choice rather than necessity.

Did financial support under RHPP1 influence customers' decisions to install a renewable heating system?

A.99 Despite the cost of energy being an important motivation, financial support to install renewable heating technology offered under RHPP1 appears to have limited influence in these customers' decision to install. While just over half (53%) of customers said that being able to get a grant/funding was a reason for installing under RHPP1 the strength of its influence appears weak. Most households (74%) reported that the RHPP was not the primary driver of their decision to install their renewable heating system. When taking early qualitative findings alongside these survey results, it appears that anticipation of the domestic RHI tariffs was a bigger driver of take-up than the RHPP itself.

A.100 While this was the case for the majority of customers, there was some variation across the technology types. Those who had installed a biomass boiler were less likely to have proceeded without the financial support offered under RHPP1 than those who had installed other technologies (65% were very/fairly likely to have proceeded compared to 78% for solar thermal panels, 76% for air source heat pumps and 72% for ground or water source heat pumps).

How satisfied are customers with the renewable heating technology they installed?

A.101 Feedback from customers immediately after installation about their experiences with their renewable heating technology was very positive.[31] The vast majority (91%) were satisfied with their new renewable heating system; with 61% very satisfied. Satisfaction levels appear to be influenced by ease of use,

31 Please note that these findings relate to initial feedback on satisfaction with the heating system and are not likely to include assessment of the system during winter. This will be collected in the follow-up surveys, the findings for which are scheduled to be published in summer 2013

provision of good information and expectations of financial savings in the long run.

A.102 Most customers would recommend installing a renewable heating technology to others. Four in five (79%) have already done so, while the vast majority (89%) of those who have not yet recommended the system say they would do so in the future.

Initial findings from the metering of the RHPP installations

A.103 The preliminary data from the RHPP metering programme is still being collected and verified. Emerging findings appear to indicate that on average there has been a measurable but modest improvement in the Seasonal Performance Factor[32] of heat pumps, both air source and ground source. It appears however that on average the results will still be a long way off the high-performing systems that are consistently being measured in Germany. Findings will be published later this year, once there is sufficient data available from meters which have been running through at least one heating season (many of the meters were installed in the middle of winter 2011-12, and hence winter 2012-13 is the first full heating season.

32 The ratio of the heating output of a heat pump over the amount of electricity it uses gives the coefficient of performance (COP) of the heat pump. The Seasonal Performance Factor (SPF), is the average COP for a heat pump over a whole year and reflects the efficiency a heat pump achieves when installed.

9. Heat-intensive industrial sector data sheets

A.104 The tables presented in this section aim to provide a representation of the six most heat-intensive industrial sectors in the UK. However, as noted in chapter 1, the characteristics of three sub-sectors of the non-metallic minerals (Cement, Ceramics and Glass) merit separate attention, and thus data on eight industries are presented in this section. The sheets are populated with both technical information and economic data which highlight the different characteristics of industrial processes, capture the market conditions under which companies operate in the UK and illustrate the contribution of each sector to the whole economy. The aim of presenting this data here is to illustrate the context for the decarbonisation challenge for each sector, as well as facilitating cross-sectoral comparison.

A.105 The data has been extrapolated from a range of official sources, including DECC's analyses, ONS statistics and reports. A large amount of information has been provided by industry and trade associations, which have actively supported DECC in producing these data sheets. DECC is grateful for this engagement and input.

A.106 Factors such as the high number of processes, products and companies have limited the accurate representation of the Chemical and Food and Drink sectors. DECC will continue to work closely with the relevant sector associations to increase its understanding of these sectors as work is taken forward in this area.

A.107 Tables are presented by industry classification as follows:

- Manufacture of pulp and paper;
- Manufacture of cement;
- Manufacture of food and drink;
- Manufacture of glass;
- Oil refining;
- Manufacture of iron and steel;
- Manufacture of chemical products; and
- Manufacture of ceramic products.

PAPER	Data				Source
1. Sector Classification	Manufacture of paper & paperboard[a]				SIC 2007 cat 17.12
2. Process Characteristics	*Route*		*Integration*	*Mill n.*	
	Mechanical Pulping		High[b]	2[c]	Confederation of Paper Industries (CPI) data (unpublished)
	Recycled Cellulose Fibre (RCF)		Medium[d]	49	
3. Sector Heat Demand (2011)	14 TWh[e]				DECC Energy Consumption in UK 2012
4. Characteristics of Heat Demand	*Process*	*Temp C*	*Main Fuel*	*Heat Carrier*	
	Re-pulping	20-180	Nat Gas	Steam	BREF Pulp and Paper industry 2012. CPI data (unpublished)
	Drying	110-150	Nat Gas	Direct Heat	
5. Direct CO_2 Emissions (2012)	*Volume*	*Process*		*Fuel*	
	1.2 $MtCO_2$[f]	0%		100 %	CILT verified emissions data 2011. CPI data (unpublished)
6. Sector Economic Data					
a) Employment (2012)	9,250				IBIS Paper and Pulp UK 2012
b) GVA £m (2010)	628				ONS Annual Business Survey (ABS) 2010
c) Energy Cost % GVA (2009)	18.5% (electricity & heat)				BIS Analysis of UK Manufacturing Sector 2009
7.uk Market Structure					
a) Business n.	35				IBIS Paper and Pulp UK 2012
b) Site n.	51				CIP data (unpublished)
c) Key Companies	UPM-Kymmene (UK) Ltd DS Smith plc Aylesford Newsprint Ltd Tullis Russell Group Ltd Smurfit Kappa UK Ltd Saica Paper UK		Iggesund Paperboard Ltd Arjowiggins Ltd SCA Hygiene Products UK ltd Palm Paper Ltd Kimberley Clark Ltd		*Ibid,* CPI data (unpublished)
d) Key Location	Scotland, North West England, South East England				*Ibid*
e) Industry Concentration	Medium				IBIS Paper and Pulp UK 2012
f) Trade Exposure	**Import:** 63.5% demand **Export:** 30% revenue				
g) Vertical Integration	Upstream & Downstream[g]				CPI data (unpublished)
8. Low Carbon/Renewable Fuel	*Site n.*	*Fuel*	*Technology*	*Trend*	
	2	Biomass	CHP	Increasing rapidly	CPI data (unpublished)
	3	Renewable Waste	Sludge Combustors		
9. CHP	*Unit n.*	*Main Fuel*	*Output*	*GWh*	
	22	Nat Gas	Heat	5,065	DECC Digest of UK Energy Statistics (DUKES) 2012
			Electricity	2,190	
10. Energy Intensity	*UK*		*EU*		
	5.9 MWh/t		4.4 MWh/t		DECC Energy Efficiency Strategy 2012
11. CCS	Unsuitable (some large CHP might be suitable to CCS)				Element Energy. Potential for the application of CCS to UK industry and natural gas power generation 2010

a Only one small virgin pulp mill in the UK. The sector is considered a "papermaking" sector.
b Includes virgin pulp processing, recovered paper processing and paper production all at the same site.
c The Irvine (UPM-Kymmene) and Workington (Iggesund Paperboard) mills are the only two integrated mills in the UK.
d Recovered paper processing and paper production only.
e Total energy consumption of SIC code 17, excluding non-heat processes such as motors, lighting, refrigeration etc.
f EU ETS data captures direct emissions from 42 out of 45 the UK mills and is representative of the whole sector.
g SCA, KC and Sofidel (tissues) are integrated downstream and have direct operation in distribution and marketing.

CEMENT	Data				Source
1. Sector Classification	Manufacture of cement				SIC 2007 cat 23.51
2. Process Characteristics	*Route*	*Type*	*Site n.*		
	Kiln	Semi-Wet[a]	1[b]		Mineral Products Association (MPA) data (unpublished)
		Dry	12		
3. Sector Heat Demand (2011)	7.8 TWh[c]				MPA data (unpublished)
4. Characteristics of Heat Demand	*Process*	*Temp C*	*Main Fuel*	*Heat Carrier*	
	Preheating	500-800	Fossil Fuel/Waste Derived Fuel (WDF)	Direct heat	MPA data (unpublished)
	Combustion in Kiln	900–1500	Natural Gas/WDF	Direct heat	
5. Direct CO_2 Emissions (2011)	*Volume*	*Process*	*Fuel*		
	6.1 $MtCO_2$	61%	39%		MPA data (unpublished)
6. Sector Economic Data (2011)					
a) Employment	2,663				MPA data (unpublished)
b) GVA £m	323				
c) Energy Cost % GVA	34.4% (electricity & heat)				
7.uk Market Structure					
a) Business n.	6				MPA data (unpublished)
b) Site n.	21				
c) Key Companies	*Firm*	*Total*	*Kiln*	*Non-kiln*[d]	
	Lafarge Tarmac Hanson Heidelberg Cement Cemex UK Hope Construction Material Quinn cement Kerneos	10 3 3 3 1 1	5 3 2 1 1 1	5 1 2	MPA data (unpublished)
d) Key Location	Midlands				MPA data (unpublished)
e) Industry Concentration	Very High[e]				IBIS Cement in UK 2012
f) Trade Exposure (2011)	Import: 13% demand[f] Export: 0%				*Ibid*
g) Vertical Integration	Upstream & Downstream[g]				*Ibid*, MPA data (unpublished)
8. Waste Heat Recovery	*% Waste Heat Recovered*	*Source*	*Current Use*		
	No data	Exhaust Gas	Process Heat[h]		MPA data (unpublished)
9. Low Carbon/Renewable Fuel	*Fuel Type*	*% of Heat Demand*	*% Biomass Content*		
	WDF	40%	17%		MPA data (unpublished)
10. CHP	Unsuitable (suitable with CCS)				Poyry Energy. Potential for CCGT CHP Generation at Industrial Sites in the UK 2008. Centre for Low Carbon Future. Technology Innovation for Energy Intensive Industry in the UK 2011
11. Energy Intensity	*UK*	*EU*			
	0.9 MWh/t	*No data*			CCA data, MPA (unpublished)
12. CCS	*Site n. (eligible)*	*Technology*	*Application*		
	13[i]	Post-combustion	Kiln		Element Energy 2010

a Uses wet raw materials.
b CEMEX plant in Rugby.
c Total energy demand for the sector excluding electricity consumption.
d Grinding and blending facilities.
e The above six Portland Cement firms account for typically 87% of UK market share.
f In 2011 from non-manufacturers and manufacturers accounted for 12% and 0.9% respectively.
g All the major companies run operations such as quarrying, concrete building product manufacturing and wholesaling.
h Include pre-heating of combustion air in kilns and raw material in cyclones.
i Includes plants at Hope, Tunstead, Ketton, South Ferriby, Ribblesdale, Rugby, Cauldon, Aberthaw, Padeswood, Cookstown, Derrylin, Dunbar, Purfleet.

FOOD AND DRINK	Data				Source
1. Sector Classification[a]	Manufacture of food products Manufacture of beverages				SIC 2007 cat 10 SIC 2007 cat 11
2. Sector Heat Demand (2008)	30.6 TWh				Food & Drink Federation (FDF) data (unpublished)
3. Characteristics of Heat Demand	*Process*[b]	*Temp Range C*	*Main Fuel*	*Heat Carrier*	
	Cooking/Heating	0-100 C	Nat Gas	Steam/Direct	FDF data (unpublished), BREF Food, Drink and Milk 2006
	Evaporation	50–100 C	Nat Gas	Steam/Direct	
	Drying	250-90 C	Nat Gas	Steam/Direct	
	Baking	100-240 C	Nat Gas	Direct	
	Frying	190-205 C	Nat Gas	Direct	
	Water Washing	–	Nat Gas	Steam	
	Pasteurization/Sterilization	63-100 C	Nat Gas	Steam/Direct	
	Hot Water	–	Nat Gas	Steam/Direct	
4. Direct CO_2 Emissions (2010)	*Volume*	*Process*	*Fuel*		
	10.7 $MtCO_2$[c]	–	100%		FDF data (unpublished)
5. Sector Economic Data (2010)					
a) Employment	402,000				BIS Business Population Estimates (BPE) 2011
b) GVA £m	25,213				ONS ABS 2010
c) Energy Cost % GVA	5.2% (electricity & heat)				FDF data (unpublished)
6.uk Market Structure					
a) Business n.	5,810				BIS BPE 2011
b) Site n.	*No data*				
c) Key Companies	*No data*				
d) Key Location	National				DEFRA F&D Analysis 2007
e) Industry Concentration	Varies[d]				FDF data (unpublished)
f) Trade Exposure	**Import:** 40% demand **Export:** 20% revenue				Data source DEFRA Pocketbook 2012, ABS 2010
g) Vertical Integration	Varies[e]				FDF data (unpublished)
7. Low Carbon/Renewable Fuel	Limited use of biogas and biomass				FDF data (unpublished)
8. CHP	*Unit n.*	*Main Fuel*	*Output*	*GWh*	
	44	Nat Gas	Electricity	2,156	DECC DUKES 2012
			Heat	3,961	
9. Energy Intensity	*UK*	*EU*			
	0.9 MWh/t	*No data*			FDF CCA 5th Milestone Report
10. CCS	Unsuitable (some large CHP might be suitable to CCS)				Element Energy 2010

a The sector covers more than 5,000 companies which vary greatly by size, process, output and location.

b Initial analysis has focused on processes in the FDF membership only; other heat intensive activities such as brewing and distilling will be covered at a later stage.

c Includes CHP.

d Both low and high degrees of concentration exist. Sugar and milk processing are among the sectors where concentration is the highest; concentration is low in baking.

e Some integration exists both upstream and downstream in the supply chain. Large producers of commodity-like products such as sugar, starch and oils own farms. Some drink companies have operations in farming, retail, or both.

GLASS	Data				Source
1. Sector Classification	Manufacture of flat glass Manufacture of hollow glass Manufacture of glass fibres				SIC 2007 cat 23.11 SIC 2007 cat 23.13 SIC 2007 cat 23.14
2. Process Characteristics	*Route*	*Type*[a]			
	Furnace	Regenerative			British Glass data (unpublished)
		Electric			
		Oxyfuel			
3. Sector Heat Demand (2011)	7 TWh[b]				British Glass data (unpublished)
4. Characteristics of Heat Demand	*Furnace*	*Main Input*	*Temp Range C*	*Heat Carrier*	
	Regenerative	Nat Gas	1350-1550	Direct heat	BREF Glass Manufacturing Industry 2012. British Glass data (unpublished)
	Electric	Electricity	1350-1550	Direct heat	
	Oxyfuel	Nat Gas	1350-1650	Direct heat	
5. Direct CO_2 Emissions (2011)	*Volume*	*Type*	*%*[c]	*Source*	
	1.9 $MtCO_2$	Fuel	75%	Direct Fuel Combustion	CILT verified emission data 2011. British Glass data (unpublished)
		Process	25%	Soda Ash/Limestone/Dolomite	
6. Sector Economic Data					
a) Employment (2012)	7,250				IBIS Glass Manufacturing UK 2012. ONS ABS 2010. BIS Analysis of UK Manufacturing Sector 2009
b) GVA £m (2012)	627				
c) Energy Cost % GVA (2009)	16% (electricity & heat)[d]				
7.uk Market Structure	*Flat*	*Hollow*	*Fibre*[e]		
a) Business n.	3	6	5		IBIS Glass Manufacturing UK 2012. British Glass data (unpublished). Mineral Wool Insulation Manufacturers Association (MIMA) data (unpublished)
b) Site n.	6	12	6[f]		
c) Key Companies	NSG Pilkington Saint-Gobain glass Guardian Industries UK	Allied Glass Ardagh Beatson Clark O-I (Owens-Illinois) Quinn Glass Stolzle Flaconnage	PPG Knauf Superglass British Gypsum – Isover Rockwool		
d) Key Location	Merseyside	Yorkshire	National		*Ibid*
e) Industry Concentration	*No data*				
f) Trade Exposure	High				IBIS Glass Manufacturing UK 2012
g) Vertical Integration	Upstream & Downstream[g]				British Glass data (unpublished)
8. Waste Heat Recovery	*Heat Recovered*	*Source*	*Use*		
	60%	Stack Gases	Combustion air preheat		British Glass data (unpublished)
9. Low Carbon/Renewable Fuel	Very Limited (biomass, gas from biomass, waste derived fuel and electricity have been investigated)				British Glass data (unpublished)
10. CHP	Unsuitable due to heat mismatch				British Glass data (unpublished)
11. Energy Efficiency	High[h]				Centre for Low Carbon Future 2011, British Glass data (unpublished)
12. CCS	Unsuitable due to scale				*Ibid*

a The majority of UK furnaces are regenerative; the only electric furnace is mothballed; oxyfuel is used for fibre glass.
b Estimated heat requirement, British Glass.
c The proportion of process/fuel emissions varies according to the ratio recycled glass/raw materials used in the process.
d Value for the whole non-metallic mineral products sector, SIC code 23.
e Includes single strand fibre (used in wind turbines) and mineral wool (insulation).
f Single strand fibreglass is produced at only one site in the UK. 5 sites produce insulations by using either rocks (2 sites) or a silica-based process (3 sites).
g Some companies own quarries (sand) and recycling facilities. Others integrate downstream operations such as filling (of bottles/jars with food etc) as well as tempering & laminating (windows glass).
h The manufacturing process has been made increasingly efficient over many years and most of the easy to implement options have already been taken up.

OIL REFINING	Data				Source
1. Sector Classification	Mineral oil refining				SIC 2007 cat 19.20/1
2. Process Characteristics	*Route*	*Main Output*	*Complexity*	*Site n.*	
	Refining only	Transport Fuel	High[a]	6	UKPIA data (unpublished)
	Integrated	Fuel & Chemicals	Very High[b]	3	
3. Sector Heat Demand (2011)	46 TWh				DECC Energy Consumption in UK 2012.ukPIA data (unpublished)
4. Characteristics of Heat Demand	*Process*	*Temp Range C*	*Main Fuel[c]*	*Heat Carrier*	
	Distillation	340	RFG/NG/FO	Direct/Steam	Draft BREF mineral Oil and Gas refining 2012
	FCC[d]	680-730	FCC Coke/RFG	Direct/Steam	
	Upgrading	480-550	RFG/NG/FO	Direct/Steam	
5. Direct CO_2 Emissions (2011)	*Volume*	*Process*	*Fuel*		
	15.4 $MtCO_2$	39%	61%		NAEI verified emissions data 2011, UKPIA data (unpublished)
6. Sector Economic Data (2011)					
a) Employment	8,542				UKPIA data (unpublished)
b) GVA £m	6				*Ibid*
c) Energy Cost % GVA (2009)	9%				BIS Analysis of UK Manufacturing Sector 2009
7.uk Market Structure					
a) Business n.	9				UKPIA data (unpublished)
b) Site n.	9				UKPIA data (unpublished)
c) Key Companies	*Firm*	*Site*	*n.*		
	Phillips 66 Ltd	Humber	1		UKPIA data (unpublished)
	Total UK Ltd	Lindsey	1		
	Valero Energy Ltd	Pembroke	1		
	Murco Petroleum Ltd	Milford Heaven	1		
	Essar Energy Plc	Stanlow	1 (integrated)		
	Esso Petroleum Company Ltd	Fawley	1 (integrated)		
	Petrolneos Refining and Trading	Grangemouth	1 (integrated)		
d) Key Location	National				*Ibid*
e) Industry Concentration	7 major refineries accounts for 98% of UK market share				UKPIA data (unpublished)
f) Trade Exposure	Import: 46% demand Export: 40% revenue				IBIS Oil Refining UK 2012
g) Vertical Integration	Upstream & Downstream[e]				*Ibid*
8. Waste Heat Recovery	Extensive[f]				Draft BREF Mineral Oil and Gas Refining 2012
9. Low Carbon/Renewable Fuel	None				UKPIA data (unpublished)
10. CHP	*Unit n.*	*Main Fuel*	*Output*	*GWh*	
	11[g]	Nat Gas	Heat	17,051	DECC DUKES 2012
			Electricity	11,083	
11. CCS	*Site n. (eligible)*	*Technology*	*Application*		
	7[h]	Post-combustion	Varies[i]		Element Energy 2010

a Includes the treatment of crude oil through fractional distillation, cracking, upgrading and blending.
b It includes on-site production of organic chemicals (e.g. olefins, aromatics etc.) normally part of the chemical industry.
c Refinery Fuel Gas (RFG), Natural Gas (NG) and Fuel Oil (FO).
d Fluid Catalytic Cracking (FCC) is used to process residue from fractional distillation to increase yield and to obtain fuels that meets appropriate quality and environmental standards (e.g. sulphur content in diesel).
e Esso (as ExxonMobil) and Total have integrated upstream and downstream activities. Esso and Murco have downstream operations including refining, distribution, marketing and retail.
f In processes such as catalytic cracking and distillation units.
g Includes oil and gas terminals. The Essar Stanlow and Valero Pembroke refineries do not currently employ CHP generation.
h Humber, Lindsey, Pembroke, Milford Heaven, Stanlow, Fawley and Grangemouth refineries.
i Includes Catalytic crackers, on-site CHPs etc.

IRON & STEEL	Data				Source
1. Sector Classification	Manufacture of basic iron and steel and of ferro-alloys				SIC 2007 cat 24.10
	Manufacture of coke oven products				SIC 2007 cat 19.10
	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel				SIC 2007 cat 24.20
	Cold drawing of bars				SIC 2007 cat 24.31
	Cold rolling of narrow strip				SIC 2007 cat 24.32
	Cold forming or folding				SIC 2007 cat 24.33
	Cold drawing of wire				SIC 2007 cat 24.34
2. Process Characteristics	*Route*	*Input*	*Site n.*	*Integration*	
	Blast Furnace-Basic Oxygen Furnace (BF-BOF)	Heat	3	High[a]	BREF Iron and Steel 2012. uk Steel data (unpublished)
	Electric Arc Furnace (EAF)	Electricity	4[b]	–	
3. Sector Heat Demand (2011)	24 TWh[c]				DECC Energy Consumption in UK 2012
4. Characteristics of Heat Demand	*Process*	*Temp Range C*	*Main Fuel*	*Heat Carrier*	
	BF-BOF	900-2000	Process Gas[d]	Direct/Steam	*Ibid*
	EAF	Up to 1800	Electricity	Direct Heat	UK Steel data (unpublished)
	Rolling Mills	1200	Process Gas Nat Gas	Direct Heat	
	Annealing	250-750	Process Gas Nat Gas Electricity	Direct Heat	
5. Direct CO_2 Emissions (2008)	*Volume*	*Process*	*Fuel*		
	20 $MtCO_2$	90%	10%		Element Energy 2010.uk Steel data (unpublished)
6. Sector Economic Data (2009)					
a) Employment	22,000				ONS ABS 2010. BIS Analysis of UK Manufacturing Sector 2009
b) GVA £m	1,615				
c) Energy Cost % GVA	16.3% (electricity & heat)				
7.uk Market Structure					
a) Business n.	50 (excluding cold forming)				UK Steel data (unpublished)
b) Site n.	*No data*				
c) Key Companies	*Firm*	*Site*	*Furnace*	*n.*	
	Tata Steel EU Ltd	Scunthorpe	BF	4 (integrated)[e]	IBIS Iron & Steel UK 2012. uk Steel data (unpublished)
		Port Talbot	BF	2 (integrated)	
		Rotherham	EAF	2	
	Celsa Steel UK Ltd	Cardiff	EAF	1	
	SSI UK Ltd	Redcar	BF	1 (integrated)	
	Outokumpu Stainless	Sheffield	EAF	1	
	Sheffield Forgemasters	Sheffield	EAF	1	
d) Key Location	National				*Ibid*
e) Industry Concentration	High				*Ibid*
f) Trade Exposure	**Import:** 50.9% demand **Export:** 50.3% revenue				*Ibid*
g) Vertical Integration	Downstream only[f]				UK Steel data (unpublished)
8. CHP	*Unit n.*	*Main Fuel*	*Output*	*GWh*	
	8	BF Gas	Heat	1,268	DECC DUKES 2012
			Electricity	315	
9. Energy Intensity	*UK*		*EU*		
	5.2 MWh/t		3.7 MWh/t		DECC Energy Efficiency Strategy 2012. uk Steel data (unpublished)
10. CCS	*Site n. (eligible)*	*Technology*	*Application*		
	3[g]	All[h]	BF/Stoves/On-site Power Stations		Element Energy 2010. uk Steel data (unpublished)

a On-site integrated processes include coke ovens, sintering plant, blast furnaces, basic oxygen furnace, rolling etc.
b Total of 6 EAF in the UK, with two furnaces mothballed due to unfavourable economic conditions.
c Energy requirement of the whole metal sector, SIC code 24, excluding non-heat processes such as motors, lighting etc.
d Includes CO gas from the coking process and a mixture of other process gases such as BF gases.
e Only two currently operating.
f Tata Steel owns several downstream operations including cold rolling and the manufacturing of pipes and tubes.
g Port Talbot, Scunthorpe and Redcar.
h Pre-combustion, post-combustion and oxyfuel.

CHEMICAL	Data				Source
1. Sector Classification[a]	Manufacture of chemicals and chemical products Manufacture of basic pharmaceutical products and pharmaceutical preparations				SIC 2007 cat 20 SIC 2007 cat 21
2. Process Characteristics	*Route*	*Main Products*	*Site n.*		
	Steam Cracking	Organic Chemicals[b]	3		Ecofys et al. Methodology for Free Allocation in EU ETS. Chemical Industry Report 2009; Chemical Industries Association (CIA) data (unpublished)
	Steam Reforming	Inorganic Chemicals[c]	6		
3. Sector Heat Demand (2011)	30 TWh[d]				DECC Energy Consumption in UK 2012
4. Characteristics of Heat Demand	*Process*	*Temp Range C*	*Main Fuel*	*Heat Carrier*	
	Steam Cracking	700-900	Refinery Gas	Direct/Steam	Ecofys et al. 2009
	Steam Reforming	700-1000	Natural Gas	Steam/Direct	
5. Direct CO_2 Emissions (2008)	*Volume*	*Process*	*Fuel*		
	13.2 $MtCO_2e$[e]	*No data*	*No data*		Element Energy 2010
6. Sector Economic Data (2010)	*Organic*	*Inorganic*	*Total Sector*		
a) Employment	13,000	5,000	159,000		ONS ABS 2010
b) GVA £m	2,272	876	20,054		ONS ABS 2010
c) Energy Cost % GVA (2009)	10% (electricity & heat)				BIS Analysis of UK Manufacturing Sector 2009
7.uk Market Structure	*Organic*	*Inorganic*	*Total Sector*		
a) Business n.	130	91	1,040[f]		IBIS Chemical Industry 2012. BIS BPE 2011
b) Site n.	*No data*				
c) Key Companies	SABIC INEOS ExxonMobil	INEOS GrowHow BOC	–		CIA data (unpublished)
d) Key Location	3 Clusters at Teesside, Humberside and Grangemouth				*Ibid*
e) Industry Concentration	*No data*				
f) Trade Exposure[g]	Import: 156% Export: 158%	Import: 43% Export: 56%	Import: 137% Export: 132%		CIA data (unpublished)
g) Vertical Integration	Upstream & Downstream[h]				CIA data (unpublished)
8. Low Carbon/Renewable Fuel	*No data*				
9. CHP	*Unit n.*	*Main Fuel*	*Output*	*GWh*	
	55	Nat Gas	Heat	15,219	DECC DUKES 2012
			Electricity	7,829	
10. Energy Intensity	*UK*	*EU*			
	2.2 MWh/k€	2.9 MWh/k€			DECC Energy Efficiency Strategy 2012
11. CCS	*Site n. (eligible)*	*Technology*	*Application*		
	6[i]	Post-combustion	*No data*		Element Energy 2010

a The sector comprises manufacturers of a wide variety of chemical products from bulk chemicals (organic and inorganic), plastics and synthetic rubber through to pharmaceuticals.
b Includes bulk chemicals such as olefins (e.g. ethylene) and aromatics.
c Includes bulk chemicals such as ammonia, nitric acid, hydrogen from industrial gases and fertiliser and nitrogen compounds.
d Total energy demand for SIC code 20 and 21, excluding processes such as electrolysis, motors, lighting, refrigeration etc.
e Excluding CHP.
f Excluding micro-enterprises.
g Import data is % of demand; export data is % of revenue
h Plastic and rubber are often produced at the same site as basic organic chemicals.
i Two Ammonia plants at Billingham and Ince, three Ethylene at Grangemouth, Wilton and Fife; and one Hydrogen plant at Teesside.

CERAMIC	Data				Source
1. Sector Classification	Manufacture of refractory products Manufacture of ceramics tiles and flags Manufacture of brick, tiles and construction products Manufacture of ceramic household and ornamental articles Manufacture of ceramic sanitary fixtures Manufacture of ceramic insulators and insulating fittings Manufacture of other technical ceramic products Manufacture of other ceramic products Manufacture of other non-metallic products Operation of gravel and sand pits; mining of clays and kaolin				SIC 2007 cat 23.20 SIC 2007 cat 23.31 SIC 2007 cat 23.32 SIC 2007 cat 23.41 SIC 2007 cat 23.42 SIC 2007 cat 23.43 SIC 2007 cat 23.44 SIC 2007 cat 23.49 SIC 2007 cat 23.99 SIC 2007 cat 08.12
2. Process Characteristics	Direct fired dryers and kilns				IEEE Brick Industry Guide
3. Sector Heat Demand (2011)	4.4 TWh[a]				British Ceramic Confederation (BCC) Climate Change Agreement (CCA) data 2011 (unpublished)
4. Characteristics of Heat Demand	*Process*	*Temp C*	*Main fuel*	*Heat Carrier*	
	Kiln	800 – 2750 C	Nat Gas	Direct Heat	2011 BCC CCA data (unpublished) IEEE brick industry guide
	Drying	100 – 650 C	Nat Gas	Direct Heat	
5. Direct CO_2 Emissions (2011)	*Volume*	*Process*	*Fuel*		
	1.5 $MtCO_2$[b]	16%	66%		CILT verified emissions data 2011, Cerame-Unie Roadmap, BCC data (unpublished)
6. Sector Economic Data					
a) Employment (2011)	14,000				ONS ABS 2011 provisional data, BCC data (unpublished)
b) GVA £m (2010)	670[c]				ONS ABS 2010. BCC data (unpublished)
c) Energy Cost % GVA	Varies[d]				BCC data (unpublished)
7.uk Market Structure					
a) Business n.	101[e]				BCC CCA data (unpublished)
	Bricks/Heavy Clay	*Tiles*	*Other*[f]		
b) Site n.	67	4	89		BCC CCA data (unpublished)
c) Key Companies	Ibstock Wienerberger Hanson Marley Eternit Wavin Michelmersh	Johnson Tiles British Ceramic Tile	Morgan Ceramics Unifrax Ideal Standard Steelite International Churchill China Imerys Minerals		BCC data (unpublished)
d) Key Location	National	West Midlands SW England	National[g]		BCC data (unpublished)
e) Industry Concentration	*No data*				
f) Trade Exposure	High				BCC data (unpublished)
g) Vertical Integration	Upstream[g]	no	no		BCC data (unpublished)
8. Waste Heat Recovery	Extensive use of cooling air in continuous kilns. problems developing durable, cost-effective heat exchangers limits recovery of exhaust air.				*Ibid*
9. Low Carbon/Renewable Fuel	Sector seeking the development of syngas and biogas				Carbon Trust IEEA Guide to the Brick Sector
10. CHP	Limited[i]				BCC data (unpublished)
11. CCS	Unsuitable due to scale, low CO_2 concentration and contamination of exhaust streams				Element Energy 2010. BCC data (unpublished)

a Sector direct fuel consumption in 2011. The fuel is mainly used for heating purposes.
b The figure does not capture direct emissions from several small installations that do not qualify under the EU ETS directive.
c Excluding kaolin and ball clay and the manufacture of other non-metallic mineral products.
d The average figure for the period 2008-2010 for ceramic sub-sectors varies between 67% for tiles manufacture through 43% for bricks, roof tiles and other clay construction products down to 13% for tableware and ornamental articles.
e Companies in British Ceramics Confederation membership. Small manufacturers (e.g. craft potters) are not included.
f This includes a variety of products ranging from technical ceramics through to tableware and sanitaryware etc.
g Cluster in West Midlands for tableware/giftware and South West England for kaolin and ball clay.
h Heavy clay (brick, roof tile and clkay drainage pipe) manufacturers will generally operate their own local clay quarries.
i Kaolin and ball clay producers have three CHP plants in operation.

Department of Energy and Climate Change
3 Whitehall Place
London SW1A 2AW

www.gov.uk/decc
URN: 13D/074