Modes Project 1:

Development of illustrative scenarios describing the quantity of different types of bioenergy potentially available to the UK transport sector in 2020, 2030 and 2050

Study for the UK Department for Transport

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E4tech

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Executive Summary

This report gives the results of a study carried out by E4tech in 2010 to develop three illustrative scenarios describing the quantity of different types of biomass feedstocks potentially available to the UK transport sector in 2020, 2030 and 2050. This Modes Project 1 is one of the steps in a larger UK Department for Transport work-stream, assessing the possible contribution that could be made to the UK's climate change targets through increased uptake of bioenergy in the transport sector. The scenarios developed in this project have been used as an input to Modes Project 2, which assesses how bioenergy could best be used across different transport modes. The scenarios are intended to represent a range of futures, which might affect the way in which bioenergy might best be allocated for use in the Modes Project 2.

UK and global supply and demand data to 2030 was provided by AEA Technology, as output from their separate 'UK and Global Bioenergy resource' project for the Department of Energy and Climate Change. E4tech extended the resource potentials, competing demands and underlying assumptions to 2050, adding in new feedstocks that might become available in this time, before assessing what proportion of the total amount of bioenergy would be available to the UK transport sector. Three availability scenarios were then developed based on different world views for output to Modes Project 2.

As shown below in Figure 1, the three scenarios demonstrate a wide range of projections of the amount of biomass available to UK transport to 2050.
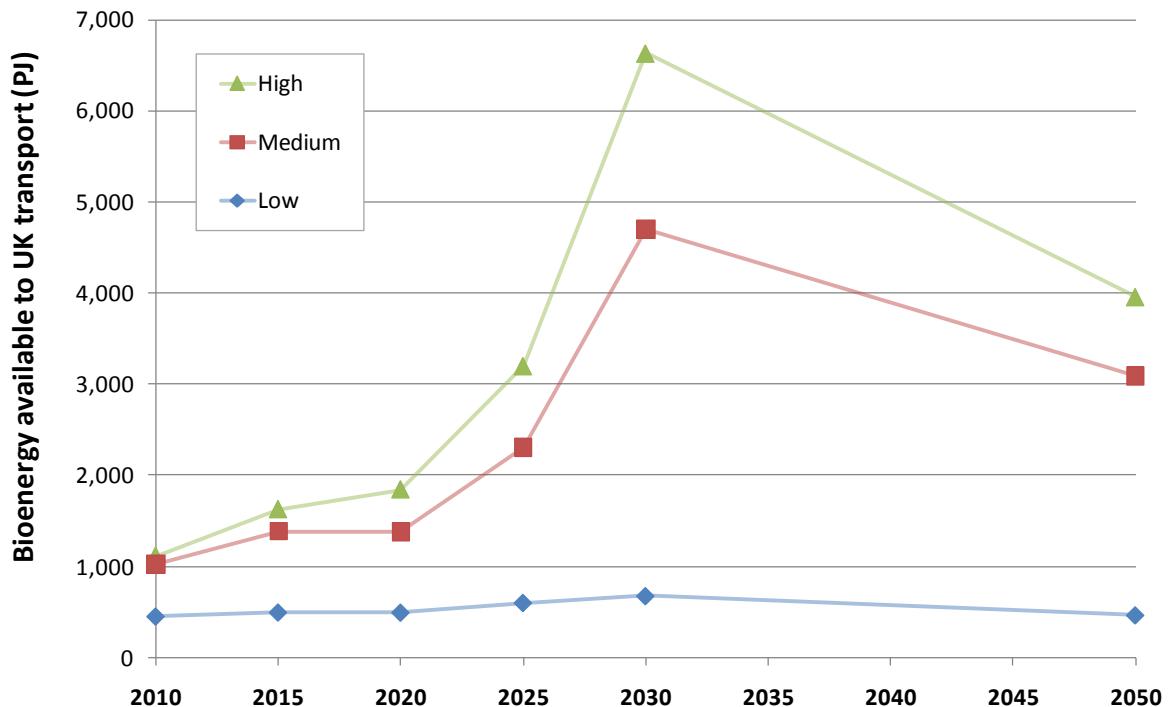

Figure 1: Output from Project 1: Total biomass and first generation biofuels availability in 3 scenarios

The main features of the results are:

- First generation biofuel import volumes are affected by sustainability constraints under the EU Renewable Energy Directive (RED) – biodiesel is particularly restricted in 2020
- With a rapid ramp-up in planting rates between 2020 and 2030, energy crops dominate global supply, and compete for the available land with first generation biofuels crops
- Overcoming supply barriers is important (e.g. investment in infrastructure, creation of efficient markets), otherwise potential supplies could be limited and RED targets not met, as in the Low scenario
- The results are sensitive to the percentage of the global market the UK can capture. After 2030, increasing global competition for resources is expected to limit potential imports to the UK.
- The total resource available to UK transport is substantial. In 2050, the total supply potential available in the Medium scenario, if used, would be ~2 EJ/yr of biofuel, which is ~80 % of the projected UK transport demand

Use of these results outside the Modes projects

There is considerable uncertainty over the potential for global biomass supply, and the magnitude of future competing demands globally and in the UK, especially to 2050. One key uncertainty is the percentage of the global supply that the UK could import. Any one scenario in this study should therefore not be used in isolation as a market forecast: the scenarios together reflect different potential views of the world in the future. Whilst the scenarios provided are illustrative, the study is based on detailed analysis in order to show the plausibility of these results.
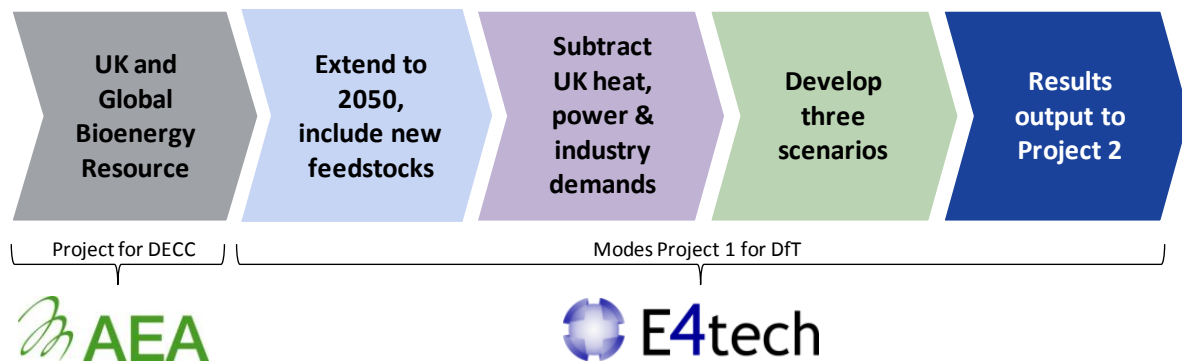
1   Introduction and scope

In 2010, E4tech and AEA Technology were commissioned to help the UK Department for Transport (DfT) assess the possible contribution that could be made to the UK's climate change targets through increased uptake of bioenergy in the transport sector. The EU Renewable Energy Directive requires that renewable energy makes up 10% of energy used in transport by 2020. With a limited supply of sustainable bioenergy and varying GHG emission savings, there is a need to ensure that the carbon savings achieved are cost-effective in the context of other options available for decarbonising different transport modes. Longer term, the 80% reduction in UK GHG emissions by 2050 under the Climate Change Act will require further decarbonisation of UK transport.

In order to produce an assessment of the relative cost effectiveness and greenhouse gas savings potential for the deployment of various forms of bioenergy across the different transport modes, there was first the need to develop illustrative scenarios describing the quantity of different types of bioenergy potentially available to the transport sector over time.

This project (Modes Project 1) was therefore designed to generate three scenarios for the quantities of bioenergy that could be available to the UK transport sector in 2020, 2030 and 2050. These results would then be fed into a parallel project (Modes Project 2), which is investigating which transport modes should be prioritised for the deployment of bioenergy, taking into account cost effectiveness, infrastructure and GHG emission savings considerations. The process followed during Project 1 is shown below in Figure 2.

Figure 2: Process followed in Modes Project 1

UK and Global Bioenergy Resource → Extend to 2050, include new feedstocks → Subtract UK heat, power & industry demands → Develop three scenarios → Results output to Project 2

Project for DECC — Modes Project 1 for DfT

AEA — E4tech

There have been many different UK and global bioenergy resource assessments conducted in the past[1,2,3], with a wide range of results. To maintain a degree of consistency across analyses commissioned by UK government departments, however, this work uses the results of a project recently conducted by AEA for DECC, assessing the availability of UK and global bioenergy resources to 2030[4].

E4tech therefore took these project outputs, and extended the UK and global resource potentials, demands and underlying assumptions to 2050. We also added in new feedstocks (microalgae and macroalgae) to the modelling. At the same time, we have conducted a detailed review of the data and assumptions used.

After calculating the total amount of bioenergy available to the UK from indigenous resources and international imports, we then subtracted UK power, heat and industry bioenergy demands, to give the amount of bioenergy that is only available to the UK transport sector.

Low, Medium and High availability scenarios were then developed. Each scenario corresponds to a different potential world view for the future, created by varying key supply and demand assumptions, both in the UK and globally.

Finally, the outputs of Modes Project 1 have been fed into Project 2, in order to test the conclusions of Project 2 under different biomass availability scenarios. Note that Project 1 does not produce projections of bioenergy cost. These have been provided to Modes Project 2 as an output of a separate DfT levelised cost work-stream, which reported provisional results in mid 2010[5].

[1] E4tech (2009) "Biomass supply curve for the UK", published as part of DECC's Renewable Energy Strategy, available at: www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/res/res.aspx
[2] Hamelinck, Suurs & Faaij (2005) "International bioenergy transport costs and energy balance" Biomass and Bioenergy 29, 114-134
[3] Hoogwijk (2004) "On the Global and Regional Potential of Renewable Energy Sources", PhD thesis Utrecht University, available at: www.pbl.nl/en/publications/2004/On_the_global_and_regional_potential_of_renewable_energy_sources.html
[4] AEA (2011) "UK and Global Bioenergy resource", yet-to-report project for UK Department of Energy and Climate Change
[5] Poyry (2011) "Levelised cost modelling", yet-to-report biofuels project for UK Department for Transport

2 Extension to 2050, and inclusion of new feedstocks

This section describes the main assumptions in AEA's project for DECC, before extending the resource and demand calculations to 2050 and including algae feedstocks. AEA's modelling involved three main steps: firstly calculating the global supply, secondly subtracting global demand and thirdly determining the global potential surplus/deficit. The second stage of this modelling has the EU as a net importer of bioenergy, we therefore assumed that the UK would attract a share of these imports, based on relative energy demand. We then assumed that a percentage of the potential global surplus could also be imported to the UK. These two potential resources were then combined with the UK's indigenous supply to establish the total resource potential available to the UK, as in AEA's approach. A different approach was used for crops for 1G biofuels, as described in Section 2.3.4.

2.1 Global supply

2.1.1 Main source data to 2030

The global resource potential to 2030 of a number of biomass feedstocks was calculated in AEA's project for DECC:

- Forestry (small roundwood, forestry residues, sawmill co-products)
- Agricultural residues[6]
- Energy crops
- 1G ethanol (from corn, wheat, sugar cane, sugar beet and cassava)
- 1G biodiesel (from rapeseed (OSR), soy, palm and jatropha)

Each of these resource supply potentials were calculated for 13 world regions, in the years 2010, 2015, 2020, 2025 and 2030. Note that AEA only considered tradable biomass feedstocks in their analysis, excluding less easily transported bioenergy feedstocks such as straw, manures and wastes. These feedstocks were instead considered implicitly by reducing regional demands for biofuels and heat, power and industry demands.

Next, percentage reductions were made in each region's available resource, according to estimates of high-level market and infrastructure barriers that exist in each particular year. In general, these constraints fall over time, and more developed countries have lower barriers than less developed countries. The lowest barriers can be found for 1G biofuels produced in OECD and some emerging economy regions, as these technologies are fully commercial and the markets are growing rapidly. AEA used three sets of resource constraints, within three investment scenarios: "Low Investment", "BAU" and "High Investment". The constraints are highest in the Low Investment scenario, and lowest in the High Investment scenario.

2.1.2 Extension to 2050

To determine the resource potentials to 2050, we assessed AEA's underlying data and set of assumptions, and extended these using a consistent approach. In some cases the data sources used by AEA already had 2050 data.

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[6] Examples include olive oil residues, palm kernel expeller, palm kernel shell, shea nut shells, sunflower pellets, tall oil, DDGS, bagasse, and other meals and cakes from oil seeds

Forestry

OECD country data for 2050 came directly from Forest Research's Carbine model, using national forest inventory and FAOstat timber statistics, as used in AEA's project. Data in other regions was estimated by AEA using FAOstat data and assuming similar management practices. The resource in non-OECD regions was increased to 2050 using the Carbine growth rate, as had been done by AEA before 2030.

Agricultural residues

None of the regional resources change over time to 2030 in the Low Investment and BAU scenarios, and so we kept these resources constant to 2050. In a High investment scenario, there is linear growth in each regional resource from 2010 to 2030. The same rate of increase was kept to 2050.

Land availability for energy crops and 1G crops

For the energy crops and 1G feedstocks, the key determinant in extending to 2050 is the amount of land available. AEA used land availability and energy crop yield data to 2050 extracted from Hoogwijk (2005), with Van Vuuren (2009) then used to assess land suitability based on water availability and land degradation. The available land area for energy uses was divided by AEA into four categories:

- Abandoned agricultural land available for energy crops and 1G crops
- Abandoned agricultural land available for energy crops only
- Grassland available for energy crops and 1G crops
- Grassland available for energy crops only

In most cases, it was assumed that the two grassland categories are not available for planting any crops, due to sustainability concerns. However, in order to test the impact of including some additional land area, we developed a high case where it was assumed 10% of the grassland is also available for planting.

There is then a choice to be made regarding which crop is grown on the land areas which are suitable for both energy crops and 1G crops:

- In the "1Gmax" scenario, all of the land suitable for 1G crops is used to grow 1G crops. Energy crops are limited to only being planted on land for which only they are suitable.
- In the "ECmax" scenario, energy crops have priority over 1G crops, and can be planted on as much abandoned agricultural land (and grassland) as the energy crop planting rates allow. It is assumed that energy crops start being grown on the land that is only suitable for energy crops, so that 1G crops production is maximised in the early years. Once that land has been covered, then energy crops are planted instead of 1G crops, and so the two scenarios only diverge in later years

AEA made the simplifying assumption that only one feedstock for 1G ethanol and one feedstock for 1G biodiesel would be grown in each region. In order to be consistent with the approach to 2030, we have kept this assumption and choice of feedstocks to 2050.

AEA also provided a percentage split of the land available for 1G crops in each region, between the land available for the 1G ethanol crop vs. the 1G biodiesel crop. These regional percentages vary in the near-term, but are usually constant from 2020 to 2030; in this case we held these percentages

constant to 2050. For the few regions where AEA assumed the percentage split continues to change to 2030, we kept the same trend to 2050.

For the 1G crop yields, AEA have assumed constant percentage increases from 2010 to 2030, varying between 0.2% and 1.2% a year according to the region and level of investment chosen. We have therefore kept these same percentage yield increases to 2050.

Energy crop planting rates

AEA provided three sets of energy crops planting rates to 2030, based on assumptions about the maximum rate at which the area planted each year could be expanded. AEA assumed that planting of energy crops starts in 2011 in developed regions, and 2013 elsewhere. An initial year planting area of 0.27% of each region's maximum available area was derived from the UK's current situation (a potential planting rate of 4 kha/yr and a maximum available area of 1,500 kha). An annual growth rate was then applied to these initial planting rates, to estimate potential planting rates to 2030. AEA set this growth rate at:

- 20% for all regions in a high case
- 20% for developed, 10% for emerging, and 5% for less developed regions in a medium case
- 20% for developed, 8% for emerging, and 2% for less developed regions in a low case

However, using these growth rates led to very large areas planted with energy crops in the years 2020 to 2030. The volume of energy crops supplied were far larger than was estimated to be demanded by heat and power globally, in addition to the demand from the limited number of lignocellulosic biofuel plants available by this time. In addition, land competition between these energy crops and 1G crops resulted in insufficient 1G crops to meet the RED target of 10% biofuels in 2020 in the UK. After discussion with DfT and AEA, we therefore reduced the energy crop planting rates, increasing the amount of 1G crops grown, such that at least two of the scenarios fed into Modes 2 would enable the UK to meet the RED. The planting rates used in the scenarios here were therefore:

- 20% for developed, 10% for emerging, and 5% for less developed regions in a high case
- 20% for developed, 9% for emerging, and 3.5% for less developed regions in a medium case
- 20% for developed, 8% for emerging, and 2% for less developed regions in a low case

We then made assumptions about the continuation of these planting rates to 2050. In a high case, we increased all the regional growth rates to 20%, assuming a step change in the development of the energy crop industry in developing countries. In the medium and low case, we kept the same planting rate in 2050 as in 2030, assuming that the industry might have reached a maximum size by 2030.

The cumulative land area planted with energy crops is shown below in Figure 3 for the medium case, with the maximum area available for any feedstocks, and the constrained area once supply barriers and competition with crops for 1G biofuels are taken into account. As a comparison, the 2050 planted area of 290Mha would be equivalent to approximately 8% of the projected global cropland area.
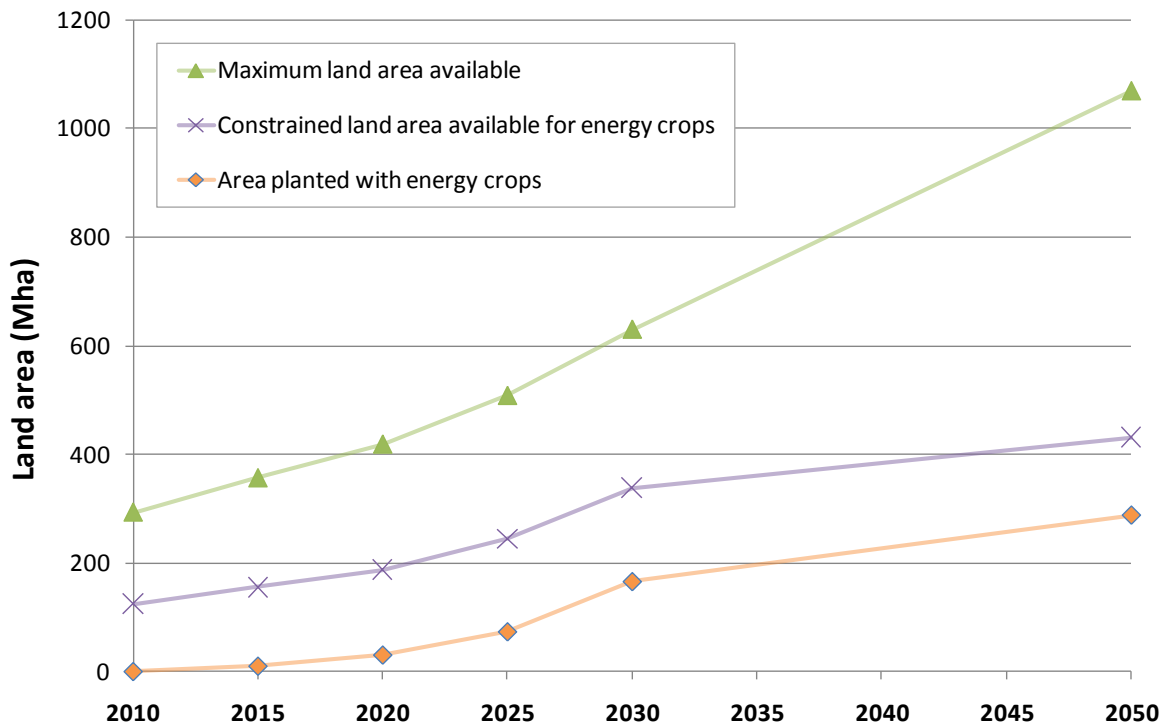
Figure 3: Global cumulative planted area of energy crops, and available land areas, in the medium case

Choice of feedstocks grown and sustainability constraints

AEA provided a current GHG savings percentage for the 1G ethanol and biodiesel produced in each region (e.g. 27% for Russian biodiesel from oilseed rape), based on RFA default values and work by E4tech in Modes Project 2. On the basis of the EU RED sustainability requirements, AEA assumed that for a biofuel to be importable, it must meet at least a saving of 35% by 2015, and a 50% saving from 2017 onwards. Therefore, biofuels produced in several world regions will not meet these thresholds, whilst in other regions, only some of the biofuel produced might be compliant. AEA estimated these sustainability constraints in 2010, 2015, 2020, 2025 and 2030 by reducing the available supply to the EU by a set of percentages, based on their judgement of the proportion of plants that could improve their GHG savings.

The sustainability constraints have a large effect in 2020, with large reductions in the amount of sustainable OSR, soy and palm biodiesel, along with corn and wheat ethanol. The supply of 1G biofuels increases to 2030 as the percentage of supply meeting the GHG savings criteria increases, which could be achieved through improved crop yields, and changes to conversion plants (e.g. retrofitting palm oil plants with methane capture equipment). We assume that the majority of these improvements will be made by 2030. As a result, we kept the same proportion of fuels meeting the criteria to 2050 as in 2030.

Market and infrastructure barriers

To extend the market and infrastructure barriers to 2050, after discussions with AEA to ensure consistency, we estimated the percentage constraints for each feedstock and region in 2050 by the following method:

- If a regional constraint was constant from 2010 to 2030, then we kept the constraint constant from 2030 to 2050
- If the constraint had already been overcome by 2030, then we kept this assumption to 2050
- If the constraint had changed over time, but not disappeared entirely by 2030, then we kept the same percentage barrier in 2050 as in 2030. This was because some barriers e.g. resource distribution and political uncertainty will remain. Also, the resource available for export might not increase if non-energy competing uses increase in line with the available local resource.

2.1.3   Algae

In addition to the list of feedstocks considered by AEA to 2030, we have also included microalgae and macroalgae within our analysis, as these resources could be significant after 2030. However, given the innovation still required before commercial scale deployment begins, which we project to be in around 2020, and current high production costs, we have also considered a case where microalgae and macroalgae are not deployed.

Microalgae grown in saline open ponds require sufficient sunlight, avoidance of low temperatures, and at least 700 ha of flat land near the coast. These criteria have been shown via GIS analysis[7] to limit the number of suitable sites globally to around 15,000, which would equate to 8.1 EJ/yr of algal biodiesel. This figure was used in 2050 as a High case.

However, many of these sites are not close to sources of CO_2 from power stations and industry, which are needed to enable algal growth, and so would require CO_2 to be transported to them. Considering only those sites near existing CO_2 sources[8] limits the number of plants to around 5,000, or around 2.8 EJ/yr of algal biodiesel. This figure was used in 2050 as a central case.

Macroalgae (seaweed) are most likely to have the lowest costs and GHG emissions if grown on vertical lines in near-shore densely used areas, or on horizontal lines between offshore infrastructure (e.g. offshore windfarms)[9]. These concepts have been estimated to have global technical potentials of 35 PJ/yr and 110 EJ/yr respectively, with the majority of nutrient-rich waters found in Asia. To estimate accessible resource potentials over time, we took the ratio of deployment of macroalgae[10] in the UK in Level 2 or 3 of DECC's 2050 Pathways Analysis, compared to the maximum Level 4, as a proxy for the global ramp-up in resource. In 2050, this gives 3.4 EJ/yr of macroalgae resource in a Central case using just vertical lines, or 28 EJ/yr in a High case using both vertical and horizontal lines.

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[7] E4tech (2010) "Techno-economics, sustainability and potential siting of algal biofuel production", analysis and report for the Carbon Trust Algal Biofuels Challenge
[8] IEA Greenhouse Gas R&D Programme (2008) "CO2 emissions database", available at:
http://www.ieaghg.org/index.php?/20091223127/co2-emissions-database.html
[9] Ecofys (2008) "Worldwide Potential of Aquatic Biomass", report for VROM, available at:
http://www.ecofys.com/com/publications/brochures_newsletters/worldwide_potential_of_aquatic_biomass.htm
[10] DECC (2010) "2050 Pathways Analysis", Available at: http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx

2.2   Global demand

In AEA's model, the global bioenergy demand was subtracted from the global supply potential in order to calculate the potential remaining global surplus. This global demand can be separated into three distinct sectors:

- Heat, power, industry and "other" sector demands for woody biomass
- 1G biofuels demand for 1G feedstocks
- 2G biofuels demand for woody feedstocks

AEA took sector demand data from two IEA scenarios, IEA Reference and IEA Blue Map[11]. However, since the global supply resource assessment only covers feedstocks for 1G biofuels and tradable "woody" biomass, the global bioenergy demands had to be adjusted to only consider these feedstocks. Biomass use in industry and other sectors was also adjusted for a number of regions to remove the influence of traditional biomass use. Assumptions were made by AEA to 2030, and kept the same by us to 2050, regarding:

- The percentage of these IEA biomass & waste demands that will come from woody biomass
- The percentage split of the biofuels demand that is 1G ethanol, 1G biodiesel or 2G biofuels. AEA assumed that all the increase in biofuels demand between the IEA Blue Map and Reference scenarios would be met by 2G biofuels, which is reasonable given that IEA expect the demand for 1G biofuels to stay relatively flat after 2020 in both scenarios
- The percentage of 2G biofuels produced from woody biomass, as opposed to 2G biofuels from non-tradable straw, manures and wastes

All of this demand analysis was done at a regional level, so that each of the 13 regions had three demands. These were then matched against the region's supply of 1G and woody feedstocks, in order to calculate the region's net surplus or deficit in each year. Figure 4 gives an overview of the process used for determining the global surplus.

Based on ease of access and likely costs, AEA assumed that sawmill co-products, then small roundwood, then forestry residues and then energy crops would be used within a region to meet its "woody" bioenergy demands. We added in agricultural residues into this order, after forestry residues, as they can also be used to meet heat, power, and biofuel demands, and so should not be considered separately from the other "woody" feedstocks.

Given that microalgae and macroalgae resources are likely to be the highest cost resources available, these resources are added in last to determine the resulting regional net surplus/deficit. It is assumed that regions with a 2G biodiesel deficit use their microalgae biodiesel to meet this deficit, with the excess available on the global market. Regions with a heat & power bioenergy deficit (after considering the supply balance of solid feedstocks) are assumed to use some of their macroalgae to produce biogas at 80% efficiency in order to meet this deficit. Any left-over macroalgae not required for conversion to biogas is then assumed to be converted into ethanol at 50% efficiency, and either used to meet the region's 2G ethanol deficit, or available on the global market.

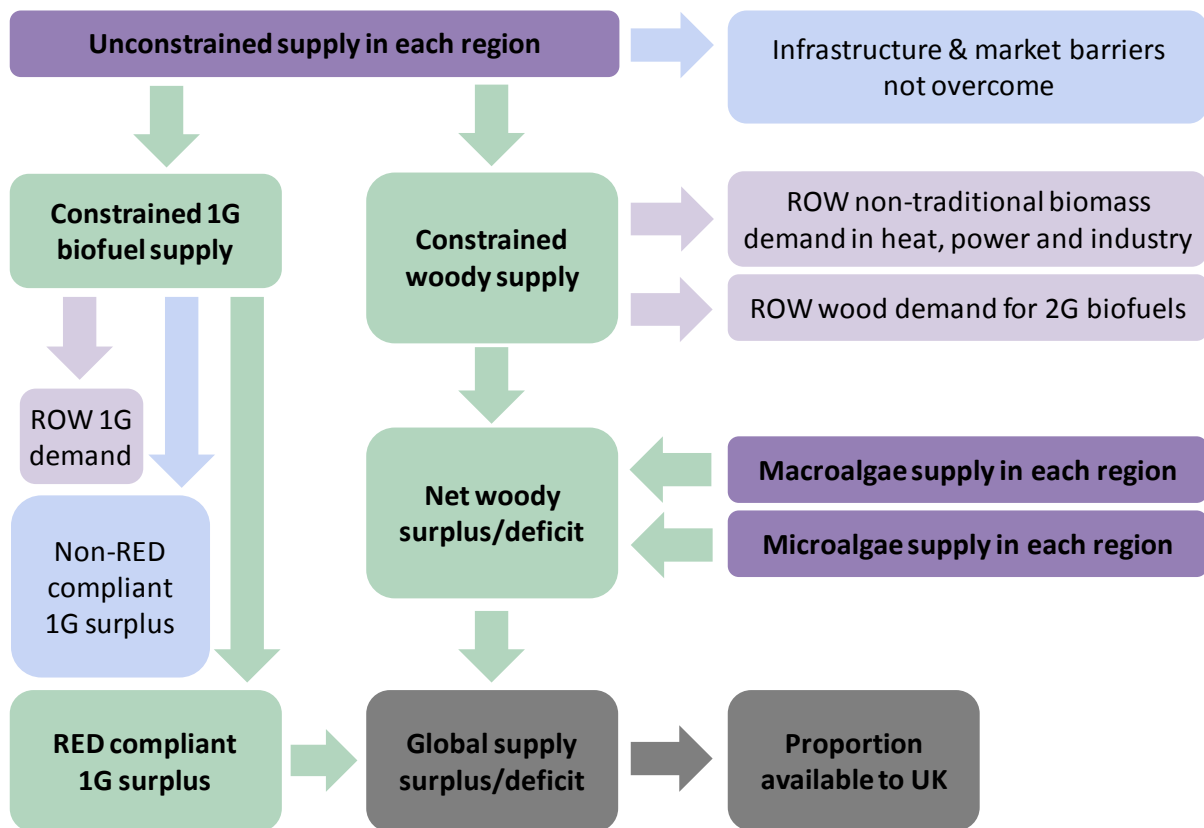[11] IEA (2009) "World Energy Outlook"

Figure 4: Model structure for calculating global surplus from supply and demand

2.3 Imports to the EU and UK

2.3.1 Imports into the EU

As a region in the analysis, the EU undergoes the same supply and demand steps above as for any other global region. However, the EU has a high demand for bioenergy in both IEA Reference and IEA Blue Map, larger than any potential EU supply, and so the EU is expected to always be a net importer of bioenergy. As the UK is included in the EU supply and demand estimates, it is reasonable to assume that the UK could capture a percentage of the imports coming into the EU, in addition to a proportion of any global surplus remaining after any regional deficits have been met.

We assumed that the UK can capture a share of the imports into the EU, based on its share of EU final energy demand. Final energy demand is considered a better metric to use than population or Gross Domestic Product, as it more accurately reflects the size of the energy market in the respective regions, and hence the likely purchasing power for feedstocks. Currently, the EU's final energy demand is 51 EJ/yr[12], whereas the UK's is 6.7 EJ/yr[13]. This would give the UK access to 13.1% of the imports into the EU. This percentage should remain relatively static, falling slightly to 12.8% in 2030, since both the EU and UK's energy demands are projected by the IEA to be relatively flat over time.

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[12] IEA (2010) "Energy Technology Perspectives", Blue Map projections
[13] DECC (2010) "2050 Pathways Analysis", Available at: http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx

2.3.2 Sustainability constraints

The RED defines sustainability criteria that must be fulfilled for biofuels and bioliquids that are to be counted towards the RED targets, whether produced within the EU or imported. Elsewhere in the world, each region could use a mix of RED-compliant and non RED-compliant feedstocks, to meet biofuel demands. The extent to which countries would use RED-compliant fuels domestically, or export them to the EU, is not yet known. Exploring this sensitivity showed:

- If we assume that countries use RED-compliant and non RED-compliant feedstocks in proportion to the ratio in which they are produced in that region, there are insufficient RED-compliant feedstocks in the global surplus to allow the UK to meet its 10% RED biofuels target in 2020.

- If we assume that each region uses its non RED-compliant feedstocks first in meeting its 1G ethanol and 1G biodiesel demands, leaving the maximum amount of RED-compliant feedstocks available for international trade, then sufficient volumes of compliant biofuels will be available for import such that the RED can be met in the UK (and the EU as a whole). We also assumed that if a region was still in deficit after using all of its RED-compliant and non RED-compliant feedstocks, then the deficit would be met by importing non RED-compliant biofuel. This approach is equivalent to assuming that the UK and EU provide a sufficient price signal incentivising the export of RED-compliant feedstocks from other regions.

2.3.3 Global surplus potential

Once the all regional deficits have been eliminated through international trading, then the remaining global surplus potential can be calculated. It is assumed that the UK can capture a certain proportion of this potential surplus for import and use in the UK. Theoretically, this percentage could be 100%, as every other country will have already met their projected bioenergy demands, and the UK should therefore be able to access all of the remaining bioenergy.

However, the UK would have to pay a very high price to access this entire surplus, since it would be distributed throughout the world. A more likely outcome is that other countries or regions might choose to use some of their extra biomass potential internally, i.e. have biomass demands higher than those projected by the IEA, as a result of high local supply potential. This could be achieved through policies to increase their bioenergy demand above their scenario estimates; how likely this is depends on the country and the resources available. There are also large uncertainties when using scenarios as far out as 2050, such as the IEA Blue Map scenario, or DECC 2050 Pathways.

In summary, the future percentage of a potential global surplus that the UK is able to access is difficult to estimate. Ultimately, it is a question of price; if the UK was willing to pay more than other countries, it could access more of the surplus, or even take biomass from other countries before their demand is met. However, if the assumption is made that the UK is only willing to pay an equivalent price for biomass compared to other countries, then the following assumptions can be made.

In their project for DECC, AEA assumed that any global surplus to 2030 would most likely be used by the EU, as a result of the EU currently having the most ambitious policy regime with respect to renewables and tackling climate change. The UK would therefore get a share based on the UK's share of EU final energy demand, with the assumption that the UK is able to access the same distribution of feedstock types as contained with the overall surplus. As calculated above in the EU

imports section, and keeping AEA's assumptions as to the likely final consumer of the surplus, this would give the UK access to 13.1% of the global surplus now, falling slightly to 12.8% in 2030.

An alternative approach would be to assume that the OECD would use the surplus bioenergy to 2030, since most OECD countries are as likely to implement policies to utilise excess bioenergy as in the EU. Under this assumption, since the current OECD final energy demand is 157 EJ/yr[12][Error! Bookmark not defined.], the share of the surplus the UK could access would be 4.3% currently, falling to 4.2% by 2030.

However, in 2050, the IEA projects that most countries will have large demands for biomass, including non-OECD countries such as China and India. Therefore, all countries are likely to compete equally for biomass; the assumption that only the EU or OECD can capture the entire global surplus cannot be reasonably made after 2030. As a result, we assume that the UK can only import a share of total global supply (rather than the surplus) in 2050, based on a projected UK share of 1.5% of the global IEA Blue Map final energy demand in 2050. This is the same approach, and percentage, as used within DECC's 2050 Pathways Analysis.

2.3.4 Trade of 1G biofuels

As described above, resources available to the UK in this analysis are calculated by summing the UK indigenous supply, the UK's share of imports into the EU, plus a proportion of the global potential surplus. The only exception to this approach is for 1G biofuel crops.

For these feedstocks, it was assumed that the UK could capture a share of the whole EU's 1G biofuels production, rather than UK production alone. This decision was taken due to the established import and export markets (including to and from the UK). It was therefore felt to be more likely that the UK would access a share of the EU market, rather than solely using its own indigenous supply. The 1G crop resource available to the UK is therefore set at ~13% of the EU's supply, plus ~13% of the imports into the EU, in addition to a proportion of the global surplus.

An analysis of the UK's indigenous potential production of 1G biofuel feedstocks has still been conducted as part of this project, for two other purposes:

- To determine the likely makeup of the 1G biofuel feedstocks available to the UK. This mix is determined based on the UK first using UK indigenous production, with the remainder determined by the global supply mix of RED-compliant feedstocks. This was done because although the UK will access a share of the EU supply, it is assumed it would use its own feedstocks first
- To determine the relative shares of land area available for 1G crops and woody energy crops.

2.4   UK indigenous supply

2.4.1   Main source of data to 2030

In the UK, the unconstrained technical resource potential for a number of biomass feedstocks was calculated in AEA's project for DECC[14], in the years 2010, 2015, 2020, 2025 and 2030:

- Wood resources (small roundwood, short-rotation forestry, forestry residues, sawmill co-products, arboricultural arisings, waste wood and energy crops)
- Dry wastes (straw & chicken litter, MSW and C&I waste)
- Biogas resources via AD (wet manures, sewage sludge, separated food waste, macroalgae) and landfill gas
- 1G ethanol (from wheat and sugar beet)
- 1G biodiesel (from OSR, UCO and tallow)

Price independent competing uses, such as the use of straw for livestock feed and bedding, were subtracted from each feedstock's unconstrained technical resource potential to calculate the maximum available resource. Next, percentage reductions were made by AEA according to the set of market, infrastructure, policy and technical barriers that are yet to be overcome in each particular year and at a particular market price. Three price scenarios were given, at £4/GJ, £6/GJ and £10/GJ, with the exception of the 1G biofuel feedstocks, which used prices ranging from £8/GJ to £24/GJ.

These barriers fall into three brackets; Easy, Medium and Hard to overcome. In general, as time progresses or if users are willing to pay more for the feedstock, then the percentage barriers decrease, and more of a resource becomes available. For example, farmers would be much more willing to grow energy crops at £10/GJ than at £4/GJ. For each feedstock, the net result after applying competing uses and barriers is the constrained resource potential, which can be used in the UK heat, power, industry and transport sectors.

2.4.2   Extension to 2050

The unconstrained potential of many UK feedstocks and their competing uses are constant to 2030 in AEA's model. In these cases, after considering the assumptions, we have kept them constant to 2050. For those resources changing over time to 2030, Table 1 shows the assumptions that have been used to derive 2050 unconstrained potentials and competing uses. We estimated the percentage barrier reductions for each feedstock in 2050 considering which of the barriers that remain in 2030 in AEA's work are price or time dependent, and therefore might change to 2050, or if prices are increased. Notes on these remaining barriers have been included in Table 1. For the definitions of the choice between "ECmin" or "ECmax" scenarios, see Section 2.4.3.

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[14] AEA (2011) "UK and Global Bioenergy resource", yet-to-report project for UK Department of Energy and Climate Change. Unconstrained technical resource potential = maximum available resource + price independent competing uses

Table 1: Extension of UK feedstock resources, competing uses and barriers to 2050

	Unconstrained resource	Competing uses	Barriers
Small roundwood	Kept constant	Kept constant	Infrastructure improves, but some technical barriers remain (terrain, ground damage)
Short-rotation forestry	Limited by planting rate, but planted area continues to increase at same rate to 2050. 15yr cycle means that in 2050 there is harvesting of areas first planted in 2035 and 2020	No competing uses, kept at zero	At high prices, all barriers fall to 0% with max planting rate reached and replanting. At medium prices, planting rate kept at 1,000 ha/yr until 20% annual ramp-up after 2018. At low prices, 100% barriers kept as prices still insufficient to stimulate planting
Forestry residues	Kept constant	No competing uses, kept at zero	Some technical barriers remain (terrain, ground damage), infrastructure improves
Sawmill co-products	Kept constant	Kept constant	Market barriers overcome by higher prices and bringing private woodlands under management
Arboricultural arisings	Continues to increase at same rate - likely to be based on population growth	No competing uses, kept at zero	Some technical barriers remain, such as achieving the right moisture content and chip quality
Straw & chicken litter	Kept constant	Kept constant	Kept constant
Wet manures to AD	Kept constant	Continued trends, as likely need more to go via AD before land spreading in the future	Hard market barriers remain: project finance, insufficient returns, upfront investment, and relative location of resource and demand
Sewage sludge to AD	Continues to increase at same rate, based on population growth and increasing treatment standards	Kept constant	Some small barriers remain, such as the dispersed nature of the resource, as they are hard to overcome
Food waste to AD	Kept constant	Kept constant	Main barrier is animal feed demand, which increases over time
Waste wood	Kept constant	Continued trends in other sectors	No barriers remain after 2020, kept at zero
MSW and C&I wastes	Annual MSW growth rate of 0.3% maintained to 2050, based on rising consumption. CIW wastes kept flat. Landfill gas value from AEA internal modelling, based on 10year decay half-life and usable gas generated over 20 years	Proportion recycled rises to 2025, held at a constant % thereafter. Assumed 50:50 split of the remainder sent to EfW and landfill from 2025 is maintained	Likely that waste policy will continue to support disposal options higher up the waste disposal hierarchy in preference to EfW, especially for MSW
Landfill gas			Waste policy and competition from AD and composting markets increasingly diverts wastes away from landfill
Energy crops	Limited by planting rate, until max area reached. In ECmax, all the abandoned agricultural land is planted on, plus up to 10% of temporary grassland. In ECmin, only land unsuitable for 1G crops is used. Yield increases extrapolated	No competing uses, kept at zero	ECmax hard market barriers decrease significantly after 2030 as experience builds. ECmin market barriers are lower and decrease to zero as fewer, more experienced farmers grow energy crops
UCO	Kept constant	Kept constant	Household collection barrier slowly falls
Tallow	Kept constant	Kept constant	Kept constant
Macroalgae to AD	Increases as larger areas cultivated	New UK feedstock, so assumed no non-energy competing uses	Barriers considered via use of less ambitious trajectories in DECC's 2050 Pathways Analysis

2.4.3   Details on land use and crop yields

Energy crops dominate UK supply after 2030, and so in this section we give more details on the land, yield and planting rate assumptions used. The main factors are shown in Table 2. Those up to 2030 are taken from AEA's project for DECC, whereas those in 2050 have been derived by E4tech.

Table 2: Key UK energy crop assumptions

	2010	2015	2020	2025	2030	2050
Ex-set aside suitable for 1G and energy crops (kha)	184	292	404	517	629	884
Ex-set aside only suitable for energy crops (kha)	296	296	296	296	296	296
Bare fallow, suitable for 1G and energy crops (kha)	175	175	175	175	175	175
Total abandoned agricultural area (kha)	655	763	875	988	1,100	1,355
Suitable temporary grassland (kha)	0	3	7	10	13	13
Max energy crop planted area (kha)	9	45	134	355	902	1,368
Miscanthus yield (odt/ha/yr)	10.0	11.5	13.0	14.0	15.0	19.0
SRC yield (odt/ha/yr)	9.0	10.0	11.0	11.5	12.0	14.0
Wheat yield (t/ha/yr)	7.6	7.95	8.3	8.65	9.0	10.4
OSR yield (t/ha/yr)	3.5	3.55	3.6	3.65	3.7	3.9

Of the 655 kha of abandoned agricultural land available in 2010[15], 296 kha is always assumed by AEA to be only available for energy crops. This segregation was made under their assumption[16] that "set aside was set to zero in 2008, but, despite high wheat prices, 296 kha remained un-cropped [...] an indication that this land is unsuitable for wheat or OSR or, if it were planted, yields would be low [...] therefore assumed that this land is not available for 1G biofuel crops". To ensure consistency with AEA's results, we have therefore kept this assumption to 2050.

Similarly to the global situation, there is then a choice to be made regarding the rest of the abandoned agricultural land area, which can be used for either 1G or energy crops:

- In the "ECmin" scenario, all of the abandoned agricultural land suitable for 1G crops is used to grow 1G crops. Energy crops are limited to only 296 kha, and so the energy crop planting rate is capped by the available area before 2030
- In the "ECmax" scenario, energy crops have priority over 1G crops, and can be planted on as much abandoned agricultural land as the energy crop planting rates allow. Any land not yet planted with energy crops is assumed to be planted with 1G crops, but this shrinks over time

The land area planted with energy crops is assumed by AEA to be 50% Short Rotation Coppice (SRC) and 50% miscanthus, both with calorific values of 19 GJ/odt. We have kept these same scenarios and assumptions to 2050. The additional land area planted with 1G crops is assumed to be split in the ratio 66% wheat and 34% OSR. This is in addition to the current 3 Mt wheat surplus exported[17], 0.65 Mt sugar beet used for 1G ethanol[18], and 23.5 kha of OSR planted for 1G biodiesel[19].

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[15] ADAS (2008) "Addressing the land use issues for no-food crops, in response to increasing fuel and energy generation opportunities", for the NNFCC, Available at: http://www.nnfcc.co.uk/metadot/index.pl?id=8253;isa=DBRow;op=show;dbview_id=2539

[16] AEA (2010) "UK and Global Bioenergy resource – Appendix 2", report to DECC

[17] HGCA (2005) "Environmental impact of cereals and oilseed rape for food and biofuels in the UK", Available at: http://www.hgca.com/document.aspx?fn=load&media_id=1909&publicationId=2309

[18] British Sugar (2009) "Bioethanol", Available at: http://www.britishsugar.co.uk/Bioethanol.aspx

[19] RFA (2010) "Year one of the RTFO 2008/9. Annual report to Parliament on the Renewable Transport Fuel Obligation"

The total abandoned agricultural area of 1,100 kha in 2030 comes from Refuel's BAU scenario[20], with the 2050 value of 1,355 kha from DECC's 2050 Pathway Analysis[21]. In addition, 133 kha of grassland could be released for biomass production, via the re-intensification of beef and sheep enterprises, without impacting on current food production[15]. As a result of sustainability concerns, we assume that only up to 10% of this grassland could be available for energy crops by 2030, but with no further intensification possible by 2050. The 7.5 Mha of permanent grassland in the UK is assumed to only be available for planting Short Rotation Forestry[15].

Based on current availability of equipment and planting material in the UK, AEA estimated that 4 kha/year of energy crops could be planted this year. The maximum rate at which this part of the industry could expand would result in the annual planting area increasing by 20% each year. Exceeding these planting rates is considered to be difficult and so planting rate constraints are considered to be independent of the delivered cost of the biomass. This planting rate reaches 150 kha/yr by 2030, and we have therefore capped the planting rate at this level, since this scale is equivalent to the planted area of the entire UK horticultural sector, and a likely upper bound on energy crop planting due to the size and number of people in the agricultural sector. In any case, the area of energy crops planted quickly becomes limited by the available land area after 2030.

The current SRC and miscanthus yields of 9odt/ha and 10odt/ha, respectively, used by AEA are a conservative interpretation of yield averages set out in Bauen[22] (2009). Current yields of wheat, sugar beet and OSR are taken from ADAS[15] (2008) and NNFCC[23] (2007). AEA predicted wheat yields to increase to 9t/ha by 2030[24], through a 0.9% per year improvement, and for OSR predicted a 2030 yield of 3.7t/ha[25], through a 0.8% per year improvement. These annual yield improvements were assumed to remain constant to 2050, as also assumed in Modes Project 2.

2.4.4   Algae

In addition to the list of feedstocks considered by AEA to 2030, we have also included microalgae and macroalgae, as these resources could be significant after 2030. However, due to the UK's climate, it is assumed that there will be no indigenous production of microalgae in UK saline open ponds, and that all microalgal biofuel used in the UK will be imported.

For UK macroalgae, resource potentials were taken from DECC's 2050 Pathways Analysis[21], with conversion of the whole resource into biogas. This conversion route was chosen in the UK, since anaerobic digestion of seaweed to biogas is more energy efficient, cheaper and more technologically advanced than ethanol fermentation. The key parameters used were a yield of 20 odt/ha/yr, energy content of 14 GJ/odt, and 80% conversion efficiency to biogas. Given the likely high production

[20] Refuel (2007) "Assessment of biomass potentials for biofuel feedstock production in Europe: Methodology and results", Available at: http://www.refuel.eu/fileadmin/refuel/user/docs/Refuel-D6-Jul2007-final6.pdf

[21] DECC (2010) "2050 Pathways Analysis", Available at: http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/2050/2050.aspx
1.355 Mha for energy crops is based on Agriculture and Land Use trajectories 3 and 4, used in most of the example pathways. Total agricultural land area in 2050 is assumed by DECC to be 2.4 Mha

[22] Bauen et al. (2009) "Modelling supply and demand of bioenergy from short rotation coppice and miscanthus in the UK"

[23] NNFCC (2007) "An Assessment of the Opportunities for Sugar Beet Production and Processing in the UK", NNFCC project 07-017

[24] HGCA (2010) "Growing wheat for alcohol/bioethanol production" Information sheet 11, Summer 2010, Available at: http://www.hgca.com/document.aspx?fn=load&media_id=6099&publicationId=7780

[25] Fischer et al. (2009) "Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures, Part II Land use scenarios", Biomass and Bioenergy

costs[26], we assumed that the maximum sea area of 0.59 Mha in 2050 would only be realised if all barriers were overcome, and at a market price of £10/GJ. To fit in with the framework of the other UK feedstocks, we derived likely resource potentials at lower prices, and including barriers, by using the less ambitious DECC trajectories.

3 Subtracting UK heat, power and industry demands

The total amount of bioenergy available to the UK was calculated to 2050, by summing indigenous UK supply, the share of imports into the EU, and a proportion of the global surplus. In the case of 1G crops, the total available to the UK is instead calculated by summing the share of total EU production, the share of imports into the EU, and a proportion of the global surplus.

The next step was to calculate the amount of bioenergy available to the UK transport sector. We therefore needed to subtract the bioenergy feedstock demands in the UK power, heat and industry sectors from the total amount of bioenergy available to the UK.

The main data source used was the DECC 2050 Pathways Analysis[21]. This models different levels of ambition across a range of technologies, including nuclear, CCS, wind and bioenergy. The role for bioenergy in the UK's power, heat and industry sectors therefore varies according to the development of other power and heat generation technologies, and the changes in total energy demand in these sectors.

DECC's 2050 Pathways Analysis[21] produced six illustrative pathways that meet the UK's target of achieving an 80% reduction in GHG emissions by 2050. We calculated the minimum, average and maximum of the non-transport bioenergy demands in these six pathways, as potentially feasible, and GHG compliant, demand scenarios. These total demands are shown in Figure 5.

These demands were subtracted from the combined supply available to the UK, using three groups of feedstocks: solid, liquid and gaseous. The feedstocks in the available supply were grouped into solid, liquid and gaseous feedstocks, with the demands in the DECC 2050 Pathways analysis also grouped into solid, liquid and gaseous feedstocks. The supply in each group was then reduced by the demand for that group of feedstocks.

We have sense-checked this demand data against other sources:

- The central modelling scenario for 2020 in the UK Renewable Energy Strategy (RES) assumes that approximately 462 PJ/yr of biomass feedstock is consumed in the heat, power and industry sectors[27]. This RES data point lies within the 258 – 609 PJ/yr range given in the DECC 2050 Pathways Analysis.

- Also, IEA Energy Technology Perspectives (2010) BLUE MAP scenario has approximately 300 PJ/yr of biomass consumed in UK electricity generation in 2050[28], which lies within the broad 120 – 1,105 PJ/yr range for the power sector given in the DECC 2050 Pathways Analysis.

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[26] Ecofys (2008) "Worldwide Potential of Aquatic Biomass", report for VROM, available at:
http://www.ecofys.com/com/publications/brochures_newsletters/worldwide_potential_of_aquatic_biomass.htm
[27] Bio-electricity demand = 25.8 TWh, which at 34% efficiency equates to 274 PJ of biomass feedstock consumed. Bio-heat demand = 45.3 TWh, which at 87% efficiency equates to 187 PJ feedstock. DECC (2008) "The UK Renewable Energy Strategy", Chart 2.3, Available at:
http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/res/res.aspx
[28] Bio-electricity generation in the UK in 2050 under the IEA BLUE MAP scenario = 30 TWh, which equates to 300 PJ/yr biomass feedstock. IEA (2010) "Energy Technology Perspectives", Figure 8.8
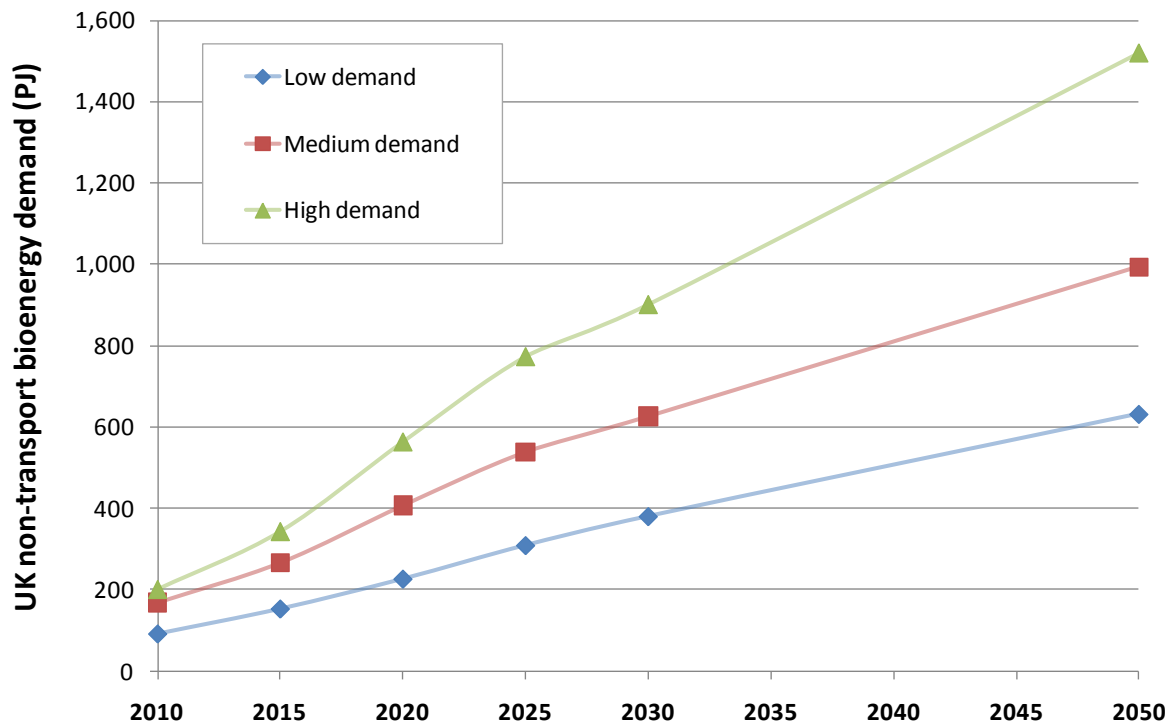
Figure 5: Demand for bioenergy in heat, power and industry in DECC's 2050 pathways

4 Developing three indicative scenarios

Three scenarios (Low, Medium and High availability) have been developed for Modes Project 2 to use in its sensitivity analysis, showing a wide range of biomass resource availability for UK transport. Each scenario corresponds to a different potential world view for the future, created by varying key supply and demand assumptions:

- A low availability scenario would correspond to a world with minimal promotion of bioenergy supply or use. There would be little investment in new feedstocks, conversion technologies, market mechanisms or infrastructure. The failure of algae and the slow uptake of energy crops would lead to a small global surplus, even with low global demands for bioenergy. UK supply barriers are not overcome, and so UK indigenous supply is also constrained. This fits within a consistent global picture of low bioenergy investment. As a result of the low UK heat & power demands for biomass feedstocks, there is little interest or competition for the supply available to the UK, and so prices paid for biomass are also likely to be low. The net result will be a low price, low availability scenario

- A medium availability scenario arises from of a world where global biomass demand is relatively high, since large amounts of bioenergy are used to meet climate change targets. On the supply side, some barriers are overcome through investment in new feedstocks, conversion technologies, market mechanisms and infrastructure. This brings forwards more supply, which combined with more optimistic energy crop and algae assumptions manages to meet the higher

demand. There is therefore the potential for a reasonable global surplus, so prices are likely to stay central. In the UK, some easy supply-side barriers are also overcome, which in combination with a medium price scenario results in a medium availability scenario

- A high availability scenario can be envisaged to be a high technology scenario, where there is considerable investment and activity in bioenergy supply and use. Most barriers are overcome, energy crops dominate due to yield increases and continued planting rate ramp-ups, and algae resources are expanded rapidly. Although the global surplus is large due to the large supply, the combination of high global demands and expensive feedstocks (from moving up the supply cost curve) is likely to mean high market prices. These imports are far greater than UK supply or high UK heat & power demands, and so prices paid for biomass are dictated by the imports, and are also high. This will bring forward extra UK indigenous supply, as will overcoming most of the UK's technical, policy and infrastructure supply barriers. The net result will be a high price, high availability scenario

These three scenarios, and the choices and parameters that influence the resulting UK transport sector biomass resource availability, are shown in Table 3 below. Each row shows a factor that was changed in our model in order to fit each scenario's world description.

Of key importance is the assumption regarding the proportion of the global resource that the UK is able to capture. The assumptions used here are:

- In the High and Medium availability scenarios, the UK can import 13% of the global surplus to 2030. This is based on the assumption that the EU likely to have the highest demands for surplus biomass feedstocks, as a result of renewable energy targets. The UK is assumed to be able to access 13% of this, as this is the current UK proportion of EU energy demand
- In the Low availability scenarios, this percentage is reduced. This is based on the assumption that all OECD countries could have policies to promote use of the bioenergy surplus to 2030, and not just the EU. UK energy demand as a proportion of OECD energy demand is 4.3% in 2010, falling to 3.6% by 2030
- In 2050, the IEA projects that all countries will have large demands for biomass, and so will all compete equally for biomass. As a result, we assume that the UK can only import a share of total global supply (rather than the surplus) in 2050, based on a projected UK share of 1.5% of the global IEA Blue Map final energy demand in 2050. Note that this share of global supply is equivalent to 3.2% of the global surplus in the Low scenario, 3.7% in the Medium scenario, and 2.5% in the High scenario.

Table 3: Choice of scenario input parameters

		Low availability	Medium availability	High availability
Global factors	**Global supply**	AEA Low investment scenario - barriers remain high	AEA BAU scenario - some barriers overcome	AEA High Investment scenario - most barriers overcome
	Global food demand, yields & available land area	UN SRES A2 - High population, low yield increases, land limited	UN SRES A1 - Central population, large yield increases	UN SRES A1 - Central population, large yield increases
	Global land choice	Energy crops minimised, 1G crops maximised	Energy crops maximised, 1G crops minimised	Energy crops maximised, 1G crops minimised
	Sustainability concerns	0% grassland available for energy crops	0% grassland available for energy crops	10% grassland available for energy crops
	Energy crop planting rates	Slow ramp-up and low maximum	Central ramp-up and maximum	Rapid ramp-up, and high maximum
	Algae success	Not successful	Successful, conservative introduction	Very successful, fast ramp-up
	Global heat, power & biofuels demands	IEA Reference	IEA BLUE MAP	IEA BLUE MAP
Import factors	**UK ability to attract global resources**	To 2030: 13% of EU supply + 13% of imports into EU + 4% global surplus 2050: 1.5% of global supply	To 2030: 13% of EU supply + 13% of imports into EU + 13% global surplus 2050: 1.5% of global supply	To 2030: 13% of EU supply + 13% of imports into EU + 13% global surplus 2050: 1.5% of global supply
	Imported biomass sustainability criteria	Applied, some 1G biofuels unavailable	Applied, some 1G biofuels unavailable	Applied, some 1G biofuels unavailable
UK factors	**UK barriers**	No barriers overcome	Easy barriers overcome	Easy and Medium barriers overcome
	UK supply	AEA resource available at Low prices (~£4/GJ)	AEA resource available at Medium prices (~£6/GJ)	AEA resource available at High prices (~£10/GJ)
	UK land choice	Energy crops minimised, 1G maximised	Energy crops maximised, 1G minimised	Energy crops maximised, 1G minimised
	Sustainability concerns	0% grassland available for energy crops	0% grassland available for energy crops	10% grassland available for energy crops
	UK heat, power & industry demand	Minimum of DECC 2050 Pathways Analysis	Average of DECC 2050 Pathways Analysis	Maximum of DECC 2050 Pathways Analysis

5 Output of results to Modes Project 2

The combinations of assumptions in the three scenarios lead to large, but plausible, variations in the potential amount of bioenergy available to UK transport to 2050. The feedstock quantities available for UK transport (in PJ and in million tonnes) have been passed to AEA in Modes Project 2. These scenarios show how much feedstock or 1G biofuel is available for Modes 2. The Modes 2 model then decides how much of each is used.

The aggregated final results are shown below in Figure 6, Figure 7 and Figure 8. Please note that the lines shown for the intermediate years (e.g. 2031 to 2049) are only indicative straight lines between modelling data years (e.g. 2030 and 2050), drawn for graphical clarity. In reality, the potential bioenergy availability in the intermediate years could be different from the straight line paths shown.

The key messages to be drawn from the Modes Project 1 work are:

- RED sustainability thresholds limit the availability of 1G biofuels in 2020, particularly 1G biodiesel. Both the Medium and High scenarios only have just enough RED-compliant 1G biodiesel in order for the UK to meet the RED 10% renewable energy transport sub-target in 2020, assuming approximately half of this target is met through the use of 1G biodiesel.
- Total resource availability increases substantially from 2020 to 2030, as the planted area of energy crops expands, and land access barriers for 1G and energy crops fall. The supply of 1G biofuels increases, as the percentage of supply meeting the GHG thresholds set by the RED increases after 2020, as crops and conversion processes improve
- After 2030, the resource availability to the UK falls, since it is assumed that global competition for bioenergy feedstocks increases, with non-OECD countries just as likely to use any global surplus as the EU or OECD
- Imports, especially energy crops and 1G ethanol, always dominate the potential resource available to UK transport, and this dependency increases over time. UK heat, power and industry bioenergy demands are larger than UK indigenous supply in the long-term, even without considering any demand from UK transport. The use of imports will be essential to all UK sectors meeting their bioenergy demands
- The Low scenario has significantly lower total resource than the Medium and High scenarios, due to a combination of key scenario choices:
    - Supply barriers remain high, since there is little investment in infrastructure or market mechanisms
    - The amount of land available is limited, due to higher population and food demand assumptions. This is compounded by lower energy crop yield increases
    - To 2030, a lower proportion of the global surplus is assumed to come to the UK, since it is assumed that there is competition from all OECD countries, and not just the EU
- The High and Medium scenarios appear similar in terms of total bioenergy resource, but in fact their feedstock composition is quite different. The High scenario has a higher proportion of energy crops, whereas the Medium scenario has more 1G biofuels crops. These scenarios therefore illustrate the land area competition between choosing to grow 1G crops or energy crops. It is also important to note that the increased energy crop resource may not be matched by build rates of plants to convert this resource to fuels

- The total supply potential to UK transport in 2050 in the Central scenario, if used, would be equivalent to around 2 EJ/yr of biofuel, which is approximately 80 % of the UK transport demand as projected by DECC 2050 Pathways Analysis. However, it is worth noting that the global surplus is always larger than the UK's total transport demand. Therefore, if the UK were willing to pay more for imports than others, then it could meet 100% of its transport demand
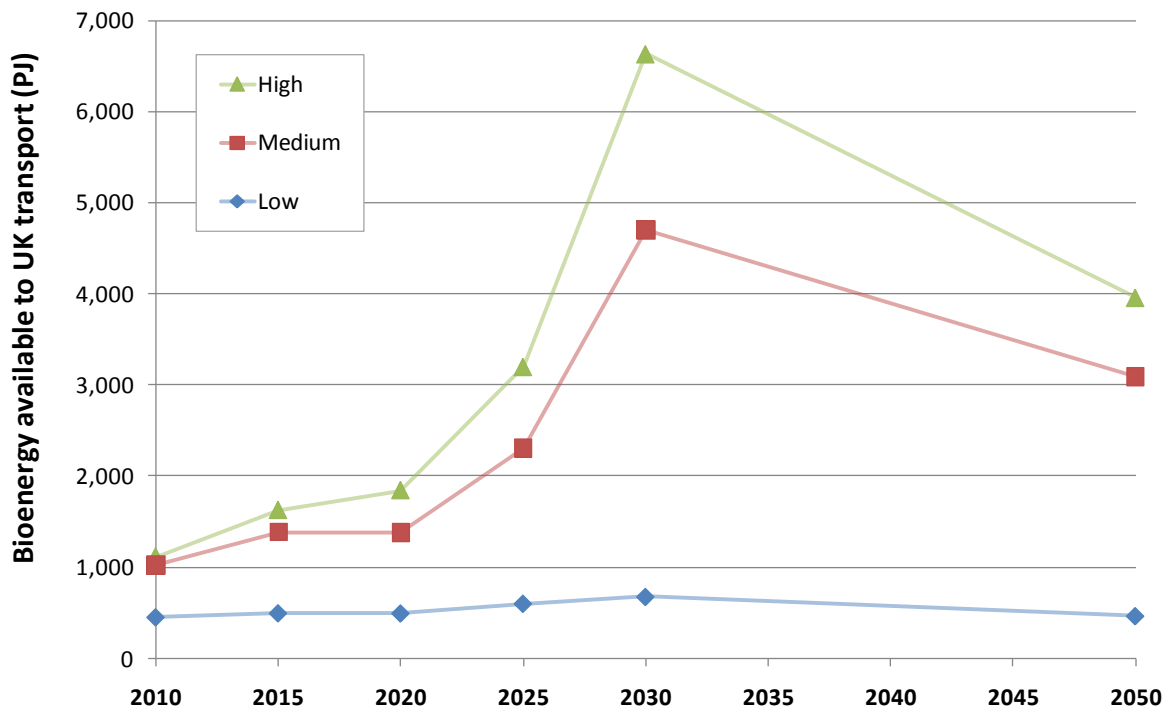

Figure 6: Total biomass and 1G biofuels availability in 3 scenarios, as output from Project 1. Lines shown for the intermediate years (e.g. 2031 to 2049) are only indicative straight lines between modelling data years (e.g. 2030 and 2050), drawn for graphical clarity.
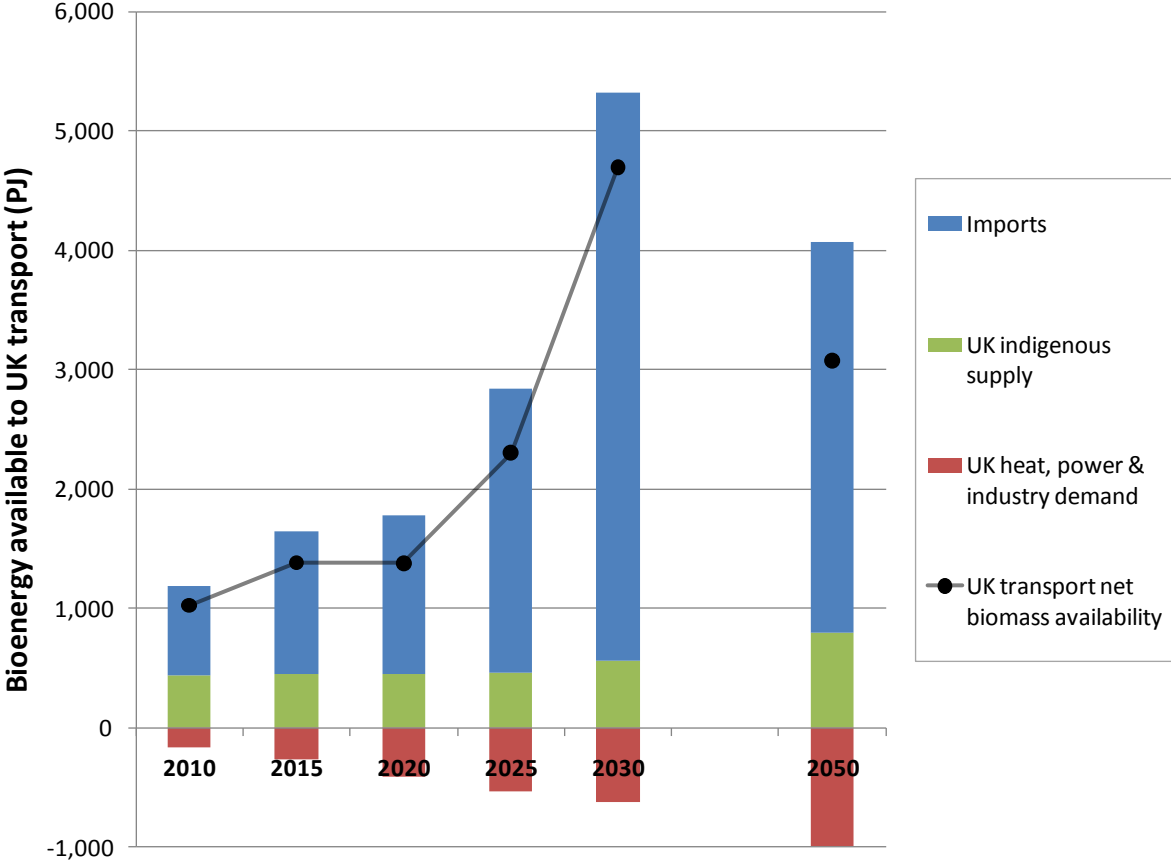
Figure 7: Split of imports, UK supply and demand in the Medium scenario. Dots show the net availability to UK transport, i.e. UK indigenous supply + imports – UK heat, power & industry demands
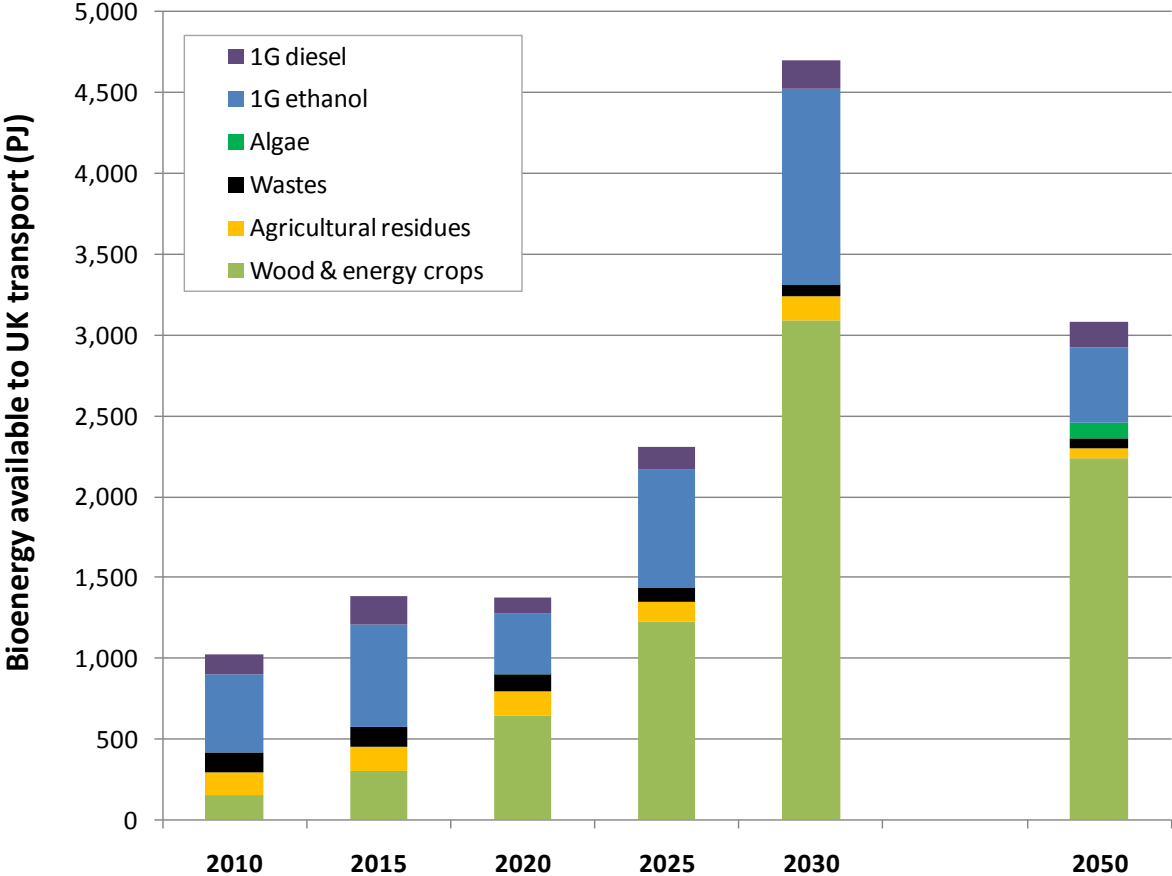
Figure 8: Split of feedstock groups in the Medium scenario