Modelling to support The Future of Heating: Meeting the Challenge

CLIENT: DECC
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Reputation built on Results

Contents

Background

- Redpoint Energy (a business of Baringa Partners) has provided analytical support to DECC for their Heat Paper (The Future of Heating: Meeting the Challenge) using a whole energy system cost-optimisation model, RESOM (Redpoint Energy System Optimisation Model). The analysis has consisted of a small number of model runs to explore potential pathways to 2050 for decarbonising heat within the context of the wider energy system, primarily in terms of the key technology options and energy vectors. The model has been used to help better understand the trade-offs between doing more or less to decarbonise heat versus other sectors as part of meeting the UK's climate change targets. This modelling was one of a number of pieces of work undertaken by DECC to help inform the Heat Paper.
- The basic framework for the RESOM model was developed as a part of a project for DECC and the CCC looking at the most 'Appropriate Uses of Bioenergy' (AUB) within the overall energy system, within the context of meeting the UK's climate and renewable energy targets.
  - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48340/5128-assessment-of-the-appropriate-uses-of-bioenergy-fe.pdf
- The RESOM model was significantly enhanced in a subsequent project for National Grid: Heat Economics Study (HES) to look at the long-term role of electricity and gas as part of decarbonising heat, again within the context of meeting the UK's overall climate and renewable energy targets.
  - http://www.baringa.com/files/documents/NG-003_-_Redpoint-Baringa_-_Heat_Economics_Study-_Final_-_v20120924-1_1.pdf
- The underlying approach and data sources are described in detail in these reports.
- *It should be noted that the RESOM results shown are not necessarily consistent with other recent DECC analysis, such as for the Gas Generation Strategy and the Impact Assessment for Electricity Market Reform, since these latter were based on the output of other modelling by DECC.*

Overview of RESOM

Redpoint Energy System Optimisation Model

- RESOM aims to minimise the total energy system costs (capital, operating, resource, etc.) to 2050. The model effectively decides what technologies to build and how to operate them to meet future energy service demands, whilst ensuring all other constraints (such as the GHG or Renewables target) are satisfied. The solution for heating is generated as part of the cost-optimal solution for the energy system as a whole; including transport, electricity and other conversions. The optimisation effectively allows all trade-offs in technologies and energy vectors, in all periods on the pathway to 2050 to be resolved simultaneously (ie perfect foresight).
- RESOM models the evolution of the energy system in 5-year steps to 2050, but 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 of these characteristic days are further subdivided into six diurnal timeslices representing contiguous 4-hour blocks, to help capture the variation and interaction between supply and demand for both electricity and heat within the day.
- It has a relatively detailed representation of buildings for an energy system model. The domestic sector draws on studies from National Grid, desegregating the buildings into 10 types, with an additional disaggregation by location and whether they are on- or off- the gas grid. The combination of sector, location and building type leads to approximately 40 heat segments in total, with some of these segments (eg domestic buildings) having a number of heat service demands (eg space heat, hot water, cooking). The heat-related technologies in the model, such as air source heat pumps (ASHPs), diurnal building heat storage or energy efficiency, 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.
- The representation for industrial heat is more aggregated and characterises this sector primarily by the grade of heat required (direct high temperature process, low temperature process and building grade) with separate technology / energy vector choices for each grade.
- Data compilation for the model has focused on recent available public sources, in particular; from DECC, CCC, and Department for Transport (DfT) as well as from National Grid’s analysis of domestic heating and network costs.

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Core scenario key assumptions

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- A core scenario for the RESOM model has been created, to provide a benchmark for comparison with other sensitivities, and with the Other DECC Heat Green Paper modelling. Assumptions are aligned as far as possible with DECC data, such as on the cost of technologies, the availability of biomass and future fossil fuel prices, and are generally consistent with the earlier AUB and HES studies; any updates since the National Grid HES study are highlighted in subsequent slides.
- An emissions target path reflects the current carbon budgets and a linear path to the 2050 target thereafter, which is consistent with the earlier AUB study. The pathway is shown by the net emissions in the subsequent GHG results chart with allowed CO2 emissions in 2050 of 63 MtCO2e/year. This effectively represents a reduction of ~89% in CO2 emission covered by the model in 2050 versus 1990 levels.
  - This reflects the full UK 2050 target of 160 MtCO2e/year, including a hypothetical UK share of international aviation and shipping emissions, minus 55 Mt for non-CO2 GHGs (assuming a 70% reduction vs 1990 levels). Further adjustments of 42 MtCO2 have been made to account for the current absence in the model of process and non-energy emissions and abatement from industrial CCS.
  - Unlike the AUB study non-UK bioenergy lifecycle emissions are not included in the target
- The overall RED (Renewable Energy Directive) target for 2020 of 15% renewables in final energy consumption and the transport sub-target of 10% renewables in final energy consumption for road transport are both included. Intermediate Renewable Transport Fuel Obligation (RTFO) targets are also included. RESOM co-optimises for both the GHG and RED targets (including the various accounting rules in the latter)
- The base energy service demands for the domestic / non-domestic building sectors and transport are broadly consistent with the "Level 2s - ambitious but reasonable" from the March 2011 version of DECC's 2050 pathway calculator. For the domestic sector this relates to building comfort levels as RESOM contains endogenous options for energy efficiency improvements, which broadly reflect the range of Levels 1 to 4 in the DECC calculator

Core scenario key assumptions (2)

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- Industry service demands are consistent with the previous AUB study based on the CCC's Extended Ambition scenario to 2020 and Medium Abatement scenario to 2030 (from their December 2008 and December 2010 advice on the first four carbon budgets), and the Spread Effort pathway from the March 2011 version of DECC's 2050 calculator
- Fossil fuel prices are taken from DECC's central scenario from the October 2011 Updated Energy Projections (UEP). Bioenergy resources are consistent with the more conservative "core lower resource scenario" from the previous AUB study, the "core higher resource scenario" is tested as part of the sensitivities. A global social discount rate of 3.5% has been applied the core scenarios were run with perfect foresight and in LP (linear program) optimisation mode.
- A number of minimum / maximum build quantity constraints are also imposed as part of the core scenario
  - Maximum build quantities by 2050:
    - 39 GW nuclear 34 GW onshore wind, 130 GW offshore wind
  - Maximum domestic energy efficiency improvements are capped at 90% of technical potential to reflect hard to treat homes
  - Various other maximum build quantity constraints as per the AUB study – eg near term deployment of Anaerobic Digestion (AD) plant and renewable heat to 2020 .
  - Electricity storage is constrained to maximum of approximately 70 GWh of storage volume and just under 14 GW of power output and heat storage is constrained to an equivalent of a typical 200 litre tank in the largest domestic building type (ie detached) and scaled down accordingly for smaller dwellings.

Core scenario key assumptions (3)

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- In addition to maximum quantity constraints a number of build *rate* constraints are also imposed:
  - A group build rate per year across all CCS technologies, effectively capping the maximum CCS deployment in 2030 to 15 GW and 70 GW by 2050
  - A similar group constraint for all hydrogen production technologies, with similar values
  - Domestic efficiency measures are restricted to the maximum implied build rates in CCC (2012) study on Options for decarbonising heat in buildings 2030-2050 mentioned in Table 2
  - Various other maximum build rate constraints on power, transport and heating as per the AUB / HES study
- Minimum load factors are applied to a number of new technologies to avoid excessively rapid transitions in technology deployment over time (since a private company would not invest if levels of operation did not generate a sufficient return)
  - 50% for large conversion plant (eg hydrogen, biofuels, etc) and power generation
  - 2% for peaking plant (to reflect emissions not covered due to the more limited diurnal temporal granularity in RESOM)
  - 10% for a range of flexible heating technologies
- Electricity interconnector capacity is set according to National Grid's Gone Green (2011) scenario rising to 12 GW by 2050; it contributes to the peak reserve margin constraint.

Key updates since DECC's 2012 Heat Strategy

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- DECC have used a number of models to inform this Heat Paper. As part of this work, a range of assumptions and technologies have been added or updated since the earlier DECC 2012 Heat Strategy and we have attempted to make these as consistent as possible in RESOM.
- The majority of the new technologies already existed in RESOM as part of our earlier HES for National Grid, but the key changes are summarised below (any other changes to RESOM since the HES made for this work are summarised on the next slide):
  - 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 heat storage is modelled.
  - Costs of heat networks: revised costs of network costs and cost of connection to buildings.
  - Additional sources of heat included – large scale heat pumps, either ground source or marine included with a maximum output of 12 TWh/year in 2050 (these are a new addition to RESOM)
  - New Building level technologies:
    - hybrid heat pumps and gas absorption heat pumps are available to domestic and non-domestic buildings
    - Micro CHP fuel cells and hydrogen boilers included as option for domestic buildings.
    - Hydrogen boilers included as a technology for domestic buildings.
    - Better modelling of heat storage within day.
  - Industrial use of hydrogen: industrial hydrogen boilers included
  - Availability of biomass Imports: consistent with the 'lower core' scenario in DECC's Biomass Strategy.

Updates since Baringa 2012 HES study for National Grid

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- A number of smaller updates have made since the earlier HES study and are summarised below:
  - The cost of urban building heat networks has been decreased by ~10%
  - Building heat network capacity was originally capped at 40% of heat demand (reflecting the District Heat Constrained Scenario from Element Energy (2012) Decarbonising Heat from 2030-2050 study for CCC) this has been increased to 80% for urban networks
  - A large scale marine heat pump has been added but with a maximum output of at ~12 TWh/year as per the above CCC study
  - Large-scale CHP with CCS capacity has been constrained to a maximum of 50% of low temperature industrial process heat (previously unconstrained)
  - The maximum use of waste heat from nuclear is capped at ~12% (up from 6%) of applicable heat demand, very broadly equivalent to the current proportion of heat demand within ~50km of new nuclear sites from the DECC heat map)
  - Gas Heat Pump efficiency COP (coefficient of performance) improves further by 2050 in line with Delta EE (2012) Pathways for domestic heat report for the ENA (Energy Networks Association)
  - Electricity generation costs have been updated to reflect DECC’s 2011/2012 publications (but not the most recent November 2012 update)

Sensitivities

- Whole energy system optimisation models are not designed to predict likely future states of the world, but to help explore the myriad trade-offs between different energy technologies and vectors. As much of the longer-term input data is inherently uncertain a number of sensitivities and ‘stress tests’ have been ***selected by DECC*** to assess how robust the core scenario results in 2050 are to changes in key input assumptions. These include:
  - *No GHG target* – this is primarily to estimate the potential costs of abatement to meet the 2050 GHG target
  - *No bioenergy* availability
  - *No new nuclear* build allowed
  - *75 GW nuclear* – reflecting the maximum total build quantity (compared to 39 GW in the core scenarios)
  - *No CCS* build allowed (of any kind) – the CO2 target is also tightened to reflect lack of industry CCS options outside of the scope of the model
  - *No domestic gas* allowed in 2050 – the model still has the freedom to decide how best to reach this end point
  - *Lower internal temperatures* – comfort levels aligned to the DECC pathway calculator Level 4 (Level 2 in the core scenario)
- The results from the model are not designed to provide detailed forecasts needed for policy appraisal; rather they provide insights to – principally technology-orientated - longer-term pathways to which policy could be adjusted to help achieve. Care is also required in interpreting the results of such modelling as the need to model the entire system necessarily involves a higher level of abstraction than sector specific models. In addition, RESOM only has a simple, indirect representation of geography by considering urban, rural and off-gas grid energy service demands and the ways these can be met.
- RESOM is focused on the cost-optimal way to meet the renewable energy and emission targets, but does not attempt to model the impact of eg nearer-term incentive policies that would be required to deliver these emissions reductions. It assumes perfect markets and information, and therefore does not attempt to capture the effects of consumer preferences for different technologies, beyond simple economic hurdle rates.

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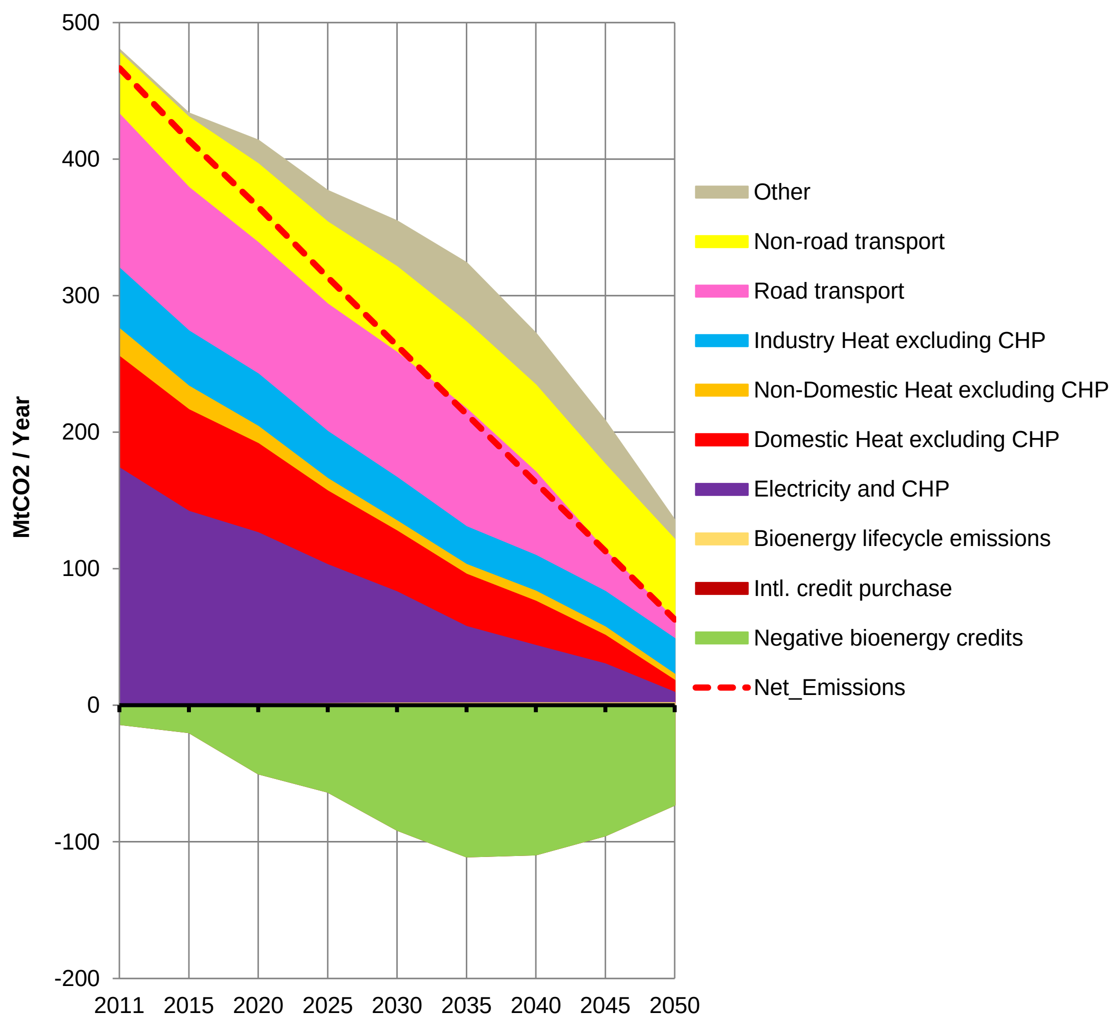
GHG emissions - core scenario



The net emissions line represents the target pathway (including carbon budgets and 2050 target) and represents an 89% reduction in CO2 for the scope of the energy system covered by the model.

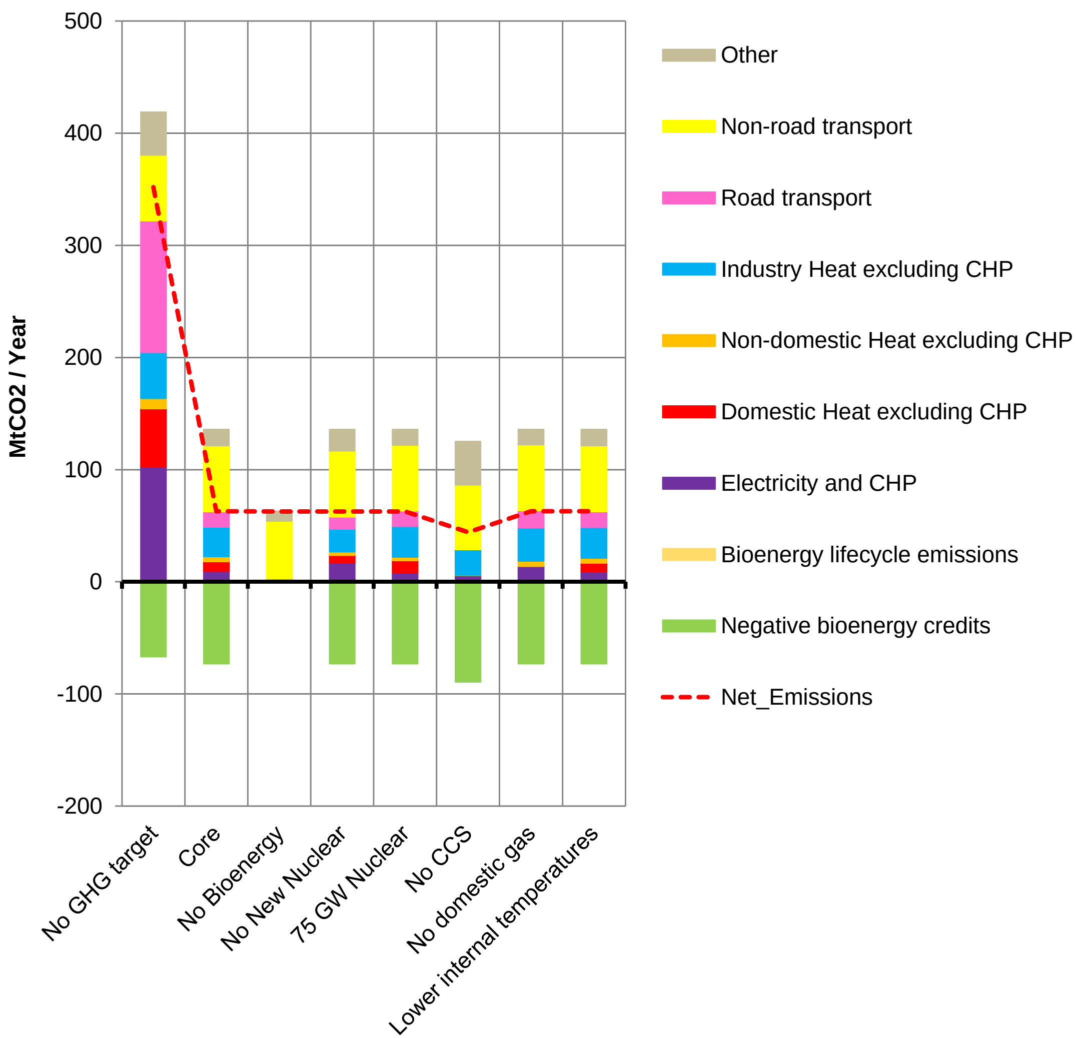
Negative bioenergy credits represent CO2 captured during growth (not bioenergy CCS credits), emissions from bioenergy end-use are released as positive emissions and broadly offset each other subject to lifecycle emissions and CCS.

The building heat sectors strongly decarbonise to 2050 in terms of their direct emissions, and indirectly via electricity from a virtually decarbonised power and large-scale CHP sector

Direct industrial emissions are broadly constant to 2050, but the sector as whole decarbonises strongly as a result of indirect emissions reduction. This is primarily from the use of biomass with CCS to produce H2 (generating net negative emissions for the system as a whole), which is used primarily in road transport, but also in industry.

Residual emissions are greatest in non-road transport given limited abatement opportunities and low preference for use of bioenergy.

GHG emissions – 2050 all sensitivities



The broad mix of emissions by sector in 2050 is similar to the core scenario across most sensitivities, with the exception of those where no bioenergy and no CCS are allowed. In both of the sensitivities the system is significantly harder to decarbonise.

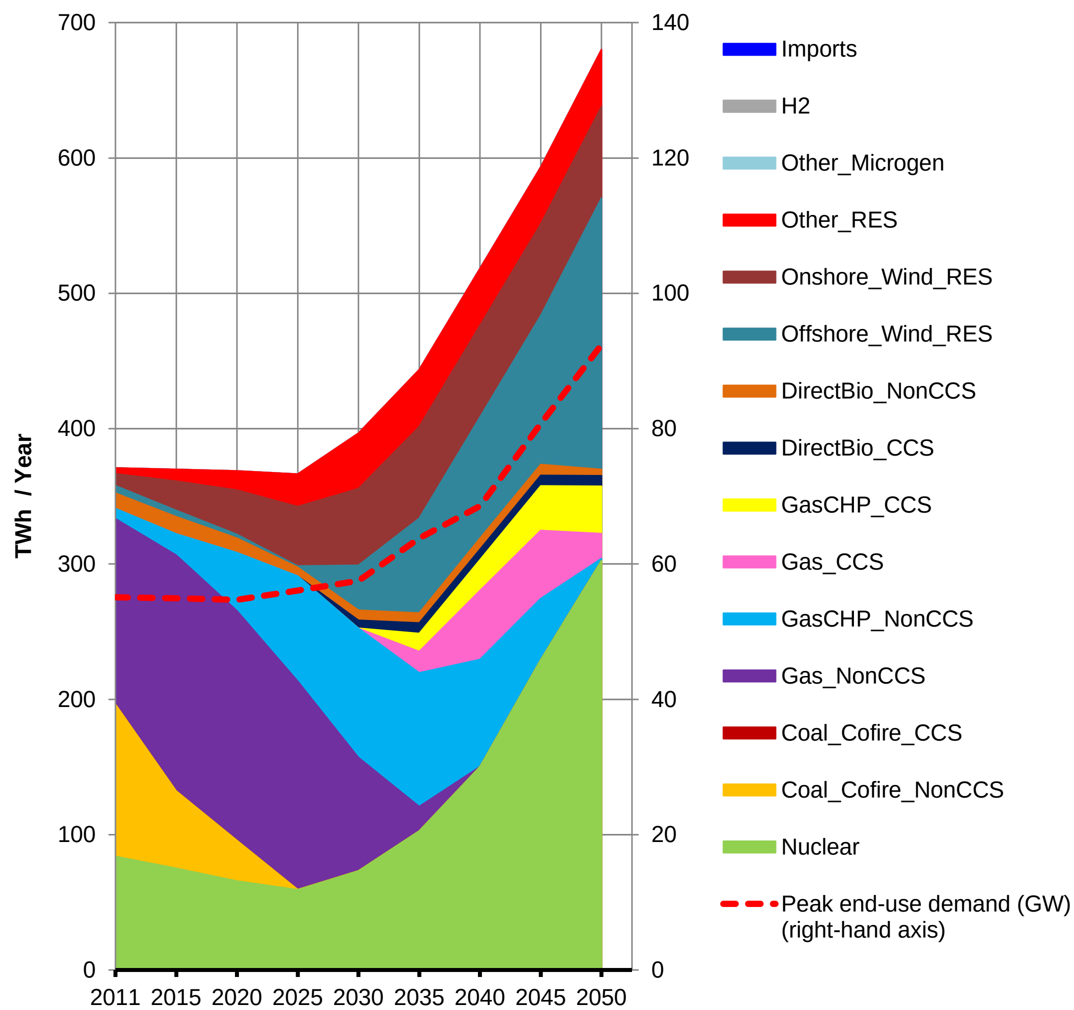
With no bioenergy available, virtually all emissions outside of non-road transport are squeezed out of the system to allow for continued fossil fuel use.

With no CCS available the model struggles to meet the emissions target (which is reduced to account for the lack of industrial CCS options), given the constraints in the core scenario. As a result it is forced to use an expensive ‘backstop’ product to reduce the equivalent of ~ 20 MtCO2 / year.

Given the difficulty in meeting the target, residual emissions are virtually eliminated from building heat and further reduced in industry.

With additional nuclear capacity available, the system leaves marginally higher direct emissions in heat compared to the core scenario as this is more cost-effective.

Electricity supply and peak demand – Core scenario



The core scenario shows an important role for electrification to facilitate decarbonisation, with annual supply almost doubling by 2050, with the most rapid increase seen post-2030.

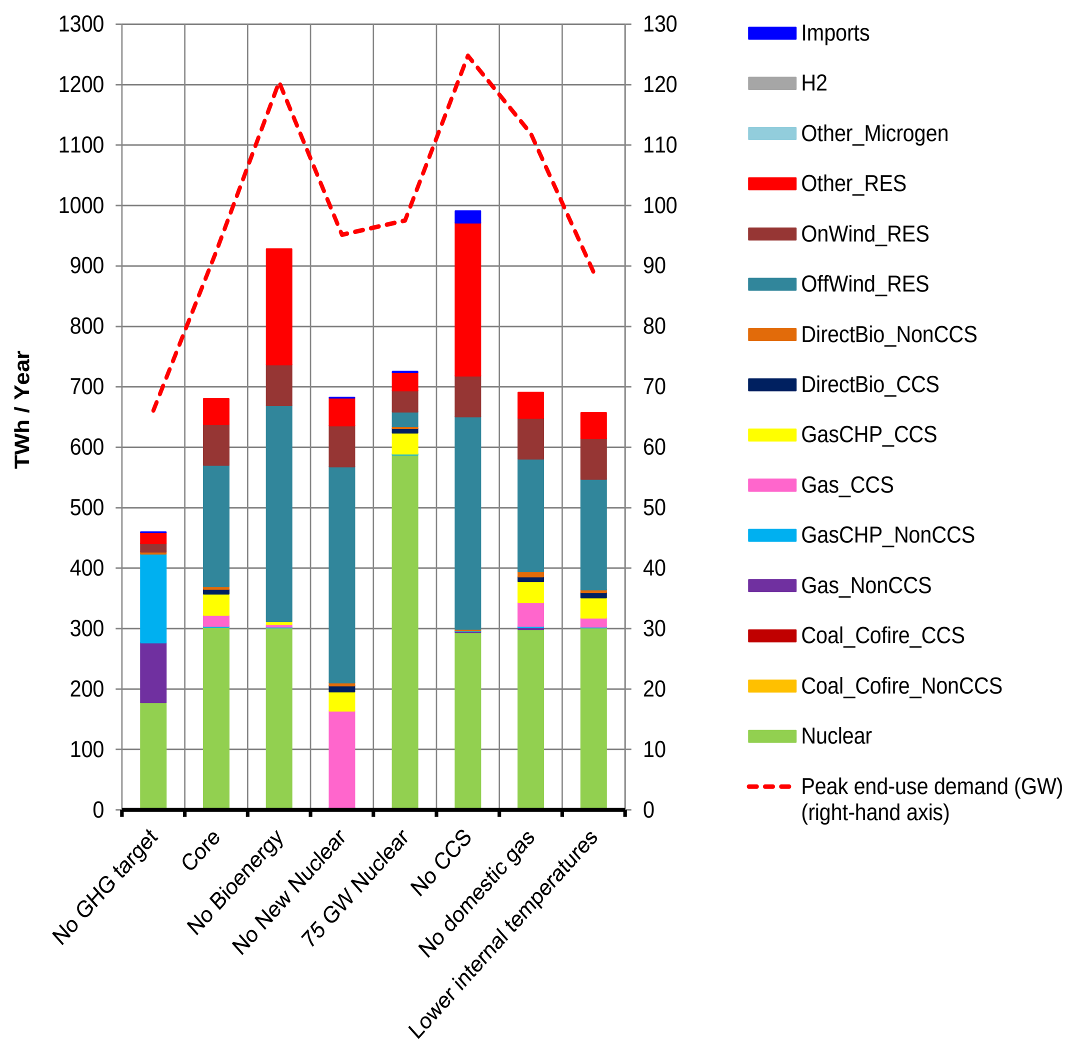
In the core run, electricity is decarbonised through a combination of nuclear and renewable sources focused primarily on onshore and offshore wind. CCS is also used with gas CCGT and large scale gas CHP appearing from 2030 onwards at the expense of unabated gas which is slowly squeezed from the mix.

In terms of capacity, nuclear power reaches the assumed maximum constraint of 39GW in 2050 in all scenarios where it is modelled (and also 75 GW in the corresponding sensitivity).

This runs as base load, complemented with intermittent generation from renewable sources. This is backed up by a mix of abated and unabated gas using CCS and increased storage and interconnection capacity.

Peak electricity demand also increases significantly, particular after 2030. It reaches just over 90 GW in the core run as a result of increased electrification of heat and transport (even after accounting for load shifting).

Electricity supply and peak demand – 2050 all sensitivities



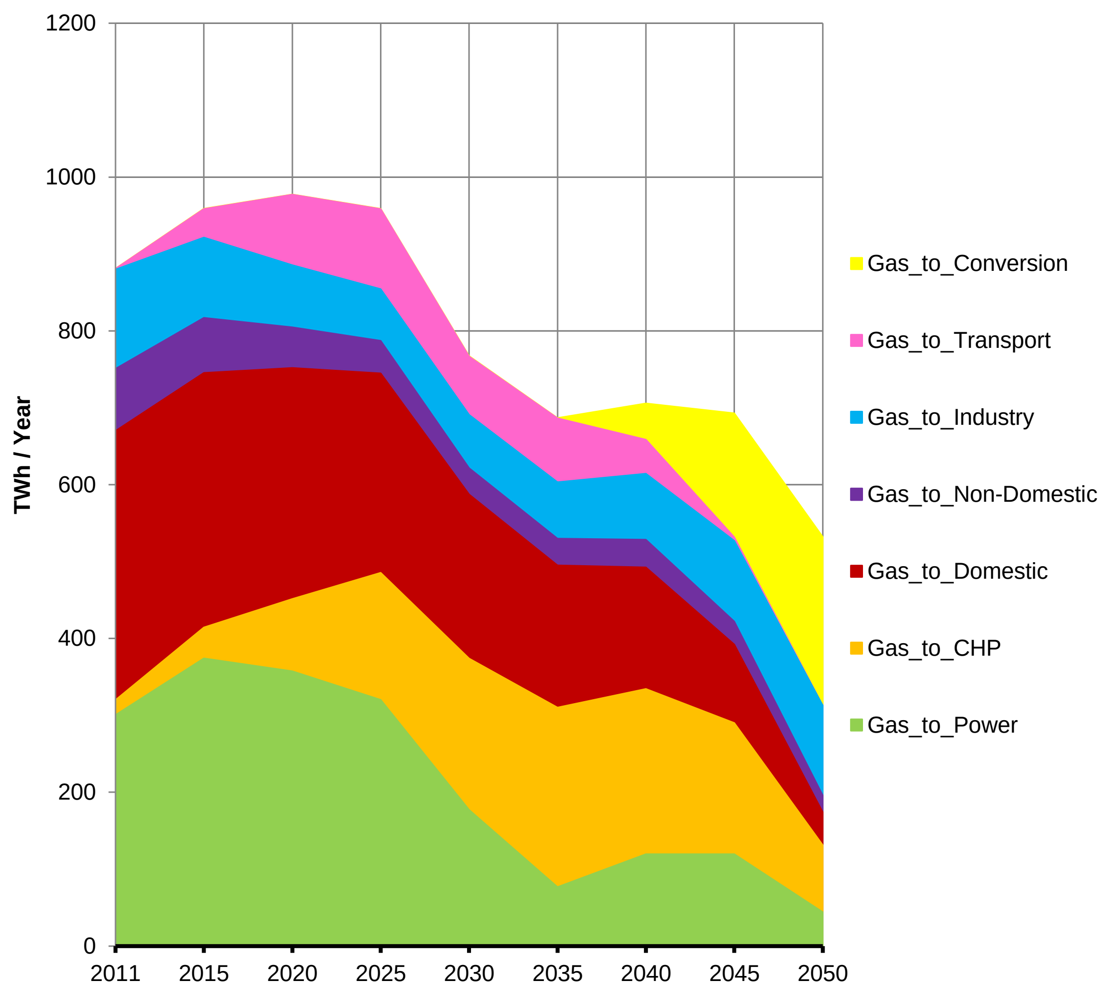
In the no bioenergy and no CCS sensitivities the difficulty in meeting the emissions target leads to additional abatement effort through the power sector, with significant increases in annual and peak electricity demand.

In the no domestic gas sensitivity, further electrification of heat increases the peak in electricity demand by 22% to over 110 GW.

Under this sensitivity, part of the electricity supply from nuclear is diverted towards generating heat for heat networks. The additional generation is supplied by additional gas generation using CCS, but with some unabated gas plant being used too.

Under the 75 GW nuclear sensitivity nuclear dominates the mix and significantly reducing the role for offshore wind. However, it should be noted that the central cost assumptions place nuclear as effectively the cheapest low carbon baseload option and a high cost sensitivity has not been undertaken.

Gas by end-use – core scenario



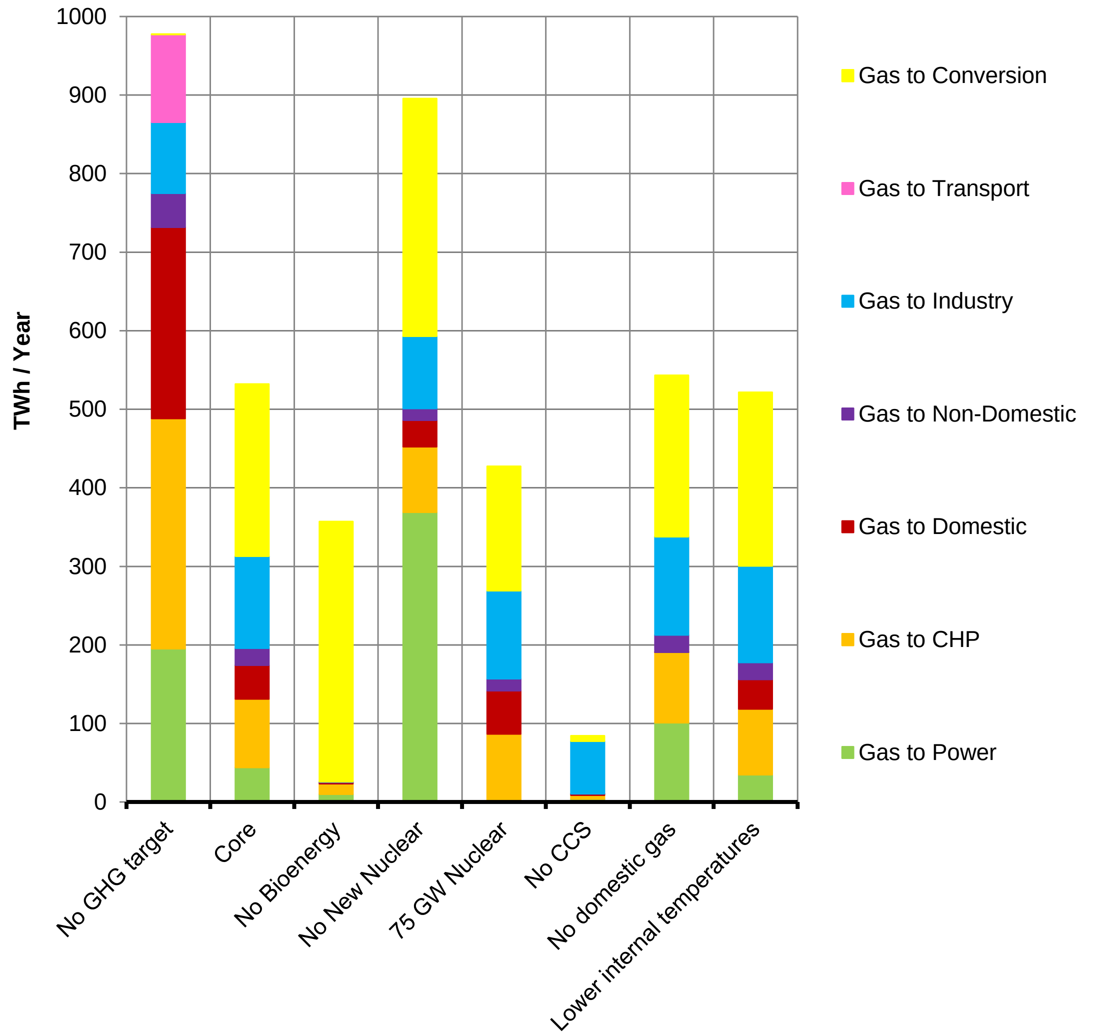
RESOM shows gas use declining sectors including electricity decarbonise. Gas demand falls by around half in the core run, as both electricity and domestic heat decarbonise.

Gas use in building heat drops by over 80% whilst in industry it drops by only around 10%. In buildings residual gas maintains a key role in seasonal top-up / peak heat supply and cooking / catering, primarily to help avoid excessive costs of generation and network reinforcement with higher levels of peak electricity demand.

The model predicts a role for gas use in freight transport as a transitional technology, and from 2035 gas begins to be used as a feed stock for hydrogen production using steam methane reforming with CCS, but this use is highly sensitive to gas prices (from the previous HES study).

The core scenario suggests that by 2050 around 200TWh of hydrogen could be needed, but with this mainly being used in the transport and industrial sectors. In addition, the model predicts around 25 TWh/year of biogas in 2050 from gasification of biomass, anaerobic digestion and landfill.

Gas by end-use – 2050 all sensitivities



The role for gas in industry is fairly consistent across all of the scenarios given the more limited abatement alternatives for decarbonising higher-temperature process heat.

An exception is the no bioenergy scenario as residual emissions are squeezed across all sectors to maintain fossil fuel use in non-road transport.

Similarly, a consistent, but significantly reduced level of gas use is maintained in building heat across most sensitivities to help avoid additional peak electricity reinforcements.

Key exceptions are the no CCS and no bioenergy sensitivities where additional pressure to abate forces out gas and requires the use of higher cost alternatives.

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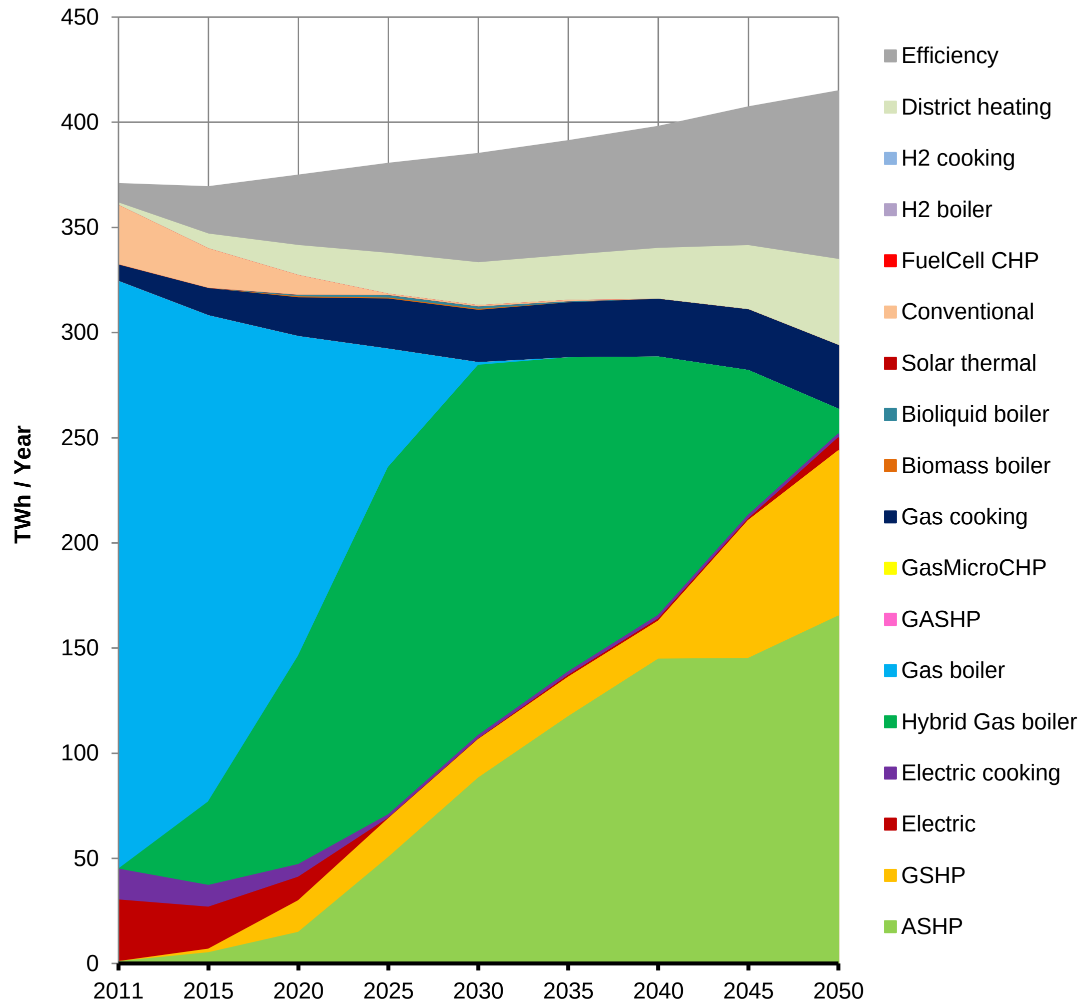
Domestic heat output - core scenario



In the core run gas remains the main fuel until the 2030s, but with gas used in hybrid systems with a gas boilers used in conjunction with heat pumps. These are adopted relatively quickly with condensing gas boilers being completely replaced by 2030.

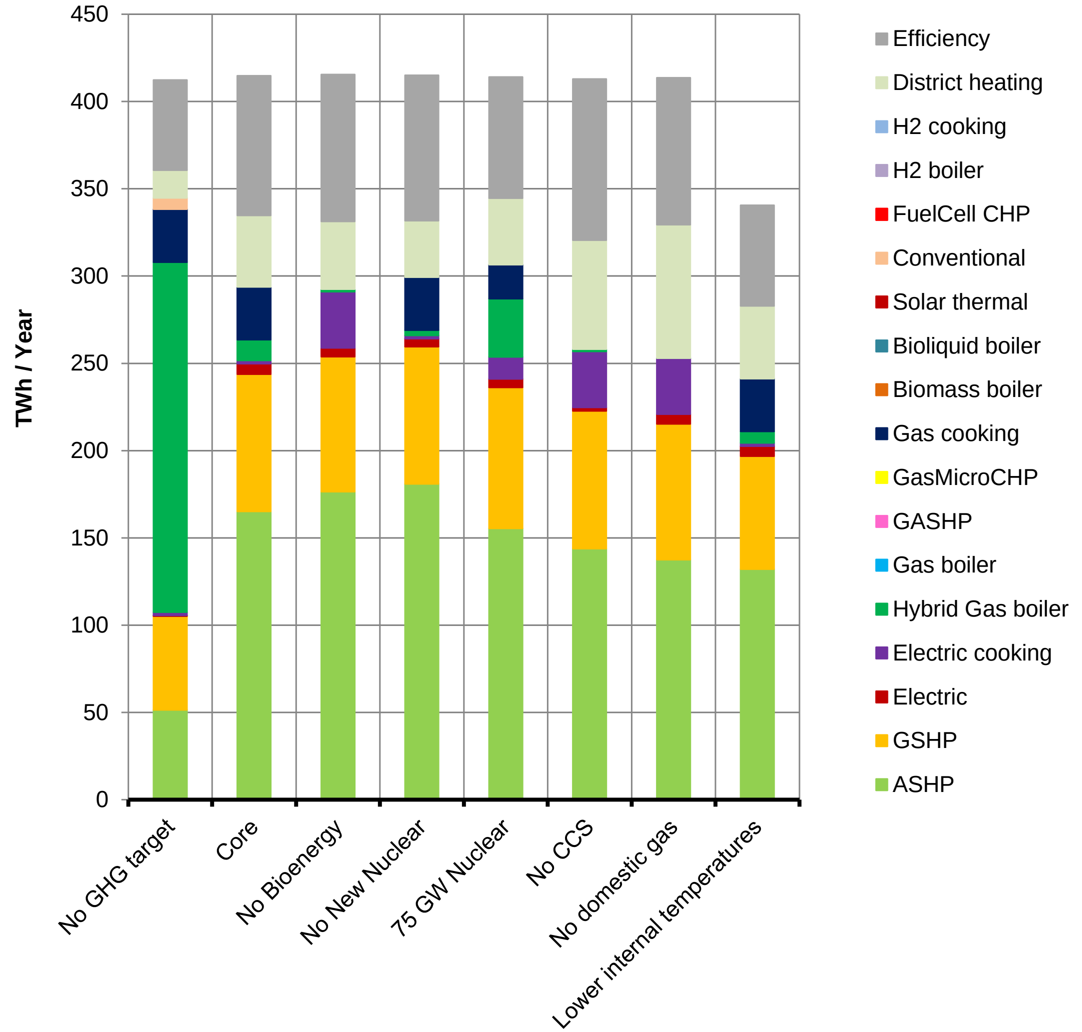
Initially hybrids generate most of their heat from the gas boiler, supplemented by a small heat pump running at night to take advantage of cheaper off peak electricity. By the 2050s gas is only used to provide 'top-up' heat supply during the winter, to avoid placing additional demand on the electricity system at this point. The vast majority of baseload heat is provided by electric heat pumps.

By contrast gas still provides the majority of the heat supply buildings on an extreme cold (ie 1-in-20) winter day.

Cooking fails to decarbonise in the model as although it could be electrified, the peaks in demand for cooking coincide with the wider system peak.

There is also a focused role for heat networks in 2050, with the heat supplied by a variety of sources shown in later slides.

Domestic heat output – 2050 all sensitivities



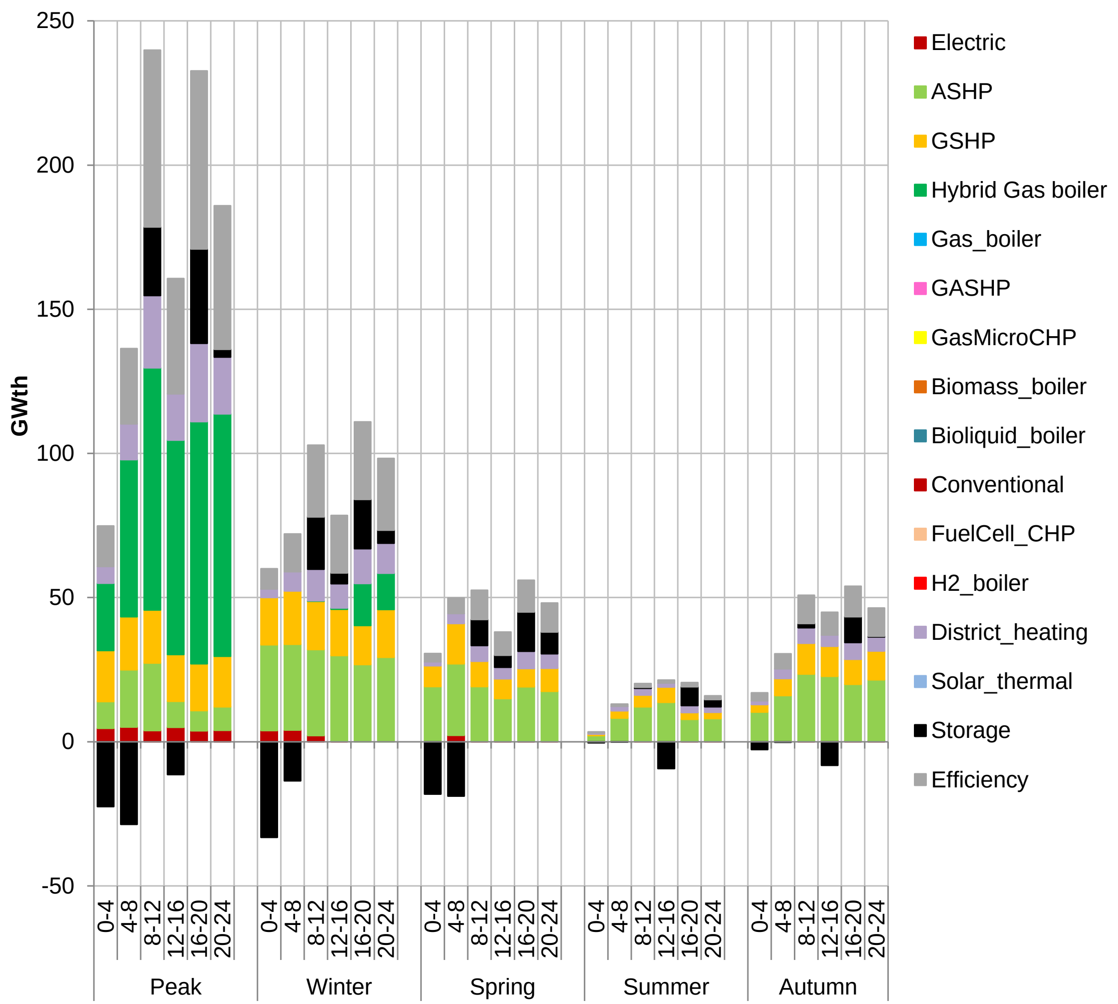
Removing gas technologies as an option for domestic buildings only leads to more heat networks and with cooking switching to electricity in order to meet the constraint. Peak electricity demand is around 20% higher in this scenario, with additional gas capacity required to supply the electrification of heat. The additional heat for heat networks is supplied by nuclear power stations supplying additional heat, at the expense of electricity.

In the case where domestic heat demand is lower hybrid boilers still remain to provide top-up and peak heat on days as there is still significant seasonal variation in heat demand.

In the case with 75 GW of nuclear more gas is retained overall, but this is focused on hybrid boilers with some offsetting from the electrification of cooking.

In the no bioenergy and no CCS worlds where meeting the CO2 target is more difficult this tends to make additional efficiency measures and electrification of heating more cost-effective, with remaining gas squeezed from domestic heating.

Domestic heat supply profile – core 2050

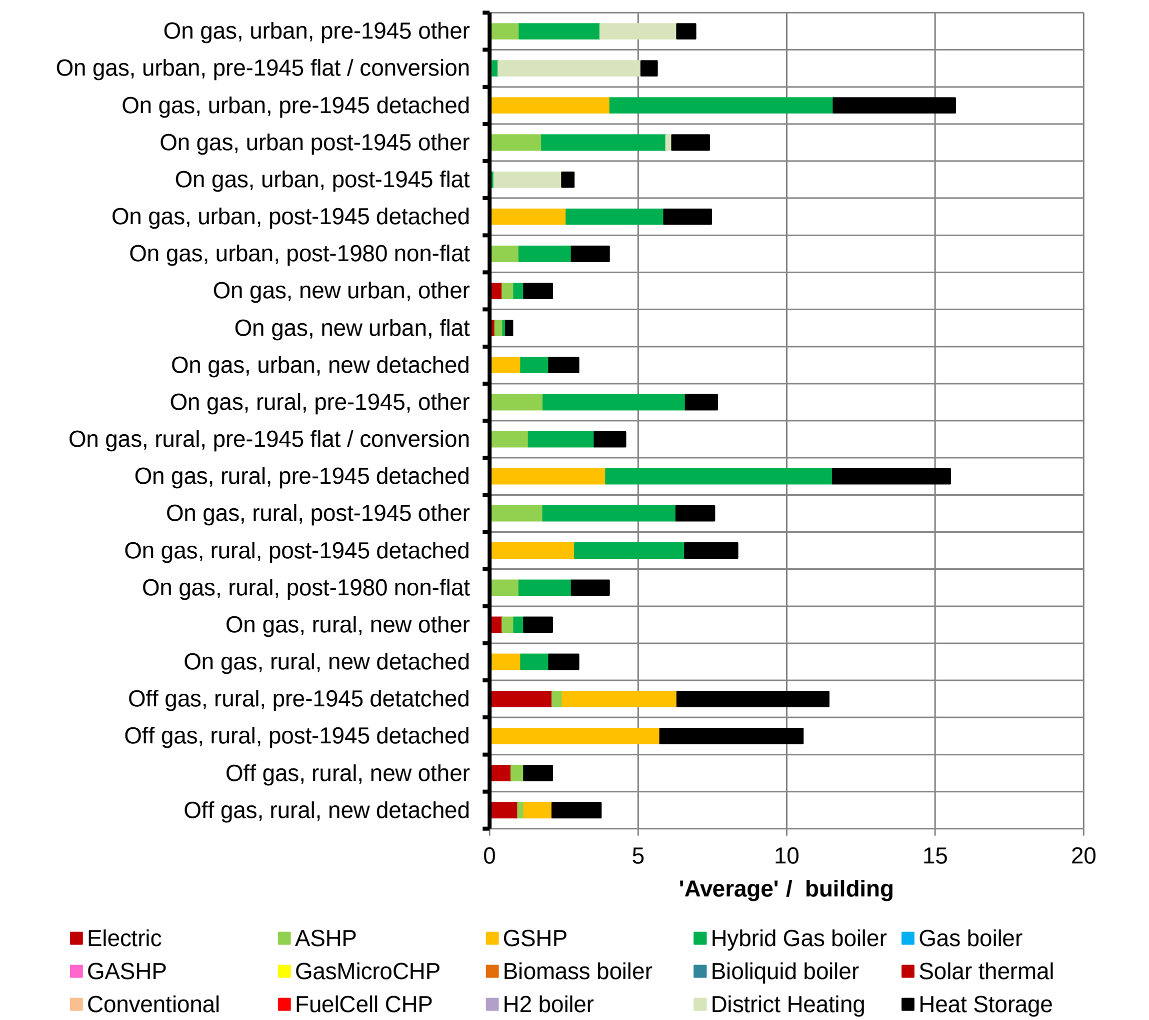


The chart shows the profile of the supply of heat demand (for space heat and hot water) in 2050 for each characteristic day modelled.

It shows air and ground source heat pumps being used continuously through the year to provide baseload heating and hot water, combined with storage primarily allowing the heat to be generated at night and used during the day.

By 2050 the gas boiler component of the hybrid systems are only used during the winter to provide 'top-up' heat supply and more extensively during peak periods to provide additional heat which cannot be supplied by the heat pumps without generating additional peak electricity demand.

Domestic heat – ‘average’ capacity in 2050



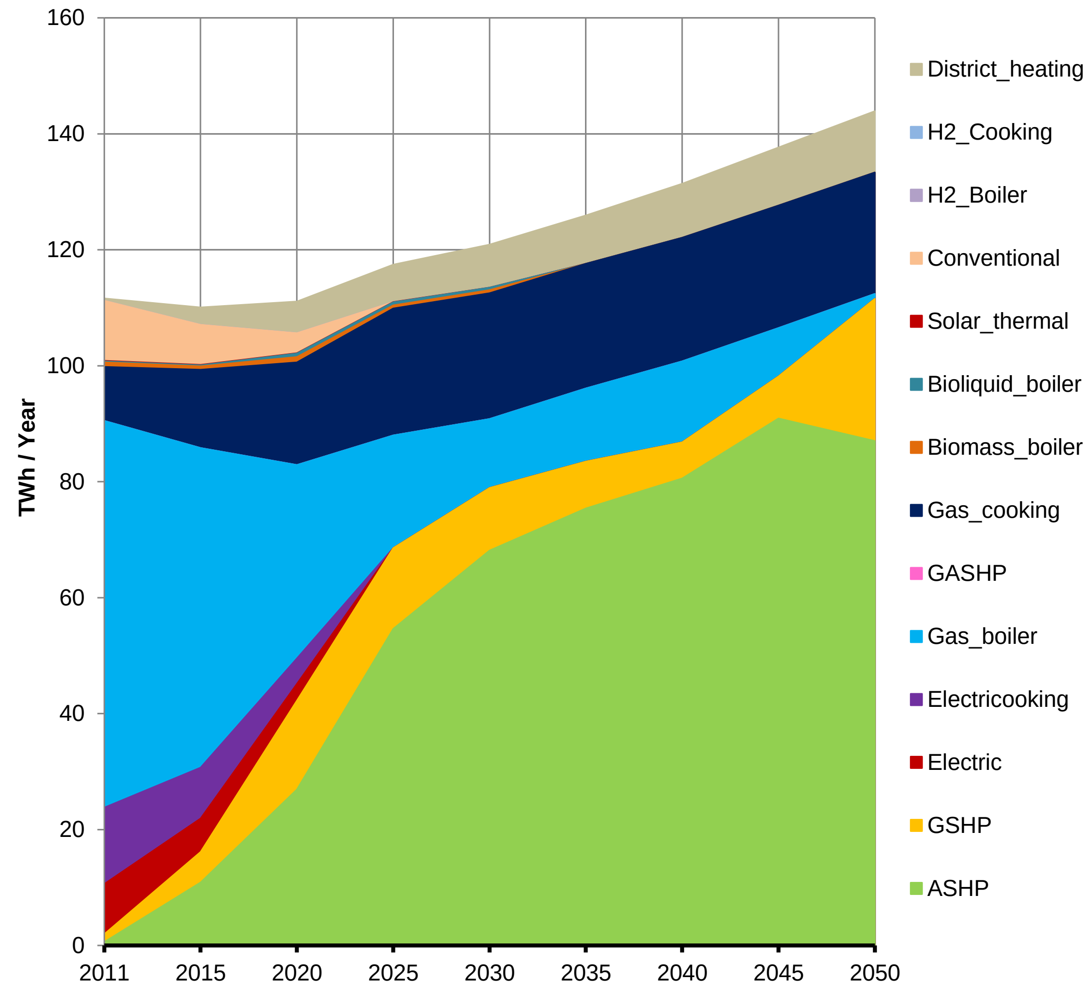
The chart shows the average mix of installed heating capacity by dwelling type. It is important to note that this does *not* imply that each individual building within each characteristic segment has this mix of technologies, but is illustrative of the broad preference for technology types by segment.

The core scenario indicates that that by 2050 rural properties off the gas grid will mainly be using ground source heat pumps incorporating storage, with a small amount of resistive heating to provide peak top up on certain days. This is cheaper overall than further sizing the heat pump to meet peak even though it leads to slightly higher peak electricity demand.

Properties on the gas grid are predicted to mainly use hybrid systems consisting of a gas boiler and an air source heat pump.

The use of heat networks tends to be focused most cost-effectively on higher density buildings (where network costs are lower) or older buildings (due to the higher heat load relative to high fixed costs of installation); as opposed to lower density and / or new buildings.

Non-domestic buildings heat output - core scenario



The non-domestic buildings show a similar pattern to domestic buildings, with the majority of heat coming from heat pumps by 2050.

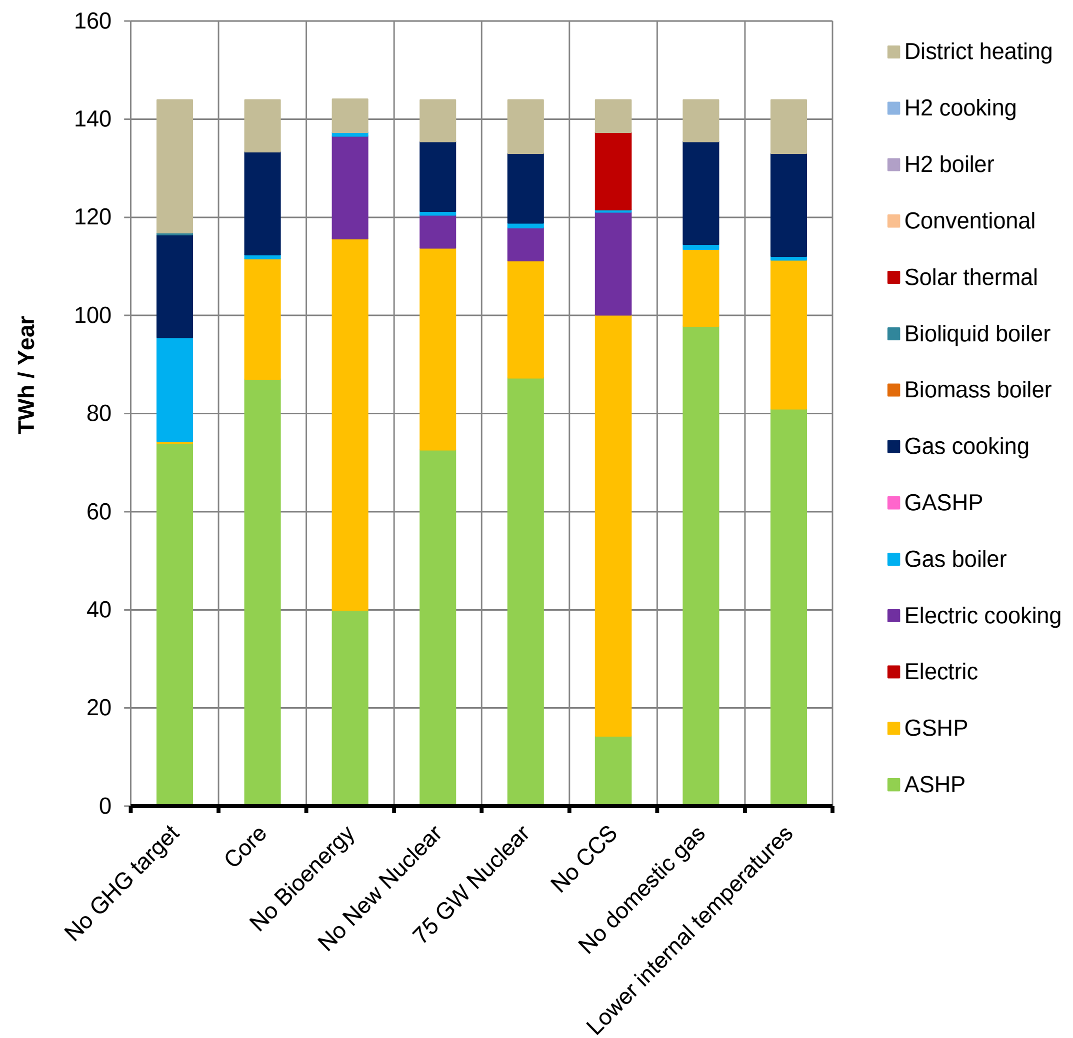
Gas boiler's share of the heating supply declines sharply between now and 2025, but continues to decline slowly from then on before falling to near zero by 2050.

However, gas is still used almost exclusively as a back-up on the peak 1-in-20 cold winter day (see later slides)

Electricity for direct resistive and cooking is shown to be phased out almost entirely by 2025, with cooking and catering being entirely by gas in 2050 helping to avoid additional peak demand from load that is difficult to shift.

Heat networks grow to provide 7% of the heat by 2030 and 9% by 2050 (excluding heat for cooking) focused on urban areas.

Non-domestic buildings heat output – 2050 all sensitivities

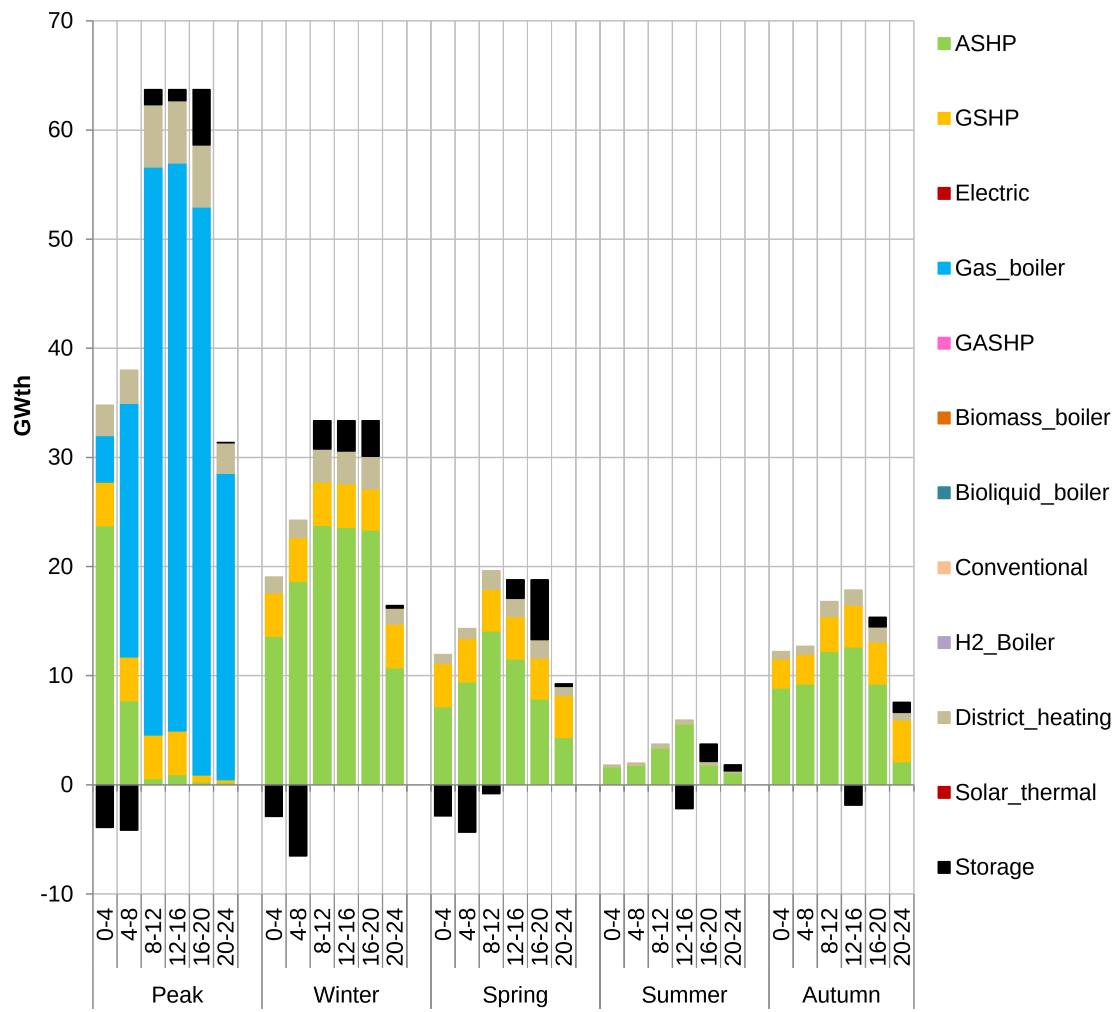


Under the no bioenergy and no CCS sensitivities (and to a lesser extent in the no new nuclear case), the additional difficulty in meeting the emissions targets means that much more extensive use is made of ground-source heat pumps over air source heat pumps. Cooking also switches to electricity.

Even though GSHPs are considerably more expensive the additional efficiency is used to help lower annual and peak electricity demand relative to what it would be with continuing ASHP use (and bearing in mind that the electricity system in these cases is already stretched).

Unlike the domestic sector, additional district heating is not considered for non-domestic buildings in sensitivities where it is harder to meet the GHG target. This is due to a limited availability of low carbon heat network supply, which is more cost-effectively used in the domestic sector. Expanding this supply is difficult due to residual emissions (even from CCS) and off-taking heat from large thermal plant imposes a small efficiency penalty, which is problematic given the increasing reliance on the electricity system to drive further decarbonisation.

Non-domestic buildings heat supply profile – core 2050

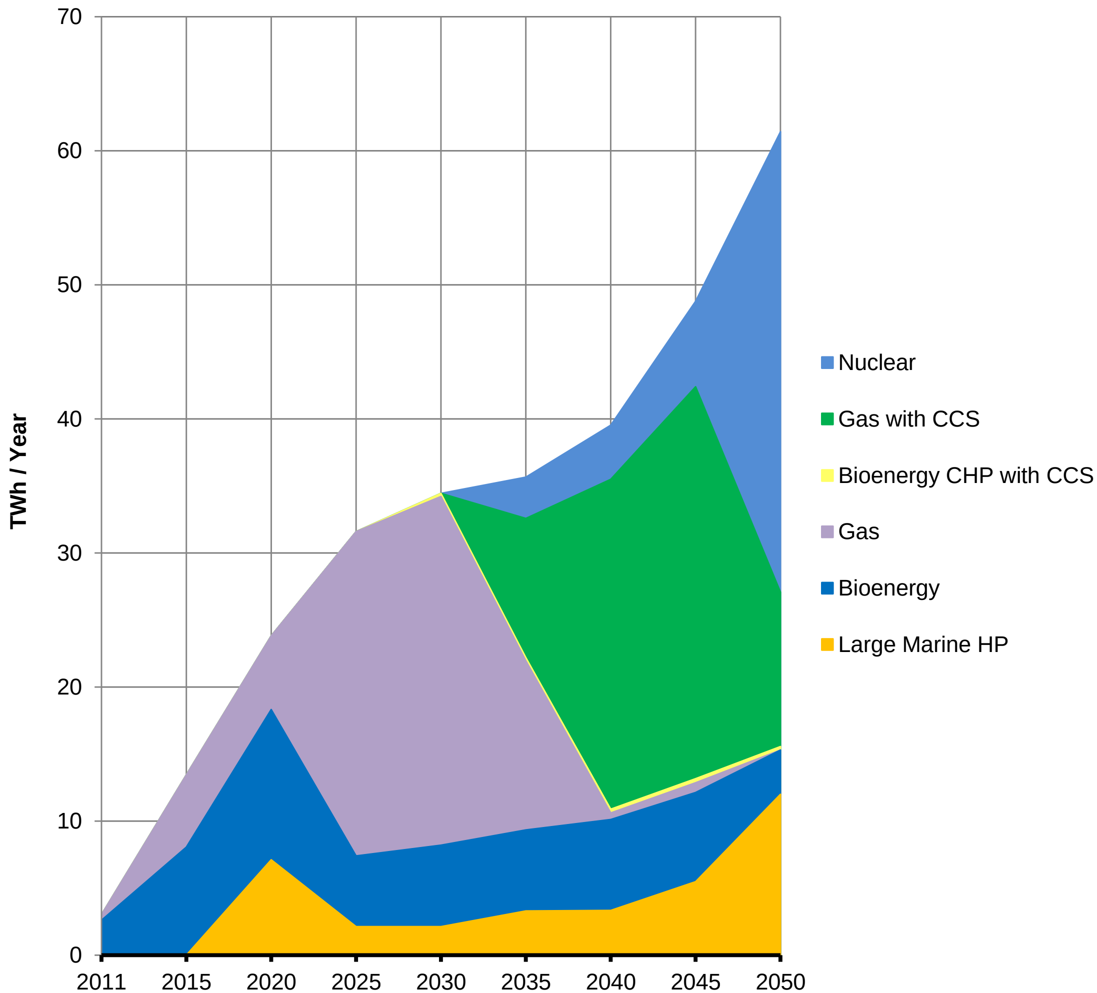


In a similar manner to the domestic sector, this chart shows the profile of the supply of heat demand (for space heat and hot water) in 2050 for each characteristic day modelled.

However, unlike the domestic sector it shows air- and ground-source heat pumps providing the bulk of heating through-out a typical year, supported by heat storage (and heat networks in a small portion of non-domestic buildings). This is due primarily to a 'less peaky' heat demand profile.

Back-up gas boilers are still required to provide the vast majority of heat requirements on a 1-in-20 peak cold weather day in a similar manner to the domestic sector, to help mitigate against significant additional peak electricity demand requirements.

Building heat network supply - core scenario

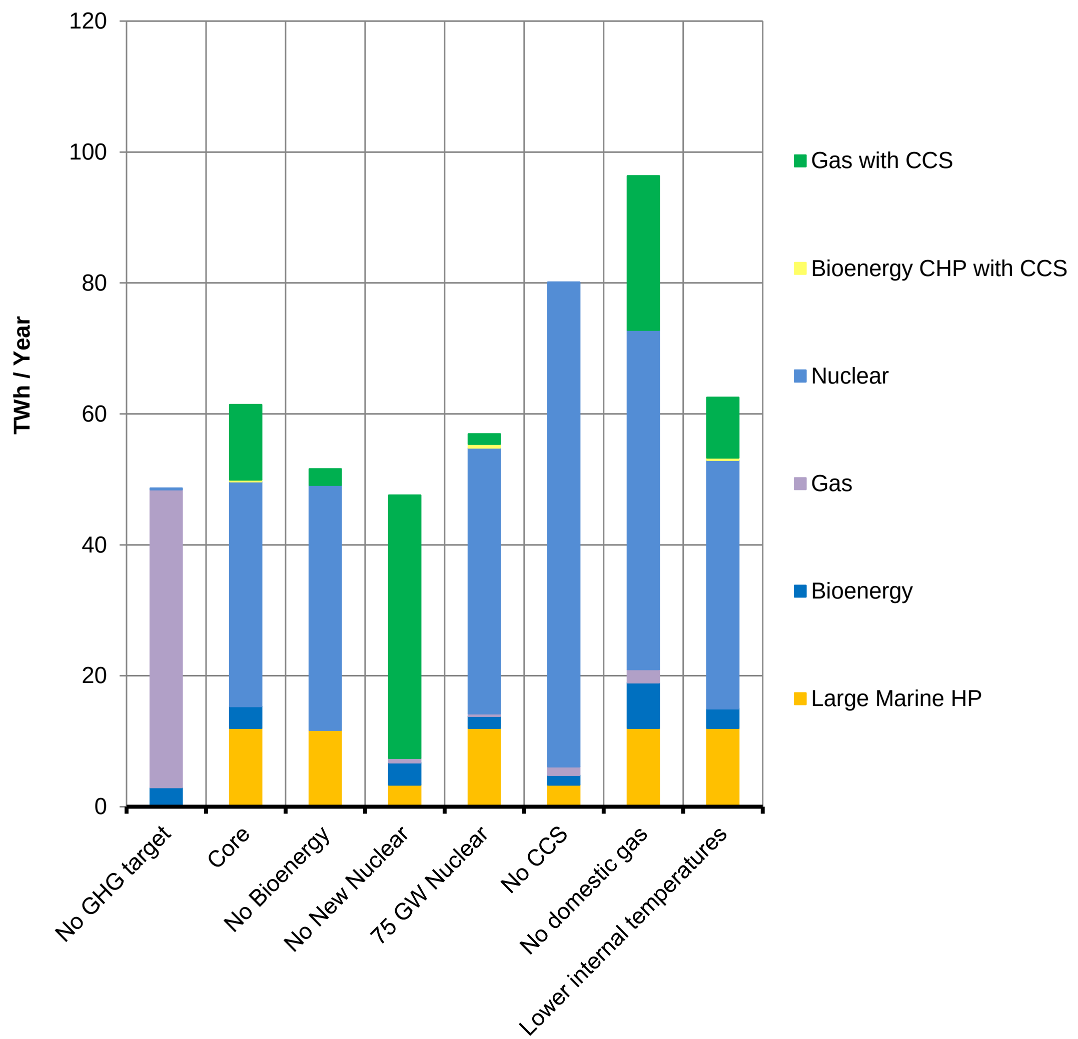


The core scenario shows heat networks supplying around 60 TWh of heat to buildings by 2050. Heat networks grow rapidly to 2030, with the majority of heat being supplied by gas sources through large scale CHP, but complemented with around a quarter of heat from biomass.

The spike in biomass and large heat-pump supply in 2020 is driven by the 'incentive' to meet the renewable energy directive target in the most cost-effective way for the system as a whole. However, after this point supply drops back to a minimum imposed load factor, indicating that a lower level of use across the pathway is more realistic in terms of contributing to overall emissions reduction.

From 2030 unabated gas use declines and the remaining gas used by 2050 will be with CCS, but with a shifting focus of this heat supply source towards industrial heat networks (see later slides). Large scale heat pumps and heat from nuclear power stations make up the majority of heat supplied to heat networks in 2050.

Building heat network supply – 2050 all sensitivities

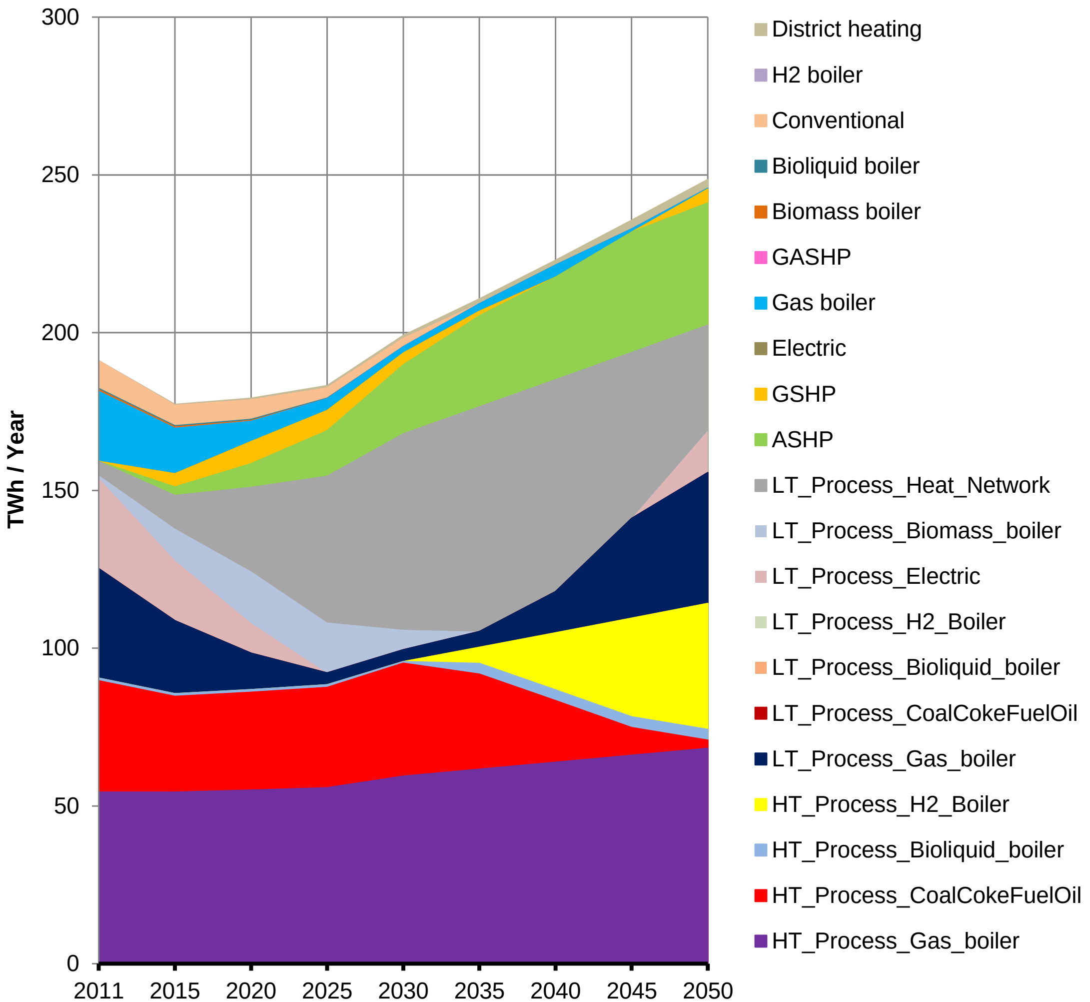


Overall heat network supply does not change significantly as a share of building heat demand (excluding cooking) except in the no CCS and no domestic gas cases where it rises from around 14% (in the core scenario) to 19% and 23% respectively.

The majority of heat network supply across the scenario is from nuclear waste heat (unless this option is unavailable), but does not get close to the imposed constraint on the contribution of waste heat from nuclear, except in the no CCS case.

In the 75 GW nuclear sensitivity it is interesting to note that this does not lead to increased heat network supply. By contrast, having greater low carbon electricity available it makes it easier to keep residual emissions in the wider energy system. As a result the model suggests it is then more cost-effective to keep additional residual gas in building heat than construct additional heat networks to take advantage of the greater supply of low carbon waste heat from nuclear.

Industry heat output - core scenario



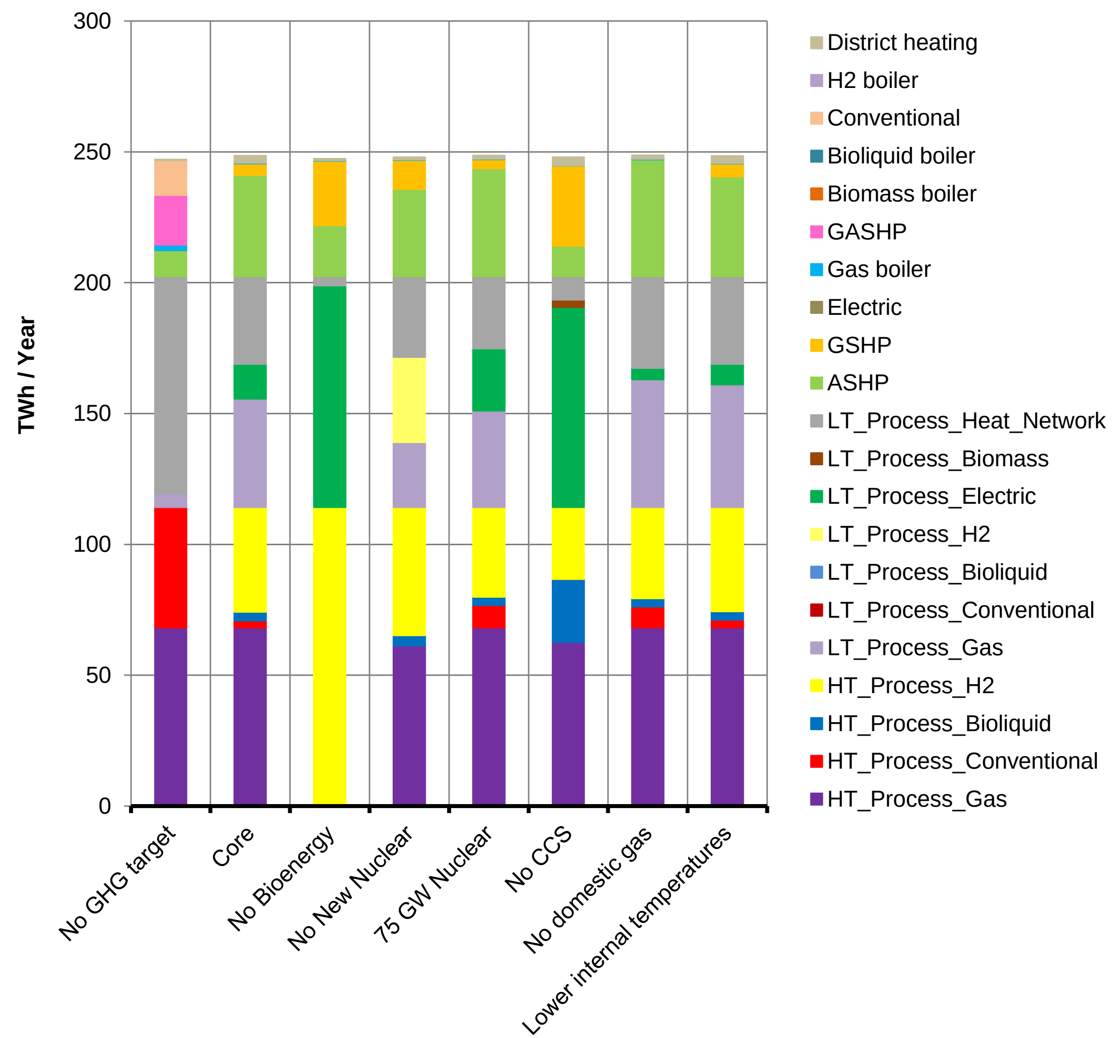
RESOM has a fairly high level representation of industrial heat demands based on the temperature required, with high temperature process (eg from furnaces), lower temperature process (steam and hot water) and building grade heat modelled separate.

The picture for high temperature applications, where there is less potential for fuel switching show a continued role for gas out to 2050 with the introduction of hydrogen post-2030.

For lower temperature processes and space heat, the core run suggests switching away from gas and electricity towards industrial heat networks sourced by CHP. However, by 2050 as the electricity grid decarbonises and given the constraint on the maximum deployment of large-scale CHP with CCS, the emissions savings from unabated CHP disappear, and a portion industry reverts to using high efficiency gas boilers. The remaining heat network supply is then from large-scale gas / bioenery CHP with CCS, as shown in subsequent slides.

For lower temperature space heating, gas boilers are replaced with a combination of air and ground source heat pumps.

Industry heat output – 2050 all sensitivities

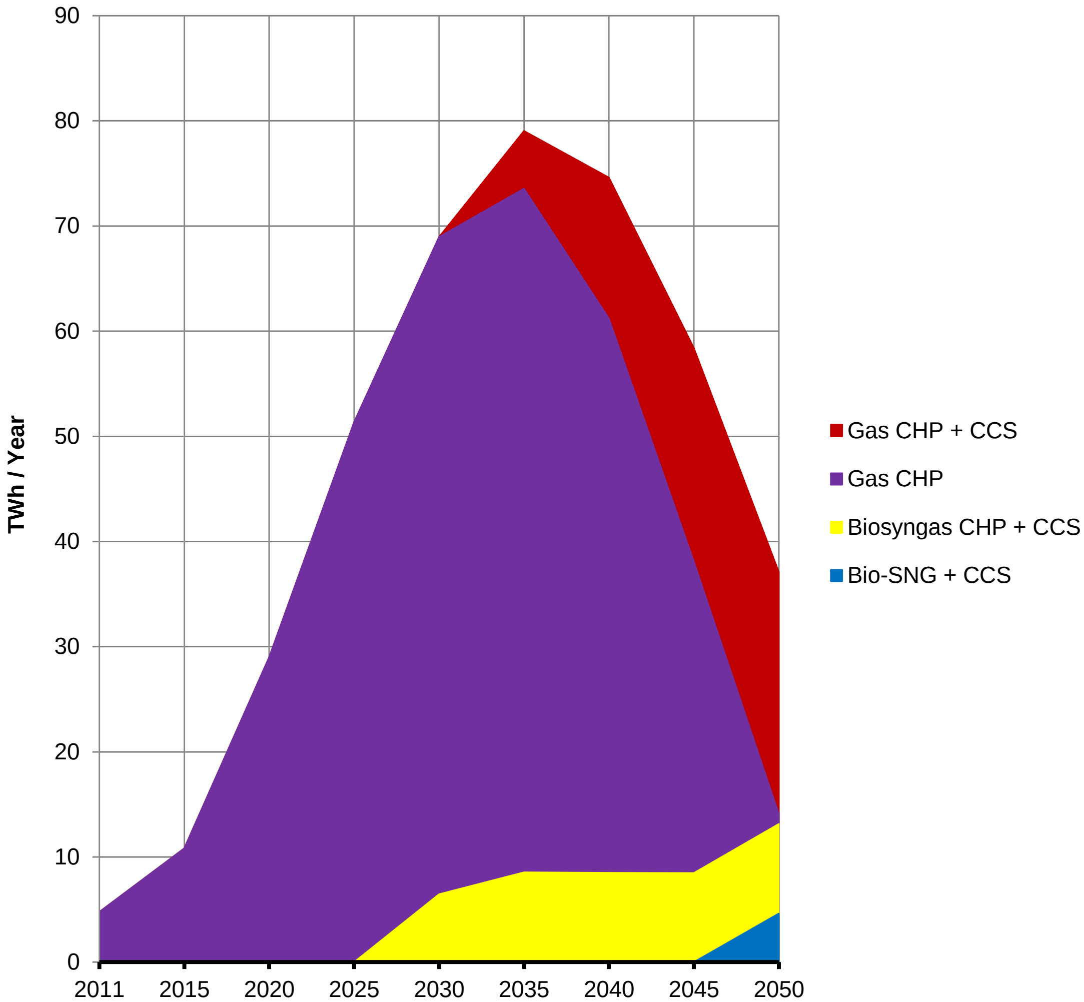


Without the option of using biomass and the negative credits that can be generated when used in combination with CCS, industry would have to make further emissions reductions. This sensitivity requires an almost total decarbonisation of industry, with hydrogen and electrical boilers replacing gas and gas CHP; to allow continued emissions in non-road transport, which now has .

Without new nuclear, industry must as a result decarbonise further, with lower gas use due to additional substitution of gas for hydrogen in lower temperature process heating.

Similarly, losing the option of CCS for the system as a whole results in some further decarbonisation of heat. In this scenario gas is only used high temperature processes, being replaced by hydrogen and bio-liquids in lower temperature applications.

Industry heat network supply - core scenario



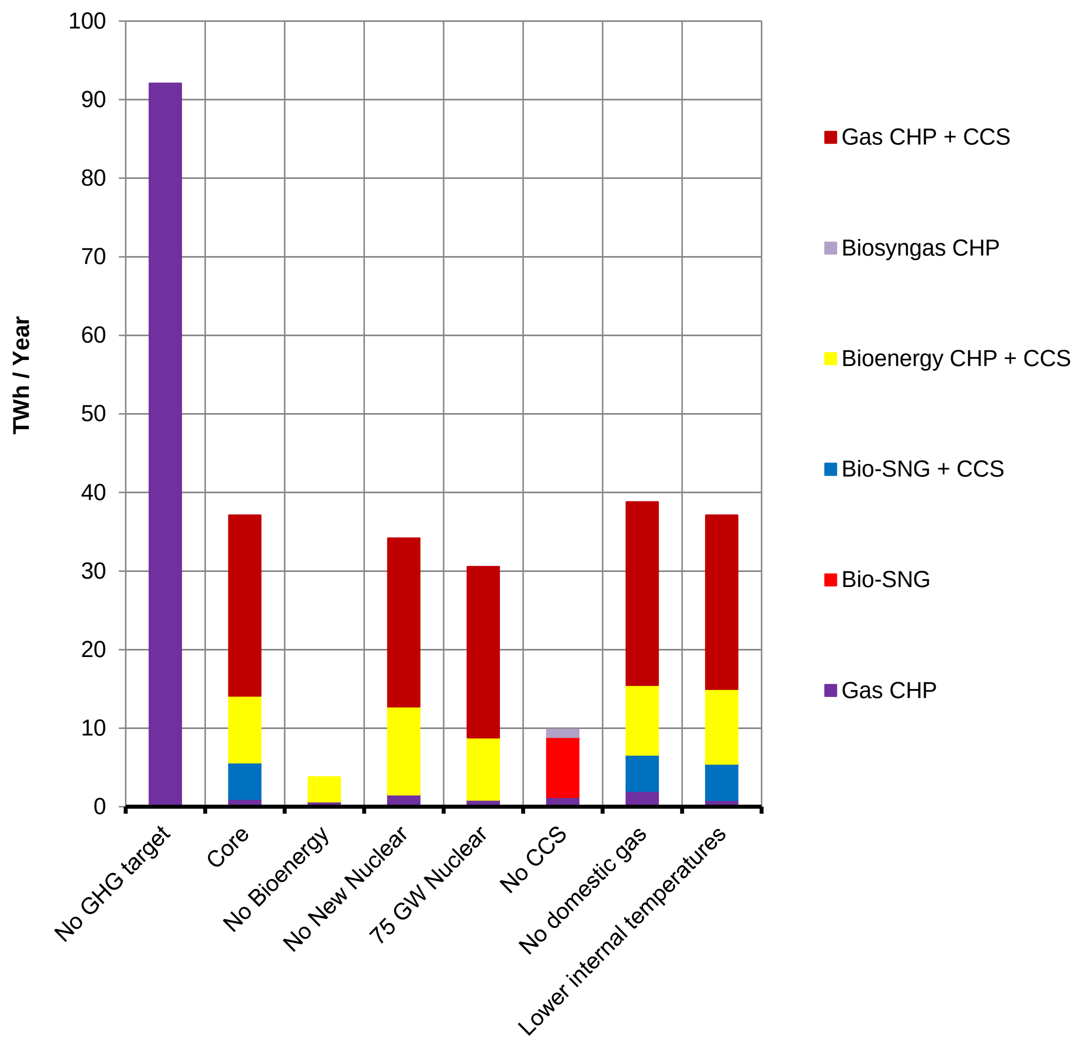
In the core scenario a significant portion of lower temperature process heat is provided by heat networks.

These are supplied primarily by unabated gas CHP until the 2030s. From 2030 to 2050 as the electricity grid decarbonises and given the constraint on the maximum deployment of large-scale CHP with CCS, the emissions savings from unabated CHP disappear, which squeezes the cost-effective supply through heat networks.

By 2050 only network heat produced from CCS-related routes, primarily gas, but also some bioenergy-related heat, is used.

As a result, the declining use in heat networks towards 2050 leads to a corresponding increase in direct gas boiler use as shown in the earlier industry slides.

Industry heat network supply – 2050 all sensitivities



The mix of industry heat network supply options in 2050 does not change significantly across the sensitivities, focusing primarily on gas CHP with CCS, and to a lesser extent bioenergy and CCS routes. The key exceptions are the no CCS and no bioenergy sensitivities.

In the former the difficulty in meeting the emissions target means that bio-SNG production is increased to try and help decarbonise some of the remaining gas use. As an indirect result of the process this some low-cost waste heat is available for industry heat networks.

In the no bioenergy case industry and most other sectors are almost completely decarbonised to allow continued emissions in non-road transport. As a result industry shifts predominately to electric and hydrogen based heat with minimal use of heat networks.

Contents

Conclusions

- Overall, the updated modelling highlights a significant decarbonisation of building heat within the overall energy system by 2050, with lower, but still substantial reductions in direct industrial emissions. Given the use of hydrogen in industry produced via bioenergy + CCS routes, which generate net negative CO2 reductions overall, the net overall emissions in industry could be considered as even further decarbonised.
- RESOM suggests a significant role for heat pumps and electrification of heat, combined with a sizeable, but focused role for heat networks. The use of a relatively detailed representation of the profile of heat demand within day and across seasons has helped to better understand how to more cost-effectively meet big seasonal and peak swings heat demand. As a result the core scenario and many of the sensitivities suggest there is still a key on-going role for gas in buildings providing winter top-up and peak heat supply. The key purpose of this is to avoid excessive, and increasingly costly, electricity generation and network reinforcements, to meet higher peak electricity demands if gas were not available.
- The sensitivities conducted have shown that the conclusions are robust to changes in the level of new nuclear that is deployed, with a domestic gas grid still part of the cost optimal solution in both the no new nuclear and 75GW scenarios we have examined. However, the modelling suggests that without the use of bioenergy sources or CCS, the much more stringent emissions reductions required would necessitate the total decarbonisation of buildings to meet the overall emissions target, given the limited alternatives for abatement in sectors such as non-road transport.
- The modelling has also highlighted the potential role for hydrogen to provide heat, primarily in industry. However, the current modelling of both hydrogen / gas networks and industry is at a relatively high-level given the need to model the entire energy system. Hence more detailed, sectoral analysis is needed to better understand the technical and economic constraints of both the use of hydrogen and the potential to repurpose or decommission parts of the local gas distribution grids for hydrogen transport.

Areas for further work

- The key purpose of whole energy system models is to help understand the trade-offs within *and* across energy sectors *simultaneously,* as part of answering questions such as how best to meet our emission targets. However, doing this limits the level of detail that can realistically be reflected in each sector. Analysis becomes an on-going cycle of exploring the impacts at a system-level followed by deep dives into specific sectors using other models and tools to understand whether the system conclusions hold, or whether there are specific issues or constraints that need to be included in new analysis at the system level. The need to meet large seasonal and peak swings heat demands at a building level, and the subsequent impact on the wider electricity system if heat is electrified is an example of this. From this analysis industry appears to be a key candidate further investigation, in particular the potential for large-scale use of hydrogen and / or heat networks sourced via CCS-connected plant, as other novel technologies which were not include in this analysis, such as electricity for high-temperature process heat.
- Other potential areas for further work include:
  - Improvements to the representation of gas and hydrogen grids, in particular better reflecting their costs and endogenously reflecting the choice to repurpose the gas network to hydrogen or decommission parts of it
  - Adding elastic demand response, as per the MARKAL-ED model used by DECC, which would allow endogenous response of energy service demands, such as for heating, to changes in price
  - Converting the model to a MIP (Mixed Integer Program) optimisation rather than the current LP (Linear Program) optimisation would allow us to better reflect investment choices and their costs in a number of areas (although this would lead to a significant model performance penalty), for example:
    - Lumpiness of large scale investment (eg in new nuclear plant or district heating) and economies of scale (eg piecemeal efficiency retrofits versus coordinated large-scale rollout)
    - Discrete choices for building heat and / or retrofit efficiency packages for different building type
- Improved geographical detail is also often discussed, however, significantly improved detail to accurately cost eg district heat networks or electricity distribution network reinforcements is likely to make a whole energy system-level problem intractable.