DEPARTMENT OF ENERGY & CLIMATE CHANGE

Bioenergy Strategy Analytical Annex

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Contents

Glossary of terms/acronyms

- AUB – Appropriate Use of Bioenergy model.
- Backstop emission credit – artificial product used as a last resort in the AUB model when other options are not sufficient to meet the GHG target.
- Biomethane – gaseous form of bioenergy upgraded from biogas to comparable quality standard to natural gas.
- Biofuels (often referred to as liquids or bioliquids for transport in modelling results) - fossil fuel substitutes, that can be made from a range of agricultural crops, usually oily crops for biodiesel and crops rich in sugars or starch for bioethanol. By-products and wastes such as used cooking oil, tallow and municipal solid waste can also be used to produce biofuels.
- CCGT – Combined Cycle Gas Turbine.
- CCS – Carbon Capture and Storage.
- Energy carriers – products only produced by technologies in the AUB model such as electricity or hydrogen.
- Feed and fodder crops – category of bioresources covering various oil, starch and sugar crops.
- Forestry and forestry residues – category of bioresources covering stemwood, sawmill co-products, short rotation forestry and various other forestry residues.
- H2 – Hydrogen.
- HGV – Heavy Goods Vehicle.
- IGCC – Integrated Gasification Combined Cycle.
- Levelised cost (of generation) – the discounted lifetime cost of owning and operating a power plant expressed on a per unit of output basis (£/MWh or p/kWh).
- Lifecycle emissions – GHG emissions associated with the cultivation, transport and processing of bioenergy.
- Negative emissions – generated by the application of CCS to bioenergy to avoid the re-release of carbon (absorbed during growth of the bioenergy) to the atmosphere.
- Non-energy use – use of bioenergy outside of the energy system, e.g. wood in construction.
- Optimisation – mathematical process to find a maximum or minimum value from a set of possible alternatives.
- Pathways – conceptual representation of the flow of energy products from initial resource, through potential intermediate technologies to delivery of the final energy service demand.
- Perfect foresight – mode of operation of the AUB model which finds an optimal solution across all time periods simultaneously.
- ULEV – Ultra Low Emission Vehicles emitting less than 75gCO2/km.
- Wastes – category of bioresources covering food and other biodegradable waste, landfill gas, sewage sludge and livestock manures.

Biomass feedstocks:

- Agricultural residues/waste – including: manures and slurries (energy recovered from anaerobic digestion); and agricultural residues (energy recovered from incineration).
- Energy crops – woody crops grown specifically for their energy content, for example, miscanthus can be burnt to generate power.
- Forestry and forestry residues/wood products - includes the following: Arboricultural arisings, forestry residues, sawmill co-products, short rotation forestry, and stemwood.
- Wastes - feedstocks including food and green wastes (e.g. grass and soft biodegradables such as garden wastes like hedge and grass trimmings) used for anaerobic digestion; the renewable fraction of solid wastes used for incineration; landfill gas[1]; recovered materials such as waste wood, tallow and used cooking oil for biofuels; and sewage sludge.
- Arable crops – crops such as wheat, oilseed rape, maize and sugar beet can be used for first generation biofuels and for anaerobic digestion.

[1] To note: Landfill gas is an energy outcome as a result of waste that has been directed to landfill, not a feedstock in itself.

Executive Summary

This Analytical Annex summarises the bioenergy pathway analysis developed to inform the 2012 Bioenergy Strategy. While recognising the risks and uncertainties and evolving nature of the evidence, this analysis is useful in informing our thinking on potential low risk pathways, highlighting trade-offs and technological tipping points. In the context of the Bioenergy Strategy this is crucial in gaining better understanding of the options for bioenergy in contributing to 2050 decarbonisation objectives, while also meeting our 2020 renewables targets. The analysis explained in this Analytical Annex represents a snap shot of the available data and our current understanding of biomass technologies and pathways. The analysis is based on a working model and the assumptions will be reviewed and updated as new data becomes available.

This Analytical Annex is structured to mirror the analytical process undertaken, and includes three key sections: bioresource supply; technology costs; and finally the Appropriate Use of Bioenergy (AUB) modelling. The first two sections provide the key exogenous inputs[2] into the AUB model.

Estimating bioresource scenarios for AUB modelling

Estimating future bioresource supply that could potentially be available to the UK is a challenging task that has been the focus of numerous studies at both global and regional level. Our analysis is based on work commissioned by DECC and undertaken by AEA Technology, Forest Research and Oxford Economics[3]. The bioresource supply scenarios were developed for use in the AUB modelling, and to test how robust the patterns of bioenergy use were to changing bioresource availability. The intention is not to forecast future bioresources available to the UK, but to provide an adequate range of estimates to test the robustness of our low risk[4] uses of bioenergy, while taking into account key considerations such as, uncertainty around planting and yield rates and land availability. Our supply ranges take into account the estimated land requirements for competing uses, such as food production. We have also considered the current state of the UK Wood Market, please see Appendix 1 for further details.

Three supply scenarios were derived, based primarily on flexing the assumptions in the AEA model, such as: global demand for bioresources; land productivity; and technological

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[2] For a full description of AUB assumptions and input data see Redpoint report (April 2012) available on DECC web site http://www.decc.gov.uk/en/content/cms/meeting_energy/bioenergy/strategy/strategy.aspx
[3] AEA 'UK and Global Bioenergy Resource' (March 2011) http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/incentive/incentive.aspx
[4] Low risk in this context refers to biomass technologies that have been found to be robust to different sensitivity runs of the model in certain time periods, e.g. medium term transition role or longer term role to 2050.

development. The scenarios also took into account feedback received from stakeholders[5], and revised information for certain feedstocks (e.g. availability of UK waste). The AEA analysis was also extended to provide estimates out to 2050 by assuming a range of decreasing linear trajectories for the UK share of global bioresources available for import. This is based on the assumption that the UK continues to be a net importer of bioresources and in the longer term demand for bioresources will increase globally as more countries will be competing for this scarce resource.

The assumption that the UK will have access to a declining share of total bioresource available on the traded market is subject to great uncertainty and in practice the UK import share will depend on a range of factors, including the willingness to pay by different countries, development of supply contracts and the incentives in place to use biomass. Estimates of global resource availability are inherently more uncertain in the longer term, however our estimated range of bioresources potentially available narrows towards 2050. This is due to the assumption that the UK has access to a declining fraction of global bioresources available for import over time which scales down the absolute values of the range. This should not be interpreted as the estimated bioresource availability becoming more certain.

The range is chosen to test the robustness of our conclusions from the AUB modelling and to gain insights from a range of different scenarios. The ranges resulting from this analysis imply total available supply from UK and imported sources at around 200–650 TWh in 2020 and 200–550 TWh in 2050[6] on a primary energy basis. Of this total, domestic supply contributes between 100–150 TWh in 2020, and 100–200 TWh in 2050. The imported supply ranges between 100–500 TWh in 2020, and 100–350 TWh in 2050, the majority of which is expected to be from energy crops. Further information on these assumptions is included in Section 1.

Estimating technology costs for AUB modelling

Biomass is a constrained resource so it is important to know where its use across the economy yields the biggest benefits. To do this we need to take into account the cost effectiveness of using bioenergy, both in renewable and carbon terms, relative to alternative technologies (e.g. wind in power or heat pumps for space heating). If the non-biomass option has a lower cost per tonne of abatement, there is strong case for prioritising bioenergy use in different sectors with fewer alternative decarbonisation options or in applications where bioenergy has a lower abatement cost.

[5] Industry, NGOs and wider stakeholders with an interest in bioenergy have contributed in shaping the analysis through a series of workshops and meetings organised by DECC over the last year. Assumptions regarding key drivers and constraints to future supply were discussed helping to develop the final range of supply scenarios.

[6] AEA provide bioresource estimates out to 2030. DECC supply scenarios are based on ranges derived from AEA to 2030. UK sourced supply is assumed to be held flat from 2030 to 2050, and imported supply is assumed to be on a downward trajectory towards 2050.

Section 2 presents a static comparative analysis of the cost of different bioenergy applications to generate renewable energy and the cost-effectiveness of using these to reduce carbon emissions, taking into account the life-cycle emissions associated with producing bioenergy feedstocks. This gives a snap-shot of the relative cost-effectiveness of different technologies and applications at a particular point in time, and outlines the technology cost data consistent with those used for the AUB modelling.

Key conclusions include:

- The bioenergy electricity technology costs generally lie between onshore and offshore wind costs, but precise costs will vary with biomass prices, gate fee costs and key operational parameters.
- For the heat sector, the data shows that some applications of bioenergy are cheaper than fossil fuels, particularly when replacing electric heating.
- In 2020, projected transport biofuel production costs are generally higher than their fossil fuel counterparts though processes that use wastes are within a similar range. By 2030, biofuels are projected to be more cost effective, primarily due to rising oil prices and improvements in advanced biofuel technologies.

In terms of carbon cost effectiveness, the analysis shows that heat applications, especially in the industrial/commercial sectors and replacing non-net bound fuels or electricity are among the most cost effective in terms of cost of abating carbon. Biomass conversions are also relatively cost-effective, driven largely by their lower technology costs and because they displace coal burnt. Imported feedstocks tend to have a higher carbon footprint than locally grown feedstocks but also a wider range because of the greater heterogeneity in key parameters such as cultivation and harvesting techniques, transport distances and modes. For the transport sector, advanced biofuels using waste feedstocks are projected to be highly cost effective. In comparison, advanced biofuels using woody feedstocks are projected to be a more expensive form of abatement, reflecting higher feedstock costs.

The Appropriate Use of Bioenergy (AUB) model

The AUB model is a least cost energy system optimisation framework that identifies an optimal technology pathway up to 2050 subject to a number of constraints, such as: the Renewable Energy Directive 2020 target; a 2050 emissions target; energy service demands; and the availability of technologies. The model looks at technology pathway options (including bioenergy, other decarbonisation options, and fossil fuels) across all sectors (heat, electricity, transport and wood in construction) and provides a high level framework that allows us to gain an understanding of the tradeoffs between sectors and technologies in the context of post 2020 decarbonisation objectives. There are considerable uncertainties surrounding the assumptions on technologies (in terms of costs and availability), especially in the longer term. Therefore sensitivity analysis is crucial to identifying low risk pathways and avoiding locking in unsuitable applications (see Section 3 and Appendix 2).

The AUB model is best suited to identifying potential long term pathways for bioenergy use across sectors, and does not include any policy incentives, for example the Renewables Obligation and the Renewable Heat Incentive. Decisions are made on economic grounds alone (subject to other constraints), and the model does not include investor behaviour or model the demand side (e.g. barriers to take up particular technologies or demand responses to different prices). This is in contrast to shorter term individual (sector specific) instrument models, used to set financial incentives, where the key aim is to contribute to the 2020 renewables target. These models can be updated quickly to respond to changing market information (e.g. on costs and deployment) and government priorities, which is crucial for setting financial incentives. AUB adds value by providing insights into the longer term and checking consistency with how financial incentives are being set (i.e. avoiding locking in bioresources in one sector, without considering its potential application across all sectors).

Prices, energy demand across sectors and the availability of resources are all entered as exogenous inputs to the AUB model. In order to carry out sensitivity analysis around these inputs the model must be re-run and results compared. The model does not include the functionality to dynamically change prices, resource supply levels or demand across sectors, in order for the market to clear. That is, there can be amounts of potential primary energy inputs (e.g. bioresources, fossil fuels, and renewables such as potential heat pump deployment) available to the model that are not fully utilised in any one run.

Over the period of analysis the constraints that the model must meet have an impact on the technology pathways taken up, for instance in the near term the 2020 renewables target is the binding constraint and will influence what types of technologies are brought in to the energy system mix, whereas in the longer term the effort to meet the binding emissions constraint becomes the key driver. Throughout the period, the availability of certain technologies, build rate limits, and meeting energy service demands will restrict what pathways the model can choose.

Key conclusions from AUB modelling

The level of bioresource availability and the availability of Carbon Capture and Storage (CCS)[7], have emerged as the two key determinants in switching the patterns of bioenergy use across sectors and technologies in the long term. The modelling results highlight the difficulty in meeting the 2050 emissions target in an environment without access to CCS technology or sufficient bioresources. The relative costs and availability of the technologies are subject to significant

[7] CCS has the potential to generate 'negative emissions' when used with bioenergy, this is highly valued by the model as it helps reduce the overall costs of meeting the emissions target by creating greater headroom for emissions in other sectors of the energy system which are difficult or more expensive to abate. When CCS is not available to generate 'negative emissions' the model uses bioenergy to displace fossil fuels in sectors with limited alternatives.

uncertainty (especially for unproven technologies in later periods, e.g. bio-hydrogen for transport), and small changes to these assumptions can lead to large changes in the technology pathways taken up by the model (see results in section 3 and appendix 2 for sensitivity analysis on this issue). **Therefore the principal message emerging from the analysis is that the availability of CCS is key in the longer term, but application to individual technologies will depend on the relative economics and availability (which is highly uncertain), and therefore options need to be kept open until we develop our understanding of emerging technologies.**

The modelling scenarios we have considered in this analysis also help identify certain bioenergy uses that emerge as low risk options. These include the following:

- Non-energy uses for biomass such as wood in construction.
- The use of bioenergy for industrial heat (specifically high temperature process).
- A medium term transition role for biomass space heating in the domestic sector.
- Use of bioenergy for conversions and co-firing in the electricity sector in the 2020's.
- Generation of heat and electricity through combined heat and power processes and with the efficient utilisation of recoverable wastes.

In addition, so long as sustainability can be assured, and while fossil fuels continue to be used in transport, some conventional biofuels can offer a cost effective contribution to reducing carbon emissions from road transport.

The modelling also identified Gasification as an important technology across sectors, e.g. for biomethane in the heat sector, and for advanced biofuels and bio-hydrogen production in the transport sector[8]. Therefore commercialising this technology is of fundamental importance.

Further discussion around these low risk uses of bioenergy, and the implications for innovation needs and policy, can be found in the Bioenergy Strategy document[9].

[8] There is considerable uncertainty around key technologies that emerge from the modelling results, such as: bio hydrogen in surface transport and CCS technology.
[9] http://www.decc.gov.uk/en/content/cms/meeting_energy/bioenergy/strategy/strategy.aspx

Introduction

1. This Analytical Annex sets out the bioenergy pathway analysis developed for the Bioenergy Strategy, which has helped develop our understanding around potential low risk uses of bioenergy to 2050. Developing a robust evidence base, while recognising risks and uncertainties, is fundamental in identifying low risk pathways, highlighting key innovative technologies and trade-offs, and providing a foundation for making informed policy decisions. The analysis explained in this Analytical Annex represents a snap shot of the available data and our current understanding of biomass technologies and pathways. The analysis is based on a working model and the assumptions will be reviewed and updated as new data becomes available.

2. The underlying modelling and analysis is intended to provide a high level view of different bioenergy uses to 2050. It does not set out to provide a forecast or projection of the feasible or intended pathways for bioenergy use in the period to 2050, neither does it provide a pathway for the whole energy system mix viewed as a whole. It is important to note that the modelling is based on a large number of highly uncertain assumptions, such as the availability and costs of unproven bioenergy technologies in the longer term. The modelling results should therefore be interpreted with an appropriate degree of caution.

3. This Analytical Annex is structured to mirror the analytical process undertaken, and includes three key sections: bioresource supply; technology costs; and finally the Appropriate Use of Bioenergy (AUB) modelling. The first two sections provide key exogenous inputs[10] into the AUB model. In addition to the analysis outlined in this annex, DECC commissioned a study looking at the carbon impacts of the use of woody feedstocks in bioenergy[11]. The findings of this study are not covered in this annex but can be found on the DECC website alongside the Bioenergy Strategy.

[10] For a full description of AUB assumptions and input data see Redpoint report (April 2012) http://www.decc.gov.uk/en/content/cms/meeting_energy/bioenergy/strategy/strategy.aspx
[11] Forestry Research (2012) 'Carbon Impacts of using Biomass in Bioenergy and other sectors: forests' (see link above).

Section 1 - Biomass Supply Scenarios for use in Appropriate Use of Bioenergy (AUB) modelling

Overview of Biomass Supply scenarios

4. In this section we set out our analysis of the potential range of sustainable bioenergy feedstock supplies that could be available to the UK over the period to 2050. We recognise that any assessment of bioenergy resource availability, especially imported supply, is subject to significant uncertainties, particularly over the longer term. In developing our supply ranges key factors affecting bioresource supply have been taken into consideration, including global demand for bioresources, land productivity and technological development, competing uses for land and biomass prices. The bioresource ranges presented here include both domestically sourced supply and imported supply; both having a potentially important role in the UK supply of sustainable bioresources in the future.

5. Developing scenarios on the potential availability of future biomass resources is a challenging task that has been the focus of numerous studies at both global and regional level. The analysis in the Bioenergy strategy is based on analysis commissioned by DECC and undertaken by AEA Technology, Forest Research and Oxford Economics[12]. This report was used rather than other studies because of the scope of the analysis, the range of scenarios used and the ability of users to change key parameters as new evidence and data emerge. The report was steered by DECC and other government departments, with individual stakeholders inputting into specific areas. Since the report was published, we have modified it to reflect feedback received from stakeholders[13], revised information that has become available for certain feedstocks (e.g. UK waste), as well as applying different assumptions for imported feedstocks based on internal Government analysis.

6. The AEA report examines potential biomass supply in the UK between 2010 and 2030, from UK and international sources, subject to a series of constraints. The report provides several

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[12] AEA 'UK and Global Bioenergy Resource' (March 2011) http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/incentive/incentive.aspx

[13] Industry, NGOs and wider stakeholders with an interest in bioenergy have contributed in shaping the analysis through a series of workshops and meetings organised by DECC over the last year. Assumptions regarding key drivers and constraints to future supply were discussed and helped develop the final range of supply scenarios.

scenarios that can be used to present a range of estimates; these are based on flexing assumptions on price and the ability of the market to overcome deployment constraints. The analysis distinguishes between UK domestic supply and global resources available to the UK. DECC supply scenarios are based on ranges derived from AEA to 2030, taking into account the key uncertainties surrounding supply estimates. UK sourced supply is assumed to be held flat from 2030 to 2050 (due to the significant uncertainties in projecting supply over the longer term), and imported supply is assumed to be on a downward trajectory towards 2050 (explained further in paragraphs 33 - 35).

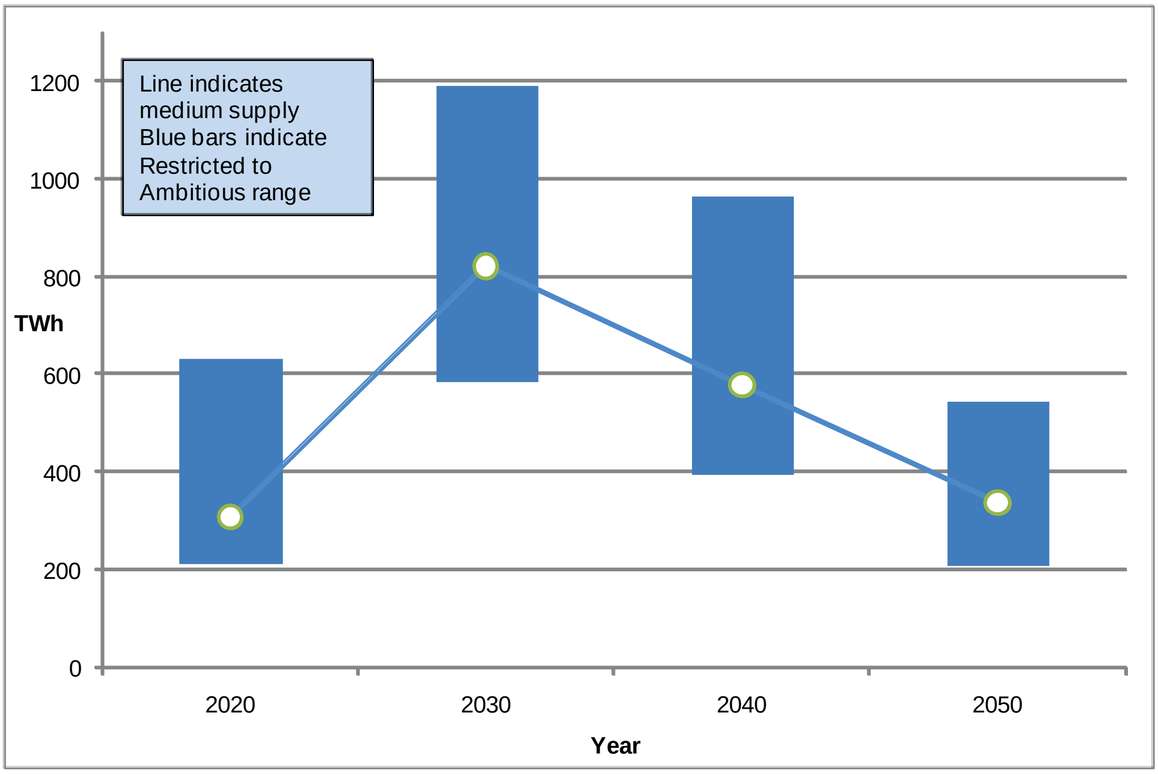
7. The supply scenarios for solid biomass do not explicitly take account of GHG emissions or of related issues such as enforcement and wider sustainability concerns such as biodiversity and indirect land use change. The land used for energy crops for all fuels is assumed to come from abandoned agricultural land[14]; however, any change of carbon stock of this land as a result of the cultivation of biofuels crops is not considered. For biofuels the Renewable Energy Directive sustainability criteria have been applied.

8. Figure 1 below shows the ranges resulting from this analysis implying total available supply from UK and imported sources at around 200–650 TWh in 2020 and 200–550 TWh in 2050[15] on a primary energy basis. Of this total, domestic supply contributes between 100–150 TWh in 2020, and 100–200 TWh in 2050. The imported supply ranges between 100–500 TWh in 2020, and 100–350 TWh in 2050. The ranges set out the scale of sustainable bioresource supply that we consider has adequately tested for the impacts of varying the resource constraint on the patterns of bioenergy use that emerge from our Appropriate Use of Bioenergy (AUB) modelling (this is explained further in Section 2). However, they do not cover the full range of scenarios developed by AEA.

[14] The Government's Foresight Report: The Future of Food and Farming concludes that we should plan for very limited additional agricultural land in future over and above currently abandoned agricultural land. AEA methodology is consistent with this given their assumption that all global land potentially available is abandoned agricultural land. It is assumed this 'abandoned' land does not have a high carbon content or that is required for other uses, however clearly there is a high degree of uncertainty regarding alternative potential uses for 'abandoned' agricultural land and potential changes to carbon stock as energy crops are cultivated.

[15] AEA provide bioresource estimates out to 2030. DECC supply scenarios are based on ranges derived from AEA to 2030. UK sourced supply is assumed to be held flat from 2030 to 2050, and imported supply is assumed to be on a downward trajectory towards 2050.

Figure 1: Bioresource supply ranges (including domestic and imported supplies) potentially available to the UK from 2020 to 2050



Source: Ranges based on DECC analysis using AEA Bioenergy Resource model

Supply scenario modelling assumptions:

Restricted supply – low biomass prices (up to £4/GJ) with high constraints to deployment of feedstocks and low international development. Of the supply that could be available to trade internationally, UK has access to 10% to 2020 reducing to 1.5% in 2050 as carbon constraints tighten and competition for resources intensifies.

Medium supply – medium biomass prices (up to £6/GJ) with medium constraints to deployment of feedstocks and medium (business as usual) international development. The UK has access to 10% of internationally traded biomass up to 2020 reducing to 2% in 2050. Increases in global planting rates of energy crops are delayed by 5 years reflecting near term uncertainties on the global development of energy crops.

Ambitious supply – high biomass prices (up to £10/GJ), low constraints to deployment of feedstocks and a high international development. The UK has access to 10% of internationally traded biomass up to 2020 reducing to 3% in 2050. In order to be cautious on medium term availability this scenario assumes a downward linear trajectory from 2025.

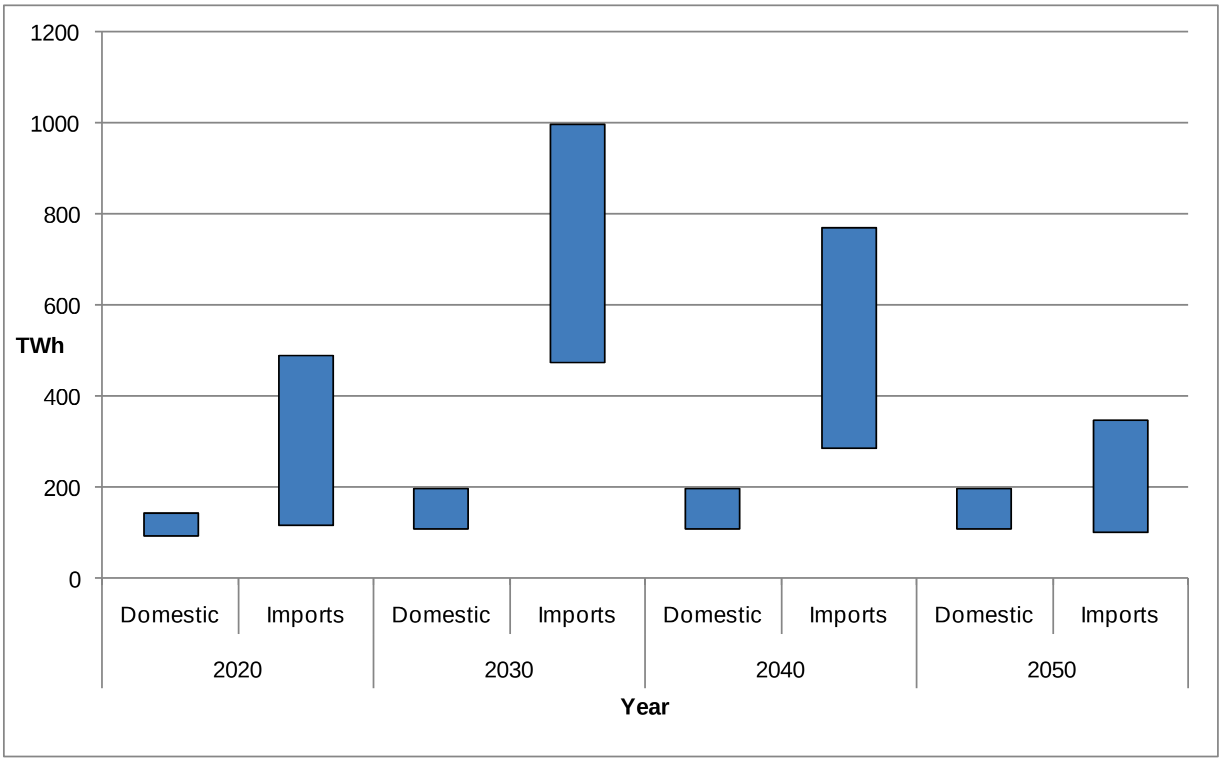
All scenarios include the latest waste availability assumptions from Defra and maximise woody energy crop production as opposed to first generation Biofuel crops.

The key assumptions behind the three supply scenarios are explained below:

Domestic supply

9. We expect imports to dominate the supply available to the UK based on our ranges (see Figure 2 below). Yet domestic resources will still play an important role in helping establish a stable and secure bioresource supply base for the UK bioenergy sector, especially for smaller bioenergy plants that wish to utilise cost effective local resources.

Figure 2: Range of available domestic and imported bioresource supply implied by DECC supply scenarios from 2020 to 2050



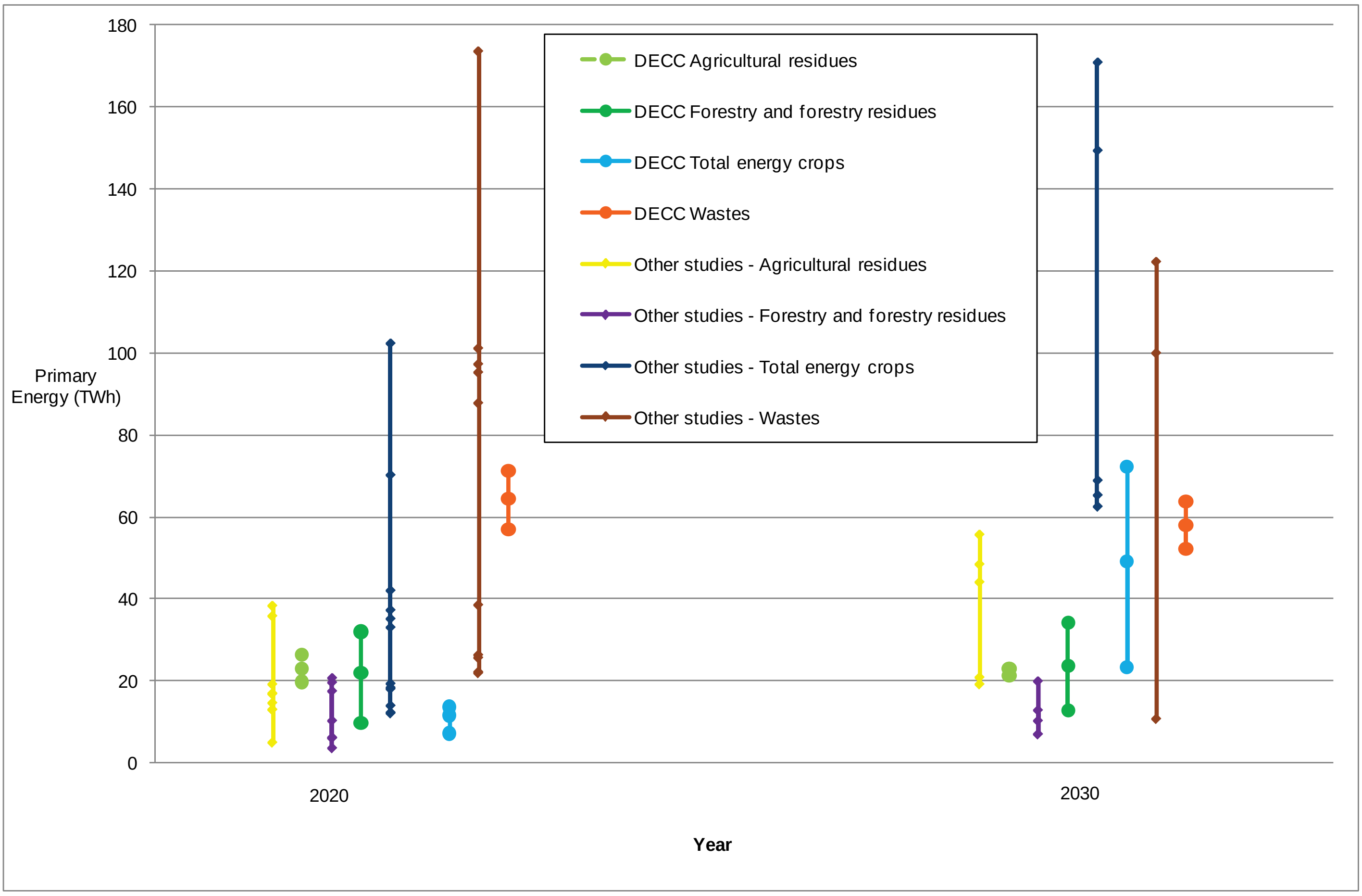
Source: DECC analysis using AEA Bioenergy Resource model

Note: Estimates of global resource availability become more uncertain in the longer term (i.e. you would expect the range of estimates to widen over time). Figure 2 shows the range of import estimates narrowing towards 2050 – this is due to the assumption that the UK has access to a declining fraction of imports over time, and should not be interpreted as the estimated import availability becoming more certain.

10. Our estimates of potential availability of domestic supplies are well within a range of studies[16] on this area (see Figure 3 below), suggesting that this potential could be realised provided the right deployment barriers are addressed. Figure 3 below indicates that the greatest growth in domestically sourced feedstock will come from wastes and energy crops.

[16] UKERC Working Paper (2010) 'The UK bio-energy resource base to 2050: estimates, assumptions, and uncertainties'

Figure 3: DECC domestically sourced biomass feedstock range in 2020 and 2030 in the context of other studies

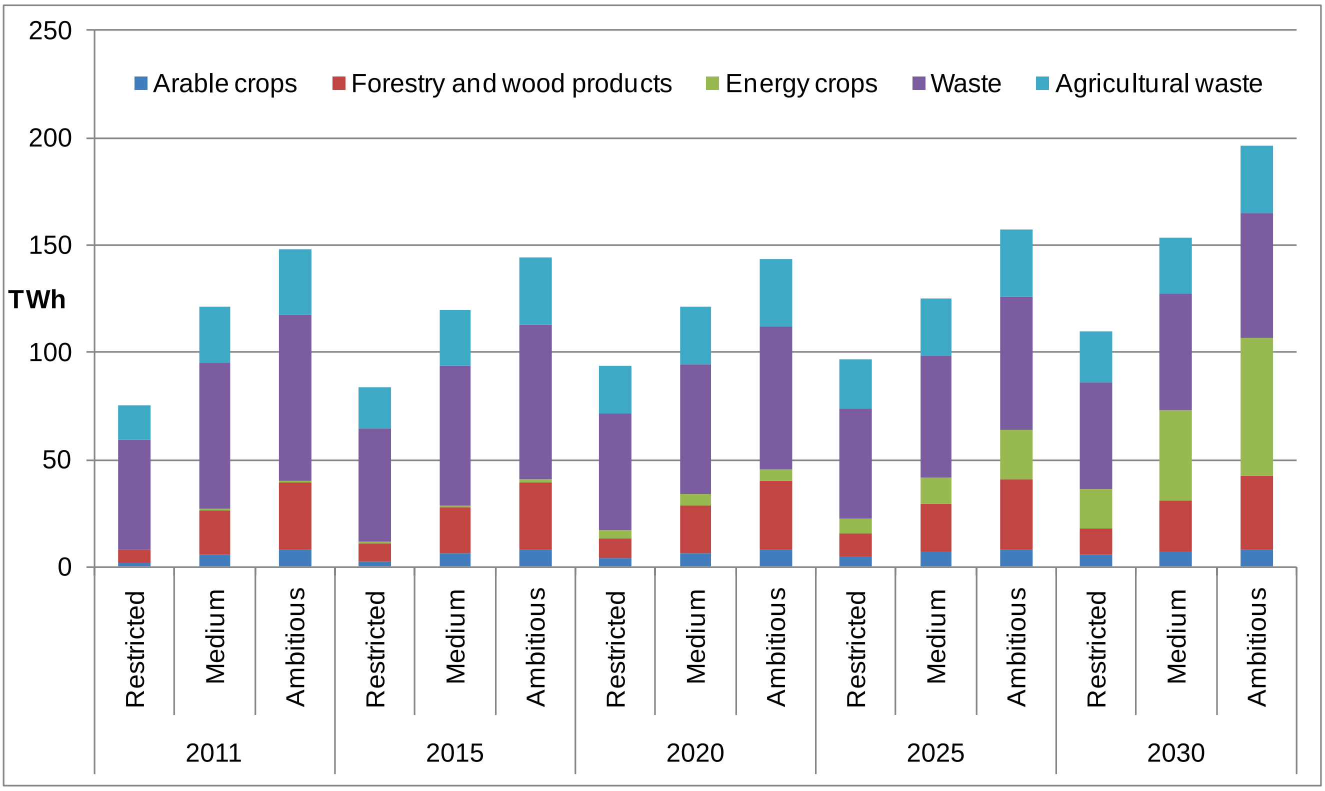


Source: Figure adapted from UKERC working paper (March 2010) ref: UKERC/WP/TPA/2010/002

Domestic supply

11. Figure 4 provides a breakdown of the UK feedstocks that are assumed in the three DECC supply scenarios. The availability of all groups of feedstocks can be seen to increase from the restricted scenario to the ambitious scenario and the ranges provide a low to high sensitivity for domestic resources around the medium scenario of approximately 20% in 2020 and 30% in 2030. In comparison to the other feedstock categories, domestically produced energy crops have the most significant ramp up in terms of availability over the period. The range between the DECC scenarios is due to assumptions around price and the ability to overcome market constraints such as: production capacity in the UK, uncertainty over sustainability standards, yields, and public acceptance.

Figure 4: UK bioresource supply broken down by feedstock for DECC supply scenarios from 2011 to 2030



Source: DECC analysis using AEA Bioenergy Resource model

Note: UK current oil crops and sugar/starch crops (bioethanol feedstocks) are included within Arable crops.

12. The feasible potential of UK feedstocks is estimated to be between 75-148 TWh in 2011 based on the supply scenarios, made up of wastes, agricultural wastes and residues, arable crops, and woodland and forestry residues. By 2020, this is projected to be between 93-143 TWh as energy crops begin to play a role. By 2030, the projection increases to between 110-196 TWh as further development of energy crops is anticipated along with increased potential of forestry and other wood products. Over time the composition of UK feedstocks is expected to change, with landfill gas showing a marked decline in each of the DECC scenarios as efforts to reduce waste to landfill succeed. Energy crops represented 0 - 0.4% of all UK feedstocks in 2011 and are estimated to grow significantly to between 16 - 33% of the total potential by 2030 as planting and yield rates increase.

Arable crops

13. Arable crops such as wheat, oilseed rape, maize and sugar beet can be used for first generation biofuels and for anaerobic digestion. They are part of the global cereals market and their use as bioenergy feedstocks is already well developed. Current potential for UK arable crops is estimated to be between 2 - 8 TWh. Their potential is expected to grow to between 5 - 8 TWh in 2030 as yield improvements release land from food production to grow

biofuels feedstocks. The DECC supply scenarios are equivalent to approximately 0.2 to 0.3 Mha (million hectares) of UK biofuel crops by 2030.

Forestry and wood products

14. Bioenergy feedstocks from existing woodlands, forests, urban spaces and transport corridors, co-products of the sawmill industry, development of short rotation forestry and small round wood markets represent a significant potential contribution to the UK bioenergy resource. The DECC scenarios estimate current potential to be between 6 - 31 TWh, rising to between 13 - 34 TWh by 2030, which implies between 2.4 and 6.5 Modt (million oven dried tonnes) of UK forestry resources[17] by 2030. This range represents the challenges around developing markets and supply chains for some of these markets, along with economic barriers related to the cost effectiveness of their collection. See box 1 below for more information.

[17] Forestry resources includes the following: Arboricultural arisings, forestry residues, sawmill co-products, short rotation forestry, and stemwood.

Box 1: Supplies from the existing UK forests

The Woodfuel Implementation Plan 2011 - 2014[1] outlines the actions that Forestry Commission England is taking to enable private businesses to consolidate and grow the supply chain. The plan builds on the 2007 Woodfuel Strategy for England that outlined ambitions for bringing 2 Million green tonnes of wood to energy markets annually on top of the current production levels. Progress has been made towards this ambition but around 48% of English woodlands remain under managed[2], partly due to a lack of viable local markets for small diameter thinnings. Broadleaved woodlands in particular remain underutilised. The deployment of more biomass boilers, supported by the RHI is helping to create a market for this underutilised resource. The Independent Panel on Forestry[3] have been asked to consider how woodland cover can be increased in England.

Scotland currently provides around 68% of the UK softwood timber harvest. Scotland's Wood Fuel Task Force estimates that, in the period 2017 – 2021 up to 2.4 Mgt of wood fibre may be available after deducting current demand. This estimate takes into account wood from all sources including waste wood and brash. Both the bioenergy and wood processing industries will use a proportion of this fibre for their growth and this additional resource includes a significant volume of sawlogs which are more suited to sawn timber production.[4]

In Wales, estimates suggest that a further 0.2 Mgt of wood could be supplied from under managed woodlands[5]. In addition to woodfuel produced by forest management, energy supply chains of all scales use significant volumes of wood supplied by tree surgeons, grounds maintenance companies and from wood processing businesses but data on the extent to which supply from these sources can be increased are not always available.

Notes:

[1] Forestry Commission England Woodfuel Implementation Plan 2011 – 2014
http://www.forestry.gov.uk/pdf/FCE_WIP_Web.pdf/$FILE/FCE_WIP_Web.pdf
[2] Forestry Commission England impact and input indicators 2011 – 2015. Headline performance report at 30 September 2011 (first release)
http://www.forestry.gov.uk/pdf/FC_ENGLAND_TOPSIX_INDICATORS_30SEP11_FINAL.pdf/$FILE/FC_ENGLAND_TOPSIX_INDICATORS_30SEP11_FINAL.pdf [Accessed 07/02/2012]
[3] Independent panel on forestry http://www.defra.gov.uk/forestrypanel/ [Accessed 07/02/2012]
[4] Woodfuel Taskforce 2. The supply of wood for energy production in Scotland. An update report by the wood fuel task force to Scottish Ministers March 2011.
http://www.forestry.gov.uk/pdf/WoodfuelTaskForceUpdateReport_2011.pdf/$FILE/WoodfuelTaskForceUpdateReport_2011.pdf [Accessed 07/02/2011].
[5] Written Response to the Welsh Assembly Government to the Sustainability Committee Report: Inquiry in to the supply and demand for woody biomass.
http://wales.gov.uk/docs/desh/publications/101014bioenergycommitteeen.pdf [Accessed on 07/02/2011]

Energy crops

15. Energy crops are crops grown specifically for their energy content, for example, woody crops such as miscanthus and short rotation coppice can be burnt to generate power. Domestic energy crops currently account for a relatively small proportion of overall UK bioresource production, however, if developed they have the potential to contribute to building a more secure supply of biomass feedstocks from a range of sources within the UK. The three DECC supply scenarios assume very low quantities of energy crops in the immediate term, reflecting the very early stage of market development for these feedstocks, increasing to between 3 - 6 TWh by 2020 and 18 - 64 TWh in 2030, this is equivalent to around 0.3 - 0.9 Mha in 2030. The greatest potential for these feedstocks is beyond 2020, demonstrating the time it will take for markets to develop.

Waste

16. Waste feedstocks encompass a variety of different sources including, food and green wastes (e.g. grass and garden wastes like hedge and grass trimmings) used for anaerobic digestion, the renewable fraction of solid wastes used for incineration, waste feedstocks producing landfill gas, recovered materials such as waste wood, tallow and used cooking oil for biofuels, and sewage sludge. Within this mix there are a number of factors driving change in the potential over time from 51 - 77 TWh currently to between 50 - 58 TWh by 2030[18]. Policies to encourage better environmental and energy outcomes (waste prevention, reuse and recycling) will drive down potential from landfill gas, but may stimulate better recovery of food (diverting food from the waste stream and into technologies such as anaerobic digestion) and waste wood leading to increased potential in these areas.

17. The wide range in potential between the DECC scenarios is due to assumptions around the ability to overcome deployment challenges to energy from waste. These include: diverting more waste from landfill; overcoming the financial barriers to waste infrastructure, especially perception of risk[19] (particularly for commercial and industrial waste); improving community acceptance; developing methods for calculating the renewable content of waste; and improving markets for using energy from waste residues. Our supply scenarios imply between 47 – 57 Mt of waste bioresources in 2030.

Agricultural wastes and residues

18. Treatment of agricultural wastes such as manures and slurries by anaerobic digestion can recover energy as a useful by-product. Similarly, other agricultural residues can be incinerated and energy recovered. Estimates of current potential available resource are between 16 - 31 TWh, rising to between 24 - 32 TWh by 2030. The three DECC supply scenarios imply around 4.0 to 5.0 Million odt of agricultural residues by 2030. This increase

[18] Waste feedstocks include: food waste; landfill gas (produced from waste feedstocks); renewable fraction of wastes; sewage sludge; tallow; used cooking oil; and waste wood.
[19] Perception of risk specifically related to anaerobic digestion (especially for large scale commercial and industrial AD plants which imply significant investments).

results largely from overcoming the majority of market barriers in the ambitious scenario as prices paid are significantly higher. These are: investor uncertainty and lack of grants for upfront capital, lack of storage and collection equipment, competition for feedstocks (particularly elsewhere on farms), and the dispersed nature of the feedstocks.

Current market for bio-resources

19. The above estimates are derived from modelling of how the bioenergy sector may develop in the future. In order to put these in context, it is useful to consider the scale of the current market (based on Defra analysis[20]):
    - The UK currently sees a small proportion of domestic arable production used for bioenergy. In 2009 around 3% of total UK arable crops (wheat, oilseed rape and sugarbeet) were used for UK biofuels, generating around 0.6 TWh of energy.
    - Landfill gas and the renewable fraction of municipal solid waste combustion were the most significant sources of bioenergy from the UK waste sector. They generated approximately 5.0 TWh and 1.6 TWh of energy respectively in 2010.
    - Anaerobic Digestion in the UK is a growing waste treatment technology with renewable energy as a by-product. It utilises a diverse supply of feedstocks such as food and green waste, agricultural manures, slurries and crop residues. In some cases, purpose grown crops such as maize are added to anaerobic digestors on farms to increase gas yield[21]. Current installations are collectively able to generate around 0.45 TWh of energy, with a further 0.96 TWh with planning permission.

20. Further information on supply and demand in the UK wood market is included in Appendix 1.

[20] Defra estimates based on RTFO quarterly reports and 'Agriculture in the UK 2011' for Arable data, DUKES data for Landfill gas and waste, and Anaerobic Digestion data from the Biogas Portal, NNFCC website (http://www.biogas-info.co.uk/images/PDFs/baseline.pdf)

[21] The Government wants limited public funds available to drive greater and wider uptake of waste feedstocks, with crops being used to support this growth where it is required and it makes sense to do so.

Imported supply

21. The global supply of bioenergy resource in the AEA analysis is based on three different world development scenarios. These are explained in detail in box 2 below, but take account of the following key factors:

- Technology development and infrastructure
- Agricultural intensification (planting rates and yields)
- Global economy and population growth and related food demands
- Trade development and political stability
- Development of international standards such as fuel quality standards and sustainability standards

Box 2: World development scenarios

The AEA analysis based their analysis on three global development scenarios:

Business as Usual (BAU) - assumes world economic growth at 2% per annum and high technology development. It is assumed current trends for bioenergy production in each region continue, implying those countries that are already successfully developing infrastructure, technology and political stability continue to do so, and those who are lagging behind continue to do so (therefore limiting the bioenergy potential of less developed countries). Central price scenarios are assumed. Prior to the planting rate constraint, if the production of energy crops is maximised (i.e. land prioritised for energy crops as opposed to first generation Biofuel crops) - approximately 208 Mha (globally) of land are utilised for energy crops in 2030. Under the same scenario approximately 333 Mha (globally) of land are utilised for first generation biofuels feedstocks in 2030. Planting rates (increase in energy crops p.a.): Developed economies 20%; Transition economies 10%; and Emerging economies 5%. Energy crop yield* increase p.a.: 1.6%. Planting rates (increase in biofuel crops p.a.): Varies by crop and region, from 0.4 to 1.2% but typically at about 0.9%.

BAU + High Investment – assumptions as BAU plus further opportunities for development of bioenergy domestically and through investment from richer countries. Product quality standards are developed to facilitate commodity trading of various grades of fuel, ensuring consistent product quality, and reliable delivery - encouraging investment by the demand side sector. Developing countries are assumed to implement sustainability requirements and demonstrate that they have been met. UK develops good infrastructure to deal with large quantities of imports. Supply is increased substantially from BAU by increased planting rates and the removal of some barriers to investment. However, a large proportion of land in some regions remains un-planted; by 2030 this is mainly due to infrastructure and market constraints rather than planting constraints. Under the BAU + High Investment scenario prior to planting rate constraint, assuming central price scenarios and maximising the production of energy crops, approximately 347Mha (globally) of land are utilised for energy crops in 2030. Under the same scenario approximately 297Mha (globally) of land are utilised for first generation biofuels feedstocks in 2030. Planting rates (increase in energy crops p.a.): Developed economies 20%; Transition economies 20%; and Emerging economies 20%. Energy crop yield increase p.a.: 1.6%. Planting rates (increase in biofuel crops p.a.): Varies by crop and region, from 0.4 to 1.2% but typically at about 0.9%.

Low Development – assumes lower technology development, less intensification of agriculture and less improvement in yields, reduced international food trade, and world economic growth at 1.6% per annum - implying lower potential land availability for bioenergy production. There is less infrastructure development in developing countries and less investment in developing biomass supply by developed countries in developing countries. Lower initial land availability, and more constraints on supply, leads to the lowest potential for bio-energy production. Under the Low Development scenario prior to planting rate constraint, assuming central price scenarios and maximising the production of energy crops, approximately 114Mha (globally) of land are utilised for energy crops in 2030. Using the same scenario approximately 150Mha (globally) of land are utilised for first generation biofuels feedstocks in 2030. Planting rates (increase in energy crops p.a.): Developed economies 20%; Transition economies 8%; and Emerging economies 2%. Energy crop yield increase p.a.: 1.2%. Planting rates (increase in biofuels crops p.a.): Yield increases are half those in the BAU scenario.

Source: International Development Scenarios used by AEA, based on Global Economic Scenarios developed by Hoogwijk (2005)

Note: World economic growth rates cannot be flexed in the AEA model and may appear low compared to the latest world economic growth rate data. If higher growth rates were assumed we would expect higher productivity and yield rates (due to higher technological growth), but may also expect greater competition for land (for food and other uses due to increased population and demand) which could reduce the amount of land available for energy crops. The balance, and overall impact on total bioresource availability to the UK, due to these changing variables, is unclear and would require further in-depth analysis.

Note*: Regional average yields for energy crops were derived from the results in Hoogwijk (2005) (1.6% per year in the BAU scenario and 1.2% per year in the low development scenario). Regional yields in 2010 range from 5 odt/yr (e.g. in Southern Africa) to 10 odt/yr (in North America) and 11 odt/yr in Former Soviet Union. By 2030, these increased by 37% in the BAU scenario and 27% in the low development scenario.

22. Figure 5 below shows current uses of global land resource, based on FAO-OECD estimates[22]. This suggests there are currently around 4.3 billion hectares of land available for crop production globally. Of this, around 1.4 billion is currently used for arable crops and a further 1.3 billion is land that is either protected or has other uses such as urban areas or forests. Estimates of the land required to feed the rapid population growth and changing dietary habits to 2050 vary. The FAO[23] estimate that this could require around 70 million hectares, whilst the Foresight Study[24] suggests an average increase of 10%-20% from current levels, implying up to an additional 280 million hectares. This suggests that there could be approximately 1.3 billion hectares of land suitable for crop production that could be used for bioenergy crop expansion or other uses[25]. Some of this will not be suitable for energy crops due to factors such as land and water degradation.

23. The DECC supply scenarios assume a lower starting point for global land potentially available for crop production. Our scenarios assume just over half (restricted scenario) to three-quarters (ambitious scenario) of 1.3 billion hectares could potentially be available for bioenergy crops by 2030. Suitable land reduces further after taking account of planting rates and sustainability constraints assumed in the AEA modelling (see paragraph 24.). By 2030, the range of land used in the DECC scenarios is approximately 0.1 to 0.5 billion hectares. The energy potential in the ambitious scenario implies up to 30,000 TWh in 2030 from energy crops grown on this land. Further energy potential is available from forestry products from existing forests.

24. Assumptions on planting rates act as a constraint on the potential land utilised for bioenergy crop production. In earlier years, the AEA modelling shows that the planting rate is a more binding constraint than the land available. The planting rate assumptions vary across regions and the three world development scenarios assumed in the modelling (see box 2 for further information). Similarly, sustainability constraints act to reduce the land available for bioenergy crop production. Only a fraction of the total potential biofuels that could be produced on the land available by 2020 are estimated to meet the GHG savings criteria set out in the Renewable Energy Directive.

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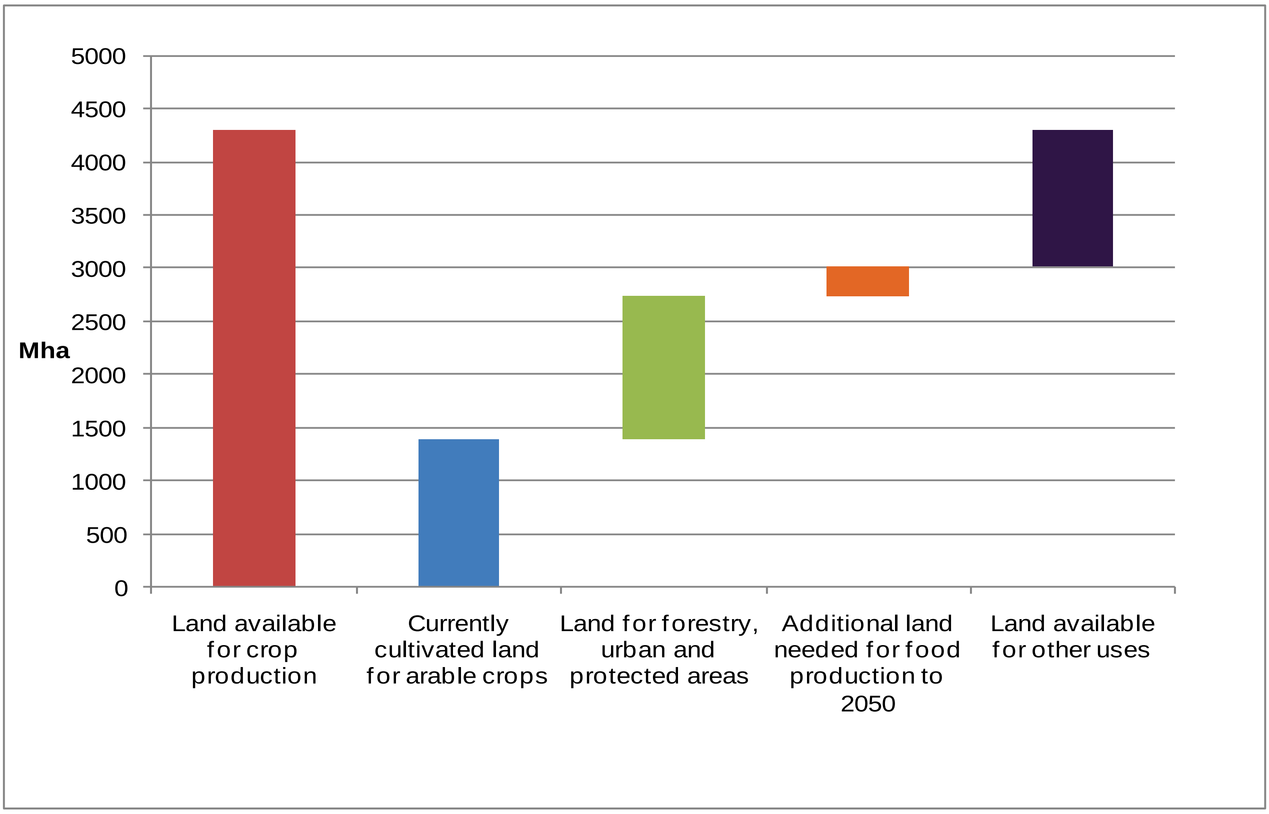
[22] FAO-OECD Agricultural Outlook http://www.agri-outlook.org
[23] FAO 'How to feed the world in 2050' http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf
[24] Foresight 'Global Food and Farming Futures, 2011' http://www.bis.gov.uk/foresight/our-work/projects/published-projects/global-food-and-farming-futures
[25] It is important to note that this land may have a high carbon content and be rich in biodiversity; it may be used for grazing livestock or subsistence farming; there is a high degree of uncertainty around productivity, including water supply (which may become more pronounced in a world subject to climate change); for land where productivity is not prohibitively low, it is unclear whether growing dedicated energy crops would be economically viable, given limited experience of this to date.

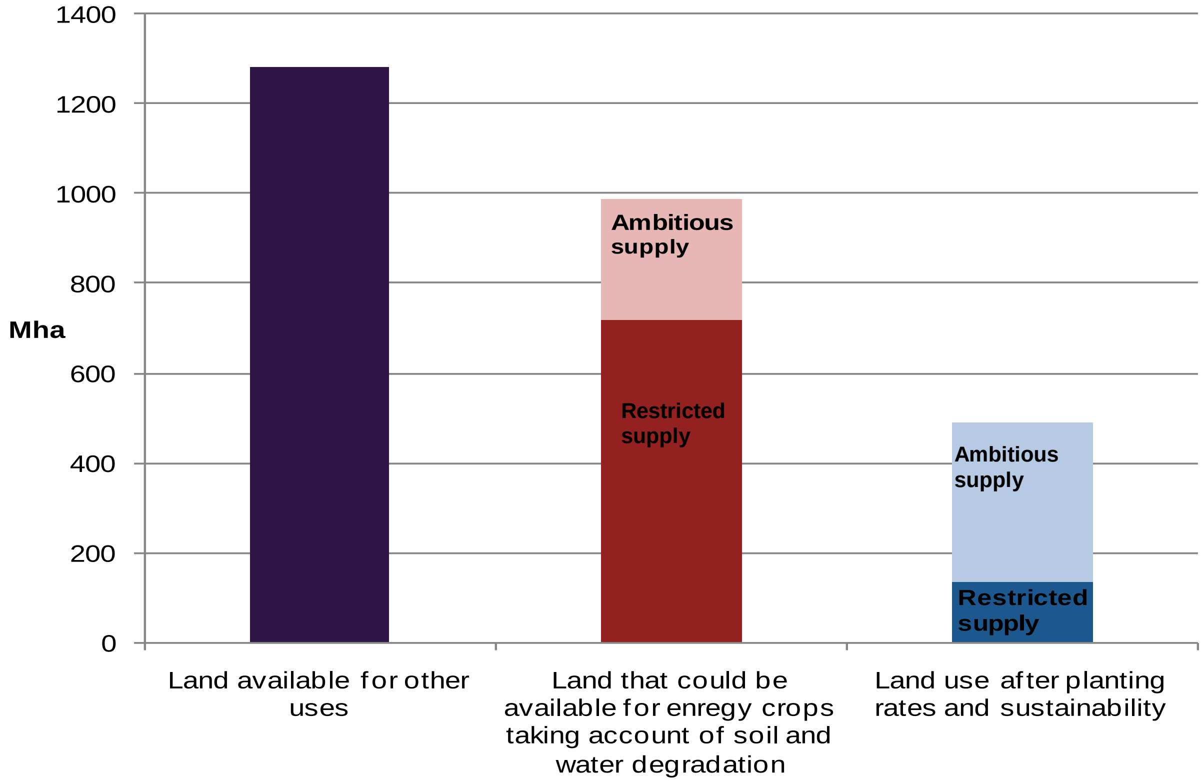
Figure 5A: Current global land use



Source: FAO-OECD Agricultural Outlook 2011

25. The last column ‘Land available for other uses’ in figure 5A above corresponds to the first column in figure 5B below. In comparison, the second and third columns show global land potentially available for other uses as assumed under AEA modelling we have used to estimate our supply scenarios, they are split to correspond with the restricted supply scenario and the ambitious supply scenario. The Mha range associated with our scenarios after planting rates and sustainability has been taken into account implies between approximately 10 – 30,000 TWh potential energy from the land available. The restricted scenario assumes the majority of this land comes from the regions of Oceania, USA and Western Europe (29%, 21% and 12% respectively), whereas the ambitious scenario assumes the majority of land is available from the regions of South America, East Asia, Former UUSR, and Oceania (17%, 17%, 13%, and 10% respectively).

Figure 5B: Global land potentially available for other uses as assumed under DECC supply scenario modelling



Source: FAO-OECD Agricultural Outlook 2011

26. The development of international bioresource production, access to global markets, the price at which bioenergy resources can be accessed and the UK's willingness to pay for them, alongside the implemented sustainability criteria, will be key factors determining the scale of bioenergy imports that will be available to the UK. Appendix 1 sets out further information on international markets and prices for woody biomass, based on DECC analysis in consultation with stakeholders.

27. Estimating the availability of global supply to the UK in the future is very difficult given the uncertainty around the key factors highlighted in paragraph 26. Therefore supply ranges must be considered in this context. Not all bioresource feedstocks are likely to be suitable for international trade, for example, currently there is only a developed international market for woody pellets[26] produced from forestry and agricultural residues. However, going forward we assume that these and woody energy crops will form tradable solid biomass products given that they have similar characteristics to commodities in the current internationally traded market. First generation biofuels are also expected to continue to be internationally traded. The distances over which these feedstocks will be transported will be constrained by the GHG and economic costs of transport (taking into account relative energy density of biomass products). A more in depth analysis of transport costs for biomass has been developed by DECC and will be available on the DECC website shortly.

[26] An international market also exists for wood chips, but is not as well established as the wood pellet market.

28. Our analysis, which estimates supply on a regional basis, suggests that the majority of woody imports will be energy crops with some forestry residues. The regions of North America and the EU will be important suppliers of forestry products, whereas energy crop production is expected to be more widely dispersed across the world, with regions such as Latin America and China having a significant role alongside North America and the EU. There will also be a smaller but significant role for imported agricultural residues in the short and medium term, but this decreases towards 2050 as increased production of energy crops become available.

29. For biofuels and bioliquids the supply modelling also incorporates the sustainability standards as laid out in the Renewable Energy Directive. This significantly reduces the amount of sustainable biofuels available to the UK. The land assumptions underpinning the AEA estimates of global energy crops and biofuels is based on land that is unused or abandoned agricultural land. This meets the Renewable Energy Directive criteria that biofuels and bioliquids should not be grown on converted land that previously had a high carbon stock. As this supply is based on projections of unused land, it is assumed that production from these areas should not induce significant Indirect Land Use Change (ILUC). The supply scenarios could therefore be realised with low ILUC risk. However, the AEA global supply model (which uses an energy model not a global agricultural model) does not test this assumption or consider enforcement issues. We also recognise that current policies and sustainability criteria may not encourage bioenergy production from this unused land, but instead production may continue to be dominated by supply from existing agricultural land. We have therefore introduced further restrictions on biomass supply under the Highly Restrictive Sustainability Standards scenario (see page 30) whereby all vegetable oil crops are excluded from the feedstock mix.

30. The modelling assumes that first generation biofuels crops require better quality land than energy crops (to note: all land is categorised as spare or abandoned agricultural land, better quality land refers to factors such as water scarcity and levels of soil degradation). In the scenarios used in the above analysis, the land is split such that better quality land is available for first generation biofuels feedstocks up until planting rates allow for energy crops to compete with first generation biofuels. This means if there is spare land available that cannot be used for energy crops because of the planting rate constraint, the land can then be used for first generation feedstocks, providing it is of suitable quality. A scenario where planting rates are much higher would result in more land becoming available for energy crops and a reduction in land available for first generation biofuels.[27]

[27] AEA developed two variants of each world development scenario: (1) where production of first generation biofuels is maximised and energy crops are only grown on land which is not suitable for first generation biofuels (2) where preference is given to planting energy crops and where planting rates for energy crops are constrained, it is assumed remaining land is utilised for biofuels production. A variant of scenario (2) has been used in our modelling as the default, however, this is a simplification for modelling purposes of the real production decision that is required by producers and does not take into account the impact of prices (which could result in producers favouring the production of first generation biofuels crops).

Imposing constraints and estimating availability of imported supply to the UK

31. International bioresource supply was examined on a regional basis and took into account the following constraints and trade barriers:

    - Infrastructure constraints - physical constraints on development of the resource such as transport infrastructure (including distribution, storage, ports etc.)
    - Market/trade constraints - constraints on the ability to establish and maintain reliable supply chains for domestic and international markets (including market maturity, political stability, international standards etc.)

32. To estimate the amount of bioresource that would be available to trade on the international market, the level of domestic demand (for each region) is subtracted from total supply to estimate the surplus available for trade. AEA uses the ‘reference’ demand predicted by IEA (2010) as a basis for the reference global bioenergy demand scenario. To test the sensitivity of results to demand side assumptions, AEA also considered a high biomass demand scenario based on a scenario created by IEA (2010) where there is a substantial increase in the use of biofuels and biomass for electricity generation.

33. Compared with the rest of the world, the EU has much more developed renewables targets in 2020, thus it is likely to be one of the regions with the highest demand for biomass. The UK will be competing with other EU countries and the rest of the world to secure biomass supply to meet UK domestic demand. As the UK has relatively limited land resources, it is likely to require a relatively large share of imports to meet this demand. The AEA study assumes that 10% of surplus tradeable biomass (after global domestic demand is met) potentially available in the international market in 2020 would be available to the UK. This is equivalent to around 4.5% of all global tradeable bioenergy resource in the medium biomass scenario (i.e. prior to meeting global domestic demand). Although this is relatively high in relation to the UK’s global share of total primary energy supply (around 1.6%[28] in 2009), we have used this as a basis for the 2020 UK share of global biomass available for import due to the factors mentioned above.

34. To extend the AEA analysis out to 2050, we assume that the UK will have access to a decreasing proportion of total global supply available on the internationally traded market. This is based on the expectation that the UK continues to be a net importer of bioresources, however in the longer term demand for bioresources will increase globally as more countries will be competing for this scarce resource. In the absence of reliable data, it has been assumed that the UK’s proportion of surplus tradeable biomass declines from 10% in 2020 to 2% in 2050 in the medium resource availability scenario with a range of 1.5% to 3%. This is equivalent to 1.5% of all global tradeable bioenergy resource in the medium scenario with a

[28] Figure based on International Energy Agency (IEA) statistics http://www.iea.org/stats/index.asp

range of 1.2% - 2.3%. The central case import share 1.5% is comparable to the UK share of current global energy supply of around 1.6% and reflects what the UK might be able to use as the world moves towards binding global carbon constraints.

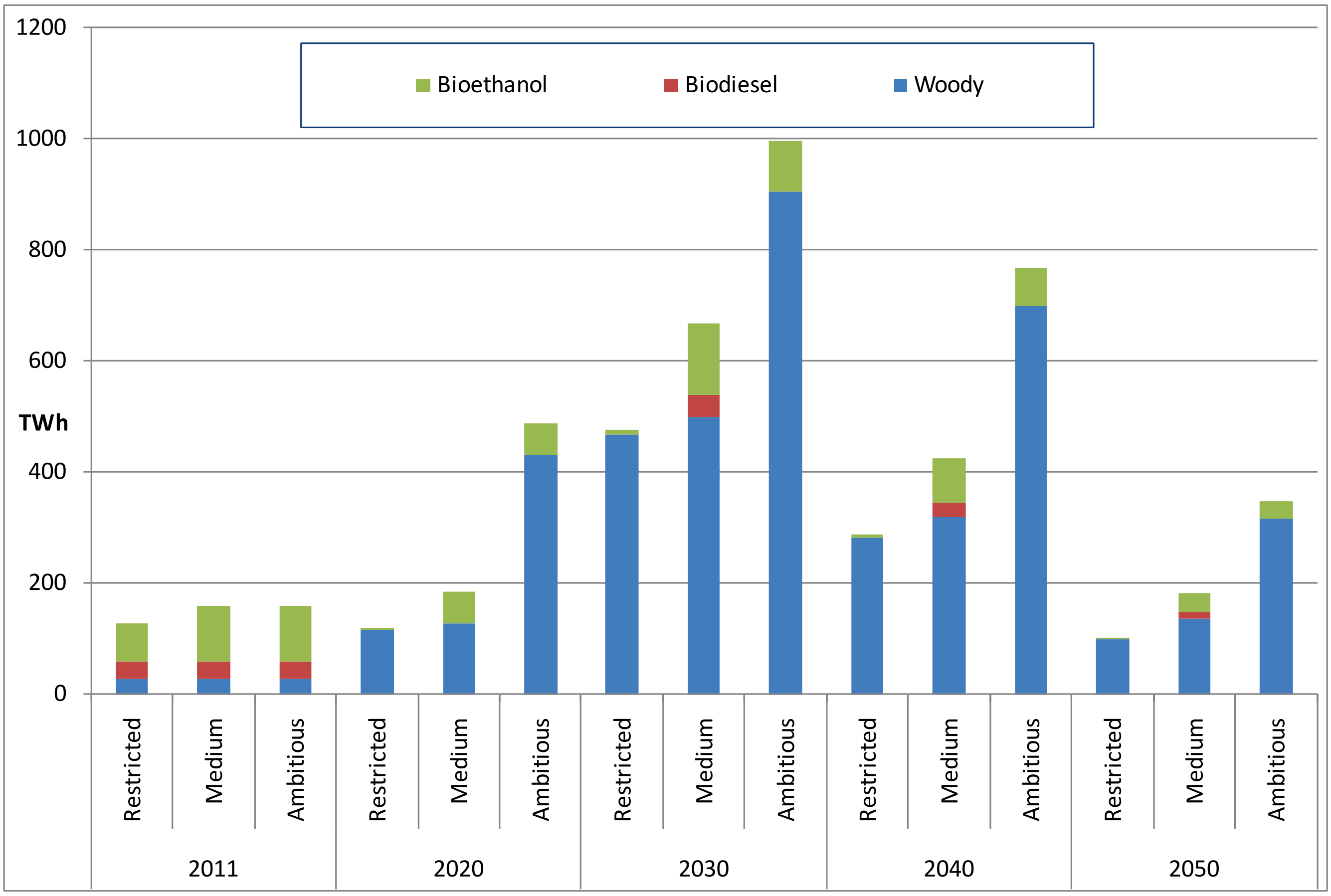
35. These assumptions are clearly very uncertain and in practice, the UK import share will depend on a range of factors including global and regional demand, development of supply contracts and incentives in place to use biomass. The range is chosen to test the robustness of results of the AUB modelling and to gain insights from a range of different scenarios. Estimates of global resource availability are inherently more uncertain towards the longer term. That our resource supply range narrows towards 2050 is due to the assumption that the UK has access to a declining fraction of imports over time, and should not be interpreted as the estimated bioresource availability becoming more certain. A sensitivity analysis was carried out to test the robustness of our conclusions on low risk uses of bioenergy towards 2050 where the import share was significantly higher in 2050 – see Appendix 2 for full details.

Breakdown of imported supply by feedstock

36. Figure 6 provides a breakdown of the imported feedstocks that are assumed in the three DECC supply scenarios: Bioethanol; Biodiesel[29]; and Woody biomass. Imported woody biomass includes agricultural residues, small roundwood, forestry residues, forestry sawmill products and energy crops such as miscanthus and short rotation coppice. Energy crops are assumed to make up the majority of woody biomass imports available to the UK, the three DECC supply scenarios imply a range between 21.7 – 40.1 Mha equivalent. The supply scenarios imply the equivalent of around 0.5 – 2.6 Mha for global agricultural residues, and 0.4 – 8.8 Mha for global oil crops (all Mha figures apply to 2030).

[29] AEA estimate energy crops and first generation Biofuels feedstocks as the equivalent amount of biofuels they would produce, rather than in raw feedstock terms.

Figure 6: Available imported bioresource supply broken down by feedstock for DECC supply scenarios from 2011 to 2050

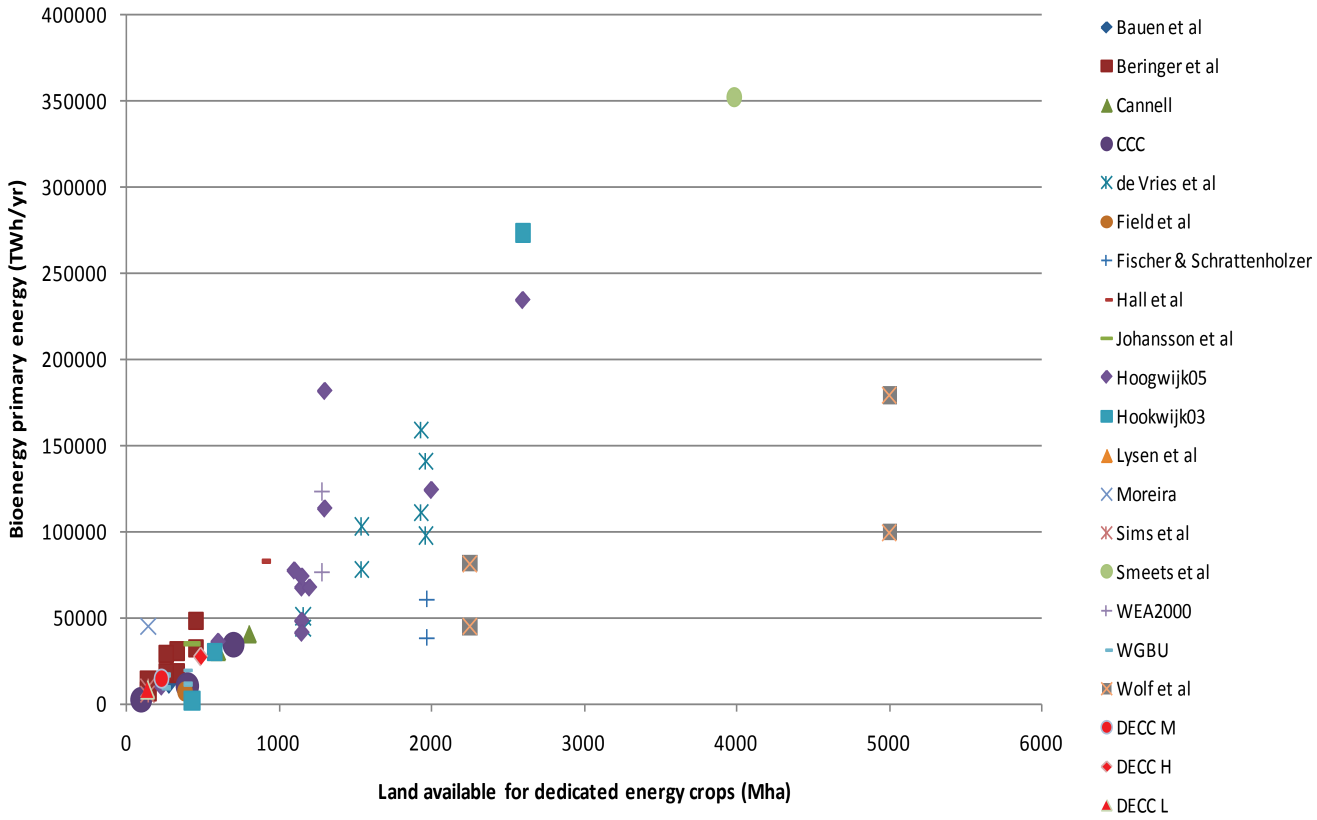


Source: DECC analysis using AEA Bioenergy Resource model

Supply ranges – comparison to existing literature

37. Our scenario approach to bioresource supply aims to build on the sensitivity analysis represented by the ranges provided by the AEA modelling. We recognise that sensitivity analysis cannot cover all areas of uncertainty and it is accepted that feedstock supply estimates need to be used with caution, especially those estimating import availability. This analysis will be open to review and updating as necessary when more information becomes available. However, as Figure 7 below shows, our current estimates are within the main cluster of estimates provided by other studies that examine land availability and production yields.

Figure 7: Estimates from recent studies of land availability for energy crops



Source: UKERC

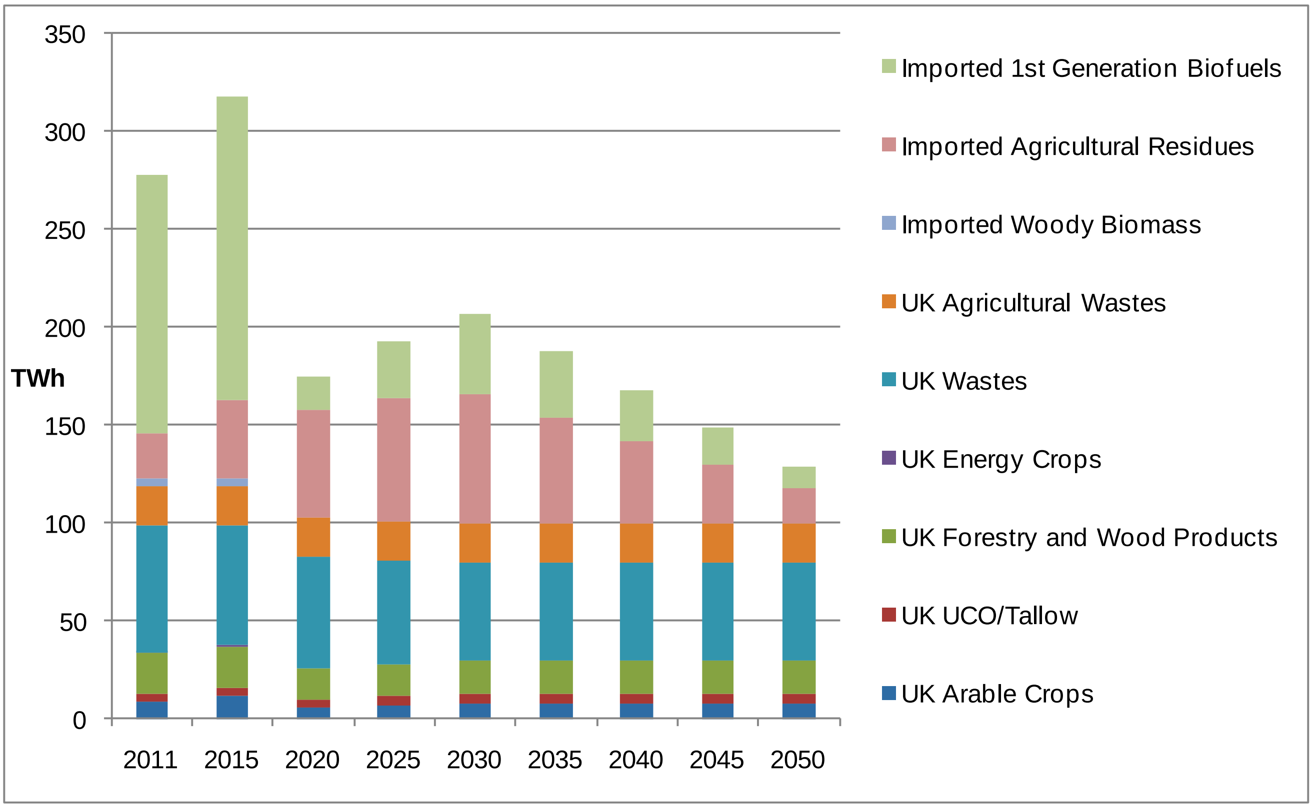
Highly Restrictive Sustainability Standards (HRSS) supply scenario

38. The impact of more stringent sustainability standards has been analysed on a feedstock by feedstock basis, considering their impact on GHG emissions, biodiversity and Indirect Land-Use Change. Defra established a working group to consider a range of low, medium and high sustainability standards encompassing changes to GHG savings, compliance with best practice and international sustainability schemes, and restricting the use of feedstocks with high risk of indirect land-use change. The full set of agreed standards can be seen in table 1 below:

Table 1: Summary of Defra sustainability standards			
	Low	**Medium**	**High**
Biodiversity			
Arable Crops and Woody Energy Crops	Cross- compliance	Cross-compliance and Entry Level Stewardship (ELS)	Cross-compliance and Enhanced ELS – mandatory specific measures to promote farmland birds and other biodiversity
Agricultural residues	10% returned to soil to protect soil biodiversity	30% returned to soil to protect soil biodiversity	50% returned to soil to protect and enhance soil biodiversity
Domestic forestry and woody energy imports	Forest Stewardship Certified (FSC) or equivalent accreditation	FSC or equivalent accreditation	FSC or equivalent accreditation
1st generation biofuels crops	Roundtable on sustainable biofuels accreditation or equivalent	Roundtable on sustainable biofuels accreditation or equivalent	Only source feedstocks from countries with zoning agreements.
Greenhouse gases			
All feedstocks	If for transport = 35% including ILUC and carbon debt. If for other = 60% including ILUC and carbon debt	If for transport = 60% including ILUC and carbon debt. If for other = 70% including ILUC and carbon debt	If for transport = 80-100% including ILUC and carbon debt. If for other = 95-100% including ILUC and carbon debt
Indirect Land Use Change			
All feedstocks	Monitor and promote the issue and use ILUC factors to internalise the effect	As low scenario with land-use zoning through specific bilateral agreements, promotion of low-risk ILUC feedstocks, flexible biofuels mandates.	As low and medium scenarios with widespread land-use zoning and Responsible Cultivation Areas.

39. The set of high sustainability standards has been considered against the medium supply scenario (Scenario 1 in Section 3) to illustrate the scale of impact they may have. This is provided as a sensitivity analysis to the main scenarios and should not be considered government policy. Figure 8 below shows the total bioresources potentially available to the UK under this scenario.

Figure 8: Total available bioresource supply broken down by feedstock assuming highly restrictive sustainability standards are applied



Source: Defra/DECC analysis modelling using model developed by Redpoint Energy and Ecofys

40. In this scenario the overall availability of bioenergy to the UK in 2050 could be around 130 TWh. This is largely made up of agricultural residues and wastes which can typically demonstrate significant GHG savings and pose little risk for Indirect Land-Use Change. The impact of the more restrictive standards have impacts from 2020 onwards, after they are assumed to come into force.

41. Only standards associated with Indirect Land-Use Change (ILUC) and GHG savings are assumed to impact on supply levels as well as the requirement to return a greater proportion of agricultural residues to land. Other standards will influence the price paid for sustainable feedstocks. The AEA supply modelling does not explicitly take account of concerns over ILUC impacts arising from biofuels production as these are not presently included in the Renewable Energy Directive sustainability criteria. However, because all supply is produced from spare or abandoned land, our global resource estimates would, in theory, be compatible with using only biofuels with low risk of ILUC impacts. However, Government takes the issue of ILUC very seriously, and in recognition that the majority of biofuels are currently produced from existing agricultural land, we include this sensitivity scenario which takes a more prohibitive approach to ILUC.

42. It is assumed that no crop-based biodiesel is able to meet the high GHG threshold, and would not meet the Indirect Land-Use Change requirements. Crop-based bioethanol potential is also reduced as only those regions that are able to meet current Renewable Energy

Directive targets with 100% of their feedstocks are assumed to be able to supply the UK, but at a reduced level of 50%. Overall first generation biofuels to the UK is 58% less than the medium scenario in 2050.

43. Analysis using the BEAT2 model considered the GHG savings of UK-grown woody energy crops for heat and electricity[30]. It demonstrated that these would not be able to meet the high GHG thresholds due to cultivation and processing (drying and chipping) emissions, and the feedstocks have been restricted accordingly in this scenario. The same restrictions have been applied to imports under the assumption that processing emissions would not differ significantly from the UK. Biomass for heat and electricity is therefore predominantly from wastes and co-products which can demonstrate high GHG savings due to avoided emissions from disposal.

44. The proportion of domestic agricultural residues returned to soils is increased from 30% to 50% to enhance and protect soil biodiversity. The combined impact of these standards is to reduce the overall solid biomass supply potential to the UK by 62% in 2050.

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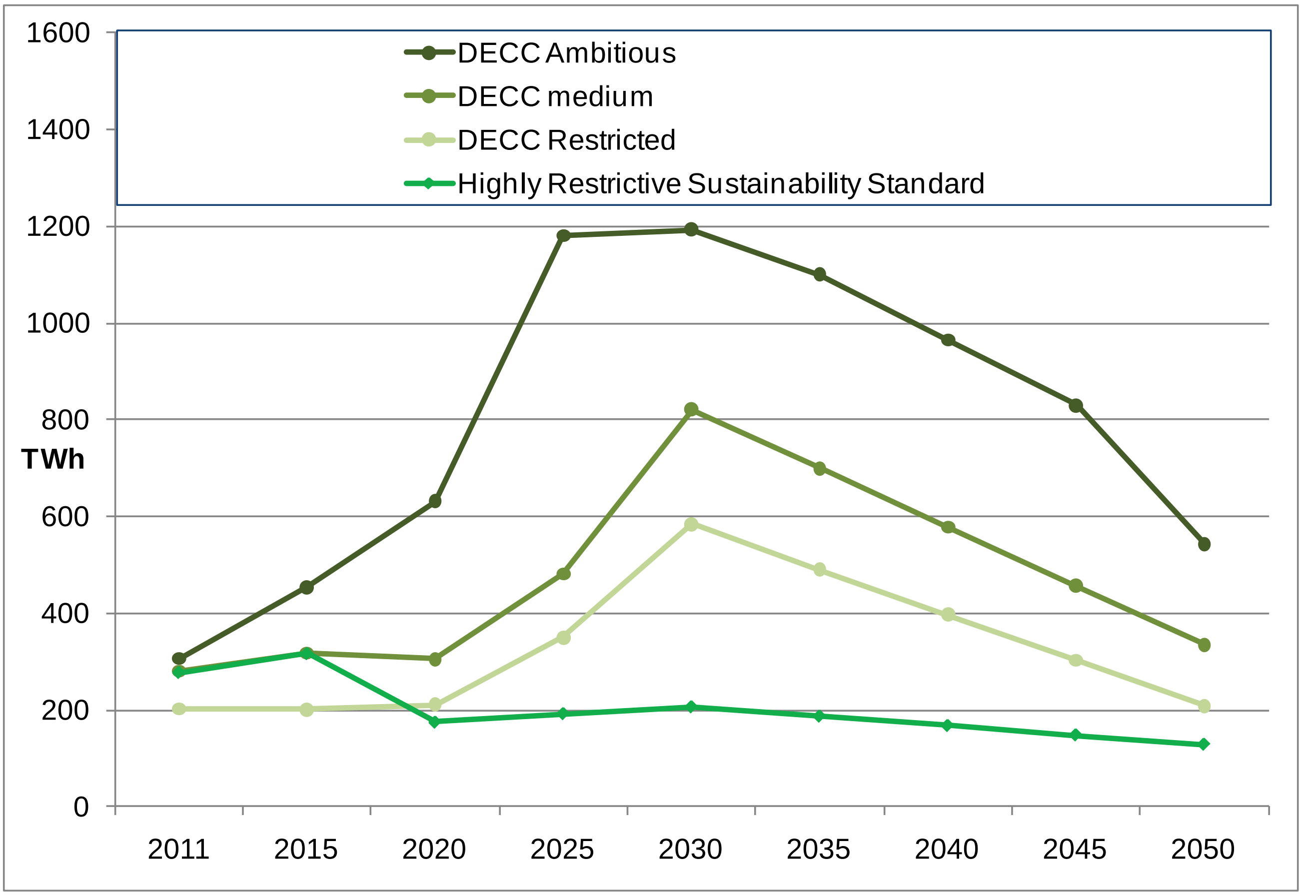
[30] The BEAT2 model does not include woody energy crops used for 2[nd] generation biofuels as an energy pathway, therefore this is not included in the analysis for this supply scenario.

Summary - Biomass Supply Scenarios for use in Appropriate Use of Bioenergy (AUB) modelling

45. The Appropriate use of Biomass model identifies different bioenergy use pathways to 2050 (explained fully in Section 3) and is run using three different resource supply scenarios. These scenarios reflect the range we consider to effectively test the different drivers of supply. We have also developed a Highly Restrictive Sustainability Standard scenario to investigate a world where we are faced with extreme sustainability constraints. Figure 9 below shows the range of DECC supply scenarios.

Figure 9: Bioresource supply ranges (including domestic and imported supplies) potentially available to the UK from 2020 to 2050



Source: DECC analysis using AEA Bioenergy Resource model

Note: Estimates of global resource availability to the UK become more uncertain in the longer term (i.e. you would expect the range of estimates to widen over time). Figure 12 shows the range of estimates narrowing towards 2050 – this is due to the assumption that the UK has access to a declining fraction of imports over time, and should not be interpreted as the estimated import availability becoming more certain.

Section 2 – Bioenergy Costs

46. This section presents a static comparative analysis of the cost of different bioenergy applications to generate renewable energy and the cost-effectiveness of using these to reduce carbon emissions, taking into account the life-cycle emissions associated with producing bioenergy feedstocks. This gives a snap-shot of the relative cost-effectiveness of different technologies and applications at a particular point in time. Given the heterogeneity of costs and technology-specific performance parameters, a range around these has been produced. There is also uncertainty around future cost estimates and differential learning rates may change the relative merit order of technologies going forward. However, this is useful in highlighting some key cost metrics that underpin the analysis presented in the Bioenergy Strategy and the results in Section 3.

47. The sources of the technology cost data used in this section are consistent with those used for the AUB, but they are not outputs from specific runs of that model. For the electricity sector, Arup (2011) data were used, for heat we used Nera/AEA (2011) and for transport estimates were taken from a number of sources which include Poyry (2010) and NNFCC (2011). These sources are the same as those used within DECC for detailed modelling of the Renewable Heat Incentive and the Renewables Obligation.

48. The key definitions used here are:

Levelised costs (£/MWh) – these are the cost per unit of energy from a given technology taking into account the capital costs annuitised over the project life at the required rate of return, operating and maintenance costs and fuel costs.

Resource costs (£/MWh) – these are the additional levelised costs of the renewable technology compared with the non-renewable alternative.

Cost per tonne of carbon (£/tC02) – these are the technology resource costs per tonne of carbon saved by using this technology in place of fossil fuel alternatives. The choice of counterfactual fossil fuel technology will depend on the application and sector.

Lifecycle GHGe emissions – these are the estimated lifecycle GHGe emissions resulting from the bioenergy chain. The system boundary used in this analysis starts with the production and cultivation of the feedstock, covers the full chain of processes such as processing, extraction, transport and distribution. The final emissions are compared post-combustion across heat and electricity i.e. per unit of electricity produced or thermal energy for heat, and are compared against “well to wheel” lifecycle emissions from alternative options in the transport sector. In the production of bioenergy feedstocks, there are a number of co-products which lead to reduced energy requirements for product manufacture elsewhere. These savings are accounted for in these chains. For further details of the sources and methodologies used in this analysis see Box 3 (below in Carbon Cost Effectiveness section).

Note that we do not take account of the lifecycle emissions associated with any other aspect of the technology chain – such as construction, operation and maintenance of the power station or boiler. For heat and power the estimates exclude any emissions from indirect land use change Indirect Land-Use Change (ILUC) due to lack of data. For transport, although ILUC emissions were not included in the AUB modelling, they have been included in this static analysis for crop-derived transport biofuels with estimates of ILUC emissions factors taken from IFPRI analysis conducted on behalf of the European Commission[31].

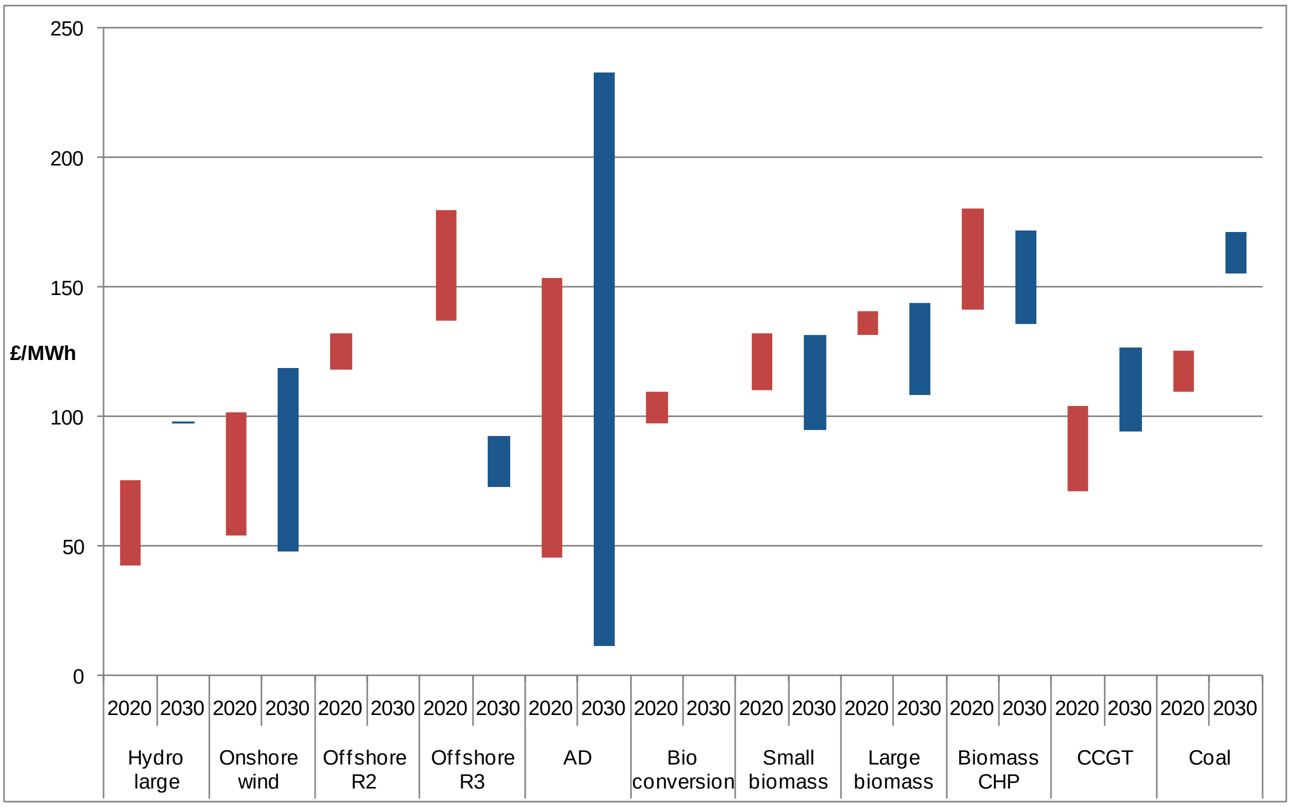
Levelised generation costs (£/MWh)

Range of levelised costs for key renewable electricity technologies, 2020 £/MWh

49. Figure 10 shows the range of costs for technologies used in the power sector, and compares bioenergy with other renewable technologies and against estimated CCGT and coal generation costs. The ranges shown are based on using the range of capital expenditure (capex) indicated from the original estimates from Arup (2011). The bioenergy electricity technology costs generally lie between onshore and offshore wind costs, but precise costs will vary with biomass prices and gate fee costs and key operational parameters. Most renewable technologies are currently more expensive than conventional technology generation costs.

[31] http://trade.ec.europa.eu/doclib/docs/2011/october/tradoc_148289.pdf

Figure 10: Levelised costs for key large scale renewable electricity technologies, 2020 and 2030



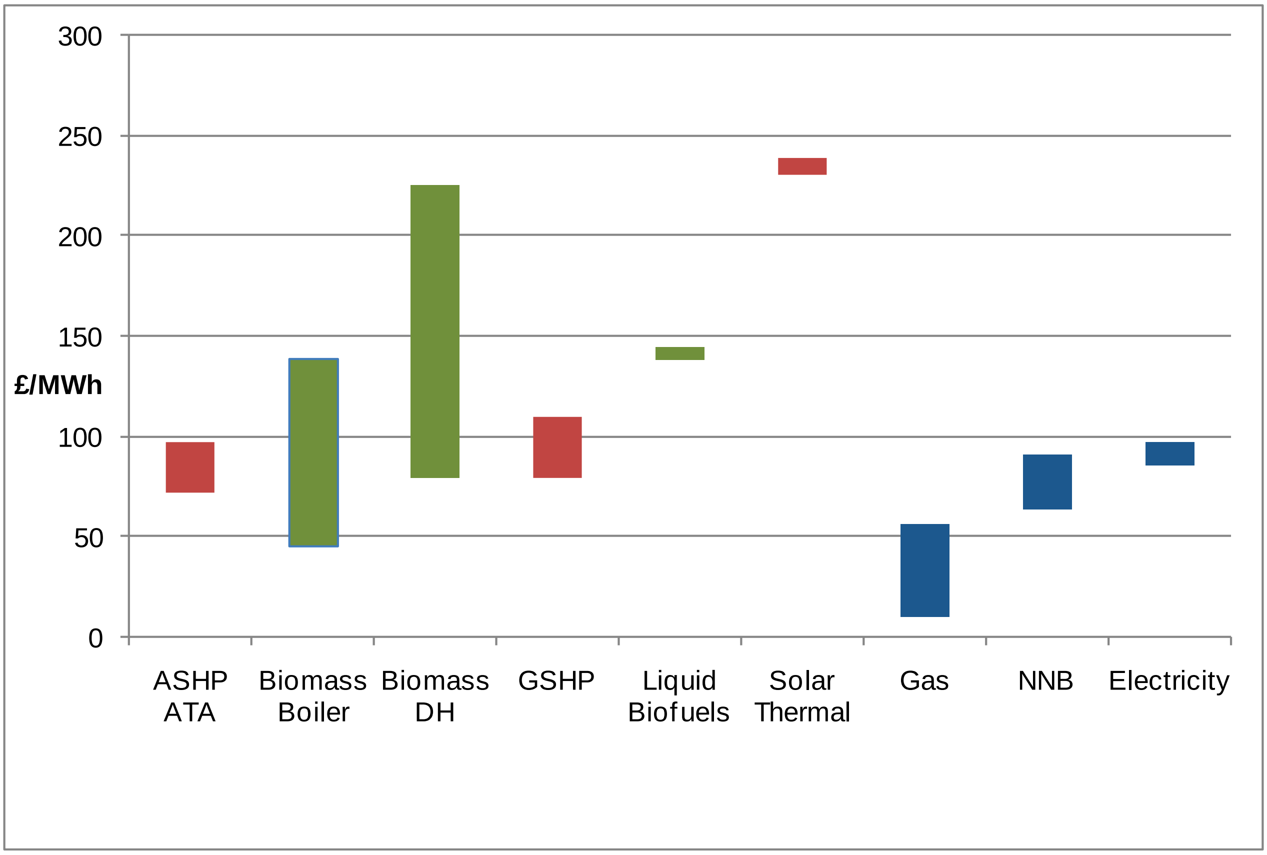
Source: Arup/Poyry costs for 2011/12 RO banding review and DECC internal analysis

Note: Coal £/MWh is variable cost only (as capital cost sunk for conversion counterfactual). AD costs based on Wrap Gate Fees Report 2011, which does not take into account collection costs (e.g. for food waste).

Levelised costs for key renewable heat technologies, 2020 £/MWh

50. Figure 11 and 12 give the range of levelised costs for renewable and non-renewable technologies in the heat sector (non-domestic and domestic sector), developed for DECC by AEA and Nera. Heat demand in this analysis is disaggregated to a fine level of detail – for example by sector, counterfactual fuel, location (urban/rural), type and age of building and other environmental indicators. The range shown is based on the 10th and 90th deciles values indicated from this supply curve. Because of the wide range of applications, a larger range is produced for most heat applications than for the power sector. The data shows that some applications are cheaper than fossil fuels, particularly when replacing electric heating.

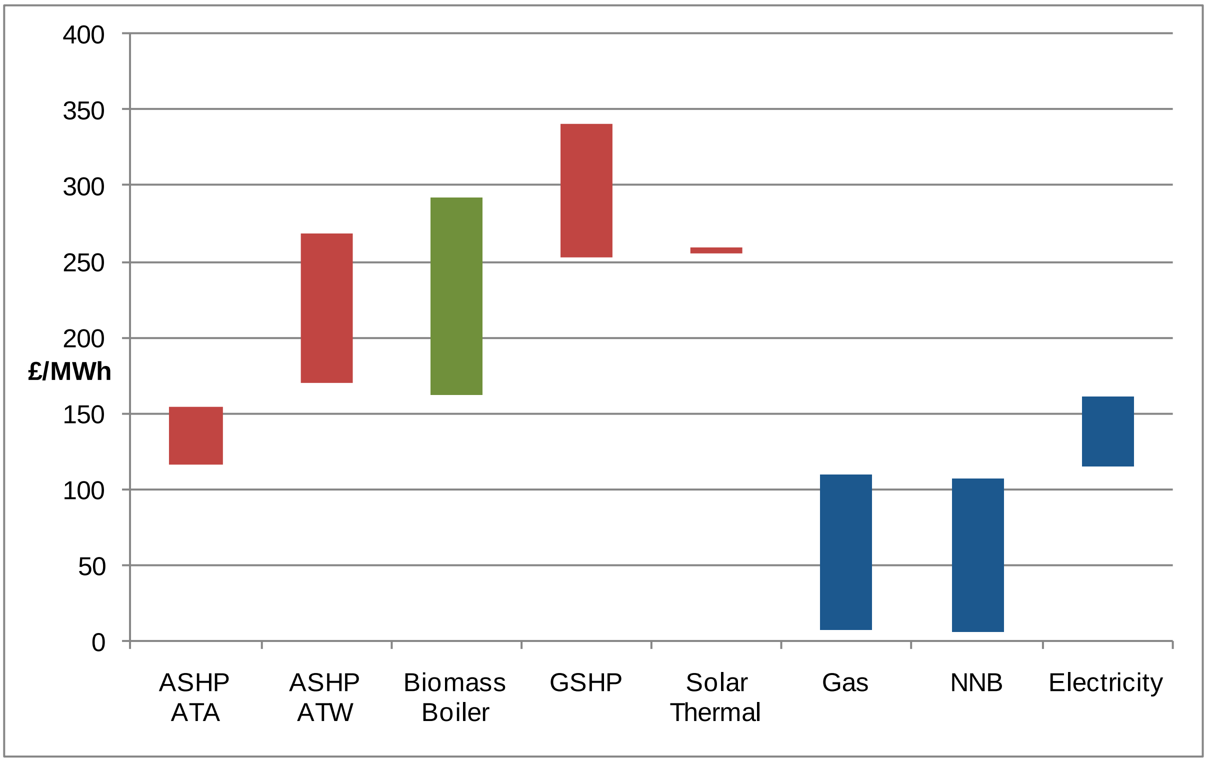
Figure 11: Levelised costs for non-domestic renewable heat technologies, 2020



Source: DECC analysis based on NERA/AEA estimates

Note: NNB refers to 'Non-Net Bound', i.e. not deliverable through gas grid network (e.g. heating oil or coal). ASHP ATA refers to Air Source Heat Pump Air to Air. GSHP refers to Ground Source Heat Pump. 2010 prices.

Figure 12: Levelised costs for domestic renewable heat technologies, 2020



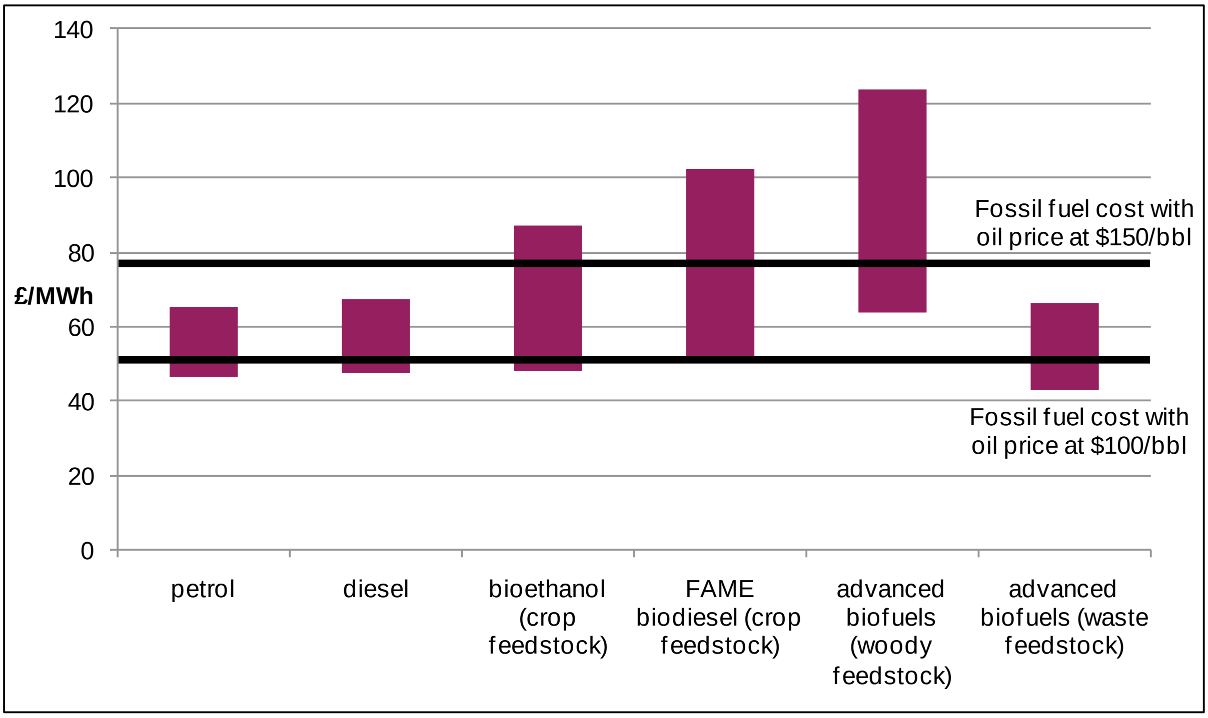
Source: DECC analysis based on NERA/AEA estimates

Note: NNB refers to 'Non-Net Bound', i.e. not deliverable through gas grid network (e.g. heating oil or coal). ASHP ATW refers to Air Source Heat Pump Air to Water. 2010 prices.

Comparison of Road Transport Costs, 2020 £/MWh

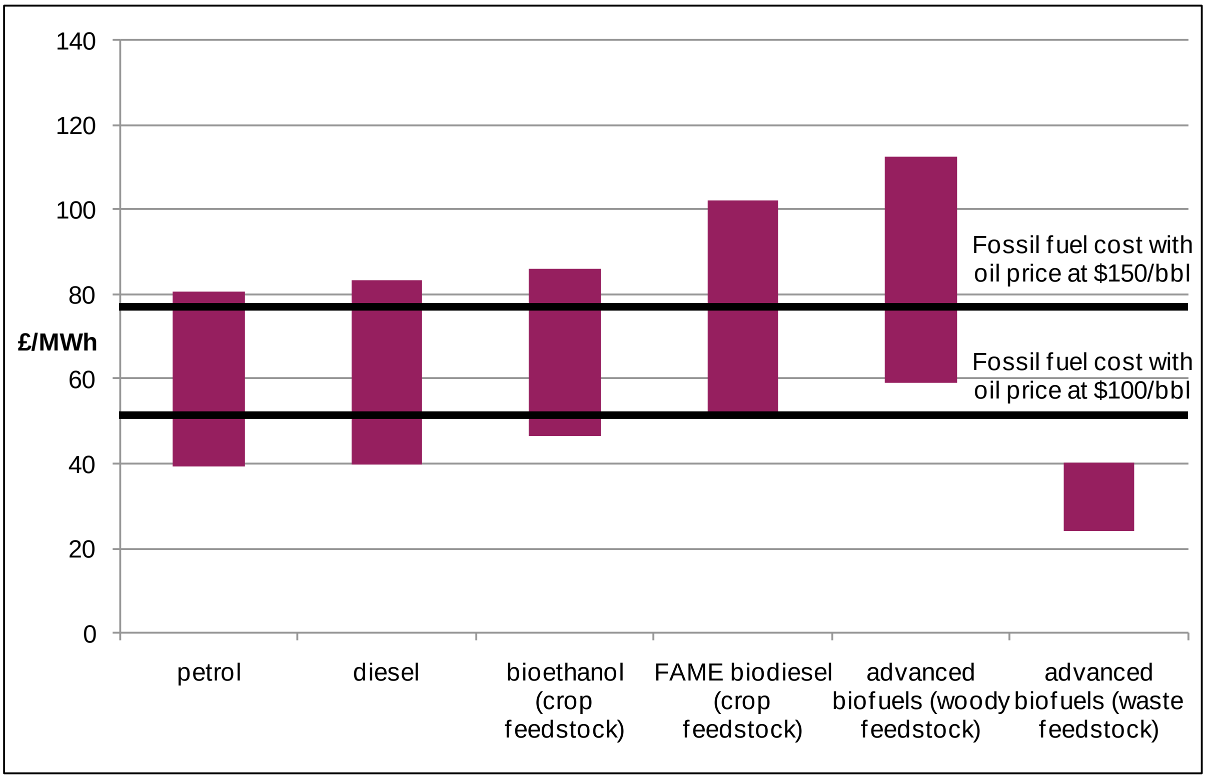
51. Estimates for biofuel applications in transport are based on refinery and capital cost estimates taken from a number of sources including Poyry (2010) and NNFCC (2011). Agricultural feedstock price projections have been estimated using the OECD Aglink-Cosimo model. In 2020, projected biofuel production costs are generally higher than their fossil fuel counterparts though processes that use wastes are within range of these. By 2030, biofuels are projected to be more cost effective, primarily due to rising oil prices and improvements in advanced biofuel technologies. The costs for the 'advanced' carriers are highly uncertain (as they have not yet been proven on a commercial basis) and should therefore be treated with an appropriate level of caution.

Figure 13: Levelised costs for road transport fuels, 2020



Source: DfT analysis based on Poyry/NNFCC/Aglink/DECC data (2010 prices).

Figure 14: Levelised costs for road transport fuels, 2030



Source: DfT analysis based on Poyry/NNFCC/Aglink/DECC data (2010 prices)

Carbon Cost Effectiveness (£/tC02)

52. The above measures focus on the cost of producing renewable energy, but it is also important to look at the cost-effectiveness of different applications and technologies in delivering carbon savings. This is usually defined as the resource cost per tonne of carbon saved (£/tC02e). Because of the convention to treat biomass as zero carbon at the point of combustion, such estimates have not generally taken account of the life-cycle emissions associated with bioenergy processes[32]. However, sources of life-cycle data now available provides a basis for developing metrics that allow us to take account of these in the carbon cost-effectiveness calculations. Box 3 below presents some sources of estimates of life-cycle analysis (LCA) for different feedstocks. The AUB model used the DECC/Ofgem carbon calculator for solid biomass and Biograce for bioliquids. However, given that there are a range of estimates of life-cycle emissions, Figures 15-19 below give an indication of how these affect the uncertainty around the cost-effectiveness indicators.

Box 3: Sources used for Lifecycle Emissions Analysis

DECC/Ofgem Carbon Calculator

The UK Carbon Calculator was developed by E4tech, with sponsorship from the Renewable Fuels Agency, the Department for Transport, and the Department of Energy and Climate Change. It uses the methodology set out in the Renewable Energy Directive. Where the EU supplies default values for particular elements of the chain, these are used in the calculator. Where there are no default values, the calculator uses values developed based on best available data through research conducted by E4Tech. The work was peer reviewed by stakeholders before being finalised. Further details are available here:

http://www.ofgem.gov.uk/Sustainability/Environment/RenewablObl/FuelledStations/cc/Pages/cc.aspx

Environment Agency / BEAT2 Estimates

The source of estimates from the Environment Agency is the BEAT2 tool. This was developed for Defra, and the Environment Agency by AEA and North Energy Associates to assess GHG emissions and environmental impacts from bioenergy schemes. BEAT2 calculates the emissions of carbon dioxide, methane and nitrous oxide over the lifecycle of a biomass energy scheme (including biofuels), from cultivation of the energy crop, processing and transportation of fuel, combustion of the crop at a power station or boiler to disposal of ashes. The focus on BEAT2 is feedstocks produced in the UK for heat and power generation,

[32] There are exceptions to this – estimates of lifecycle emissions are routinely used in transport sector biofuels analysis and reporting. Latest UK biofuel GHG emissions data can be found on the DfT website: http://assets.dft.gov.uk/statistics/releases/verified-rtfo-biofuel-statistics-2010-11/year-3-verified-report.pdf

but does include some import chains. Full documentation and methodology used to estimate GHG emissions can be found here:

http://www.biomassenergycentre.org.uk/portal/page?_pageid=74,153193&_dad=portal&_schema=PORTAL

Rowe et al (2011)

This is a review of 150 studies that have looked at detailed LCAs of feedstocks grown used for heat and power and bioliquids. For solid biomass, data was extracted from 29 bioenergy publications and 45 bioliquid publications. The aim of the study was to identify sources of variation and the record median, 25th and 75th percentile ranges (as well as 19th and 90th percentiles and outliers). The study looks at the whole LCA chain – from land preparation to cultivation and harvesting to pre and post-combustion, and highlighted sources of variation and uncertainty in different studies.

Rowe, Whitaker, Freer-Smith, Chapman, Ryder, Ludley, Howard and Taylor (2011) 'Counting the cost of carbon in bioenergy systems: sources of variation and hidden pitfalls when comparing life cycle assessments. Future Science November 2011, Vol. 2, No. 6, Pages 693-707 , DOI 10.4155/bfs.11.131. Available here:

http://www.future-science.com/doi/abs/10.4155/bfs.11.131?journalCode=bfs

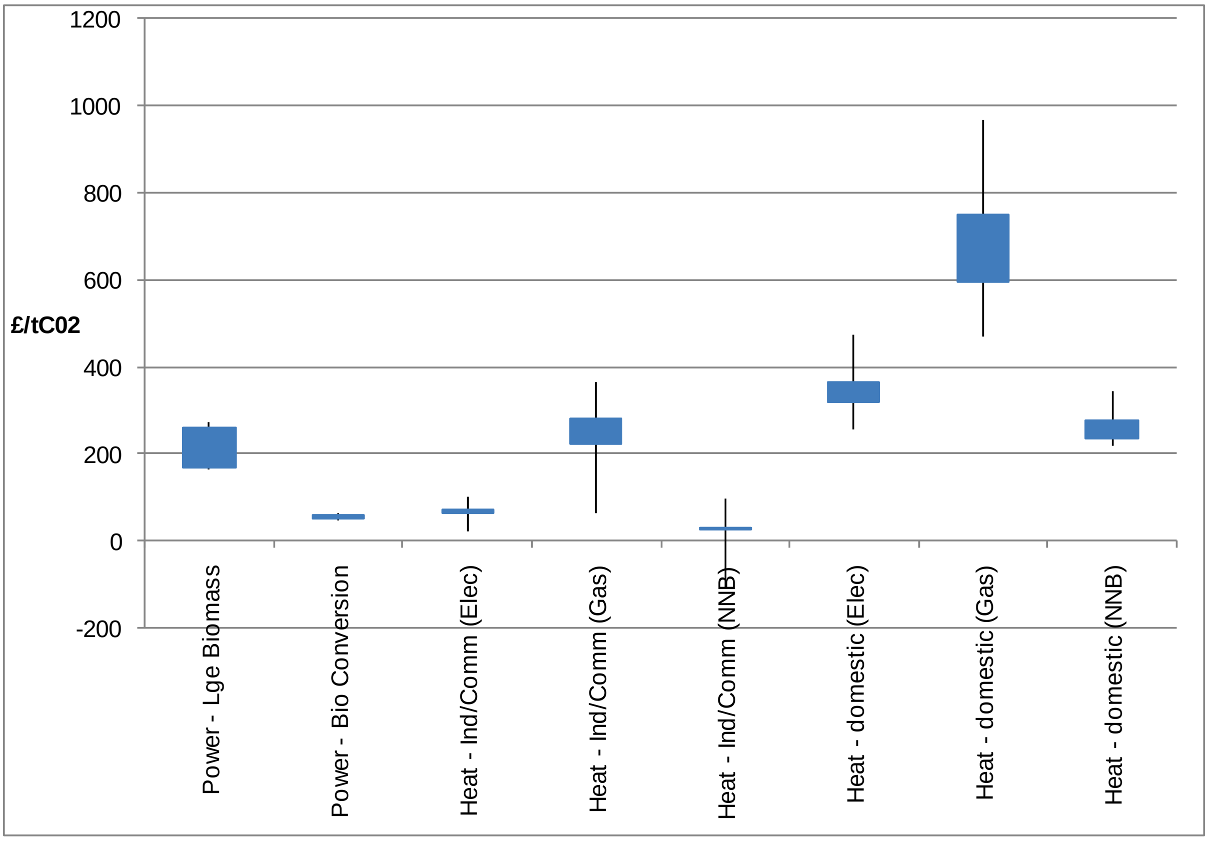
BioGrace

BioGrace is a project funded within the Intelligent Energy Europe Programme. It deals with the harmonisation of greenhouse gas (GHG) emission calculations of biofuels throughout the European Union. The EU Directive give default values for GHG emission savings of 22 biofuel production pathways (Annex V of the Renewable Energy Directive or Annex IV of the Fuel Quality Directive), but there is no information on how these are derived. The BioGrace project traces and publishes how the default values were calculated to elaborate a uniform and transparent list of standard conversion values for GHG calculations. http://www.biograce.net/

53. Figures 15 to 17 below show the range of relative cost-effectiveness of using different solid feedstocks in heat and power based on the methodology outlined above. The solid bars are constructed by using median technology costs from the sources above, and the larger ranges represented by the line use a wider range of technology costs. In both cases, the carbon saved is calculated by taking the emissions factor from the relevant counterfactual fuel and subtracting the life-cycle emissions in the bioenergy feedstocks. For the latter, the highest and lowest lifecycle GHG emissions values were used from the sources in Box 3 to determine the range of estimates for carbon saved. The counterfactual emissions assumed in this analysis are given in Table 2 below.

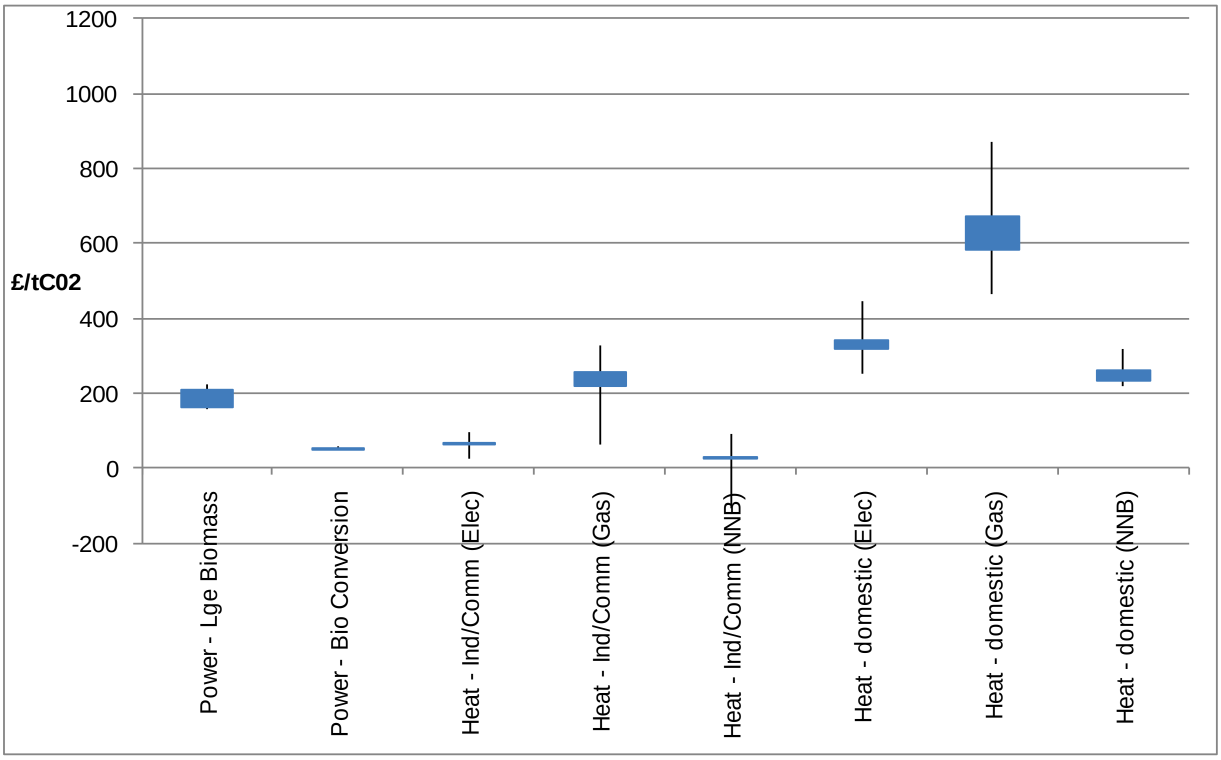
Table 2: Fossil fuel emissions factors		
	KgC02/MWh	**Source**
Power – marginal technology (CCGT)	374	IAG guidance
Power – coal (for biomass conversions)	909	Dukes 2011
Heat Gas boilers - **Industrial** - **Domestic**	 226 285	Nera analysis
Heat – Non-net bound fuels (NNB) - **Industrial** - **Domestic**	 217 293	Nera analysis

Figure 15: Cost effectiveness of using forestry products in heat and power applications, 2020 £/tC02



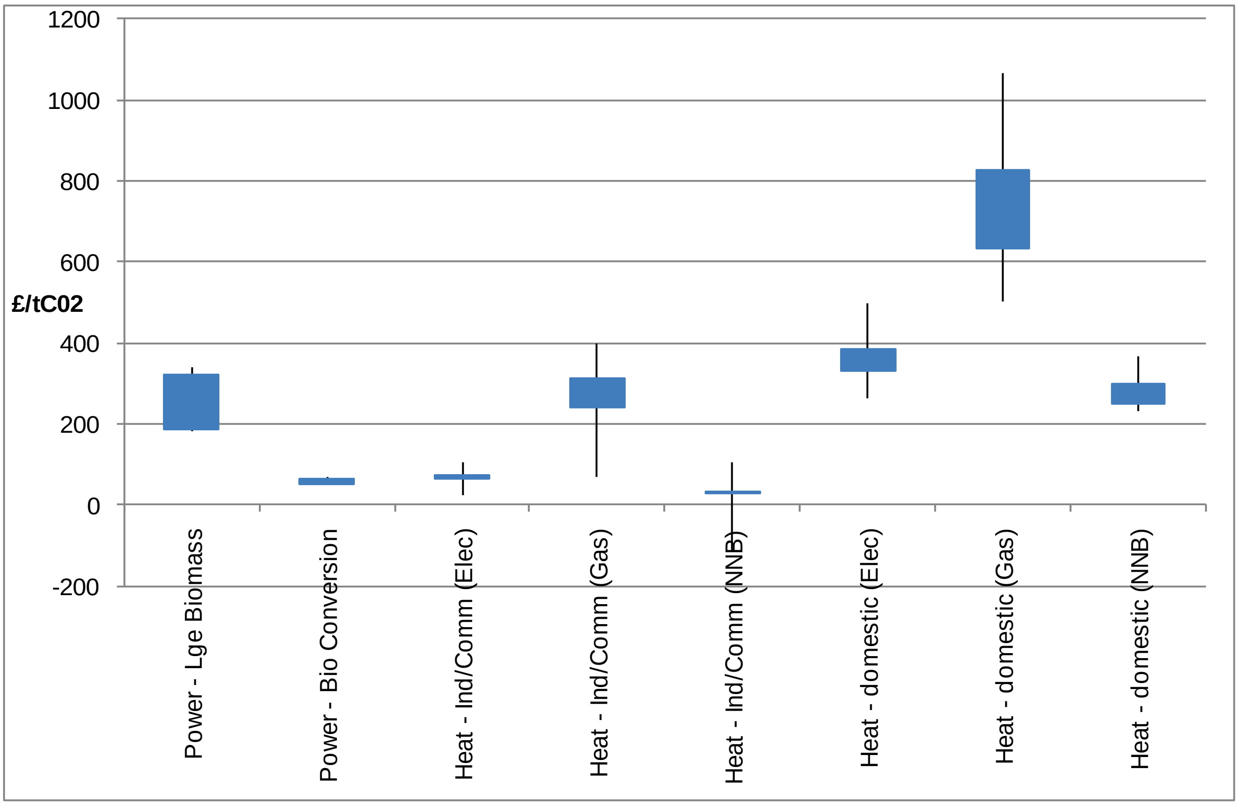
Source: DECC analysis based on sources outlined in Box 3.

Figure 16: Cost effectiveness of using SRC in heat and power applications, 2020 £/tC02



Source: DECC analysis based on sources outlined in Box 3.

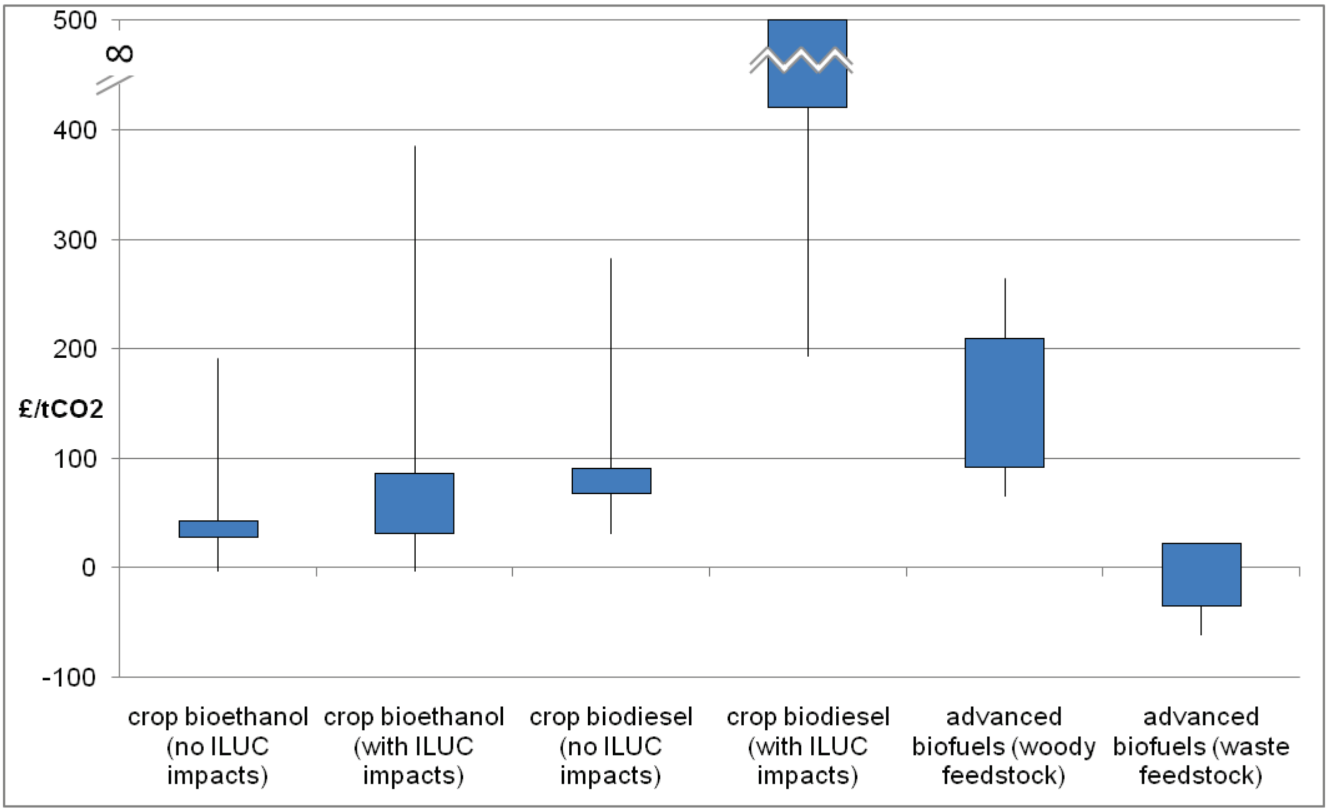
Figure 17: Cost effectiveness of using woody imports in heat and power applications, 2020 £/tC02



Source: DECC analysis based on sources outlined in Box 3.

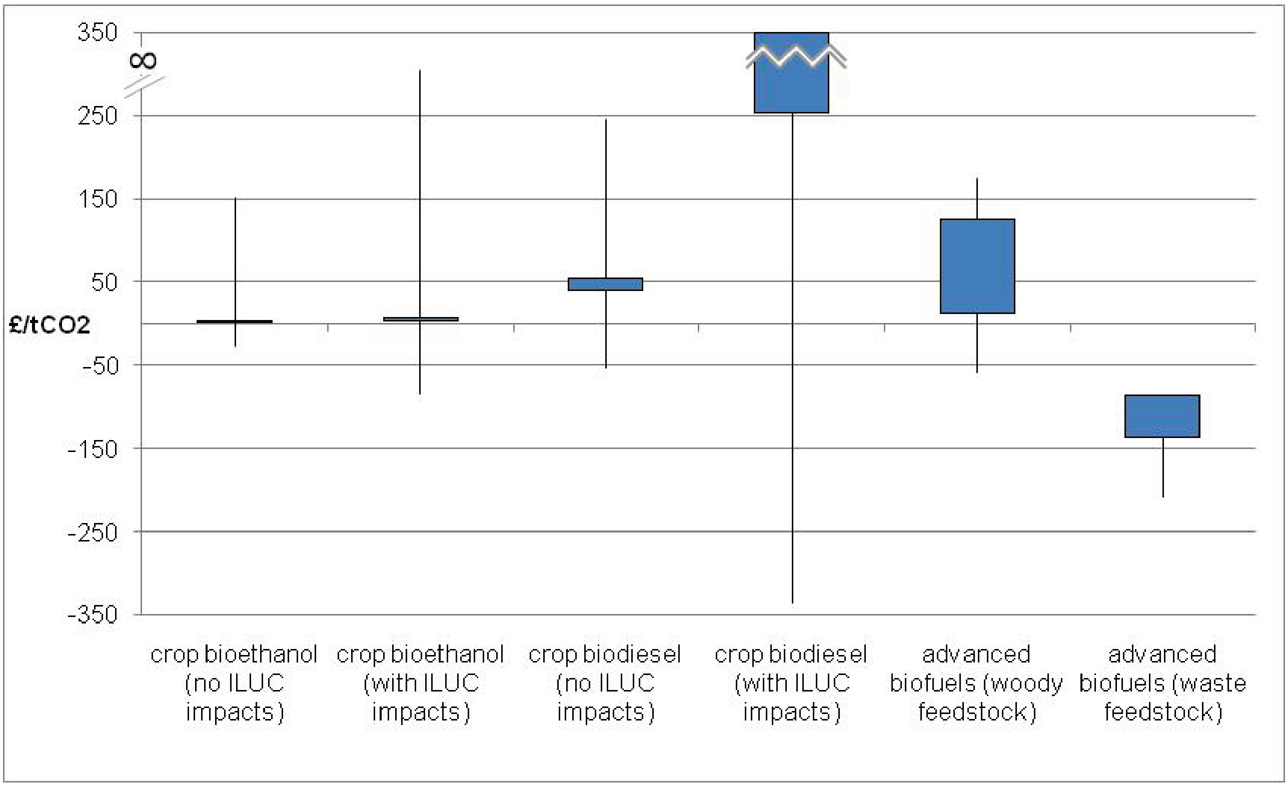
54. Where Figures 15 - 17 above show the range of cost-effectiveness estimates of using different feedstocks in the heat and power sectors, Figures 18 - 19 below provide equivalent estimates for different transport applications in 2020 and 2030.

Figure 18: Cost effectiveness of abating carbon in the transport sector, 2020 £/tC02



Source: DfT analysis based on Poyry / NNFCC / Redpoint / Aglink / IFPRI / DECC data.

Figure 19: Cost effectiveness of abating carbon in the transport sector, 2030 £/tC02



Source: DfT analysis based on Poyry / NNFCC / Redpoint / Aglink / IFPRI / DECC data.

55. The figures show that heat applications, especially in the industrial/commercial sectors and replacing non-net bound fuels or electricity are among the most cost effective in terms of carbon abatement. Biomass conversions are also relatively cost-effective, driven largely by their lower technology costs and because they displace coal burnt. Imported feedstocks tend to have a higher carbon footprint than locally grown feedstocks but also a wider range because of the greater heterogeneity in key parameters such as cultivation and harvesting techniques, and transport distances. For the transport sector, advanced biofuels using waste feedstocks are projected to be highly cost effective. In comparison, advanced biofuels using woody feedstocks are projected to be a more expensive form of abatement, reflecting higher feedstock costs. Under central assumptions crop-derived bioethanol and biodiesel appear to be cost-effective by 2030. However, varying assumptions on feedstock prices and indirect emissions increases the uncertainty over outcomes considerably, particularly for crop-derived biodiesels. The AUB analysis has not taken Indirect Land Use Change impacts into account, therefore the results should interpreted with this in mind.

Section 3 – The Appropriate Use of Biomass Modelling (AUB)

Background and methodology

56. The Appropriate Use of Biomass (AUB) model was developed for DECC and the Committee on Climate Change (CCC) by Redpoint Energy, with the aim to apply a framework to help determine the most appropriate use of bioenergy to 2050. An independent review of the input data was carried out by E4Tech, and modelling assumptions have been further refined by CCC and DECC in consultation with expert stakeholders[33]. Full information on the modelling methodology is included in the published Redpoint report available on the DECC website[34].

57. The AUB model is best suited to identifying long term pathways for bioenergy use across sectors, and does not include any policy incentives such as the RO and RHI. Decisions are made on economic grounds alone (subject to other constraints), and the model does not include investor behaviour or model the demand side (e.g. barriers to take up particular technologies or demand responses to different prices). Individual instrument models, that are sector-specific, used to set financial incentives generally consider a few years in advance, where the key aim is to contribute to the 2020 renewables target. These models can be updated quickly to respond to changing market information (e.g. on costs and deployment) and government priorities, which is crucial for setting financial incentives. AUB adds value by providing insights into the longer term and checking for consistency with how financial incentives are being set (i.e. avoiding locking in bioresources in one sector, without considering its potential application across all sectors).

58. Prices, energy demand across sectors, and the availability of resources are all entered as exogenous inputs to the AUB model. In order to carry out sensitivity analysis around these inputs the model must be re-run and results compared. The model does not include the functionality to dynamically change prices, resource supply levels or demand across sectors, in order for the market to clear. That is, there can be amounts of potential resource inputs (e.g. bioresources, fossil fuels, and renewables such as potential heat pump deployment) available to the model that are not fully utilised in any one run.

59. The AUB model is a whole energy system optimisation model which allows analysis of least cost trajectories to meet user-defined carbon or other constraints under different assumptions on variables such as technology costs and resource availability. The model has been developed to look at decision making up to 2050 in 5 year intervals. It assumes a carbon

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[33]Industry, NGOs and wider stakeholders with an interest in bioenergy have contributed in shaping the analysis through a series of workshops and meetings organised by DECC/CCC over the last year.

[34] http://www.decc.gov.uk/en/content/cms/meeting_energy/bioenergy/strategy/strategy.aspx

constrained energy system with limited supplies of sustainable energy. These supplies are allocated to certain technologies and sectors based on relative market prices and cost assumptions, i.e. taking into account the costs and prices associated with all the competing technologies in different sectors (including non-bioenergy renewables and conventional technologies). The stock of technologies built and operated over time ensures that energy service demands are met (heat, transport, etc) whilst also ensuring GHG emissions constraints and the Renewable Energy Directive target are met. The model is also constrained by energy balances and build rate limits. The model considers alternative uses across sectors (e.g. biomass can be used for heat generation in industry or, via various transformation processes, as liquid biofuels for use in surface transport or aviation).

60. The model can be run either with perfect foresight or period-by-period foresight[35], which is considered more representative of the investment cycle. It also has the ability to account for non-energy biomass use. It is important to note that wood used in construction is currently the only option considered in the analysis for non-energy uses, therefore the analysis does not take into account potential cost effective emissions savings (and therefore bioenergy use pathways) from the use of biomass feedstocks in other non-energy uses, such as plastics or pharmaceutical production. The assumptions for wood in construction are based on a report to the Committee on Climate change by Poyry[36].

61. The model can be run by varying key parameters: the availability of bioresources, availability and cost of technologies (proven and innovative)[37] and fossil fuel prices. The outputs from the model are a series of metrics, showing optimal use of resources, for example:

- Which technologies are deployed in different sectors
- Where and how much biomass resource is used
- Which biomass pathways are chosen
- The emissions profile
- The shadow price of carbon[38]

62. For the Bioenergy Strategy, the model was used to help identify the most appropriate patterns of bioenergy use given the pathways included within it, across a range of abatement options and time horizons. Sensitivity analysis was used to take account of uncertainties

[35] Period by period foresight (or myopic foresight) is implemented such that the model bases it optimisation on costs and technology availability information in 5 year periods. Perfect Foresight allows the model to optimise with full sight of costs and technologies and the targets out to 2050.

[36] http://hmccc.s3.amazonaws.com/Poyry%20(2011)%20alternative%20uses%20of%20biomass%20in%20decarbonising%20industry.pdf

[37] Cost and availability assumptions take into account innovation over time, based on the latest assumptions (for further detail see the Redpoint report)

[38] The shadow price of carbon is calculated as the marginal increase to the total system costs in the model from tightening the emissions target by one unit.

(such as availability of supply, prices, and energy demand) that will impact investment and policy decisions now and in the future.

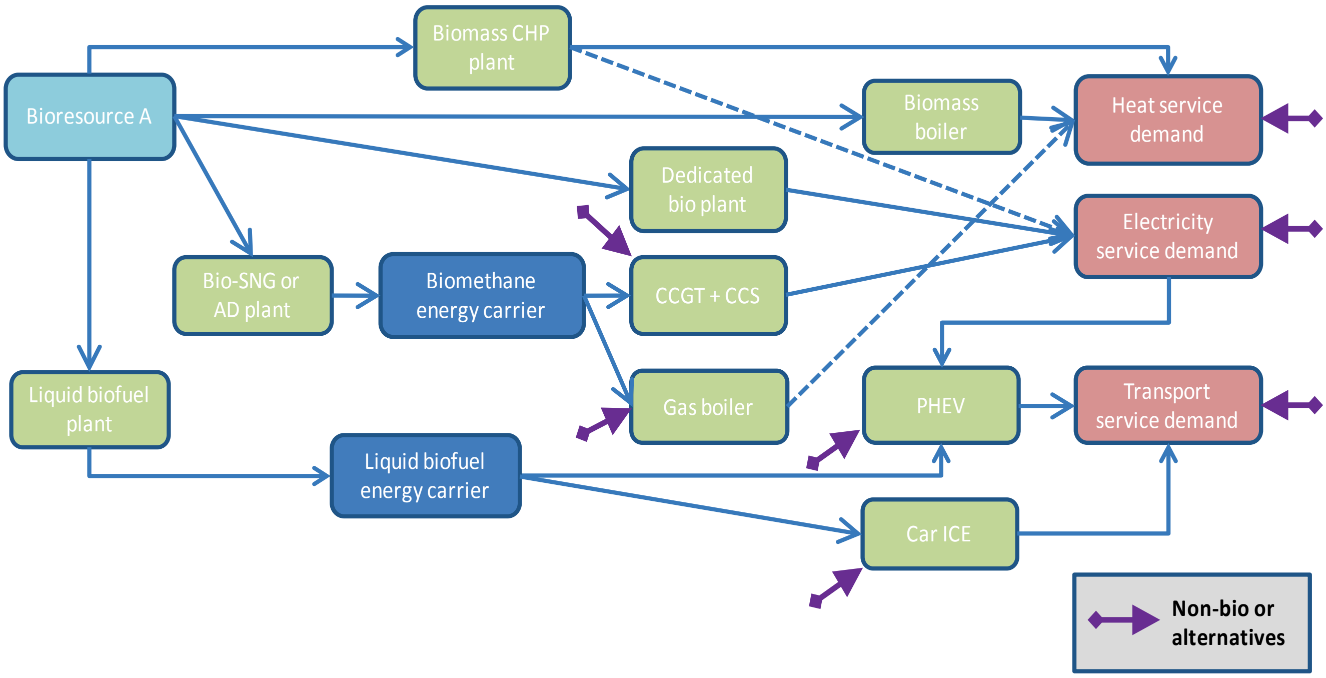
Bioenergy pathways

63. The optimisation model is required to find the optimal pathway given a very complex range of technology and energy source choices across the whole energy system. There are approximately 50 different bioresources and energy carriers[39], and around 50 unique bioenergy technologies. In total the model includes over 2000 technologies including conventional fossil fuels and other renewable and low carbon alternative technologies. In terms of bioenergy choices, the model can choose dedicated bioenergy options (e.g. biomass boilers), fuel switch options (e.g. biomethane used in a gas boiler), and also allows for complex pathways (see Figure 20 below). The remaining energy supply options (e.g. other Renewable Electricity, nuclear) are represented as competing supply curves.

64. Bioenergy pathways can consist of one or more bioresources directly being used for a bioenergy application and satisfying final output demands. Alternatively, one or more bioresources could feed into a bioenergy-conversion technology to produce a biomass carrier which is then used in a number of ways to satisfy service demands. The most complex bioenergy pathway could involve one or more bioresources feeding into a conversion technology to produce a biomass carrier which is then used as an input to further conversion process to produce the final product, e.g. the steps to produce Bio-Hydrogen.

[39] Biomass carriers refer to bioresources that are generated in the model from other bioresources and technologies, e.g. Biomethane.

Figure 20: Showing illustrative bioenergy pathways in AUB modelling



Source: Redpoint Energy 2012

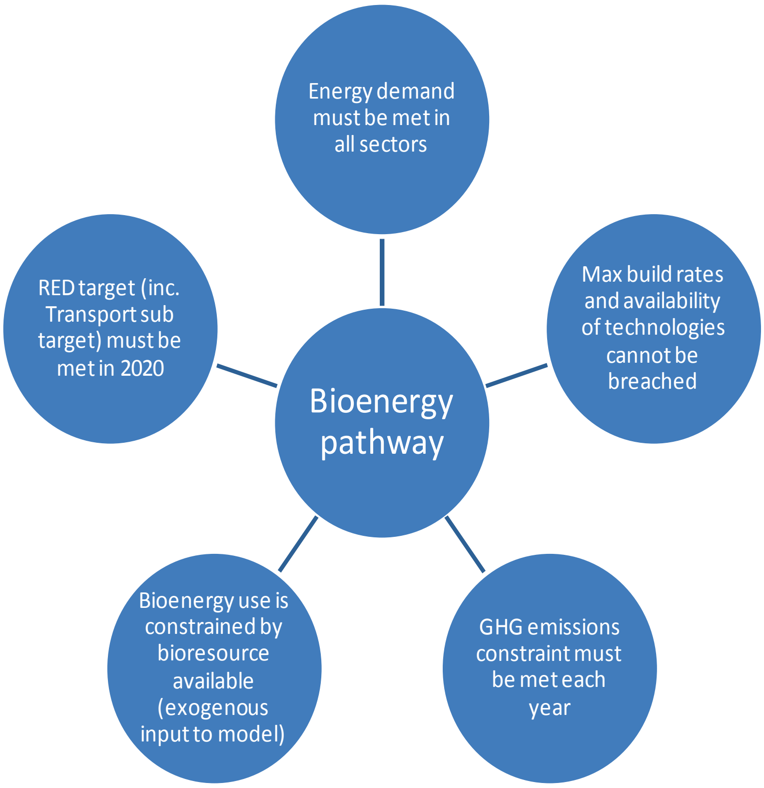
65. The model includes detailed bioenergy and lifecycle GHG emission estimates for bioresources and bioenergy carriers. These estimates include emissions occurring in the following stages: cultivation and harvesting; UK and international transport; UK and international processing; and UK distribution. UK biomass carrier lifecycle emissions are in addition to bioresource lifecycle emissions and therefore only include production process and distribution related emissions[40].

Model constraints

66. The model is designed to minimise overall energy system costs to optimally meet two key constraints: a 2050 GHG emissions target and the 2020 Renewable Energy Directive target. It does this given the available bioresources, assumptions on other constraints that need to be met, and the set of assumptions regarding other technologies to reduce emissions and energy efficiency improvements. The diagram below outlines the key constraints assumed in the AUB modelling.

[40] For further information on estimating lifecycle GHG emissions see Redpoint report, section 3.3.

Figure 21: Summary of key constraints in the AUB model that shape the chosen bioenergy pathway



Source: DECC figures based on Redpoint Energy 2012

Note: AUB considers energy on an input basis and converts to an output basis (end use) in order to calculate the service demand constraint.

67. The model is constrained to meet a binding emission constraint in each year, this is based on the reduction of all greenhouse gas emissions in 2050 by 80% on 1990 levels. Carbon emissions are reduced from current levels of around 540 $MtCO_2$ to 105 $MtCO_2$ in 2050 assuming a 70% reduction in non-CO_2 levels compared to 1990 levels. Emissions from international aviation and shipping are included in the model, although they are not currently included in the UK's 2050 greenhouse gas emission reduction targets[41]. Therefore the results should not be interpreted as a plan for meeting those targets, but rather how biomass could be most appropriately deployed up to 2050 in a carbon-constrained world. The model is constrained to meet the 2020 renewables target in each run of the model based on the specific accounting rules set out in the Renewable Energy Directive[42].

68. A range of options for energy efficiency improvement in buildings, industry and transport are included in the model, and the modelling assumptions on technology characteristics are

[41] The Climate Change Act 2008 requires us to lay regulation to the extent and circumstances in which emissions from international aviation and shipping should be brought within the target, or explain to Parliament why we have not done do so, by December 2012.
[42] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF

consistent with advice provided by the Committee on Climate Change for the fourth carbon budget report and DECC renewables modelling. The available biomass supply is entered as an exogenous input (see Section 1), and can be flexed to test patterns of bioenergy use given more or less availability of resources.

69. The model includes emissions associated with the production of bioenergy both within the UK and in other countries (e.g. as embodied emissions in imported biofuels). This makes the emissions constraints harder to achieve in the model compared to the current basis for the calculation of the 2050 target which does not include international lifecycle emissions[43]. The model is constrained to meet forecast energy service demands[44] from each sector (i.e. transport, heat, power), and its choices are limited by assumed maximum levels of availability from certain technologies in different time periods and build rates in different years.

Key uncertainties and sensitivities

70. The assumptions and data included in the AUB modelling are based on recent available evidence and data. However, there is still a high degree of uncertainty, not all of which can be adequately explored through sensitivity analysis. Key modelling uncertainties include, but are not limited to, the following:

- The availability and price of bioenergy resources (domestic supply and import availability).
- The availability and price of competing energy sources including non-bioenergy renewables and conventional fossil fuels.
- GHG emissions from bioenergy pathways and processes.
- The potential role for cost effective emission savings from non-energy uses of biomass feedstocks in comparison to use for energy purposes (only wood in construction is currently included in the model).
- Technologies excluded from the model but with potentially important role; for example, industrial bioenergy CCS options are not included explicitly as technologies (however an adjustment to the GHG emissions target has been included to account for this[45]).
- The costs and feasibility of smaller scale CCS options for CHP/heating or larger-scale gasification options for biomethane.
- Longer-term technology costs, efficiencies, and build rate assumptions for novel and unproven technologies (e.g. second generation biofuels or ultra low emission vehicles).

[43] The modelling results taken into consideration all include international and domestic lifecycle emissions, however it is possible in the model to run a sensitivity analysis excluding international emissions.
[44] The energy production from the outputs of technologies must at least equal the assumed demand for energy services in each period. Energy service demand on an output basis is a constant constraint. However, total energy demand will vary depending on the pathway chosen.
[45] This adjustment refers to a general adjustment made to reflect the lack of process emissions and industrial CCS options in the model (not a specific adjustment for industrial bioenergy CCS).

- External policy drivers, such as air quality objectives, that might drive the adoption of technologies in a way such that the AUB model would consider suboptimal.
- Long term feasibility of deployment of certain technologies in specific roles (e.g. deployment of fuel cell electric powertrains in heavy road and rail vehicles).
- The role of consumer preferences for alternative technologies is not included in the model – this is particularly important for ultra low emission vehicles as the choice between, for example, an electric or petrol car which may be more obvious to consumers than whether their electricity is generated from renewable or fossil sources.
- Indirect Land Use Change emissions have not been included in lifecycle emissions[46].

71. Further areas of uncertainty include factors such as changing global demand for bioresources, global development of biomass technologies (including global policies on bioenergy), and overall levels of energy demand. In addition, the role of the EU Emissions Trading System, and any subsequent international emissions trading markets, in achieving emissions reductions in traded sectors has not been included in the analysis, but would be likely to have a significant impact on the results. The production processes of a number of the technologies included in the model include elements that are in both the traded and non-traded sectors under the existing system. Furthermore, the model requires that emission reductions must be achieved domestically[47] as there is no modelling of overseas abatement options. In reality it may be more cost effective for industries in the traded sector, such as electricity or international aviation, to purchase allowances than use the technologies selected by the model.

72. It is important to note that the model's optimisation can lead to significant switches in technology uptake over short time periods due to relatively small changes in assumed costs of technologies over time. This is mitigated to some degree in the model by the use of minimum load factors, which reduce the speed of transitions between technologies. In reality we would not expect such rapid switches to occur (i.e. model does not take into account investor behaviour), the results should be interpreted as signalling time periods (due to technology availability or cost) for potential key tipping points where the energy system may divert to alternative bioenergy pathways, this should not be interpreted as a projection or forecast of what is actually likely to occur. This is explained further in paragraph 77 and *'Key modelling results'* section, and further sensitivity analysis is carried out in Appendix 2.

73. Given these uncertainties we have used the AUB model to run various sensitivity analysis, including flexing resource availability and removing the availability of key technologies such as CCS and hydrogen, and have presented the results at the most appropriate level of detail. As new and improved data becomes available for biomass technologies, the model can be

[46] The bioresource supply scenarios assume the land used for bioresource cultivation is spare/abandoned agricultural land, and therefore not in direct competition with other uses such as for food production or grazing. Therefore there should not be any Direct land use change emissions associated with the bioenergy use.
[47] If feasible. The exception is a very high cost dummy credit purchase option in the model which can be used to solve the optimisation if the GHG constraint cannot be met through the modelled abatement options.

updated to take these developments into account. The data currently included in the model represents a snapshot of the best available data at this time.

Interpretation of AUB modelling results

74. The AUB model is intended to provide a high level view of different bioenergy uses to 2050, identify trade-offs and risks, as well as key innovative technologies and pathways. The AUB modelling does not provide a forecast or projection of the feasible or intended pathways for bioenergy use in the period to 2050, neither does it provide a pathway for the energy system mix viewed as a whole. Rather than indicating policy intent, the modelling results should be viewed, alongside wider evidence sources, as a guide to understanding key issues (such as constraints to specific technologies and technology lock in risk), trade-offs (between use of bioenergy resource in different end use sectors and for different technologies) and technology innovation needs, that are highlighted in the various runs of the model. It is also useful in identifying certain low risk bioenergy technologies or pathways that appear robust to the key sensitivity analysis.

75. While the focus of AUB is to identify longer term pathways, the model is also constrained to meet the 2020 Renewable Energy Directive (RED) target. Interpretation of the results for this year requires special consideration given the various other models used to model the RED target. The key difference between AUB and other models underpinning analysis for policies such as the Renewables Objective, the Renewable Heat Incentive and Feed In Tariff Scheme is that AUB does not model subsidies, investor behaviour or consider all deployment barriers. Therefore it cannot provide the level of detail on costs, take-up, tariff levels and carbon savings that these applied models are designed for. Rather, the AUB sets out an overall view of key bioenergy applications and the relative mix of resource across different sectors. The key findings from AUB can then inform the basis of more detailed analysis within the applied models.

76. It should be noted that other modelling studies, (such as the Energy Technologies Institute's, or DECC's recently undertaken technology Innovation Assessment Needs study for biomass) suggests that substantial amounts of biomass might be directed into electricity with CCS, rather than transport fuel production with CCS. This suggests that, whilst CCS technology inevitably alters the relative attractions of deployment pathways for biomass, the use of specific deployment pathways are highly dependent on future costs and remain uncertain at present. Therefore we should not put too much weight on the specific CCS applications that might be best deployed in the future but that the availability of CCS will be an important application across the energy sector should it demonstrated.

77. When interpreting the modelling results it is important to note that the model does not take into consideration demand side issues, such as consumer preferences to take up of ultra low emission vehicles (ULEVs), that would impact on the feasibility of particular technology pathways. Similarly, the modelling does not include comprehensive analysis of all infrastructure costs associated with the ramp up of technologies, this is particularly important when considering the sizeable switches in technology pathways that are evident in the

modelling results for the longer term. It is to be expected that modelling assumptions for unproven technologies in the longer term will be subject to higher uncertainty than near term technology options. With this in mind, the long term results (particularly the rapid switching from non-CCS liquid biofuels to hydrogen produced from biomass with CCS between 2045 and 2050) should be interpreted as useful illustrations of potential key technology tipping points where the pathway for bioenergy use may change significantly in the longer term. Whether these pathways are realised in practice would depend on factors outside the scope of this model – for example consumer preferences, incentives in place to drive particular behaviours, and the feasibility of building new infrastructure and distribution systems for novel fuels.

Modelling Results

78. This section includes analysis of the AUB modelling results for the following scenarios:

- ***Scenario 1****:* Assumes medium assumptions for feedstock availability, central fossil fuel prices, perfect foresight (of costs and technology availability) to 2050 and availability of Carbon Capture and Storage (CCS) technology.
- ***Scenario 2****:* As Scenario 1 but excluding CCS technology.
- ***Scenario 3****:* As Scenario 1 but with high oil prices.
- ***Scenario 4****:* As Scenario 1 but excluding perfect foresight (model run with period by period (5 year) foresight).
- ***Scenario 5****:* As Scenario 1 but with Restricted supply scenario assumptions for feedstock availability.
- ***Scenario 6****:* As Scenario 1 but with Ambitious supply scenario assumptions for feedstock availability.
- ***Scenario 7****:* As Scenario 1 but with Highly Restrictive Sustainability Standard supply scenario assumptions for feedstock availability.

Results for specific sectors:

- Power sector
- Heat sector
- Transport sector

Key modelling conclusions

79. The AUB modelling provides a high level view of different biomass uses to 2050, identifying trade-offs, risks, and key innovative technologies and pathways. The modelling scenarios included in this section help identify certain bioenergy uses that emerge as low risk[48] options, such as: non-energy uses for biomass such as wood in construction; the use of bioenergy for industrial heat (specifically high temperature process) and near to mid-term role for conversions and co-firing in the electricity sector. In addition, so long as the sustainability can be assured, and while fossil fuels continue to be used in transport, some conventional biofuels can offer a cost effective contribution to reducing carbon emissions from road transport. The results also identify Gasification is an important technology across sectors, e.g. for biomethane in the heat sector, and for advanced biofuels and bio-hydrogen production in the transport sector.

80. The level of bioresource availability and the availability of Carbon Capture Storage (CCS), have emerged as the two key determinants in switching the patterns of bioenergy use across sectors and technologies. The modelling results highlight the difficulty in meeting the 2050 emissions target in an environment without access to CCS technology or sufficient bioresources. The relative costs and availability of the technologies CCS can be applied to are subject to significant uncertainty (especially for unproven technologies in later periods such as bio-hydrogen for transport), and small changes to these assumptions can lead to changes in the technology pathways taken up by the model. To further analyse the longer term switches in technology, sensitivity analysis was carried out on the costs and availability of these technologies (see Appendix 2).

81. Over the modelling time frame (2011 – 2050) the constraints that the model must meet have an impact on the technology pathways taken up. For instance in the near term the 2020 renewables target is the binding constraint and will influence what type of technologies are brought in to the energy system mix, whereas in the longer term the effort to meet the binding emissions constraint becomes the key driver. Throughout the period, the availability of certain technologies, build rate limits, and meeting energy service demands will restrict which pathways the model can choose.

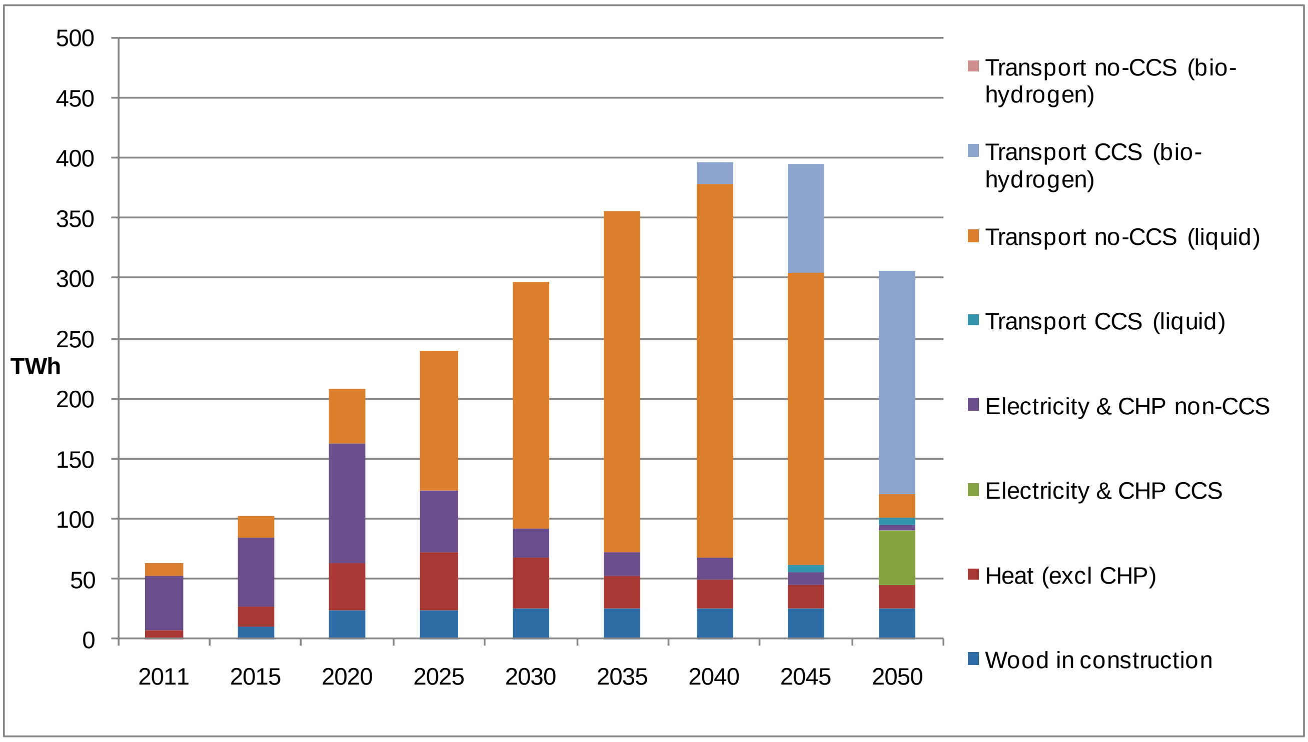
Modelling results (scenarios 1 to 4)

82. This section includes a summary of the total bioresource use on a primary energy basis in TWh per year for all sectors. Figure 22 below shows a model run for Scenario 1 assuming medium resource availability and including CCS technology. This scenario can then be

[48] 'Low risk' in this context refers to biomass technologies that have been found to be robust to different sensitivity runs of the model in certain time periods, e.g. medium term transition role or longer term role to 2050.

compared to the following sensitivities: without CCS technology availability; high oil prices; and assuming only 5 year period by period foresight in the modelling.

Figure 22: Total Bioresource use on a primary energy basis per year for all sectors for Scenario 1



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

83. Scenario 1 is run with perfect foresight and assumes central assumptions for feedstock availability, fossil fuel prices, and availability of CCS technology from 2025. As with all runs of the model, the 2050 GHG constraint and 2020 Renewable Energy Directive targets are met in this scenario.

84. The model suggests an important near term (up to 2020) role for biomass in electricity generation, heat and liquid transport biofuels. In the medium term (from 2025 to 2035) biomass use is dominated by non-CCS liquid biofuels in transport. In the longer term (up to 2050) the focus for biomass use shifts to CCS technologies, specifically CCS technologies for hydrogen fuels, primarily in transport with some in the power sector. There is also a consistent role through to 2050 for biomass heat in industry and wood in construction.

85. The rapid switching from non-CCS liquid biofuels to hydrogen produced by biomass CCS between 2045 and 2050 would be unlikely in the real world and should not be interpreted as a projection of what we consider feasible or likely in the long term. The switch implies that the international aviation and shipping sectors will revert back to fossil fuels in one 5 year period by cutting levels of imported bioresources, and either the previous existence of a fleet of hydrogen vehicles that is not demonstrated implicitly by the model or a switch to such vehicles at a speed that is unlikely to be achievable in the real world. However, the switch in

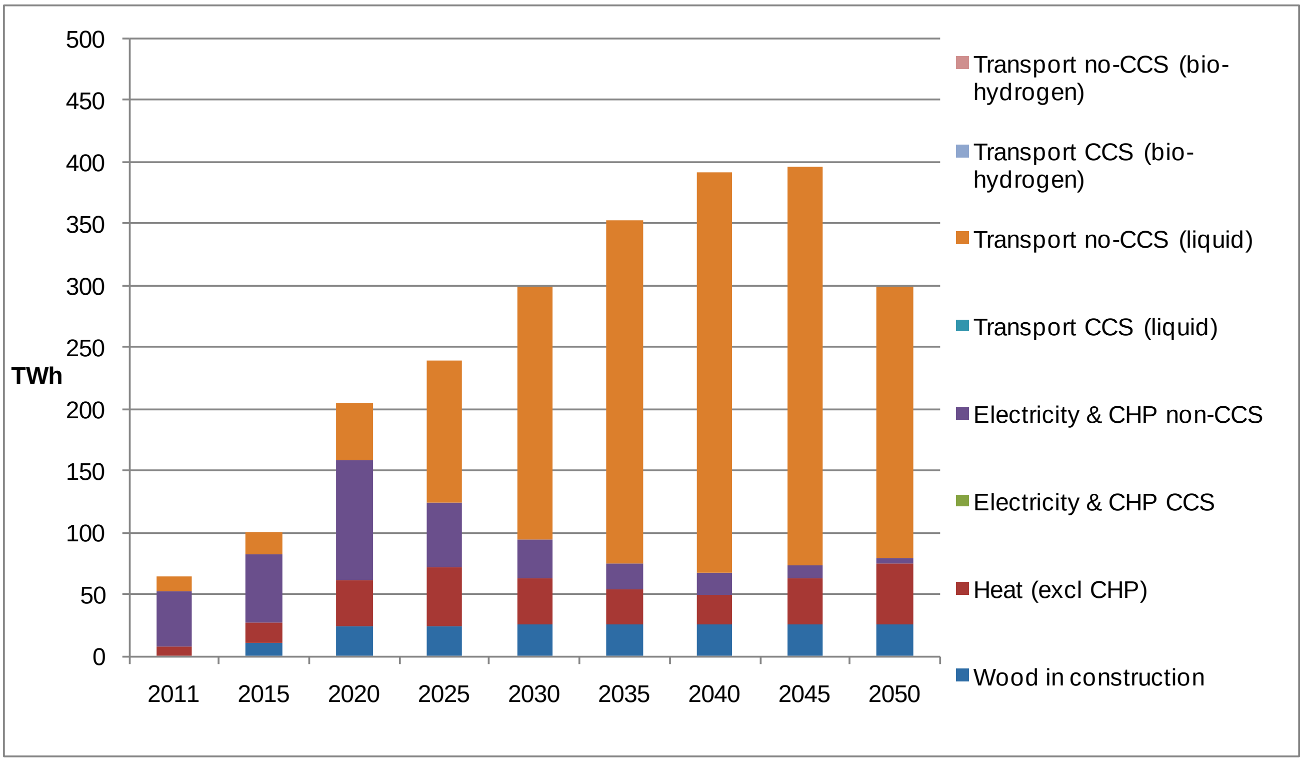
technologies identified by the model provides a useful signpost in terms of key technology tipping points, where the pathway for bioenergy use may change significantly, that we may potentially face in the longer term. This highlights the importance of keeping technology options open and avoiding locking into certain pathways (that could incur sunk costs) before we understand more about the potential and timeframe for CCS deployment. For further sensitivity analysis on the longer term switching in technology pathways see Appendix 2.

86. The model leaves significant amounts of woody biomass imports and ethanol imports unused in near and medium term. This suggests that import availability for this type of biomass is not a binding constraint in the near and medium term. Imported bioethanol is the only resource left unused in 2050 due to blend wall[49] assumptions throughout the period which act as the binding constraint to bioethanol deployment.

87. As CCS is an unproven technology and it's longer term feasibility is yet to be determined, Scenario 2 includes the same assumptions as Scenario 1 but assumes CCS is not available. This scenario leads to an increase in biomass use in heat in the longer term, a continued small (and decreasing) role for biomass in non-CCS electricity in the longer term, and a continued use of non-CCS liquid transport biofuels to 2050 (which provides the main replacement for CCS technologies for hydrogen transport fuels seen in the scenario with CCS). The use of wood in construction remains consistent through the whole period as in the medium run.

[49] The 'blend wall' refers to the mandatory limit at which conventional biofuel can be blended with fossil fuel as dictated by engine design in the current car fleet and regulations that limit the amount of biofuel that can be blended with fossil fuel (bioethanol/petrol, biodiesel/diesel).

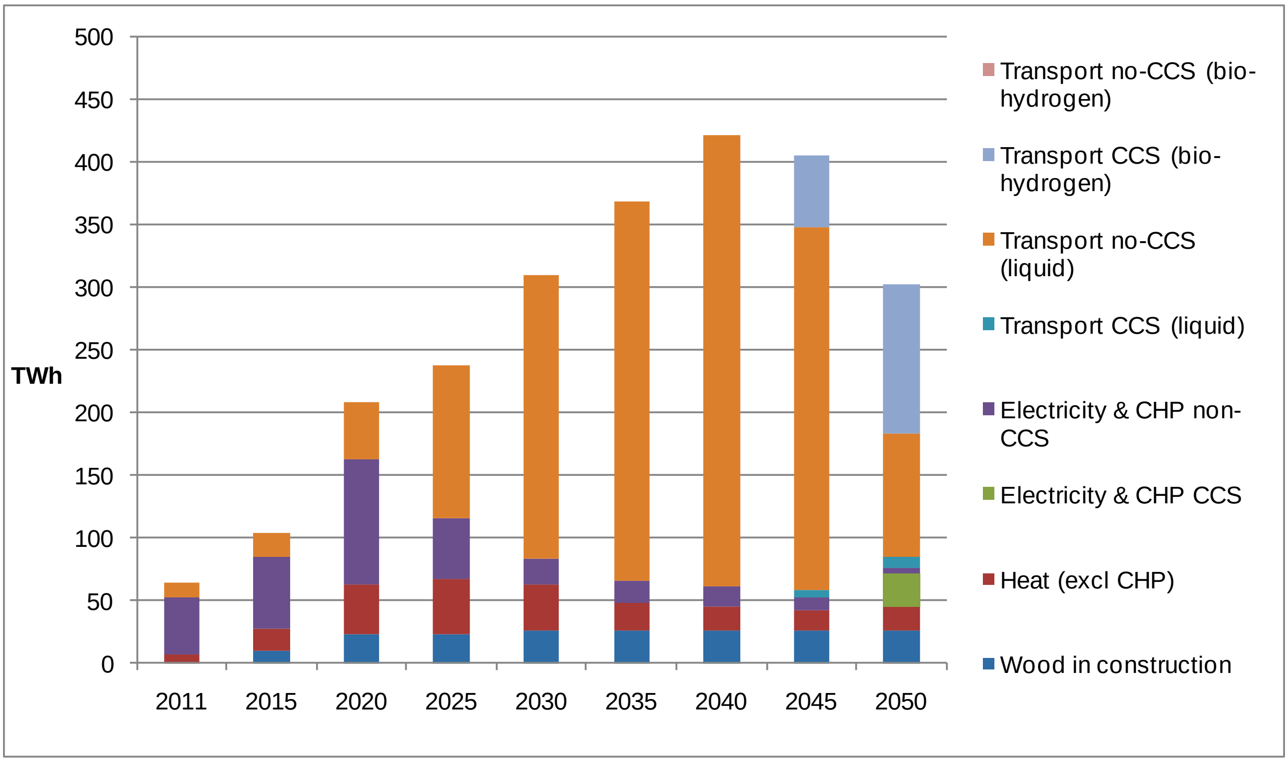
Figure 23: Total Bioresource use on a primary energy basis per year for all sectors for Scenario 2



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

88. Scenario 3 is consistent with Scenario 1 run but includes high oil prices (while keeping other energy prices at central assumptions). Higher oil prices lead to increased total biomass use in the medium term, arising primarily from increased use of biomass in non-CCS liquid transport fuels. In the long term to 2050 the results show switching from non-CCS liquid biofuels to hydrogen produced by biomass CCS, but this is less pronounced than in Scenario 1 and there is a greater role for non-CCS liquid biofuels given the higher relative price of alternatives. This switch should be interpreted as in Scenario 1.

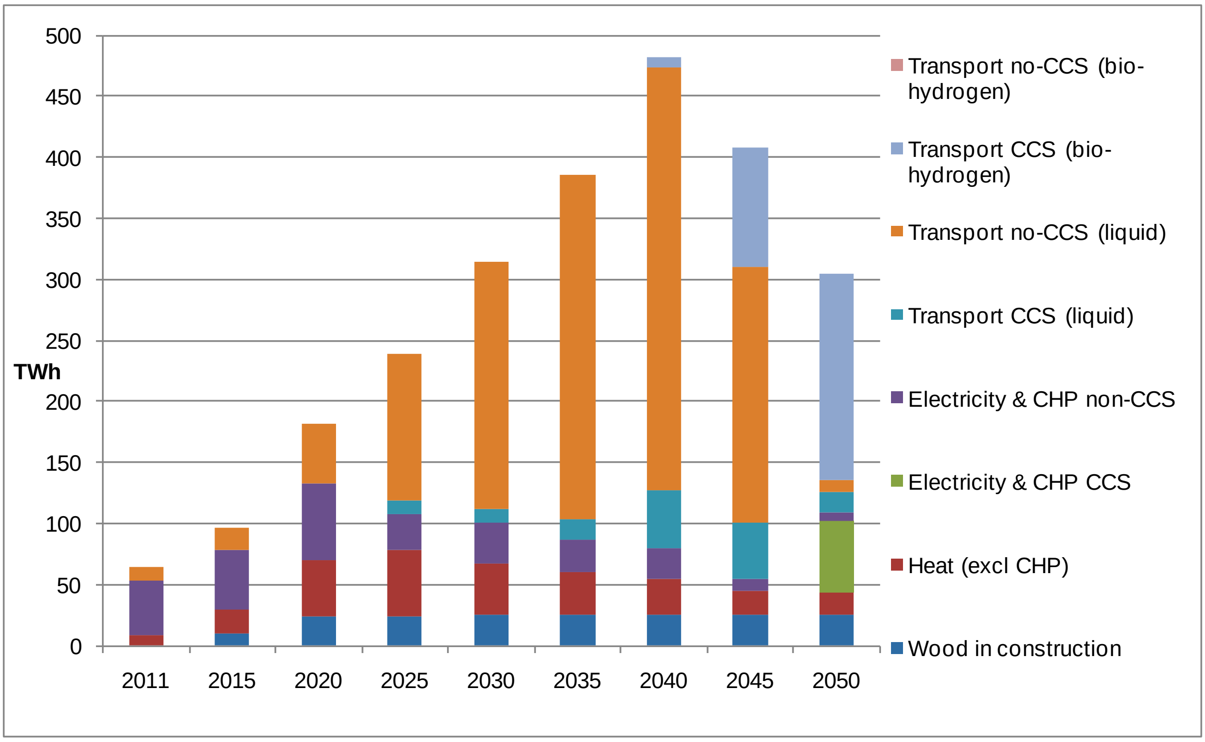
Figure 24: Total Bioresource use on a primary energy basis per year for all sectors for Scenario 3



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

89. In Scenario 4 the model can only consider information 5 years ahead of the point from where it must make a choice in terms of the resources to allocate to different technologies and sectors. This should help identify any changes in patterns of biomass use given a more realistic level of foresight. Without perfect foresight the model can only consider the target in each period, but will not be considering the impact of targets at later stages in the future, such as the consequences of infrastructure lock-in and sunk costs. The model may therefore choose a technology pathway in earlier periods such that certain cost effective technologies are not available in later years due to the model being locked into another technology pathway.

Figure 25: Total Bioresource use on a primary energy basis per year for all sectors for Scenario 4



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

90. The key differences when comparing to Scenario 1 with perfect foresight are found in the medium term. The near term and 2050 patterns remain similar as it is difficult in those periods to meet the binding targets in 2020 and 2050[50], and certain combinations of technologies (assuming they are available) will be prioritised by the model. Without perfect foresight total biomass use increases throughout the midterm and liquid biofuels with CCS in surface transport are taken up at the earliest opportunity and at increased levels. Biomass in heat is also increased in the near to midterm. The role for wood in construction remains consistent with the perfect foresight scenario. These decisions are made without the knowledge of more cost effective options available in later periods.

91. A similar rapid switch from non-CCS liquid biofuels to hydrogen produced by biomass CCS can be seen between 2045 and 2050, and should be interpreted in the same way as explained for Scenario 1.

Modelling results (scenarios 5 to 7)

92. The availability of sustainable supply is a fundamental issue for the appropriate use of bioenergy out to 2050, and is entered as an exogenous input to the AUB model. Given the

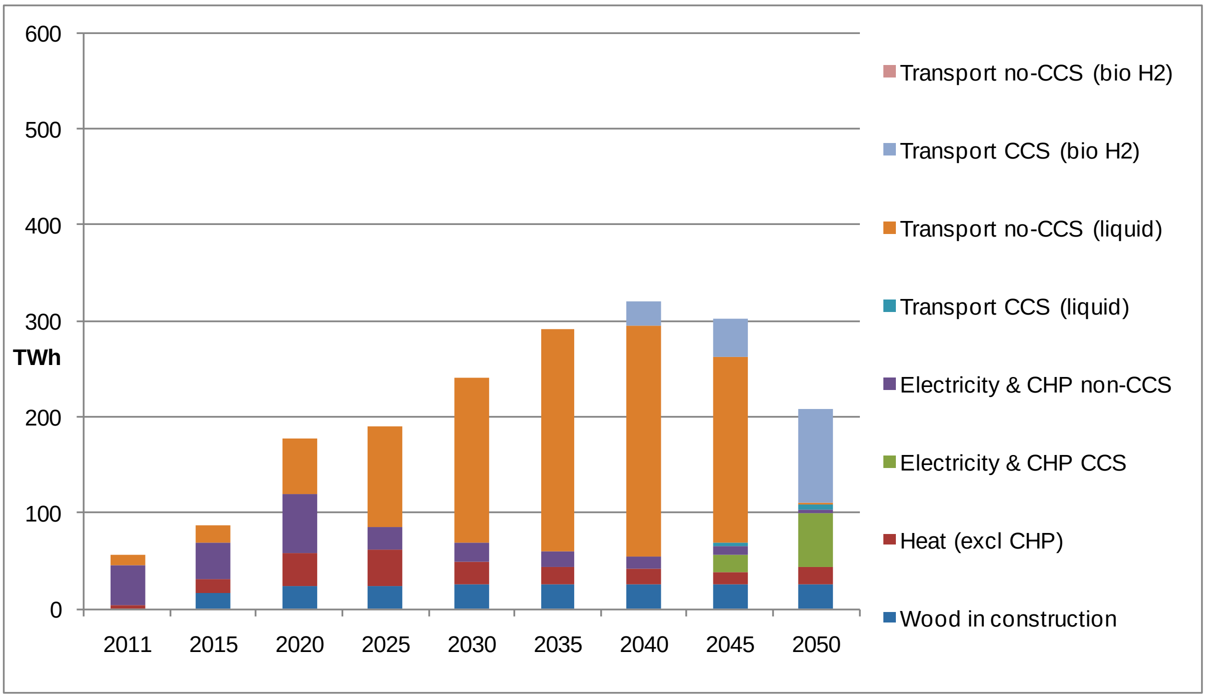
[50] The model must meet an emissions constraint in each year to 2050, however the constraint becomes increasingly challenging to meet towards 2050 (i.e. there is less headroom) and therefore choices are limited in 2050 by the necessity to meet the target.

supply and price assumptions are set exogenously in this model (and the assumption that total levels of bioresource are falling from the medium term towards 2050) the model will not make use of all bioresources potentially available in all years (i.e. the model will report both used and unused bioresources). The model will see the falling bioresource availability towards the longer term and take that into account when making technology deployment decisions over the whole period, which results in left over resources leading up to 2050. This explains why we see levels of unused imported woody biomass over the medium term across the supply scenarios (but at different absolute levels) – this is shown in bioresource used and unused charts presented for scenarios 5 to 7 in this section.

93. As explained in Section 1, three supply scenarios (in addition to the medium estimate) covering a wide range of availabilities have been estimated in order to test the impact on bioenergy use patterns of varying availability of feedstocks. For further information on the supply scenarios please refer to Section 1 (for a breakdown by feedstock see Figure 4 and 6). This section includes a summary of the total bioresource use on a primary energy basis in TWh per year for all sectors, varying resource availability while holding all other assumptions constant. Figures 26 to 34 show the following scenarios: Scenario 5 Restricted supply; Scenario 6 Ambitious supply; and Scenario 7 a Highly Restrictive Sustainability Standard supply scenario.

94. Scenario 5 (Restricted supply) results in similar overall patterns of bioresource use to the Scenario 1 (see Figure 22), but with reduced total levels of bioresource use overall (by around 15% in 2020 and 30% in 2050).

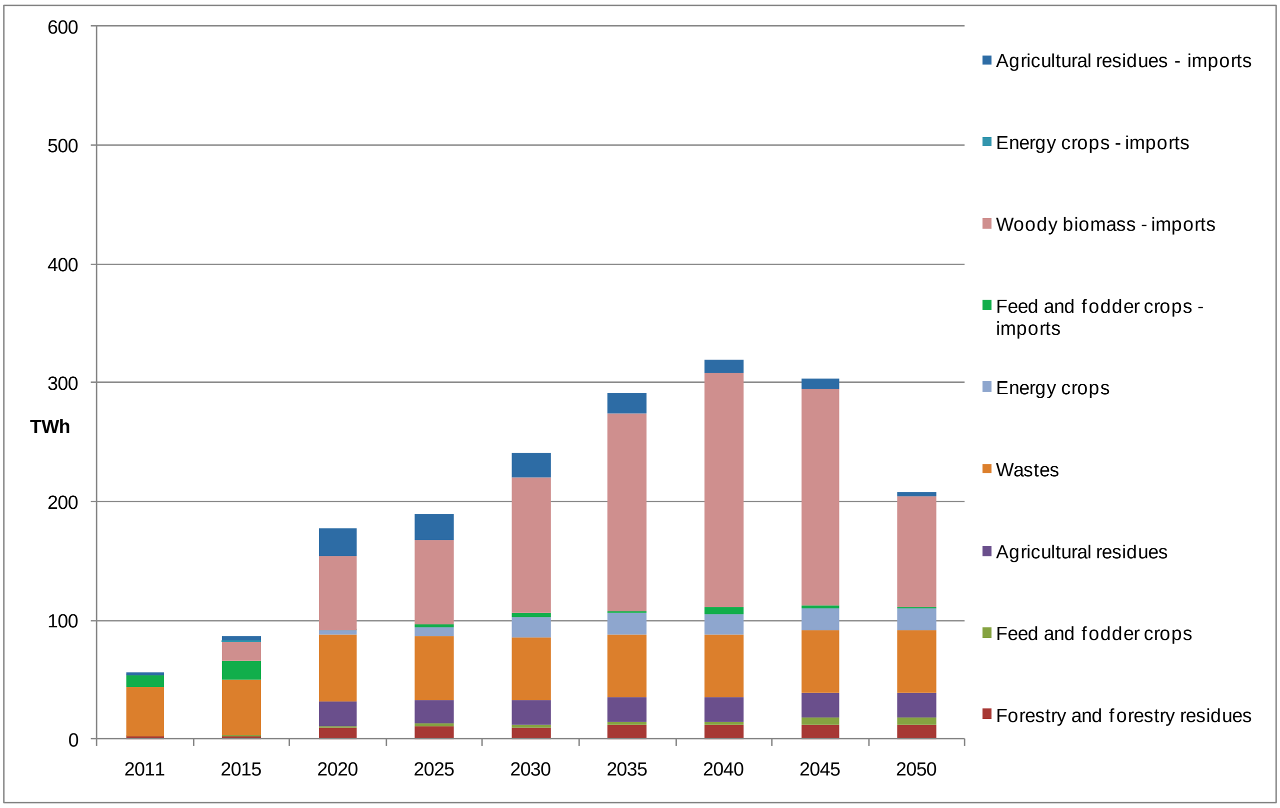
Figure 26: Total Bioresource use on a primary energy basis per year for all sectors for the Scenario 5 (Restricted supply)



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

95. The model is constrained in its choices by the levels of bioresource feedstock available. Figures 27 and 28 show how much of the available feedstock the model takes up in the restricted supply scenario, and what resources were left unused. The amount of feedstock available declines from the midterm towards 2050 due to the assumption that the UK will secure a declining proportion of globally traded imports. This is reflected in the profile of used imported woody biomass. The increase in utilisation of resources between 2015 and 2020 to meet the Renewable Energy Directive target in 2020 can be seen from the graph and is evident for all supply scenarios.

Figure 27: Bioresource used by aggregated product (TWh / year) for Scenario 5 (Restricted supply)



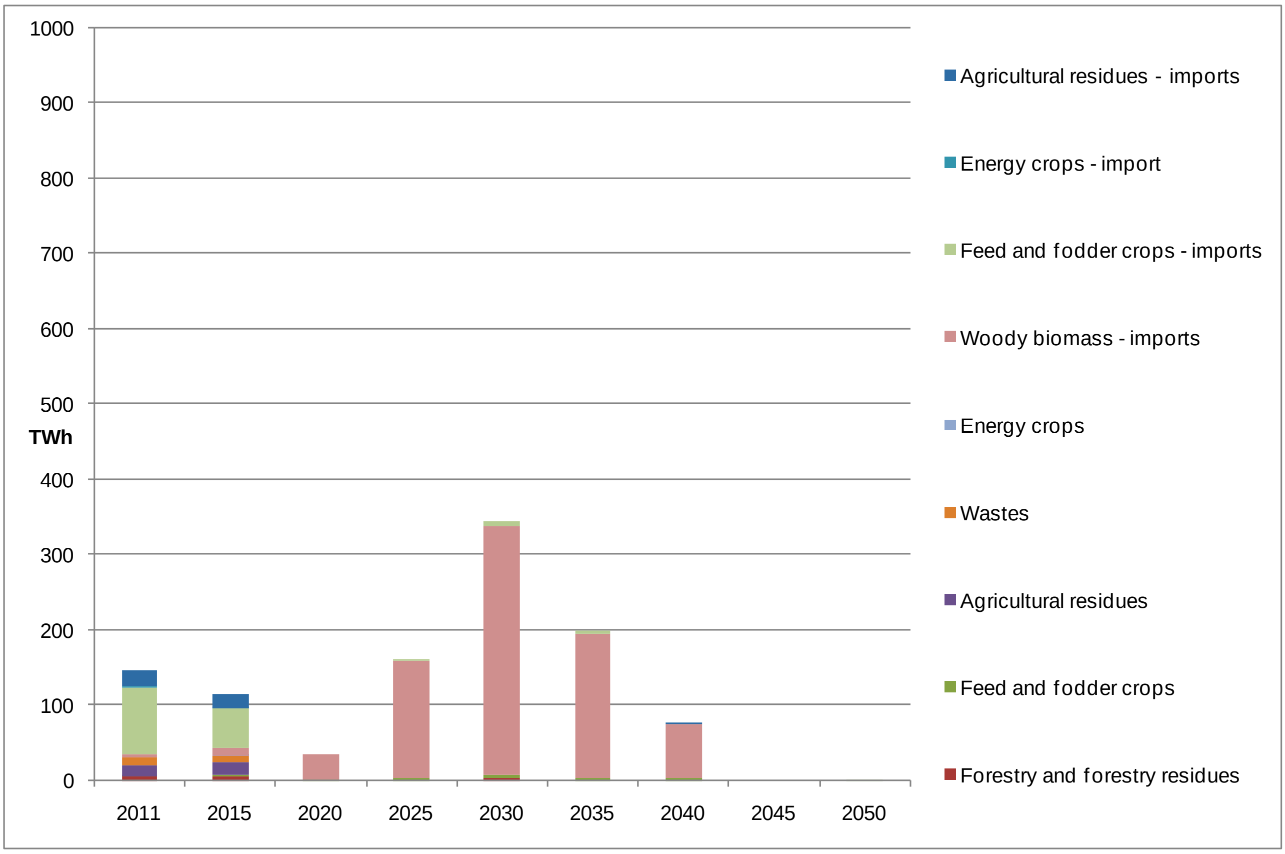
Source: DECC modelling using model developed by Redpoint Energy and Ecofys

Note: Domestic bioethanol crops are inlcuded within feed and fodder category in bioresource used charts.

96. In all runs of the AUB model we see levels of bioresources that were available to the model left unused, i.e. given the set of assumptions and constraints regarding bioresource availability and relative costs and availability of technologies over the whole time period, the technology pathway taken up may not fully utilise all the available bioresources potentially available. Assumptions on prices, costs and demand are all entered exogenously, and the model does not have the functionality to adjust these assumptions in order for markets to clear. Similarly, in any run of the model, there can be potential capacity from technologies such as heat pumps and wind power that may go unused if a particular technology pathway does not require that capacity in order to meet the modelling constraints set.

97. Figure 28 below shows bioresources left unused by the model for the restricted supply scenario. UK bioresources are virtually all used from 2020 onwards, with imported woody biomass being the key left over resource in the medium term largely due to their higher transport costs compared to UK bioresource. Virtually all biomass resources are fully utilised in the long term as the emissions constraint tightens towards 2050.

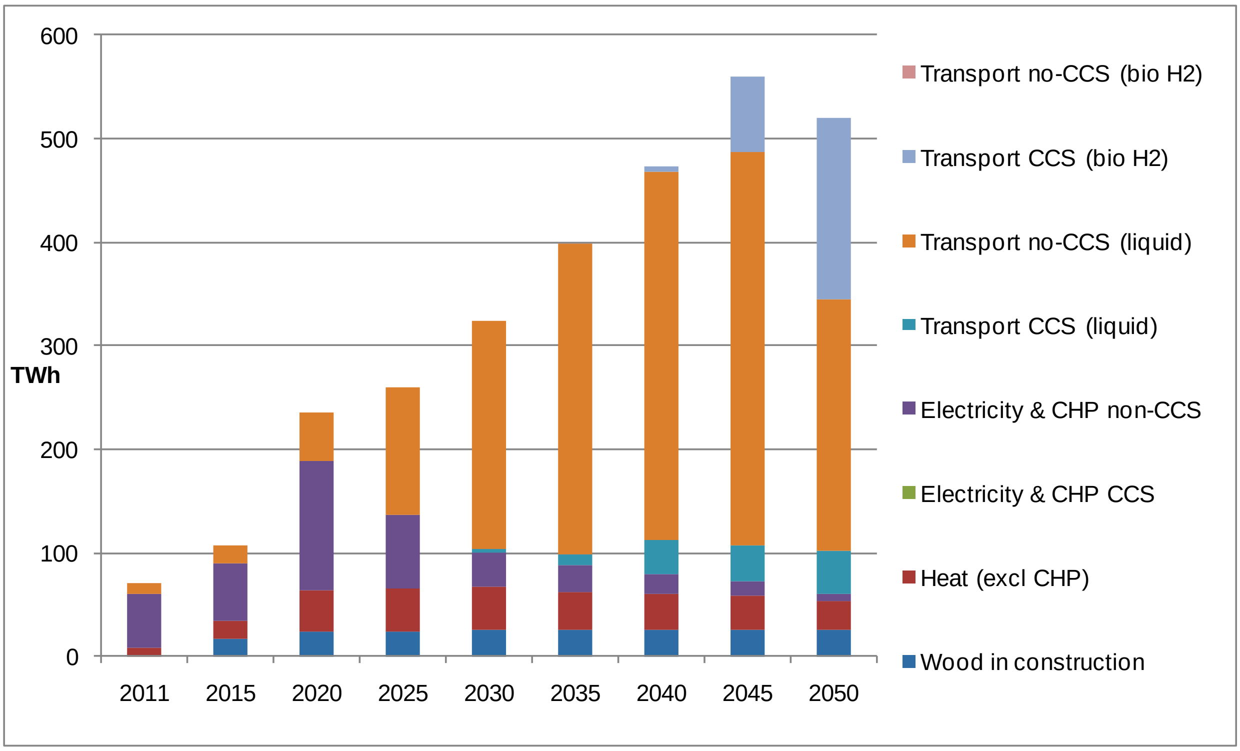
Figure 28: Available bioresource unused by aggregated product for the restricted supply scenario



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

98. Scenario 6, the Ambitious supply scenario implies significantly higher levels of feedstock availability in all years. A similar pattern of bioresource use to the Scenario 1 is seen in the near and medium term (albeit at higher overall levels). However in 2050, given the high levels of resource available, the model shows an increased use of bioresources for liquid biofuels and a reduced role for biomass hydrogen in transport, due to relative cost effectiveness of liquid biofuels. Overall this scenario shows an increase in overall levels of bioresource use of around 13% in 2020 and 70% in 2050 (when compared to Scenario 1).

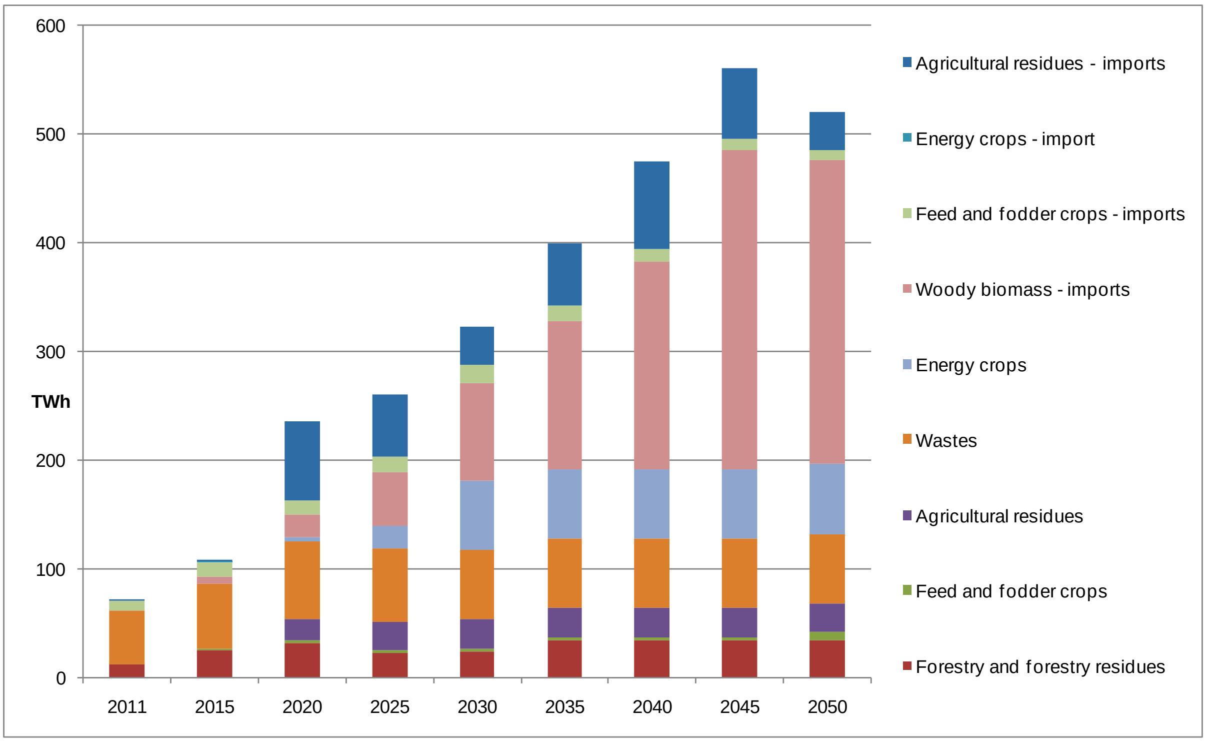
Figure 29: Total Bioresource use on a primary energy basis per year for Scenario 6 (Ambitious supply)



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

99. Figure 30 below shows the importance of imported woody biomass availability in the rapid growth of bioresource use that is evident in Figure 29 above. In this scenario, although the amount of feedstock availability declines from the midterm towards 2050 due to the assumption that the UK will secure a declining proportion of globally traded imports, the model uses increasing amounts of the available resources until 2045, the largest increase being from imports of woody biomass.

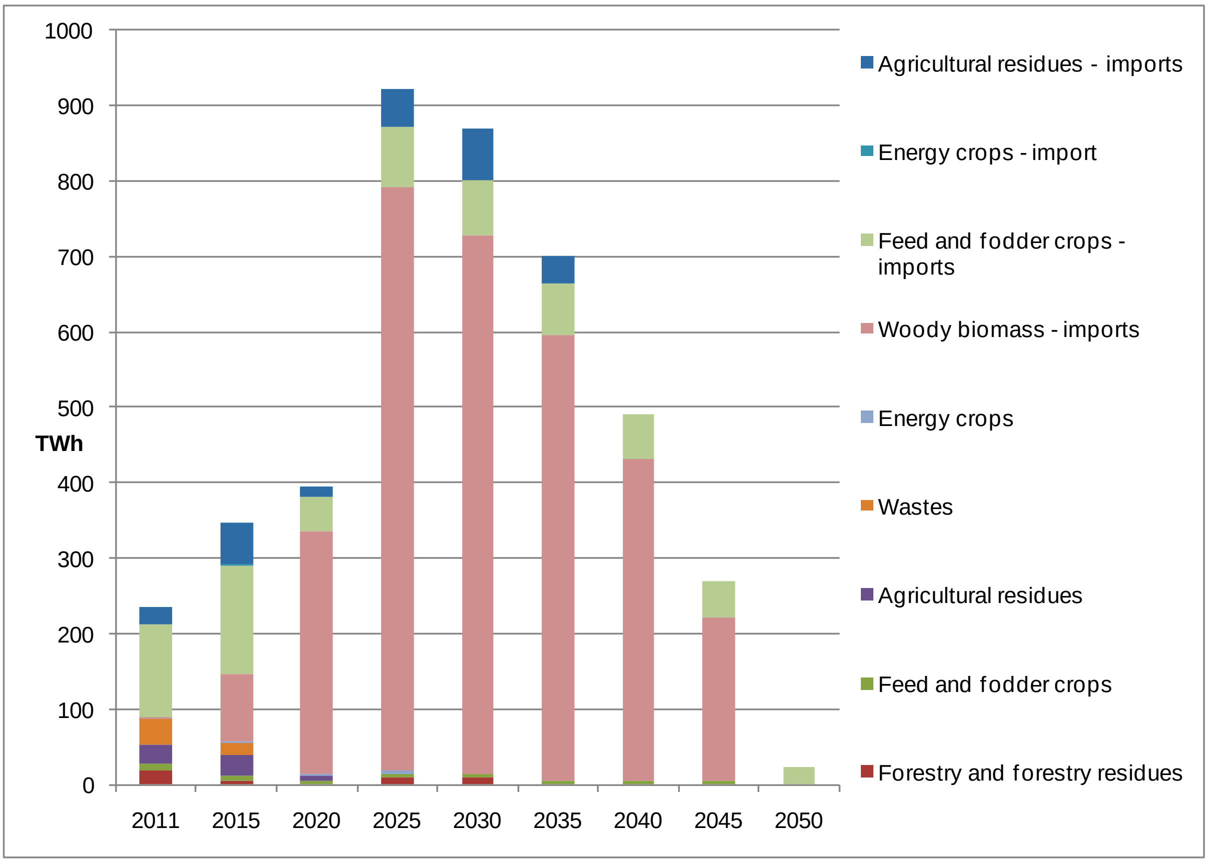
Figure 30: Bioresource used by aggregated product (TWh / year) for Scenario 6 (ambitious supply)



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

100. Figure 31 below shows bioresources left unused by the model for Scenario 6 (ambitious supply). UK bioresources are still virtually all used from 2020 onwards (with the exception of some domestic feed and fodder crops). Imported woody biomass remains the key left over resource in the medium term (albeit at much higher levels than Scenario 5 with Restricted supply). With higher availability, it is not necessary to use all of the bioethanol available for import.

Figure 31: Bioresource unused by aggregated product for Scenario 6 (ambitious supply)



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

101. Scenario 7, the Highly Restrictive Sustainability Standard supply scenario, provides the lower bound sensitivity for bioresource supply. This scenario allows enough resource to make up approximately 6%[51] of total primary energy demand in 2050. At this level of bioenergy supply, the model has to rely on purchasing 'credits' in 2050 to meet the emissions target. Scenario 7 significantly reduces the availability of imported woody feedstocks and biofuels; this results in a declining profile of total bioresource use from an earlier point (2020-25 as opposed to 2040 in Scenario 1) and overall much lower total bioresource use across all years after the higher standards have come into effect.

102. There continues to be an important near and medium term role for biomass in electricity, heat and transport. Biomass use in non-CCS liquid transport fuels in the medium to long term is significantly reduced as a proportion of total bioresource use due to the feedstock constraints. The 2050 picture is similar to Scenario 1 in that CCS technology becomes the focus for bioresource use.

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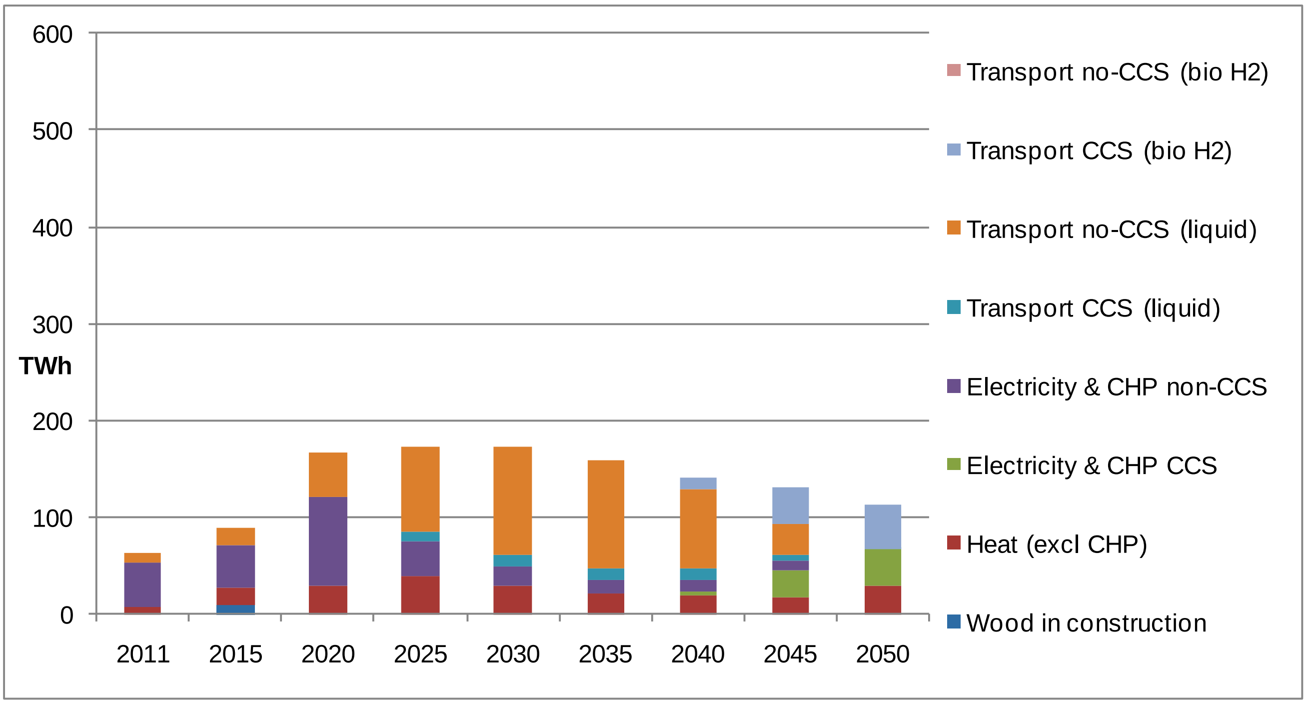
[51] Calculation based on the total primary energy demand estimated in the Highly Restrictive Sustainability Standard supply scenario run of the model. This figure is an illustrative proportion of potential bioenergy contribution to the overall energy system, is highly uncertain and should not be interpreted as a target.

Figure 32: Total bioresource use on a primary energy basis per year for all sectors for Scenario 7 (Highly Restrictive Sustainability Standard supply)

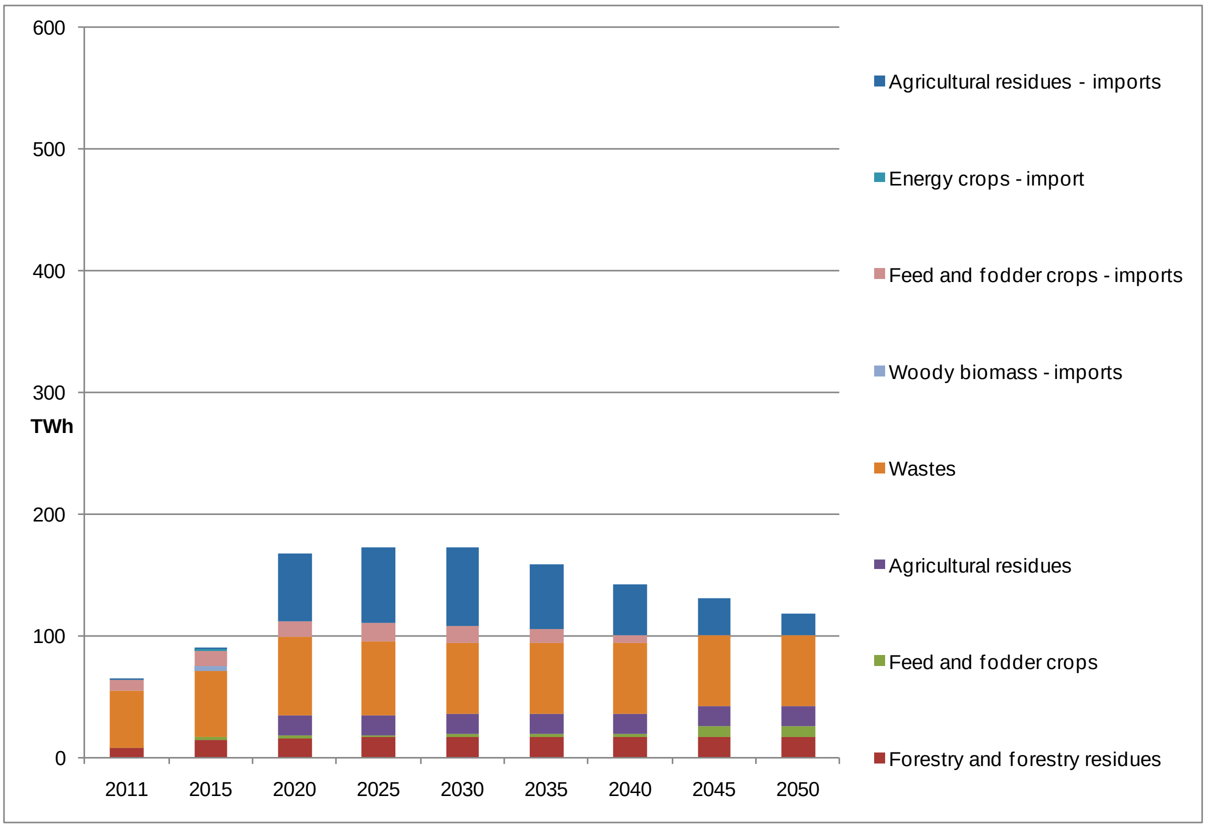


Source: DECC modelling using model developed by Redpoint Energy and Ecofys

103. A key conclusion from this sensitivity is that when bioresources are extremely tight the use of biomass for non-energy uses (e.g. wood in construction) becomes less cost effective over the whole period than energy use alternatives. However, the replacement of wood products with non-wood resource can lead to higher greenhouse gas emissions, so must be considered carefully. In other resource supply runs there is a consistent role to 2050 for wood in construction. Overall this scenario shows a reduction in overall levels of bioresource use of around 20% in 2020 and 63% in 2050 (when compared to Scenario 1).This run severely constrains resources from 2020; this can be seen by comparing the total resource used and left unused by the model in this run (see Figures 33 and 34 below).

104. Figure 33 shows a more balanced use of domestically produced feedstocks and imported supply. This is due to the higher sustainability standards having a far bigger impact on the amount of imported supply we expect to pass the thresholds in comparison to the resources produced in the UK. Further information on the assumptions made in this scenario can be found in Section 1.

Figure 33: Bioresource used by aggregated product for Scenario 7 (Highly Restrictive Sustainability Standard supply)



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

105. Figure 34 shows bioresources left unused by the model for Scenario 7. In this scenario the pattern of unused resources has changed; now the same small levels of domestic feed and fodder crops are left unused as in previous scenarios, but all woody imports are utilised to 2050 and, again, some of the feed and fodder crops available for import are not used. The higher sustainability standards only come into effect from 2020, meaning there is a significant reduction in resource availability from 2020, leading to the large reduction in the proportion of unused feedstock between 2015 and 2020[52]. The model will chose a certain technology pathway to 2050 given the resources, technology options available, and costs over the whole period to 2050. Therefore, even when there is low resource availability we may see some resources left unused due to the model being unable to utilise certain technologies that require higher levels of resource. It should also be noted that in Scenario 7 the model is forced to purchase high cost credits in order to meet the emissions target. This will impact on the levels of other technologies taken up by the model.

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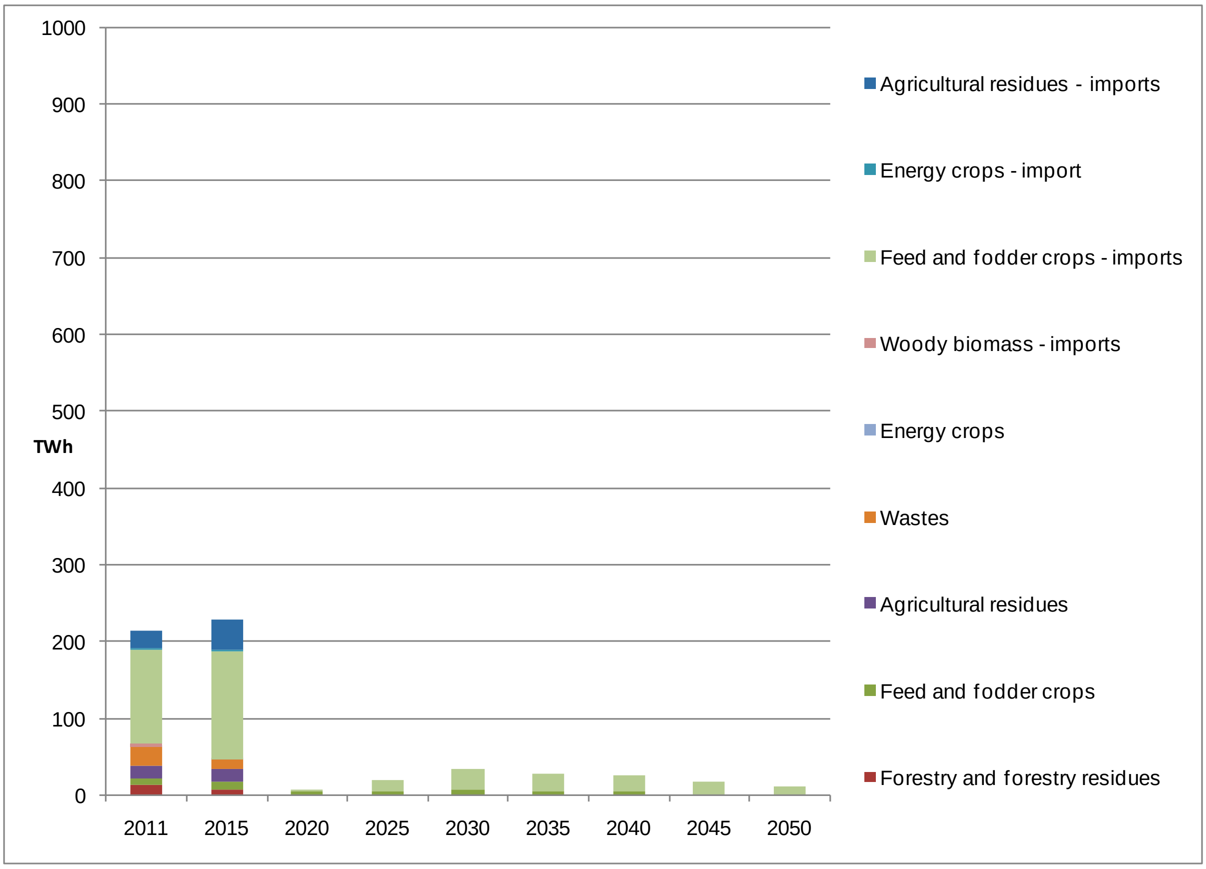
[52] The Highly Restrictive Sustainability Standard supply scenario applies higher GHG emission thresholds to the bioresource availability assumed under the medium supply scenario, hence the higher availability in 2011 to 2015 when compared to the Restricted supply scenario.

Figure 34: Available bioresource unused by aggregated product for Scenario 7 (Highly Restrictive Sustainability Standard supply)



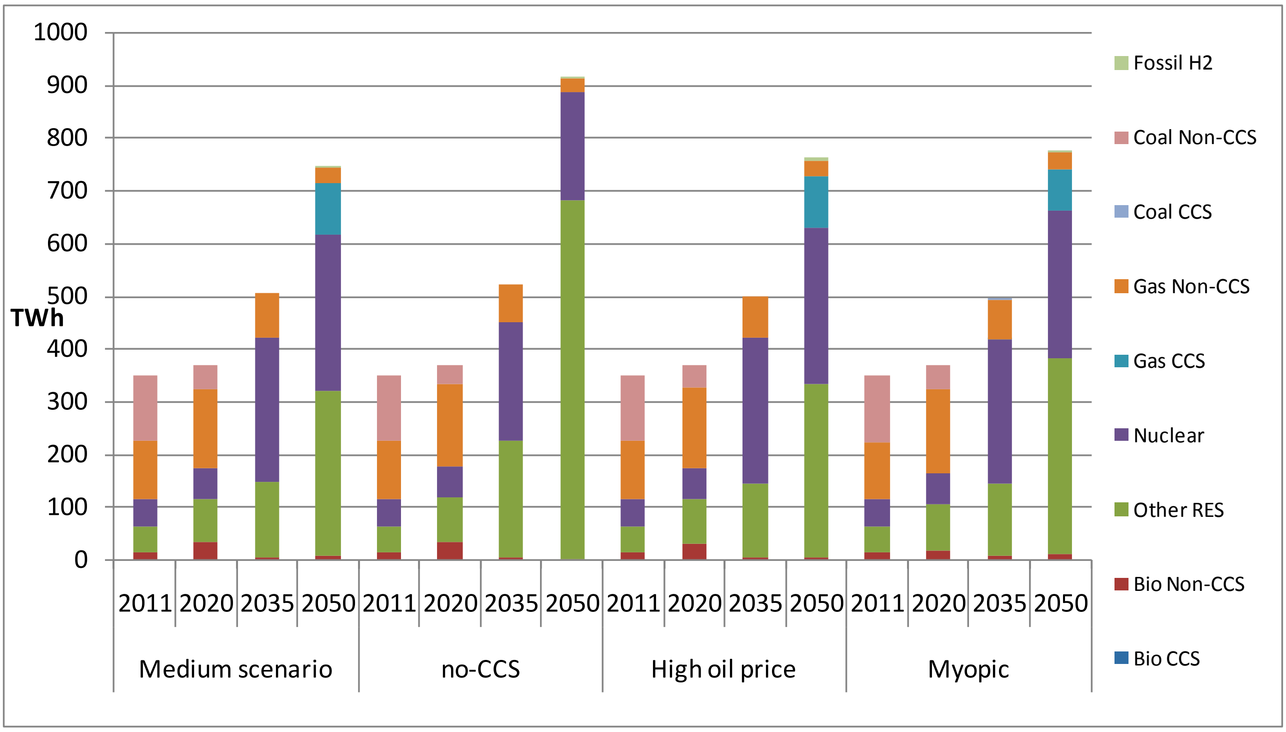
Source: DECC modelling using model developed by Redpoint Energy and Ecofys

Sectoral Analysis

Power sector

106. Bioenergy has an important transitional role in the near term in contributing to the Renewable Energy Directive target in 2020. This remains robust in different runs of the model (see Figure 35 below). However, towards 2050 the modelling indicates a relatively small role for biomass in the power sector when compared to other renewable technology, nuclear and conventional fossil fuels.

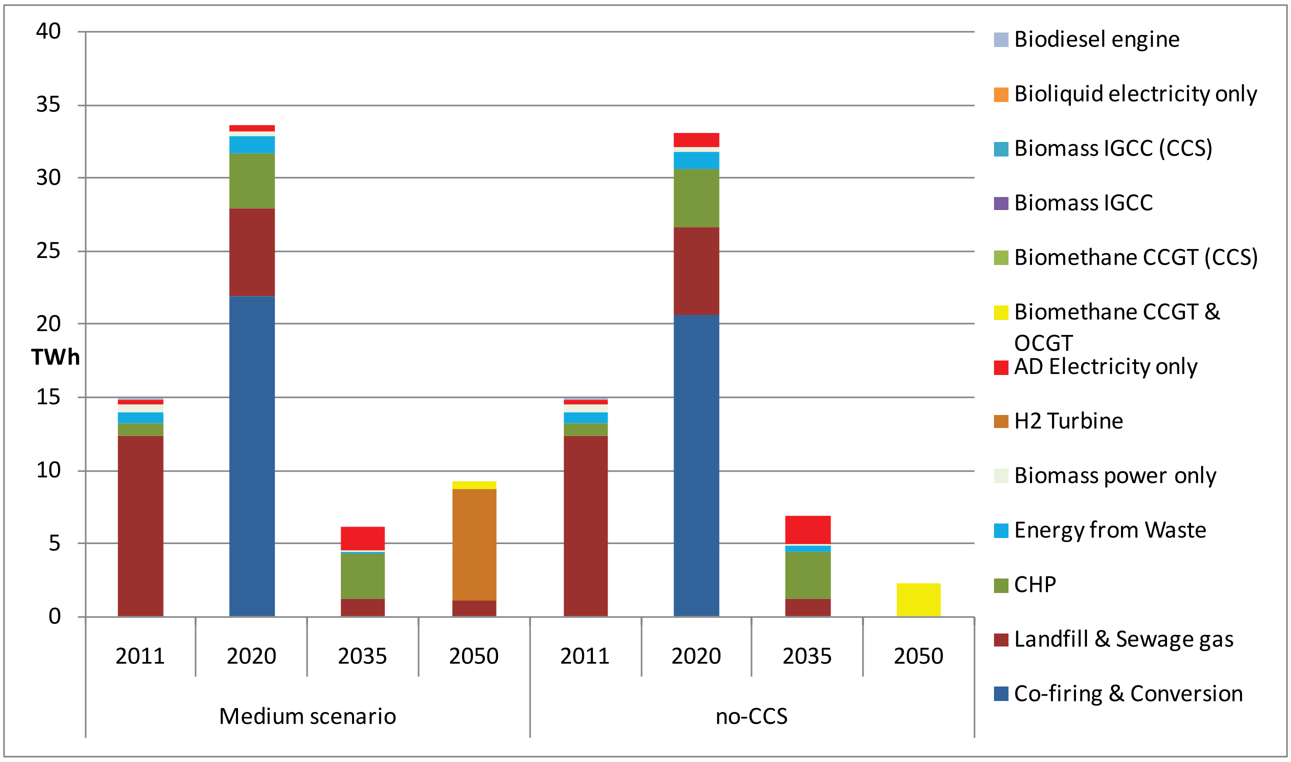
Figure 35: shows a summary of electricity generation (TWh/ year) for Scenarios 1 to 4



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

107. Figure 36 below sets out the share of biomass-derived electricity production by technology type for Scenario 1 and Scenario 2 (excluding CCS availability). In both scenarios rapid growth in deployment to 2020 in order to help meet the Renewable Energy Directive target is evident; this is mainly from co-firing and conversion of coal plants, which is a cost effective transitional technology option for the power sector. In the long term the role for bioenergy in the power sector becomes reduced to mainly hydrogen turbines in Scenario 1 (predominantly for use with CCS technology), and where CCS technology is not available the use in 2050 is confined to biomethane in CCGT. In the near term a significant role for landfill gas is evident in all scenarios, declining by the midterm due to declining resource availability. There is small midterm role for AD and CHP (mainly biomethane) generation in all scenarios.

Figure 36: shows bioenergy production of electricity by technology (TWh/year) for Scenario 1 and Scenario 2 (excluding CCS technology)

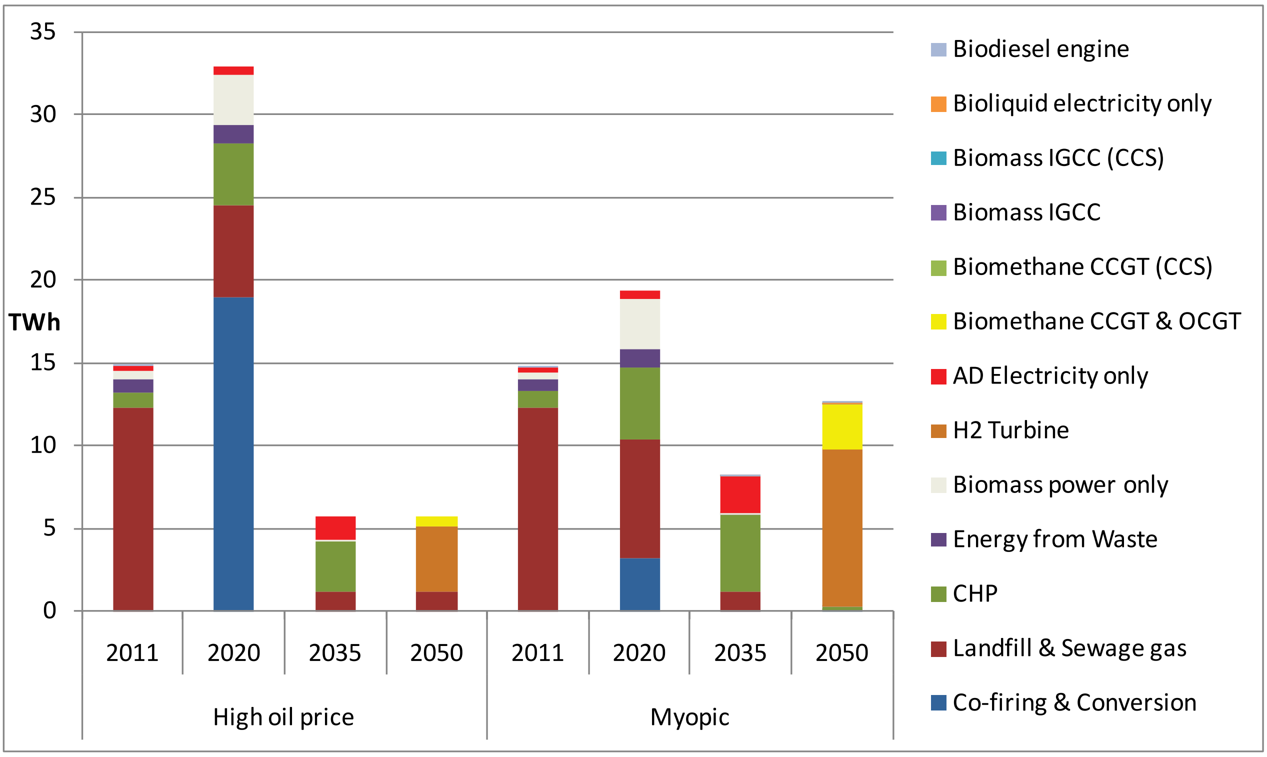


Source: DECC modelling using model developed by Redpoint Energy and Ecofys

108. Figure 37 below sets out the share of biomass derived electricity production by technology type for Scenario 3 (high oil price) and Scenario 4, assuming 5-year rather than perfect foresight. In Scenario 3, there is lower hydrogen in 2050 as bioenergy is diverted towards non-surface transport fuels (due to the higher relative costs of alternatives). By 2020, there is a higher level of dedicated biomass generation from existing plants, which becomes more cost effective with higher oil prices.

109. The key difference to the 2020 picture under the Scenario 4 is the lower uptake of co-firing and conversion. With only 5 year foresight, the most cost effective choices in 2020 to meet the Renewable Energy Directive target are not available due to the technology pathway decisions made in earlier periods (largely in higher levels of renewable heat deployment).

Figure 37: shows bioenergy production of electricity by technology (TWh/year) for Scenario 3 (high oil prices) and Scenario 4 (myopic foresight)



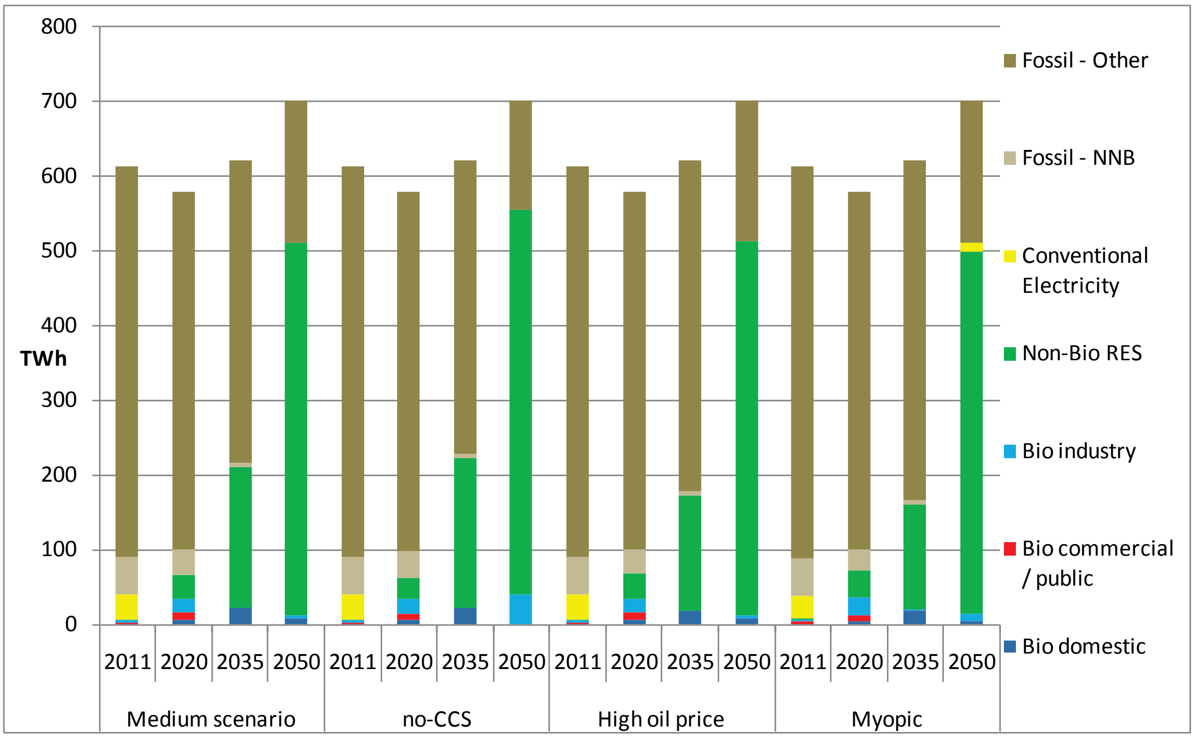
Source: DECC modelling using model developed by Redpoint Energy and Ecofys

Heat sector

110. Bioenergy use in the heat sector has a relatively small but important role to 2050, making a key contribution to the UK's 2020 Renewable Target. Bioenergy for use in industrial heat (predominantly process heat) has a consistent long term role in all scenarios. There is also a potential midterm role for bioenergy use in space heating in the domestic and commercial/public buildings, where there is a lack of suitable alternatives[53]. Where CCS technology is not available the modelling shows a significant increase of biomass for heat generation in the industrial sector, due to the lack of alternative options for decarbonisation. Figure 38 shows heat production for Scenarios 1 to 4, including production from biomass, non-biomass renewables (mainly heat pumps), and conventional fossil fuels.

[53] To note: the RHI provides further incentive for biomass space heating, which has not been included in this analysis but has a key role in short and medium term. The RHI is expected to incentivise such biomass use to 2040.

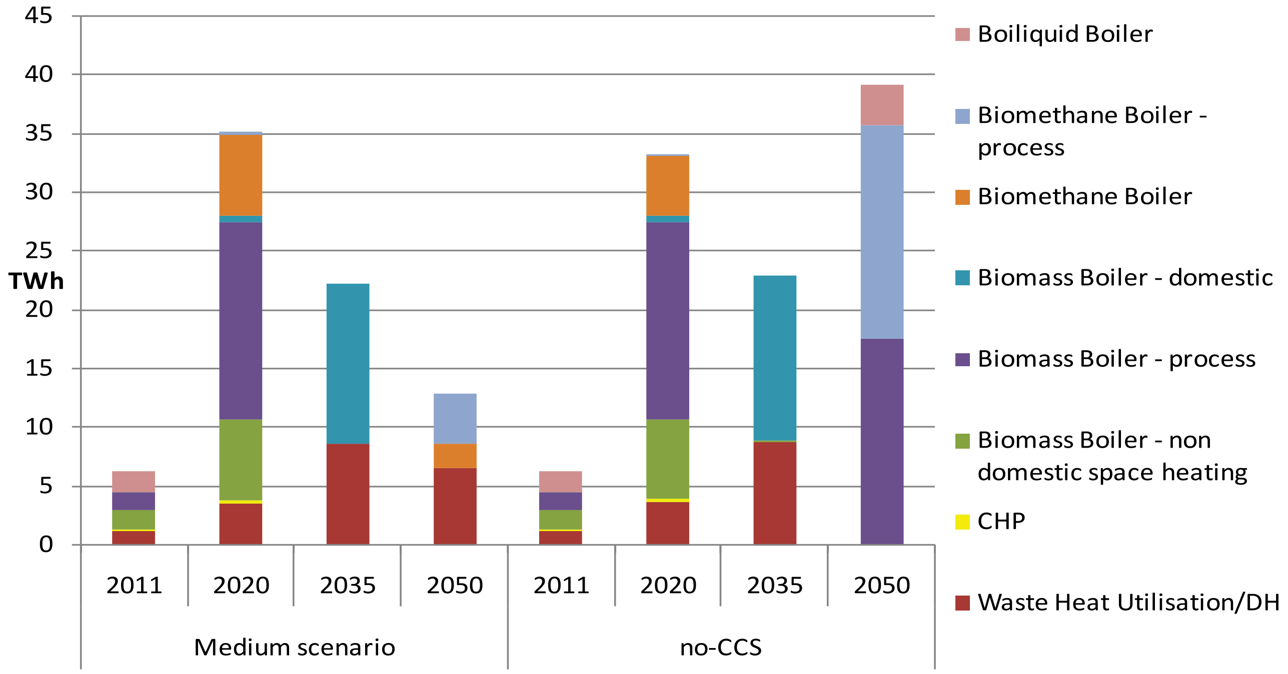
Figure 38: shows a summary of heat production (TWh/ year) for Scenarios 1 to 4



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

111. Figure 39 sets out the share of biomass heat production by technology type for Scenario 1 and Scenario 2 (excluding CCS availability). Similarly to the power sector the jump in bioenergy use to 2020 can be seen as the model pushes to meet the Renewable Energy Directive target, this involves a medium term transition role for biomass boilers for domestic and non-domestic sectors, and a significant near term role for biomass boiler process heating (predominantly high temperature processes). Recovered waste heat is used throughout the period in Scenario 1. Large scale switching between biomass resource uses for heating purposes should not be seen as realistic, but rather as an indicator of the sensitivity of most attractive uses to small cost changes.

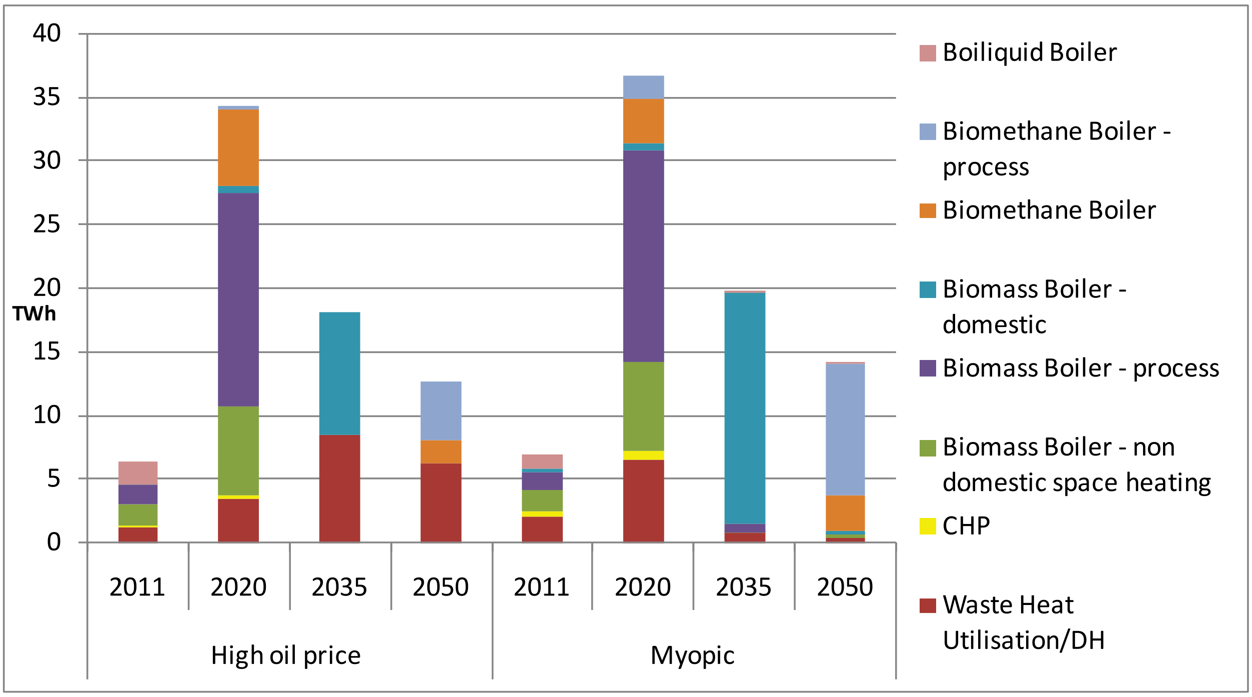
Figure 39: Bioenergy production of heat by technology (TWh/year) for Scenario 1 and 2 (excluding CCS technology)



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

112. Figure 40 sets out the share of biomass heat production by technology type for Scenario 3 (high oil price) and Scenario 4 (myopic foresight). The results for Scenario 3 are similar to Scenario 1. However, there are lower levels of biomass boilers for the domestic sector as bioenergy gets diverted towards bioliquids for aviation and shipping. With 5 year foresight, the modelling shows lower levels of recoverable waste take up, and an increase midterm use for domestic biomass boilers; however the focus on use in the industrial process is still evident by 2050.

Figure 40: Bioenergy production of heat by technology (TWh/year) for Scenario 3 (high oil price) and Scenario 4 (myopic foresight)



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

Transport sector

113. If sustainability can be assured, bioenergy has a potentially significant role in the transport sector, alongside other low carbon technologies, such as Ultra Low Emission Vehicles (ULEVs). In the longer term, biofuels are likely to be needed to de-carbonise transport modes where there are few low carbon alternatives to high energy density fuels. It is important to note that the modelling is based on a large number of highly uncertain assumptions (e.g. hydrogen and electric vehicle costs, future agricultural commodity prices, future oil prices, technological development of advanced biofuels, constant consumer preferences across vehicle types). There are also some carbon abatement pathways which have not been modelled (e.g. modal switching between road, rail, shipping and air travel). The modelling results should therefore be interpreted with an appropriate degree of caution.

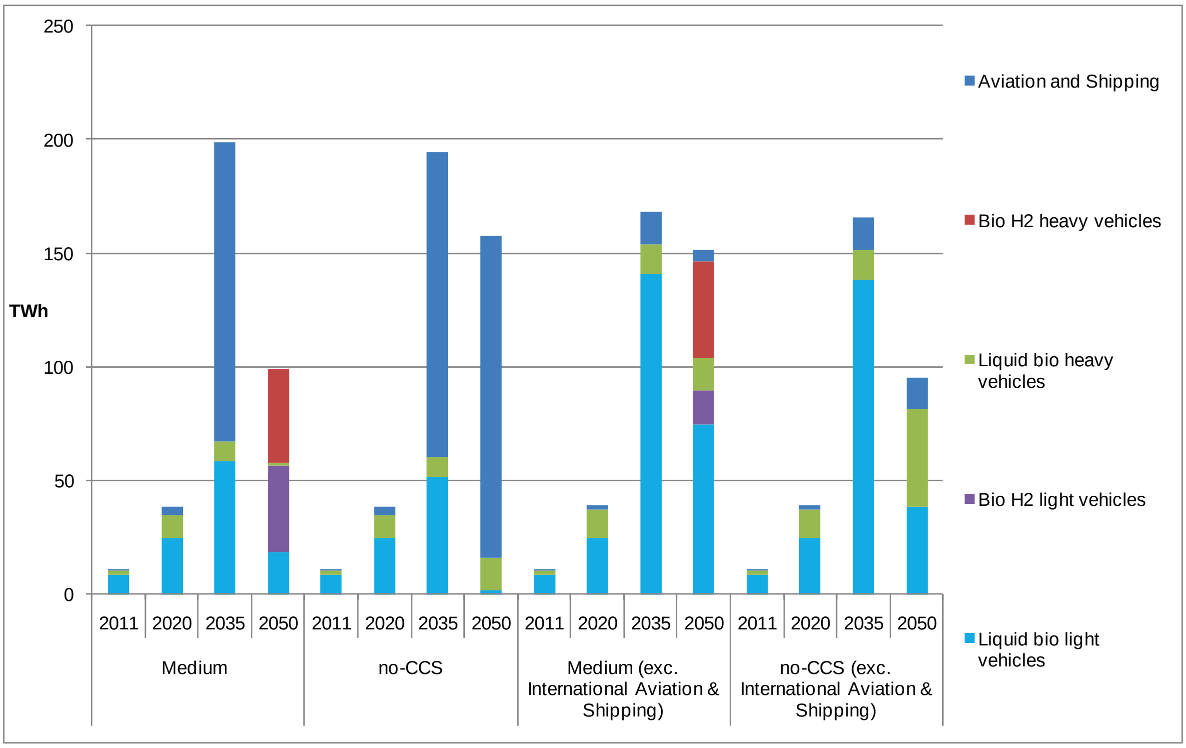
114. Figure 41 shows a breakdown of bioenergy transport inputs indicated by four different modelling scenarios: Scenario 1 and 2; and additional scenarios where international aviation and shipping have been excluded. This sensitivity was carried out due to the uncertainty surrounding the future inclusion of these sectors in the UK's 2050 greenhouse gas emission

reduction targets, and the absence of the role of an EU Emissions Trading System in the modelling[54].

115. Scenario 1 (which includes CCS) and Scenario 2 (excluding CCS technology) show biomass use in international aviation and shipping dominating in the medium term, and a smaller but significant role for biomass in light vehicles (cars and vans) in the midterm. In the scenarios where international aviation and shipping are excluded from the modelling use of biomass in light vehicles dominates in both the near and midterm.

116. In Scenario 1, by 2050 biomass hydrogen with CCS has a significant role in road transport, due to the value of the associated negative bioenergy emissions. When CCS technology is excluded, biomass hydrogen becomes less attractive as negative emissions are no longer produced, and wide scale deployment of liquid biomass in international aviation and shipping continues to 2050. Where CCS is available but international aviation and shipping is excluded from the modelling, liquid biomass in light vehicles has an important role alongside biomass hydrogen in road transport. Where CCS is excluded, liquid biofuels play the dominant role in road transport in 2050, and a smaller but sustained role in domestic aviation and shipping.

Figure 41: Summary of biomass transport inputs (final energy of the fuel) in TWh per year for Scenarios 1 and 2 (with and without international aviation and shipping)

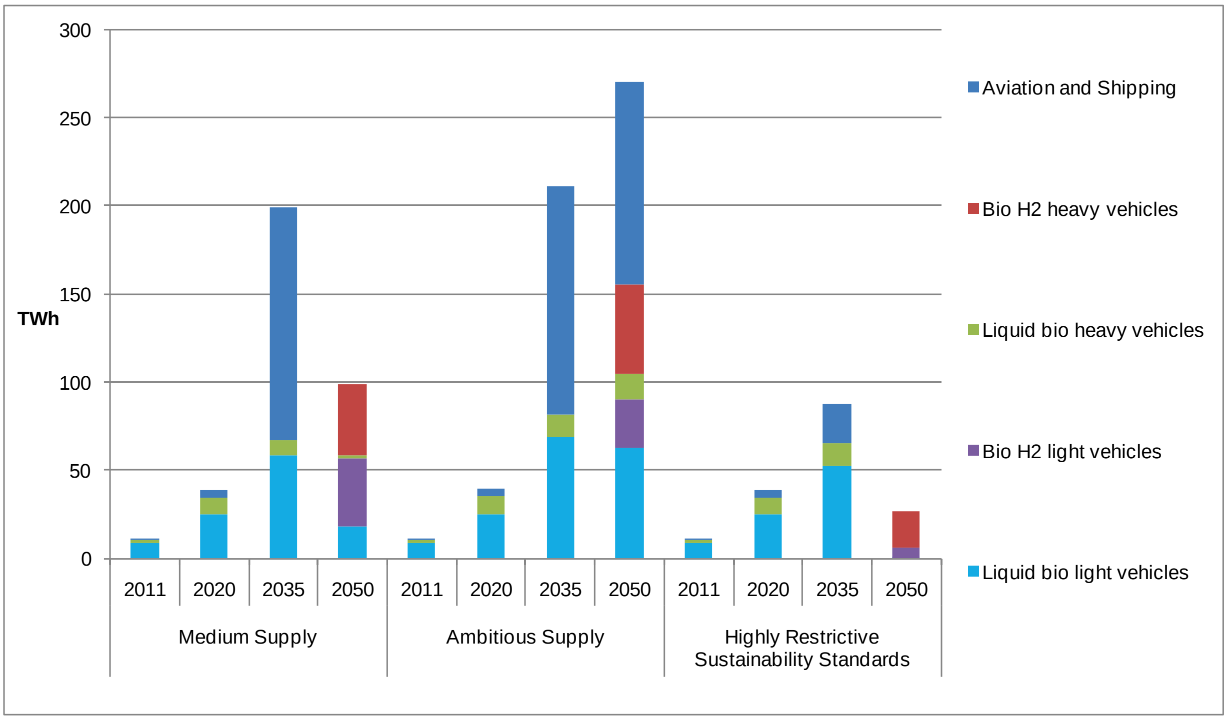


Source: DECC modelling using model developed by Redpoint Energy and Ecofys

[54] The modelling does not include the potential role of the EU Emissions Trading System, and any subsequent international emissions trading markets, in achieving emissions reductions in traded sectors. In reality it may be more cost effective for industries in the traded sector, such as international aviation, to purchase allowances than use the technologies selected by the model.

117. Figure 42 shows a breakdown of bioenergy transport inputs for three different modelling scenarios assuming different levels of bioresource supply: Scenario 1 (medium); Scenario 6 (ambitious); and Scenario 7 (highly restrictive sustainability standards supply). The key points to note from these scenarios are the continued use of liquid biofuels in international aviation and shipping in Scenario 6 (ambitious) due to the increased availability of bioresource supply and an increased role for bioliquids for light vehicles. In Scenario 7 (highly restrictive sustainability standards) the overall levels of biomass use in the transport sector is severely constrained by the availability of sustainable feedstocks, and by 2050 biomass resource is confined largely to biomass hydrogen for use in heavy vehicles. In reality, the use of hydrogen in heavy vehicles is highly uncertain, due to the technical challenge of achieving the power densities in fuel cells necessary to make power-to-weight ratios and costs of these vehicles attractive. Whilst additional drivers, such as air quality regulations, might encourage the use of fuel cell heavy vehicles in niche applications, the feasibility of their wider deployment remains uncertain.

Figure 42: Biomass transport inputs for a range of supply scenarios (medium, ambitious, highly restrictive sustainability standards) (including international aviation and shipping)



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

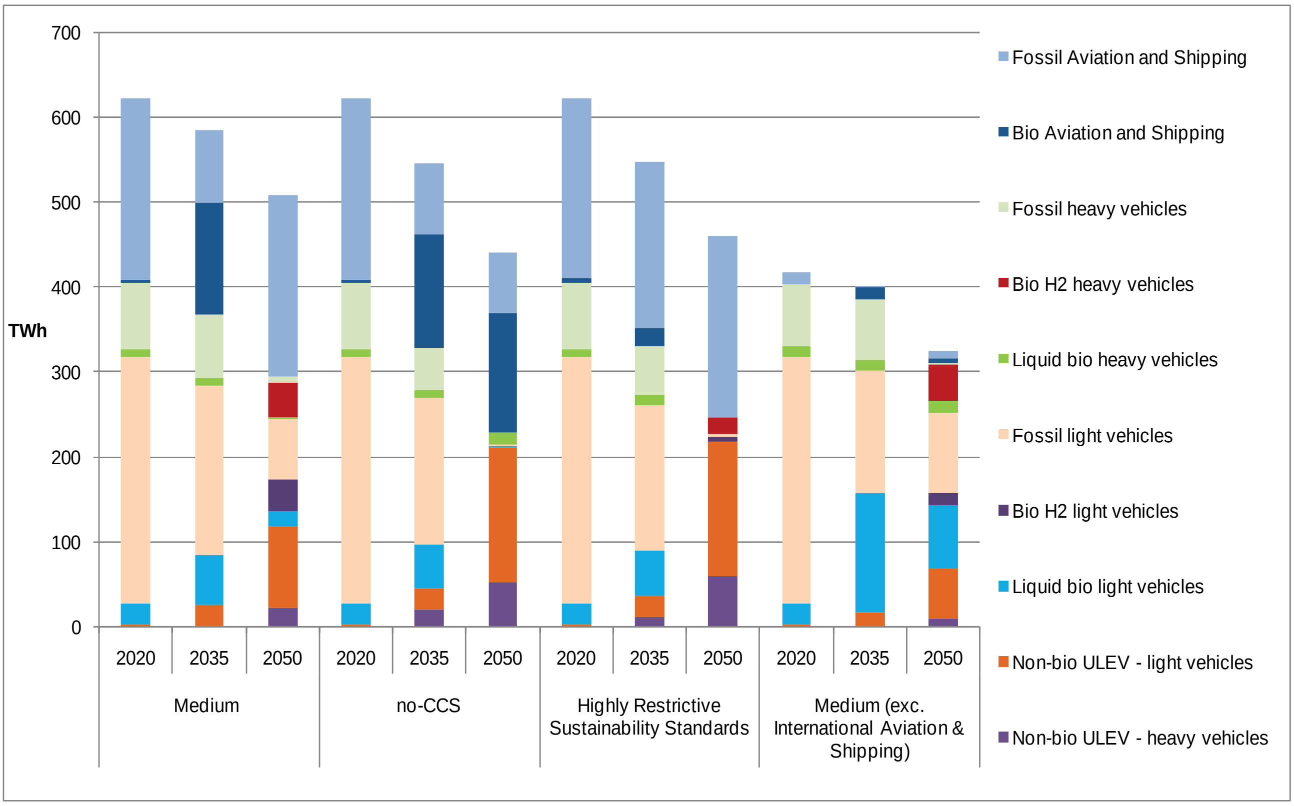
118. Figure 43 shows the breakdown of total transport inputs (including bioenergy, fossil and non-biomass low carbon technologies) for four modelling scenarios: Scenario 1 (with and without international aviation and shipping); Scenario 2; and Scenario 7.

119. The analysis shows the availability of technologies, such as CCS, and bioresources and the treatment of international aviation and shipping emissions can all have a significant impact on the biomass and non-biomass technologies used in transport. The different patterns of technology deployment are particularly evident in 2050. When CCS technology is

available, Ultra Low Emission Vehicles (ULEVs) dominate for both heavy and light vehicles in 2050. For heavy vehicles most of this is from bio-hydrogen but non-biomass ULEVs play the most important role for light vehicles. For both heavy and light vehicles there is still some fossil fuel use in 2050 so liquid biofuels still play a role.

120. Without CCS technology bio-hydrogen is less attractive so non-biomass ULEVs become more important for both heavy and light vehicles. The lack of CCS technology makes the emission constraint more difficult to achieve so almost no fossil fuel is used in surface transport in 2050, and therefore very little liquid biofuel is used. Therefore the available bioresource is used predominantly in international aviation and shipping, where there are limited alternative abatement options.

Figure 43: Summary of total transport inputs (including bioenergy, fossil and non-biomass low carbon technologies) (TWh / year) for a range of scenarios



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

Note: ULEV refers to Ultra Low Emissions Vehicles, and includes fossil H2 and electric vehicles.

121. With limited available bioresource, the outlook for surface transport is similar to Scenario 2 (without CCS): non-biomass ULEVs dominate in surface transport and the available bioresource is used in bio-hydrogen as CCS technologies are available. However, the major difference from Scenario 2 is that there is insufficient available bioresource for continued use of biofuels in international aviation and shipping.

122. If international emissions are excluded from the emissions constraint, the model shows that some biofuels will still be used in domestic aviation and shipping. Liquid biofuels and

ULEVs both play an important role in light vehicles in 2050, and overall there is a reduced role for non-biomass ULEVs for light and heavy vehicles. For heavy vehicles, nearly all energy is from bio, with bio-hydrogen being the dominant technology.

Key conclusions from AUB modelling

123. Overall our analysis shows that bioenergy is likely to play an important role in the longer term for meeting the 2050 emissions reductions target cost effectively, and also in contributing to the 2020 Renewable Energy Directive targets[55]. Scenario 1 indicates a 12%[56] contribution from bioenergy as a proportion of total primary energy demand in 2050. Although subject to great uncertainty, it provides an indication of the potential magnitude of bioenergy contribution to the energy mix. For some sectors bioenergy may only make up a small proportion of the total energy required to meet demand, however this is likely to be in sectors where there are few other low carbon alternatives available, and are therefore highly valued. The technological uncertainty increases over the time period towards 2050. Therefore it is important that technology pathways chosen in the near and midterm do not restrict potentially cost effective options that may become available in the longer term.

124. The level of bioresource availability and the availability of key technologies, such as CCS (which has the potential to generate highly valued negative bioenergy emissions), have emerged as the two key determinants in switching the patterns of bioenergy use across sectors and technologies. The data uncertainty around many technology options included and excluded from the modelling will have an impact on the results, and as these assumptions are refined for future work as new data becomes available we will be able to analyse how the patterns of bioresource use change across technologies. However, whether CCS technology, which can be utilised across different sectors, and adequate bioresources are available is projected to have an overriding impact on the appropriate use of bioenergy. Given the uncertainty over the relative costs and availability of technologies, it is less important now to prescribe where CCS will be best deployed, and more important to avoid locking into long-lived assets until the technological feasibility of CCS is better understood.

125. We consider the bioresource supply ranges used in this analysis to adequately test the impact on the pattern of bioenergy use over a wide range of potential scenarios. The Highly Restrictive Sustainability Standards scenario allowed enough resources to make up approximately 6%[57] of total primary energy demand in 2050. At this level of Bioenergy supply, the model had to rely on purchasing ‘credits’ in 2050 to meet the emissions target. At the other end of the sensitivity analysis range, the ambitious supply scenario allowed enough

[55] To note: AUB does not include policy incentives and is best suited to exploring long term bioenergy pathways. Individual sector models developed to model RED take policy incentives into account and are more suited to the consideration of forecast deployment levels to 2020.

[56] Calculation based on the total primary energy demand estimated in the medium run of the model. This figure is an illustrative proportion of potential bioenergy contribution to the overall energy system, is highly uncertain and should not be interpreted as a target.

[57] As above but assuming Highly Restrictive Sustainability Standard supply scenario bioresource availability.

resources to make up approximately 21%[58] of total primary UK energy demand in 2050. It is useful to note that for all modelling runs assuming different levels of resource supply, UK feedstocks are almost always fully utilised, indicating their relative cost effectiveness compared to imports (predominantly due to transport costs).

126. The underlying modelling and analysis is intended to provide a high level view of different biomass uses to 2050, identify trade-offs, risks, and key innovative technologies and pathways. Modelling assumptions are inherently uncertain and stylised across technology groups and sectors, and the results should be viewed as illustrative patterns of appropriate use of bioenergy as opposed to a prescriptive hierarchy of technologies and sectors where bioenergy should be deployed. Neither does it provide a pathway for the whole energy system mix viewed as a whole. However, it is possible from the analysis to identify certain bioenergy uses that emerge as low risk options, either as shorter term transition technologies or longer term options, these are:

- Non-energy uses for biomass that cost effectively capture carbon emissions, such as wood in construction, are consistently utilised by the model over the period to 2050[59]. It is important to note that wood in construction represents only one type of non-energy use for biomass in the modelling and further uses may represent cost effective deployment paths for bioresources.
- The use of bioenergy for industrial heat (specifically high temperature process) is consistently utilised across modelling runs, with the highest use occurring where CCS technology is not available.
- The modelling indicates a medium term transition role for biomass space heating in the domestic sector.
- Generation of heat and electricity through combined heat and power processes and with the efficient utilisation of recoverable wastes.
- In the near to midterm (2020's) there is an important transition role for conversions and co-firing in the electricity sector.
- So long as sustainability is assured and while fossil fuels continue to be used in transport, some conventional biofuels can offer a cost effective contribution to reducing carbon emissions from road transport. There is potential for significant growth in biofuel use, in road and other sectors, in the medium and long term, if advanced biofuel technologies using wastes and woody feedstocks are commercialised.

[58] As above but assuming Ambitious supply scenario bioresource availability.
[59] Wood in construction is taken up in all scenarios to 2050 apart from the highly restrictive sustainability standards supply scenario. This suggests that biomass use in wood in construction falls slightly in attractiveness when resources are extremely constrained.

- Gasification is an important technology across sectors, e.g. for biomethane in the heat sector, and for advanced biofuels and bio-hydrogen production in the transport sector[60]. Therefore commercialising this technology is of fundamental importance.

[60] There is considerable uncertainty around key technologies that emerge from the modelling results, such as: bio hydrogen in surface transport and CCS technology.

Appendix 1 - UK Wood Market: Current supply and demand

Virgin wood

1. About 13% of the total land area of the UK is covered by forest. From this area total production of wood in 2010 was approximately 10 million green tonnes (Mgt) of which 9.6Mgt were softwood and 0.5Mgt hardwood.

Table 1: Deliveries of UK grown hardwood and softwood, 2008-2010 (Thousands green tonnes)

	Year	Sawmills	Pulpmills	Woodbased Panel	Fencing	Woodfuel	Other	Exports	Total
Hardwood	2007	66	0	5	-	300	69	-	440
Hardwood	2008	66	0	2	-	300	63	-	431
Hardwood	2009	76	0	1	-	400	59	-	536
Hardwood	2010	75	0	1	-	400	59	-	535
Softwood	2007	5 565	472	1 362	319	200	133	759	8 790
Softwood	2008	4 933	515	1 219	359	128	128	733	8 187
Softwood	2009	5 133	511	1 135	367	160	160	347	8 304
Softwood	2010	5 616	428	1 375	349	1 050	135	467	9 419

Source: Forestry Commission 2011

2. Of the total UK wood supplies in 2010, around 57% went to sawmills (for multiple uses including wood panel production), 14% to wood panels and 15% was used as wood fuel. Another 5% was exported, and the remainder went to fencing, pulp mills and other products e.g. animal bedding. Of the wood used in sawmills, around 50% was sawn softwood production (2.8Mgt) with the remaining 2.7Mgt accounting for softwood products (chips,

bark, sawdust, etc). Of these 2.7Mgt sawmill products 1.6Mgt was used from the wood panel industry[61] (in total wood panelling consumed 30% of the UK wood supplies (1.3 Mgt of virgin wood and 1.6 of sawmill products)).

3. These sawmill products accounted for around 40% of the wood panel industry's total use of wood inputs (4.1Mgt). The remaining 35% came from small roundwood while 25% came from recovered wood. Almost all of the non recovered wood came from softwood.

Table 2: 2010 wood inputs to the wood panel industry (by type), 2008-2010, Thousand green tonnes

Year	UK Roundwood		Sawmill Products		Imports		Total		
	Soft Wood	Hard Wood	Soft wood	Hard Wood	Soft wood	Hard wood	Soft wood	Hard wood	Recycled wood
2007	1 362	5	1 940	0	2	0	3 304	5	1 230
2008	1 219	2	1 591	0	0	0	2 810	2	1 119
2009	1 135	1	1 435	0	0	0	2 570	1	1 065
2010	1 375	1	1 631	0	7	1	3 013	2	1 120

Source: FC/WPI data

4. In recent years significant progress has been made in developing the woodfuel supply chain. The wood supplies that went to bioenergy in 2010, were three the amounts used in 2007[62]. From the available data it appears that the additional demand was met from increases in the overall supplies (wood supplies increased by 7% between 2007 and 2010) rather than reduction in the demand for wood from sawmill or wood panels. This has been possible as a result of the increasing annual supply of wood available from maturing 20th century plantings and other sources of wood fibre.

5. According to Ofgem statistics[63] the total demand for wood from power generation in 2010 was approximately 2.8Modt. Of that around 20% was classified as some sort of recovered wood while from the non waste feedstocks around 40% were classified as by-products. Around half of the wood used in power generation has been reported as sourced from the UK (approximately 1.4 Modt), with the remaining sourced from international markets. The

[61] Based on FC data: softwood consumption by all sawmills covered by the detailed sawmill survey was 5.3 Mgt. Sawn softwood production was 2.8 Mgt and other softwood products (chips, bark, sawdust, etc) amounted to 2.7 Mgt.)

[62] UK Wood Production and Trade (provisional figures 12 May 2011) http://www.forestry.gov.uk/pdf/trprod11.pdf/$FILE/trprod11.pdf [Accessed 07/02/2011]

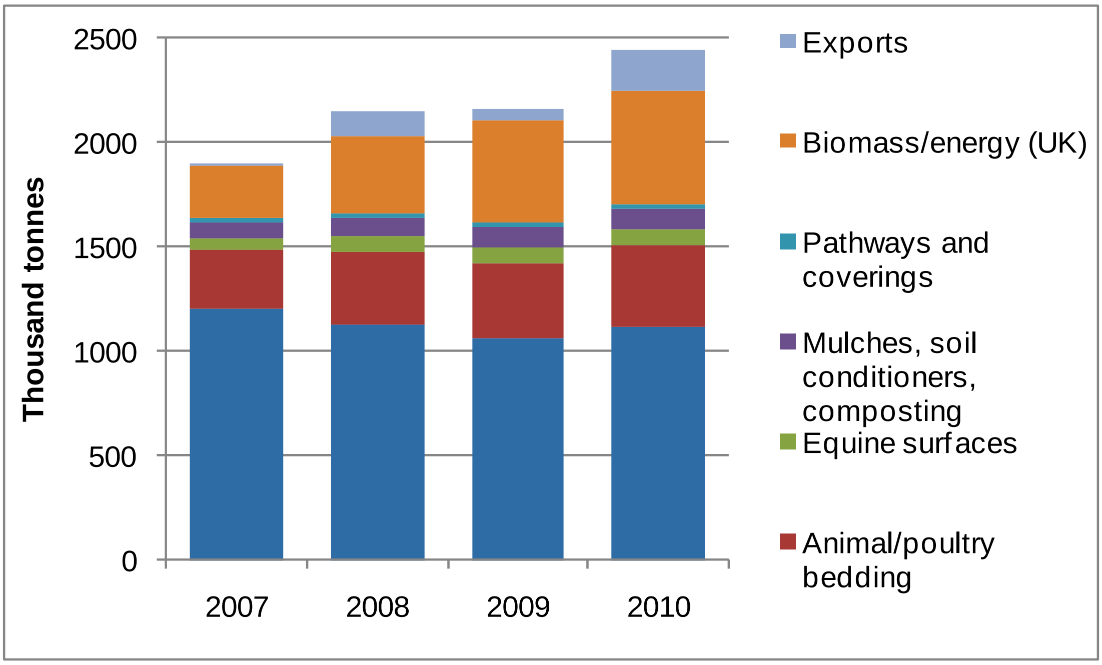
[63] Source: Ofgem Annual sustainability report dataset 2010-11

availability of data on the exact sources and characteristics of wood used in the heat market are significantly more limited. However, according to DECC statistics[64] demand for wood for heat in 2010 was around 1.4 Modt.

Recovered wood

6. Analysis undertaken by WRAP indicates that the panel board is currently the most significant player in the recovered wood market in the UK (around 50% of the total 2.4Mgt of recovered wood). The demand from the panel board sector has seen a drop of around 7% since 2007 as a result of a contraction on their output due to the recession. At the same time the overall market of recovered wood in the UK has grown, leading to an increase in the volume used for bioenergy (from around 0.25Mgt in 2007 to 0.5Mgt in 2010) as well as increased volumes of exported recovered wood (rising to 195,000 tonnes in 2010 from 15,000 in 2007).

Figure 1: Summary of recovered wood markets, from 2007 to 2010



Source: WRAP, Realising the value of recovered wood, Market Situation Report, Summer 2011

Projected availability of domestic supplies

7. As set out above, the current size of the virgin wood supplies in the UK is around 10 Mgt (equivalent to 5 Modt under 50% moisture content). In addition, the recovered wood market

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[64] DUKES 2011

is currently around 2.4 Mgt (equivalent to around 1.9 Modt assuming 20% moisture content).

8. Based on the analysis outlined in Section 1 of this Analytical Annex, there is significant potential for expansion of domestic biomass supplies, both from forest and non-forest feedstocks. In total, based on the supply ranges used for the Bioenergy Strategy, supplies of UK woody biomass feedstocks could increase to between 10-16 Modt by 2020 depending on the constraints overcome and the emerging price (corresponding to the Restricted and Ambitious supply scenarios).

Table 3: Range of deployment potentials to 2020 for UK biomass feedstocks based on Restricted and Ambitious supply scenarios

Feedstock	Million oven dried tonnes
Arboricultural arisings	0.6 – 2.4
Dry Agricultural Residue	3.7 -5.0
Forestry residues	0.1 -0.5
Sawmill co-products	0.8 -1.3
Stemwood	0.4 -1.8
Energy Crops	0.6 –1.1
Recovered Wood	4.2
Total UK biomass feedstocks	10.4-16.3

9. In order for the upper end of these potential domestic supplies to materialise prices will have to rise. Predicting these price movements is extremely difficult, especially due to the limitations of available data. In informing the Bioenergy Strategy, we have looked at the current historical evidence on the links between UK wood prices and domestic bioenergy activity as well as the links with international price movements.

International markets and prices

10. Wood prices are affected by a complex range of factors and as wood is sourced and traded globally many of these are driven by international forces. Exchange rates, changing patterns of demand, the general level of economic activity and new technologies affect the levels of supply and demand and prices. Isolating and quantifying the impacts of any one factor domestically is therefore difficult.

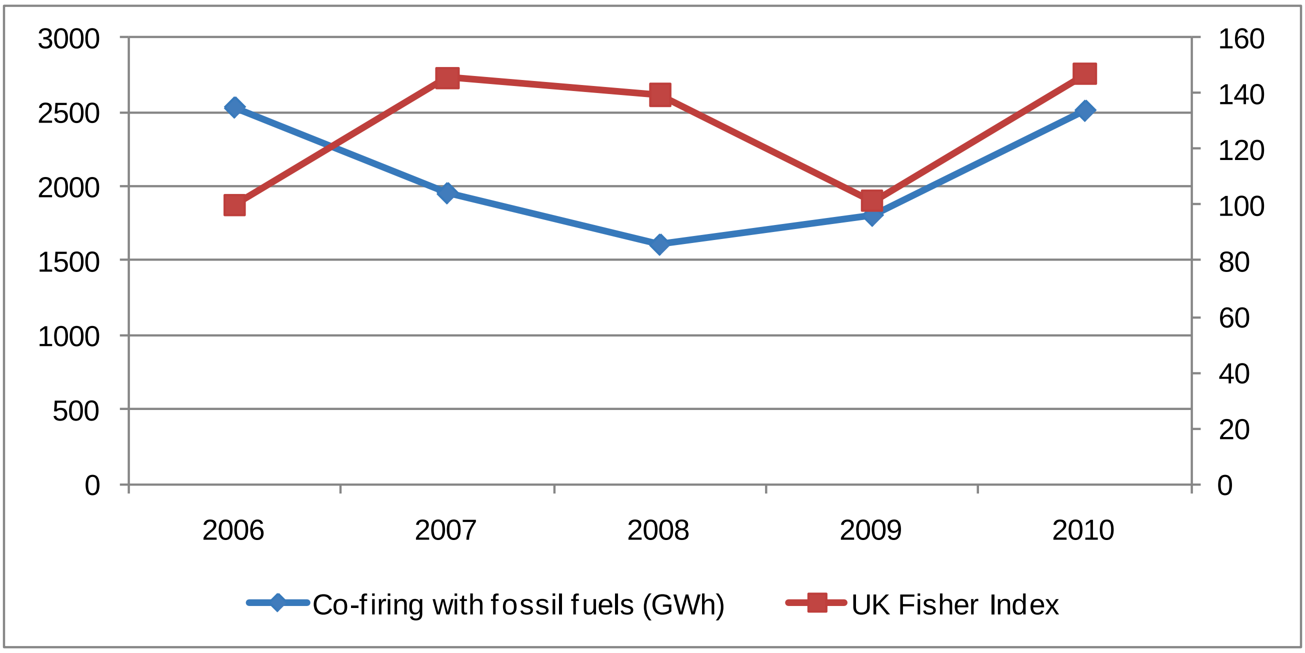
11. Any Government intervention that affects the demand for biomass feedstocks can however affect the prices associated with these feedstocks, with potentially unintended consequences to other industries that compete for them. However the exact link between government intervention and the impact on demand and the subsequent impact on prices will depend on the nature of the market in which these feedstocks operate. In a truly global, commoditised market, a UK government intervention will only have a limited effect on UK wood prices as any impact will be divided across the global market. Furthermore, interventions by foreign governments will similarly have small impacts on UK prices. In a highly localised market however, UK government interventions will have stronger impact on wood prices, and the impact of foreign countries interventions will have a weaker impact.

12. Looking at recent wood prices, Forestry Commission statistics for coniferous standing sales in 2011, shows that although standing timber prices have risen over the past five years, prices are still around half the price paid in real terms 20 years ago[65].

13. The drivers behind the price fluctuations in this market are subject to uncertainty. However, based on the available data it is not possible to establish a correlation between demand for bioenergy in co-firing generation and fluctuations in prices of UK wood (see Figure 2). However there appears to be a clear correlation between movements in the domestic UK wood prices and the international prices of wood (see Figure 3).

[65] Coniferous Standing Sales Price Index for Great Britain (Firsher Index year ending September 2006 =100, real terms) Forestry Commission, 2011

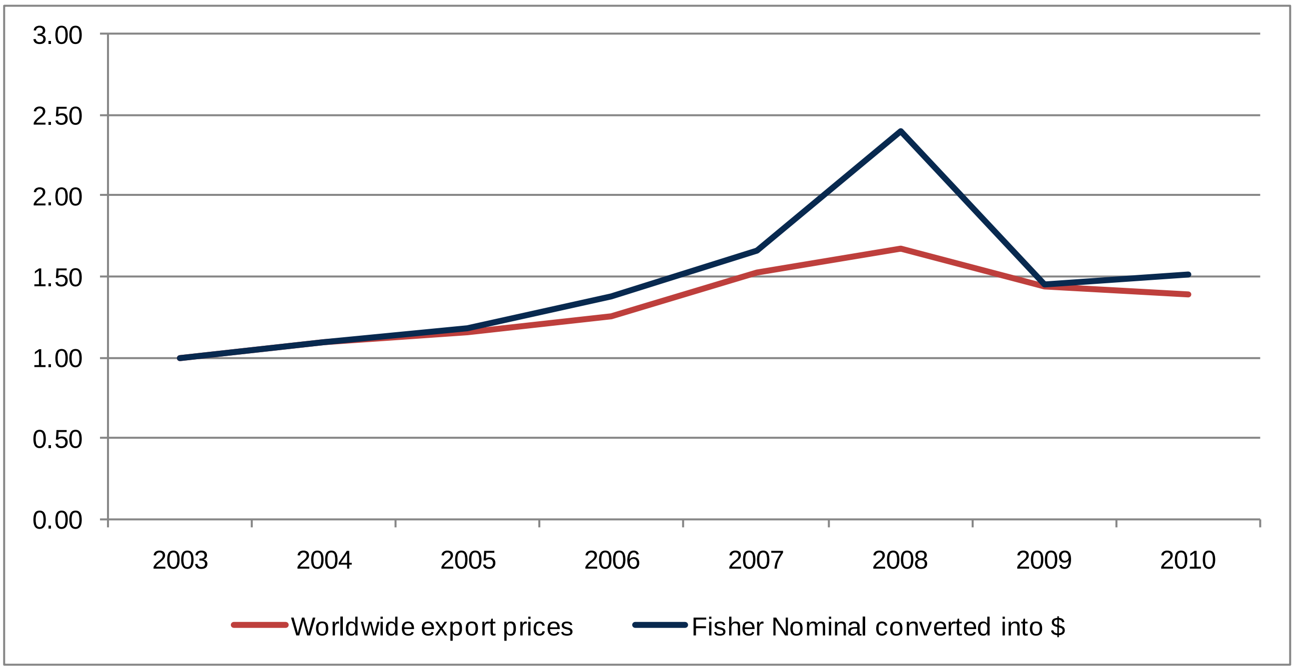
Figure 2: Co-firing with fossil fuels and UK wood prices



Source: DECC analysis based on DUKES and Forestry Commission data

Note: Axis on right relates to UK wood prices (fisher index). Axis on left relates to co-firing in GWh.

Figure 3: UK wood prices (the UK Fisher Index, nominal, converted into $) and the worldwide export price



Source: DECC analysis based on FAOStat and Forestry Commission
Notes: 2003=1.00; Linear relationship with R^2 of 0.87

14. The fall in the value of the pound over the last few years relative to a basket of international currencies, and the euro in particular, is also believed to have resulted in upward pressure on UK wood prices. For example, currency changes have largely believed to have been responsible for the resumption of modest exports of round-wood (i.e. un-processed) to Scandinavia and Germany.

15. The links with international markets is in line with the expectation that UK will be price taker on the global market for wood supplies as it will be just one of a large number of countries competing for sustainable woodfuel. In 2010, the UK demand for biomass feedstocks for energy accounted for only 0.2% of the world primary demand for biomass and waste (and only 3% of the total EU demand). Based on the current projections by 2020 although these shares are expected to increase (to 0.6% and 6% respectively) the UK will remain a very small player in this market[66].

16. On the recovered wood market, its increasingly international nature is illustrated by the rapid increase in recovered wood exports from the UK to the rest of Europe. A recent report by WRAP[67] highlighted that demand for and prices of recovered wood are likely to be influenced by international biomass developments (particularly in Germany, Sweden, Belgium and Denmark), exchange rate fluctuations and government support for biomass in other countries. However localised supply-demand imbalances can also cause price fluctuations as the market develops.

[66] Based on the UK Renewables Roadmap deployment levels and IEA data.
[67] Realising the value of recovered wood, Market Situation Report, Summer 2011

Appendix 2 – Further Sensitivity Analysis

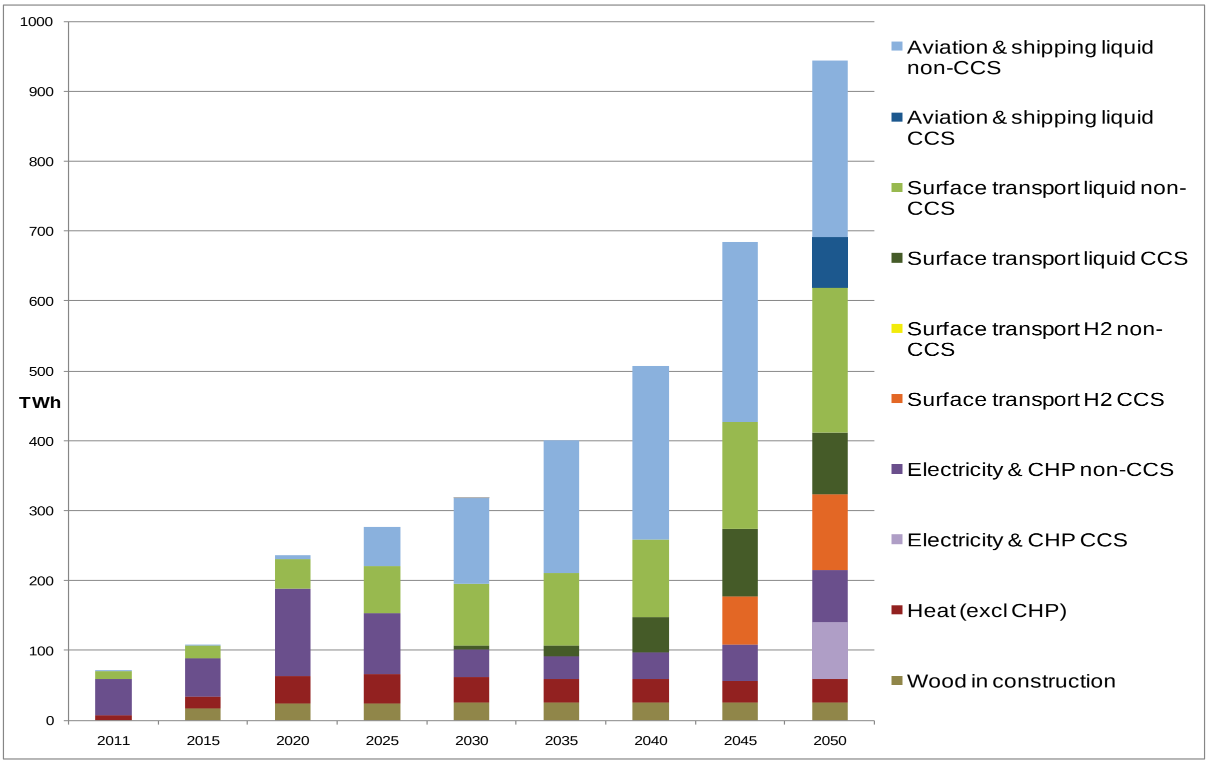
(A) Higher import share sensitivity

1. To test the impact of a larger UK share of global imports, the scenario shown in Figure 1 below represents a 6% import share in 2050 (compared to 1.5 – 3% range in our 3 core supply scenarios). Other assumptions (e.g. world development, yield rates etc) are consistent with the ambitious scenario. This results in a 82% increase in total bioresources potentially available to the UK in 2050 compared to the ambitious scenario. In this scenario total bioresource use taken up by the AUB model run is equivalent to approximately 43% of UK primary energy demand in 2050 – therefore presenting a significantly higher deployment of bioenergy (compared to the 8 – 21% range provided by the restricted to ambitious scenarios).

2. Figure 1 shows a similar pattern of bioresource use in near and medium term as the ambitious supply scenario shown in Figure 29 (scenario 6 in results section of Section 3) (albeit at higher absolute levels), but a more diversified technology mix in 2050: increased bioliquids for international aviation and shipping (CCS and non-CCS); increased use of bioliquds for surface transport to 2050 (CCS and non-CCS); and increased electricity & CHP (CCS and on-CCS). The higher availability of bio in these applications allows for an offsetting reduction in hydrogen with CCS for transport in 2050. The higher bioresource means there is not so much imperative to prioritise it into hydrogen applications where carbon savings are highest.

3. This sensitivity analysis supports the key conclusions in the results section. CCS is key in the longer term, but there is high uncertainty around the technologies that CCS will be applied to. Hydrogen is one potentially important option in the longer term, but because the economics and feasibility of particular applications are uncertain, we should keep options open until these are clearer.

Figure 1: Summary of bioresource use - primary energy basis for high resource scenario assuming 6% import share in 2050



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

(B) Sensitivity around long term switching in technology pathways

127. The majority of modelling scenarios (where CCS is availabile) show a significant switching in the longer term from bioliquids for international aviation and shipping to hydrogen with CCS for transport. There are high levels of uncertainty surrounding the role for yet unproven technologies in the longer term, therefore it is useful to analyse the modelling results when different assumptions are made on the cost and availability of such technologies. The overall message remains: CCS is key in the longer term but given the high levels of uncertainty around technologies CCS can be applied to (e.g. hydrogen) options should be kept open.

128. The AUB model does take into account plant lifetime capital costs when choosing to build, however it does not take into account investor behaviour and makes stylised assumptions on factors such as minimum levels of operation of the plant over its lifetime. These factors help explain the models ability to switch technology pathways rapidly in later years. The following points explain further the scrapping assumptions in the model:

- There is no voluntary retirement of capacity in the model, e.g. the model cannot avoid further Fixed Operating Costs (FOM) for the full lifetime of plant once it has been built. The model is aware of these costs under the perfect foresight mode. However, the model can choose not to run the plant at full potential to avoid Variable Operational & Maintenance and input costs.

- As part of finding a least cost solution the model will try to get the most out of any plant it builds given the CAPEX/FOM costs it must incur, but wider factors (e.g. emissions target in 2050) may dictate effective 'early retirement' of existing plant, and build of new plant before the existing plants lifetime has expired.
- In the long term the results are heavily driven by meeting the tightening emissions target and therefore the model will prioritise emissions savings over the most obviously cost effective routes (or more realistic investor behaviour).
- It is useful to remember that the model is examining an optimal pathway, in a stylised centrally planned world where the emission target is binding. It is not an agent based model of real world investor behaviour and therefore cannot be used to forecast what real world investors would do at certain points. These are very different approaches and likely to result in very different results. The analytical annex contains an explanation of how the higher level results from the AUB will be used in conjunction with other models in DECC that do take these into account (e.g. the RO/RHI/FITs modelling).
- The modelling does not contain any retrofit technology options apart from the coal to biomass option, this means it cannot upgrade existing plant, i.e. adding on CCS and reconfiguring conversion technology to produce hydrogen. In the future the model could potentially be developed to include other technology options such as, retrofit biofuel in aviation to CCS part way through the plant life, this would be a more realistic alternative to building separate new plants from scratch.

129. In order to provide a sensitivity around the longer term switches in technology pathways evident in Scenario 1, two further modelling scenarios have been carried out:

(a) assuming a 50% increase in the long-term capital costs of fuel cell vehicles and hydrogen turbines. All other assumptions are consistent with Scenario 1; and

(b) extending minimum load factors (minimum level plant must be run at) and reducing maximum availability and build rate assumptions by a half for hydrogen for transport technologies and all CCS technology routes. All other assumptions are consistent with Scenario 1.

130. Sensitivity analysis (a) - This analysis shows the results are very sensitive to the cost assumptions, which become increasingly uncertain towards the longer term. By 2050, surface transport with hydrogen has fallen by 26%, which is substituted largely by CCS in electricity and CHP. This again stresses the importance of identifying low risk pathways and not locking in investment decisions at this stage.

131. Sensitivity analysis (b) - This analysis supports the conclusion from the analytical annex that CCS is highly valued by the model in the long term but options must be kept open in regards to specific technologies and sectors the CCS is applied to. By reducing the assumptions around maximum build rates and availability for specific individual technologies the results show a more gradual take up and decline in technology pathways and a more

diversified mix of technologies in 2050: surface transport with hydrogen has fallen by 28%, which is substituted largely by bioliquids for aviation and shipping with CCS and a continuation of bioliquids for surface transport.

(a) High Hydrogen cost sensitivity

132. In order to provide sensitivty analysis around the longer term switching in technology pathways (bioliquids in international aviation and shipping to hydrogen with CCS in transport) in Scenario 1, a modelling scenario was run assuming a 50% increase in the long-term capital costs of fuel cell vehicles and hydrogen turbines. All other assumptions are consistent with Scenario 1.

133. As shown in tables 1 and 2 and Figures 3 and 4 below, total overall levels of bioresource use is virtually the same over both Scenario 1 and the high hydrogen cost scenario in each period. However, the technology mix has changed: surface transport hydrogen with CCS is reduced by approximately 26% compared to Scenario 1; electricity and CHP with CCS increases in 2050 by approximately 71% compared to Scenario 1; and there is increased take up of biomass in surface transport liquid with CCS in the high hydrogen cost scenario.

Table 1: Total bioresource use for high hydrogen cost sensitivity

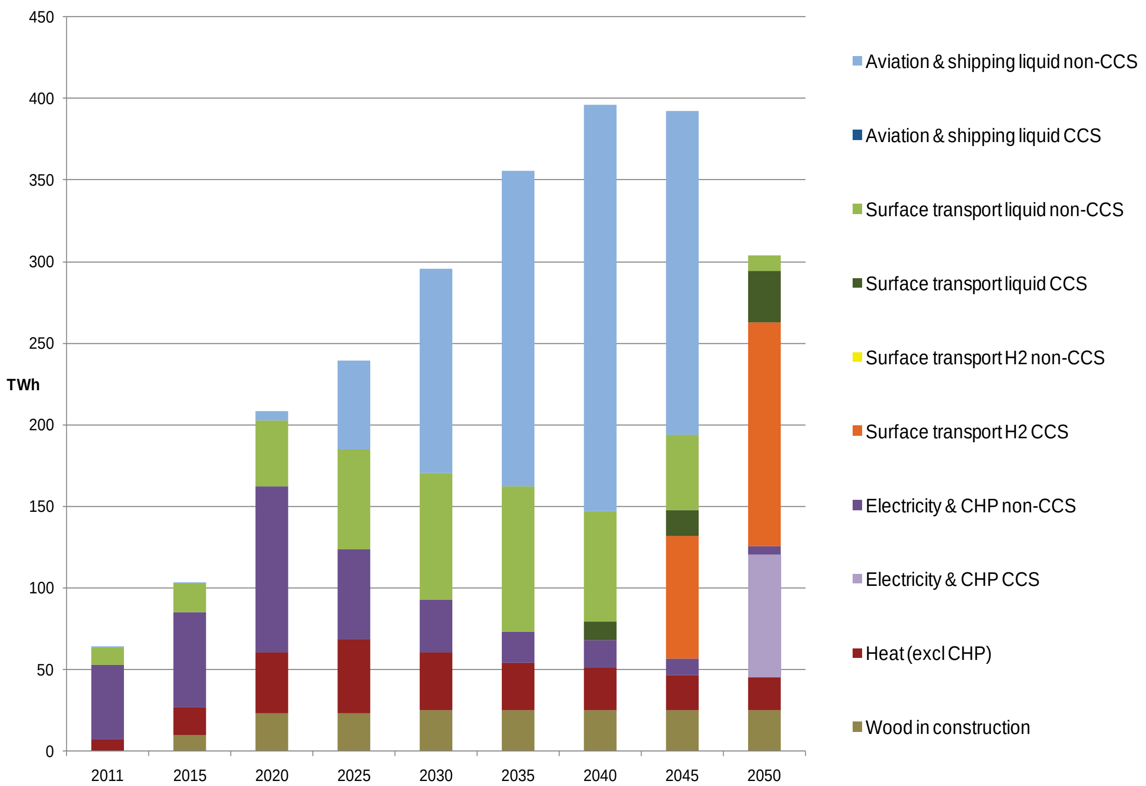
Table 1: Total bioresource use for high hydrogen cost sensitivity

	2011	2015	2020	2025	2030	2035	2040	2045	2050
Wood in construction	0	10	23	23	25	25	25	25	25
Heat (excl CHP)	7	17	37	45	35	29	26	21	20
Electricity & CHP CCS	0	0	0	0	0	0	0	0	76
Electricity & CHP non-CCS	46	58	101	55	32	19	17	10	5
Surface transport H2 CCS	0	0	0	0	0	0	0	75	138
Surface transport H2 non-CCS	0	0	0	0	0	0	0	0	0
Surface transport liquid CCS	0	0	0	0	0	0	12	15	31
Surface transport liquid non-CCS	11	18	41	61	78	89	67	47	10
Aviation & shipping liquid CCS	0	0	0	0	0	0	0	0	0
Aviation & shipping liquid non-CCS	0	0	6	54	125	194	250	198	0
Total	64	103	209	239	296	356	396	392	304

Table 2: Total bioresource use for Scenario 1

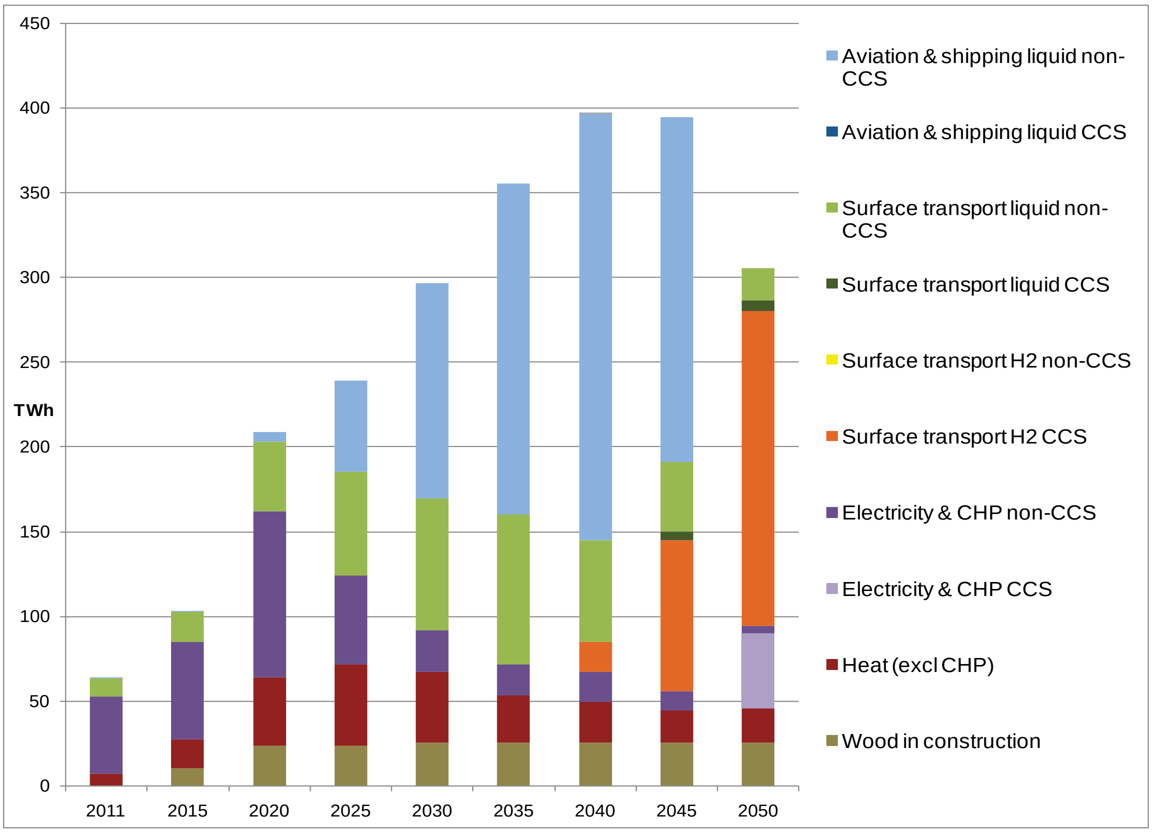
Table 2: Total bioresource use for Scenario 1									
	2011	2015	2020	2025	2030	2035	2040	2045	2050
Wood in construction	0	10	23	23	25	25	25	25	25
Heat (excl CHP)	7	17	40	48	42	28	24	19	20
Electricity & CHP CCS	0	0	0	0	0	0	0	0	44
Electricity & CHP non-CCS	46	58	98	52	24	19	18	11	5
Surface transport H2 CCS	0	0	0	0	0	0	18	89	185
Surface transport H2 non-CCS	0	0	0	0	0	0	0	0	0
Surface transport liquid CCS	0	0	0	0	0	0	0	5	6
Surface transport liquid non-CCS	11	18	41	61	78	88	60	41	19
Aviation & shipping liquid CCS	0	0	0	0	0	0	0	0	0
Aviation & shipping liquid non-CCS	0	0	6	54	127	196	252	203	0
Total	64	103	209	239	297	356	396	394	306

Figure 3: Summary of bioresource use - primary energy basis for high hydrogen cost sensitivity scenario



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

Figure 4: Summary of bioresource use - primary energy basis for the Scenario 1



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

(b) Extending minimum load factors and reducing maximum availability and build rate assumptions by a half for Hydrogen for transport and CCS technology routes

134. Key drivers of the switch to hydrogen in the longer term are:

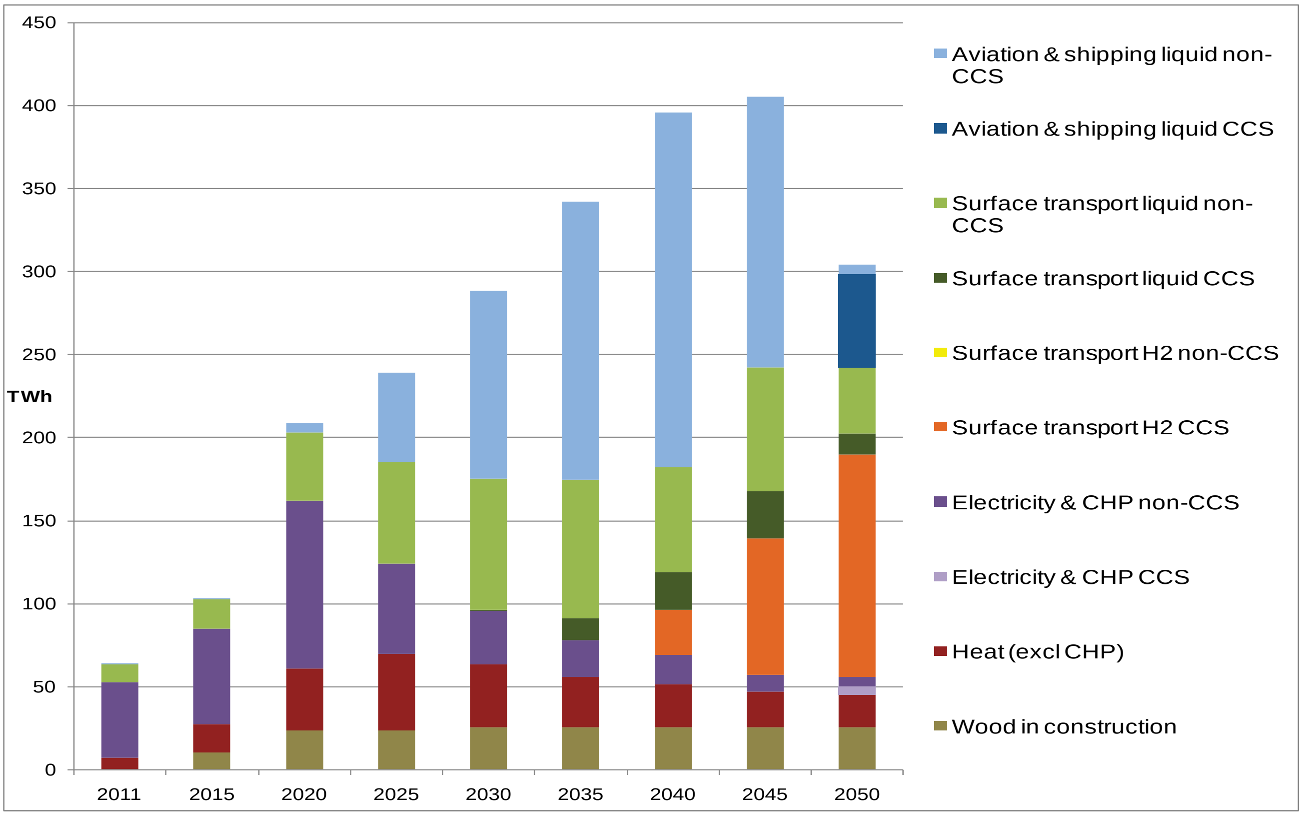
- Maximum build rate assumptions – these are very difficult to set given the uncertainty over how quickly they can be ramped up.
- Assumptions over how long (and at what operational level) assets will be run for once a decision has been made to invest in them.

135. In order to provide further sensitivity analysis around these, we have reduced maximum availability and build rates by half and extended minimum load factors (where they are applied these were extended all the way to 2050, and applied to all technologies related to the key switch). These changes were made to Hydrogen for transport technologies and all CCS technology routes. All other assumptions (including hydrogen cost assumptions) are unchanged. Figure 5 shows the technology mix to 2050. It shows that the technology mix has become more diversified in the longer term – there is now a more gradual ramping up and down of technologies over time. By 2050, surface transport hydrogen with CCS is reduced by around a third, which is replaced by a mixture of bioliquids for aviation and shipping with CCS and a continuation of bioliquids for surface transport.

Table 3: Total bioresource use for sensitivity analysis 2 (extending minimum load factors and restricting availability of Hydrogen and CCS routes):

Table 3: Total bioresource use for sensitivity 2 (extending minimum load factors and restricting availability of H2 and CCS routes)									
	2011	2015	2020	2025	2030	2035	2040	2045	2050
Wood in construction	0	10	23	23	25	25	25	25	25
Heat (excl CHP)	7	17	37	46	38	31	26	21	20
Electricity & CHP CCS	0	0	0	0	0	0	0	0	5
Electricity & CHP non-CCS	46	58	102	54	33	22	18	10	6
Surface transport H2 CCS	0	0	0	0	0	0	28	82	134
Surface transport H2 non-CCS	0	0	0	0	0	0	0	0	0
Surface transport liquid CCS	0	0	0	0	1	13	23	29	13
Surface transport liquid non-CCS	11	18	41	61	79	84	63	75	39
Aviation & shipping liquid CCS	0	0	0	0	0	0	0	0	57
Aviation & shipping liquid non-CCS	0	0	6	54	113	168	213	163	5
Total	64	103	209	239	288	342	396	406	304

Figure 5: Summary of bioresource use on a primary energy basis for sensitivity analysis 2 (extending minimum load factors and restricting availability of Hydrogen and CCS routes)



Source: DECC modelling using model developed by Redpoint Energy and Ecofys

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