Institute for European Environmental Policy

SHIFTING AWAY FROM CONVENTIONAL BIOFUELS

Sustainable alternatives for the use of biomass in the UK transport sector

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ABBREVIATIONS

AD	Anaerobic digestion
BEC	Biomass Energy Centre
CAP	Common Agricultural Policy
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbine
CHP	Combined heat and power
CO_2	Carbon dioxide
DECC	Department for Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
FQD	Fuel Quality Directive
GHG	Greenhouse gas
ILUC	Indirect land use change
LCVP	Low Carbon Vehicle Partnership
LCW	Landscape care wood
MSW	Municipal solid waste
MTBE	Methyl tertiary butyl ether
NREAP	National Renewable Energy Action Plan
REA	Renewable Energy Association
RED	Renewable Energy Directive
RTFO	Renewable Transport Fuel Obligation
UCO	Used cooking oil
WFD	(EU) Waste Framework Directive

UNITS

GJ	Gigajoule equal to 10^9 joules
kg	Kilogram
kWe	Kilowatt-electric
m^3	Cubic metre
MJ	Megajoule equal to 10^6 joules
Modt	Million oven dry tonnes
Mt	Mega(=million) tonnes
MW	Megawatt
PJ	Petajoule equal to 10^15 joules

EXECUTIVE SUMMARY

Scope and context of the report

An important debate is underway about the future of biofuels in Europe and the UK specifically, ***triggered by the realisation that current biofuel consumption has greater environmental and social impacts than first anticipated***. The impacts on land use of increased cultivation of crops for biofuel use and the consequences for the greenhouse gas (GHG) profile of biofuels are major environmental concerns. Increasing global demand for key staples and other crops for biofuel production results in additional pressure on global agricultural markets; these trickle down to consumer prices to varying degrees with particular impacts in developing countries (Kretschmer *et al*, 2012). This together with land acquisitions from mainly subsistence farmers for large scale biofuel crop production (ActionAid, 2013) is the principal cause of concern about the social impacts of conventional biofuels.

Advanced biofuels produced from wastes and residues are seen as a way to improve the environmental and social performance and credentials of the sector as well as providing greater GHG savings over conventional fuels. Questions remain, however, about the sustainability of some feedstocks and the volumes of biomass that would be available as a feedstock for the biofuel sector. Given the need for the decarbonisation of transport fuels in the UK the report considers:

- the potential domestic wastes and residues that can help reduce the environmental, social and economic consequences of UK biofuel consumption, including overseas ILUC impacts;
- the sustainable volumes of these wastes and residues that could be available for advanced biofuel production; and
- the UK job creation potential as a result of building a sustainable advanced transport fuel industry.

To date, the UK advanced biofuel production capacity is still in its infancy. The current sources of biofuels in the UK are still derived primarily from land based crops, but there are exceptions, such as Used Cooking Oil (UCO). However, broadening the biofuel feedstock base to increase the use of wastes and residues is not without risks, necessitating environmental safeguards and adherence to the principles of waste policy which seeks to reduce waste or promote environmentally favourable waste treatment options in line with the waste hierarchy.

Potentially sustainable UK wastes and residues, their volumes and processing routes

The report considers straw, UCO, manure, sewage sludge, food and green waste, the (non-segregated) biological fraction of municipal solid waste (MSW) and certain woody residues as potentially sustainable and domestically available sources. However, these feedstocks have a variety of different uses currently, some of which provide carbon savings and deliver environmental benefits over energy recovery. ***As a consequence, safeguards need to be put in place to prevent any perverse environmental, social or economic consequences arising from energy use.***

Overall, there is potential to increase the mobilisation of the wastes and residues reviewed here. The ease with which this can be achieved will vary but there are some common barriers such as poor collection infrastructure. Good potential exists for straw, food waste, green waste and non-segregated MSW, and woody biomass residues. However, none of this should contravene ongoing efforts to prevent waste arising in the first place. There is more limited scope to increase the amount of UCO available for energy uses as a result of collection barriers. Our survey of five categories of feedstocks suggests that biofuels from the selected wastes and residues could contribute between 31 and 129 per cent of total UK biofuel demand in 2020; or between 3.1 and 13.0 per cent to total UK transport energy demand in 2020. However, these figures are driven by the feedstock availability estimates; additional constraints that could not be studied in detail here would reduce them. Particularly a realistic gauge of the investments in biorefinery capacity likely to occur over the short time span remaining until the end of 2020 would be needed. Previous work taking into account such projections suggested that advanced biofuels could contribute between 1.3 to 2.6 per cent to total UK road and rail transport energy demand in 2020 (Nattrass *et al*, 2011).

The (environmental) performance of advanced biofuels partly depends on the processing technologies used as well as the feedstocks. Three conversion routes stand out for the wastes and residues considered here: anaerobic digestion (AD) to produce biogas for heat and electricity generation or for upgrading to biomethane; and biochemical and thermochemical advanced conversion technologies that are still relatively costly, both with regard to capital investment required and ongoing operating costs. Both approaches are characterised by varying feedstock tolerance as well as water and energy use footprints.

The potential for a UK industry based on wastes and residues

Estimates of future industry and job creation potentials are subject to considerable uncertainty. The most widely available infrastructure in the UK at present is that of AD with around 214 facilities in 2011 and a capacity to process around five million tonnes of feedstock per year. The commercial viability of biofuel plants varies enormously from small scale AD using between three and five thousand tonnes of raw material per year, up to large-scale biorefineries that require around one million tonnes of raw material per year. It is estimated that considerable scope to increase AD generation exists based on available waste and residue streams. Based on the available UK straw resources and acknowledging uncertainty due to ongoing technological development, we estimate that there is the potential for between one to seven commercial-scale straw-based plants in the UK.

There is significant potential for job creation following the development of an advanced biofuel industry, both within and outwith the direct biofuels sector particularly in rural areas. Attributing an actual number to this potential is challenging given the infancy of the sector. Despite these challenges, ***there are some quantified estimates of job creation potential for the UK, which summed together range from in the order of one thousand to more than ten thousand***.

Conclusions and policy recommendations

Utilising biomass resources to decarbonise the UK transport sector has significant potential, and the use of sustainable biomass wastes and residues can and should be part of this solution, both in the direct production of transport fuels (liquid and gaseous) as well as in providing renewable electricity generation potential to decarbonise the UK grid and (indirectly) fuel a future electric vehicle fleet. There is also considerable potential in fostering the use of wastes and residues to create jobs within the UK. We therefore see a case for the UK Government to enhance efforts to ensure the sustainable mobilisation of wastes and residues and suggest a mix of responses including:

- Supporting appropriate changes in EU policy to encourage ***a shift from conventional biofuels towards appropriate advanced biofuels*** from wastes and residues;

- ***Formulating clear safeguards*** to accompany the use of wastes and residues in the transport sector;

- ***Commissioning research to enhance understanding of priority uses for wastes and residues,*** taking into account the market situation in the UK with regard to domestically available supply and existing (energy and non-energy) uses; and of ***the sustainable level of straw and woody residue extraction rates***;

- ***Cross sectoral advice*** to promote the sustainable sourcing and processing of wastes and residues. This will contribute to ***overcome existing barriers to collection and mobilisation of key resources***;

- ***Providing investment support*** to promote new technologies in the area of advanced biofuels processing. This is likely to include capital support for new installations as well as support for the development of existing infrastructure.

Initiatives in these directions will be necessary not just to support the convergence of an advanced biofuels industry for transport but also to create an appropriate path for the wider biofuels and biomass utilisation industry. There is an opportunity to capture multiple benefits by generating more renewable energy, enhancing technological know-how, and creating economic benefits by putting currently under-utilised wastes and residue resources to productive uses. Provided that safeguards are implemented, environmental and social benefits will accrue from decarbonising the UK's transport sector and achieving a reduced reliance on conventional fuels.

1 INTRODUCTION

An important debate is underway about the future of biofuels. This has been sparked by the realisation that current biofuel consumption has greater environmental and social impacts than first appreciated. The impacts on land use of increased cultivation of crops for biofuel use and the consequences for the greenhouse gas (GHG) profile of biofuels are major environmental concerns. Increasing global demand for key staples and other crops for biofuel production results in additional pressure on global agricultural markets; these trickle down to consumer prices to varying degrees with particular impacts in developing countries (Kretschmer *et al*, 2012). This together with land acquisitions from mainly subsistence farmers for large scale biofuel crop production (ActionAid, 2013) is the principal cause of concern about the social impacts of conventional biofuels.

If biofuels are to contribute to reductions in GHG emissions, as intended, then the full consequences of producing the feedstocks that they are made from need to be taken into account. This includes the indirect land use change (ILUC) arising from growing crops for biofuels in many parts of the world. To address ILUC and other issues, the European Commission recently proposed new legislation to amend existing EU law in this area. This proposal is now under scrutiny with the views of national governments and MEPs emerging week by week. If adopted, the proposal could result in a major increase in the use of advanced and alternative biofuels. In formal terms, the recent European Commission proposal (COM(2012) 595 final) would amend the EU Renewable Energy Directive 2009/28/EC (RED) and Fuel Quality Directive 2009/30/EC (FQD) particularly to address ILUC. Advanced biofuels produced from wastes and residues[1] as well as from other selected feedstocks (such as (ligno-)cellulosic crops) are seen as one means of reducing the use of food and feed crops for energy purposes that result in ILUC effects. The Commission has proposed to incentivise the use of these feedstocks by counting their energy content two or four times towards meeting the ten per cent target for renewable energy in transport that Member States should meet by 2020. The renewable energy in transport target is contained within the Renewable Energy Directive.

However, the sustainability of some of these feedstocks and the volumes of biomass that would be available for the biofuel sector are unclear and the use of wastes and residues is not without risk to the environment or to society. This is particularly true where feedstocks currently contribute towards other environmental or social benefits, or where other uses exist, such as in different industrial sectors where wastes and residues would be replaced by unsustainable alternatives. The impact assessment accompanying the Commission's proposal does not provide the background analysis necessary to better understand the contribution an advanced biofuels industry could make towards meeting EU transport fuel needs in a sustainable way or the targets set out in the RED and FQD.

The report focuses on domestic sources of wastes and residues as a means of reducing the UK's overseas land footprint[2] and related environmental and social impacts. The report aims

[1] Residues: a material that is not deliberately produced in a production process but may or may not be a waste. For example forestry residues (eg branches, bark and needles) and agricultural residues (eg straw). Many residues already have established uses.

[2] The UK uses currently over one and a half times its land area to provide the nation with products such as food, clothing and bioenergy (FoE, 2013)

to clarify the relative desirability of certain wastes and residues as well as the environmental impact if used for energy generation. Further, it seeks to evaluate the potential of shifting from conventional biofuels to more sustainable energy alternatives for the transport sector. These would include domestic and sustainable quantities of wastes and residues, whether in the form of advanced (liquid) biofuels or biogas derived from organic wastes to generate electricity or for biomethane upgrading. The report considers:

- the potential domestic wastes and residue streams that are environmentally and socially sustainable, ie those which would not result in harmful knock-on effects if diverted towards biofuel production;
- the sustainable volumes of these wastes and residues (and resulting biofuels), including a discussion of whether they should be used for advanced biofuels or for other energy and non-energy uses; and
- the job creation potential as a result of building a sustainable advanced transport fuel industry in the UK.

This report is offered as a contribution to the ongoing debate around the future sustainability of the UK transport sector but will have relevance to discussions taking place in other EU countries[3]. Given the many and often complex issues involved we aim to identify some of the most important ones. However, many issues will require further investigation before definitive conclusions can be drawn.

[3] Of course the supply of domestic bioenergy feedstock at sustainable levels and the resulting advanced transport biofuels industry will likely differ between Member States and regions.

2 UK POLICY CONTEXT AND CURRENT BIOFUEL USE

This section sets out some of the most relevant elements of the current policy context surrounding the uptake of advanced biofuels from wastes and residues and relevant statistics on current sources of biofuels in the UK. This includes a summary of the key elements of UK renewable energy policy as the driver behind biofuel deployment; as well as an identification of important waste policy strategies relevant to the feedstocks set out in the Commission's proposal. The different sectoral policies, particularly those in relation to agriculture and forestry residues, play a relevant but slightly less direct role and are covered in sections 4 and 5 where the sustainability and sourcing of residues is addressed.

2.1 The UK policy context

Both the UK and the EU as a whole are working towards long-term objectives in relation to climate change. These are guiding the development of relevant policies in a number of sectors including transport. The European Commission's 2011 low carbon roadmap (COM (2011) 122) sets out a high level strategy for delivering a reduction in the EU's GHG emissions of between 80 and 95 per cent by 2050 compared to 1990 levels[4]. In the UK, the UK's Climate Change Act[5] requires that, by the same year, the UK's GHG emissions should be at least 80 per cent lower than they were in 1990.

Central to reaching these ambitious targets are emission savings from all energy using sectors including the transport sector. GHG emissions from the UK transport sector are increasing both in absolute terms and as a proportion of the overall national emissions. Between 1990 and 2010, GHG emissions from transport increased by 11 per cent, while total GHG emissions in the UK fell by 21 per cent[6] (Skinner, 2013). Despite such increases, the UK does not have a target for GHG emission reductions specifically for the transport sector. However, the Committee on Climate Change (CCC)[7] estimates that GHG emission reductions of more than 90 per cent will be needed from surface transport[8] by 2050 in order to meet the emission reductions target as a whole (CCC, 2010).

It is clear that the road transport sector will have an important role in meeting the UK's long-term GHG reduction targets. Broadly, there are three ways to reduce road transport's GHG emissions (apart from modal shift):

- Decarbonising transport fuels;
- Improving the energy efficiency of vehicles; and
- Influencing the way vehicles are used.

These options are not unique to the UK and are found in the transport sector GHG mitigation strategies in various EU countries (ITF/OECD, 2008). For Europe as a whole, the contribution from each of these options might be roughly of a similar magnitude if GHG

[4] Both of the UK and EU targets reflect the conclusions of IPCC's fourth assessment report that developed countries will need to reduce their GHG emissions by between 80 and 95 per cent by 2050 (IPCC, 2007).

[5] See Climate Change Act 2008 at http://www.legislation.gov.uk/ukpga/2008/27/section/1

[6] Transport's GHG emissions have increased from 18 per cent of the UK's total in 1990 to 26 per cent in 2010 (DfT, 2012).

[7] Established by the 2008 Climate Change Act and advising the Government on climate change policy.

[8] 'Surface transport' is the term used by the CCC to designate transport that is not international aviation or international shipping.

emission reduction targets are to be reached by 2050 (Skinner *et al*, 2010). So, though policy focus on transport fuels is important, there needs to be progress on other fronts as well (see Box 1).

Box 1: Energy efficiency and influencing the way vehicles are used

Energy efficiency
The significance of energy efficiency measures in reducing the UK's energy consumption and greenhouse gas emissions is highlighted by the government Carbon Plan 2050 scenarios (DECC, 2012). These scenarios estimate the required per capita energy consumption reductions from efficiency measures at between 31 and 54 per cent by 2050 (compared with a 2007 baseline) in order to meet the 2050 GHG reduction target. The range of percentages varies across scenarios and depends on the extent to which measures other than energy efficiency, such as increased renewable energy use, are used to mitigate emissions. The need for efficiency improvements becomes more compelling when considering the realistic contribution that energy from renewable sources can make towards meeting increasing demand for energy.

Influencing vehicle use
Many policies influence the way in which vehicles are used. These include measures that influence how vehicles are driven, such as fuel-efficient driving and speed limits, measures that encourage cars to be used less often and measures to encourage shorter journeys, such as land use and planning policies. All of these have the potential to contribute to reducing transport's CO_2 emissions to varying degrees. For example fuel-efficient or 'eco-driving' in could achieve CO_2 emission reductions of around 10 per cent for cars (UK ERC, 2009) and around five per cent for road freight (AEA and Ricardo, 2011). The rigorous enforcement of existing speed limits on major roads could deliver annual CO_2 emissions reductions of around two to three per cent of total transport emissions (UK ERC, 2009).

Source: Skinner (2013)

2.1.1 Decarbonising transport fuels

One of the main sources of renewable energy to meet both the UK's GHG reduction targets and the overall renewable energy target (15 per cent in 2020 as set out in the RED) is biomass, in the transport as well as the heat and power sectors. This is not without controversy, as serious questions remain about the GHG emission savings that can be obtained by using bioenergy (see also Box 2). Bioenergy production is also subject to constraints such as limitations in global land and water availability (CCC, 2011). The CCC advocates the use of bioenergy to partially decarbonise specific areas of the energy and transport industries where alternatives such as electrification are not practicable or economically viable. However, it points out that bioenergy will become an increasingly scarce resource in relation to rising worldwide energy demand and projects 'a very limited role' for liquid biofuels in road transport due to its rising price, demand exceeding supply and competition for use between sectors (CCC, 2011).

However, this perspective is not entirely reflected in shorter-term transport policy. Currently, the Government clearly mandates the use of biofuels in road transport through the RTFO. Other fields of intervention to reduce emissions from the transport sector include vehicle efficiency standards (where UK policy is partly determined by the EU CO_2 regulation for cars) and promoting the use of electric vehicles (for a wider description of measures and initiatives see Skinner, 2013).

The RTFO requires fossil fuel suppliers to blend a certain percentage of renewable fuels into road transport fuels supplied to the UK market. This share rises over time, as shown in Table 1. The Government has not yet proposed a blending share beyond five per cent and with the limited current uptake of electric vehicles it is unclear whether the UK will meet its target of 10 per cent renewable energy in transport by 2020.

Table 1: Biofuel blending targets under the RTFO and actual shares achieved

Obligation Period	Year	Target % biofuel	Actual blending share (%)
2008/09	1	2.5	2.7
2009/10	2	3.25	3.33
2010/11	3	3.5	3.27
2011/12	4	4.0	4.1
2012/13	5	4.5	3.0#
2013/14 onwards	6 onwards	5.0*	N/A

Source: based on various reports by the Renewable Fuels Agency and the Department for Transport. *The Government has proposed to revise the blending target from 2013/14 onwards to 4.7 per cent in order to account for changes in the RTFO to include fuels used in Non-Road Mobile Machinery (as defined in the Fuel Quality Directive); #share for first two quarters only.

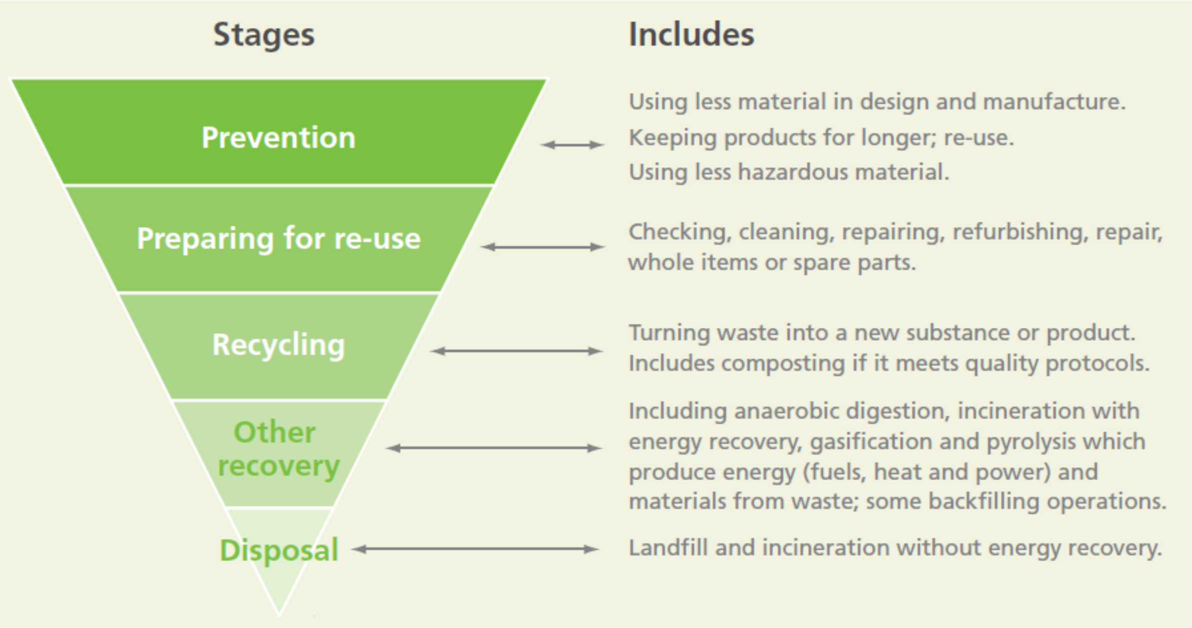
2.1.2 Waste policies relating to the use of biomass for energy

UK waste policy and associated guides and action plans play a significant role in determining the sustainable use of wastes and residues and thus their potential role as a biofuel feedstock.

Waste policy in the UK and other EU countries follows the EU Waste Framework Directive 2008/98/EC (WFD). The WFD sets out the now well-established waste hierarchy to ensure that any given material is used in the most environmentally compatible way possible. The waste hierarchy (see Figure 1) advocates prevention, re-use, recycling (and composting) over (energy) recovery with disposal (ie landfill or incineration without energy recovery) at the bottom of the hierarchy.

The use of wastes and residues for biofuels in principle should follow the rules underlying the hierarchy although there is some flexibility. According to the hierarchy, only non-recyclable/compostable waste should be available for energy recovery; but energy recovery can be justified for reasons of technical feasibility, economic viability or environmental protection. Higher GHG savings from energy recovery through anaerobic digestion (AD) compared to composting, for example in the case of food waste, would be a justified reason to divert from the waste hierarchy. Apart from these potential exceptions, adherence to the waste hierarchy is crucial to prevent energy policy from running counter to ongoing efforts to reduce waste and increase recycling rates. In the UK, the waste hierarchy is implemented as part of the England and Wales Waste Regulations 2011 and implemented through national waste planning policy (Defra, 2013a).

Figure 1: Illustrating the waste hierarchy



Source: Defra (2011, p11)

The Zero Waste Strategy

The UK Coalition Government announced its commitment to working towards a 'zero waste' economy in May 2010, with the stated long term aim of developing a 'green economy' where no waste is consigned to landfill or incinerated without energy recovery (in line with the EU waste hierarchy). Although no specific time frame has been set to achieve this aim, a more elaborated 'Waste Prevention Programme' is due to be published in December 2013 (Defra, 2011). This is likely to contain further targets and initiatives to add to the raft of proposals included in the series of 'waste reviews' whose first set of findings were published in June 2011 (Defra, 2011). The Zero Waste Strategy involves a multi-faceted approach, currently including the following stated measures:

- Working with business and industry to drive voluntary initiatives and innovation, rather than regulatory enforcement, as well as promoting reuse and recycling of products and materials to minimise waste arisings;
- The abolition of punitive fines for inappropriate placement of household waste into specifically allocated bins. Instead, separation of municipal waste at source is to be encouraged by incentives and with better and more frequent doorstep rubbish collection and recycling services provided by local authorities, to boost recycling rates and to meet targets;
- Increased recycling targets to 2017 for plastic, steel aluminium and glass;
- Further reductions in the amount of waste going to landfill. However, following a consultation held in 2012 on the banning of biodegradable waste, metals and textiles from landfill, as well as on the restriction of wood going to landfill, no new restrictions on sending wood to landfill are envisaged on the basis that it will reduce significantly without such restrictions (Defra, 2013c). Decisions on whether to impose restrictions on the landfilling of the other waste streams have yet to be made;

- Increased action against persistent 'fly-tipping' (illegal dumping of waste) with confiscation of vehicles and compulsory clean-up by offenders as proposed measures. This would involve better enforcement of the legal provisions set out in the Environmental Protection Act of 1990, which, although in force for many years, has still failed to prevent fly-tipping from being a serious environmental issue.

UK Anaerobic Digestion Strategy and Action Plan

In conjunction with the 'zero waste' strategy, the Coalition Government launched the Anaerobic Digestion Strategy and Action Plan in June 2011 (DECC and Defra, 2011) with the aim of promoting AD as a means of energy recovery from waste as well as materials and nutrient recycling (for instance via digestate products reapplied to land as fertiliser). This initiative reviewed the existing AD industry to address barriers to growth and seek ways of helping it reach its full potential as part of the national waste and energy strategies.

As part of the Action Plan, an assessment of the potential for AD derived biomethane for use as an alternative fuel in the road haulage/freight industry was carried out by the Low Carbon Vehicle Partnership (LCVP). This research included identifying specific barriers to the upgrading of biogas from AD to biomethane and subsequent use as vehicle fuel. Recommendations for the development of the market were also made (Brightman *et al*, 2011).

The Action Plan included other measures relevant to production of biomethane by AD for transport use, including:

- Identifying the biogas yields, availability and sustainability of various feedstocks and for the industry as a whole, drawing on existing research. This included assessment of the economic viability and environmental impacts of various AD models (ie community, on-farm, large-scale etc).
- Measures to help grow the industry by making finance more readily available for new plants as well as helping to ensure the renewable energy incentive schemes (feed-in tariffs and the Renewables Obligation) would encourage uptake of this technology, particularly in rural areas.
- Assessing and addressing barriers to small scale AD plants' ability to upgrade and inject biomethane to the gas grid[9] or supply electricity, from on-site combustion, to the electricity grid.

Defra Energy from Waste Guide

The Defra Energy from Waste Guide outlines the various techniques and economic and environmental issues relating to energy recovery from 'residual waste' arising in the UK (Defra, 2013a). It is not a source of new information, but its stated aim is to propagate existing information to stakeholders involved with waste and energy issues and to raise awareness of waste management policy, incorporating the waste hierarchy and relevant techniques for energy recovery. Thus it should contribute to meeting the goals of the 'zero waste' strategy. Its focus is solely on 'residual' municipal, commercial and industrial waste

[9] An industry led initiative known as the 'Green Gas' Certification Scheme (GGCS) was launched in 2011, in order to spur the development of the nascent market for such direct grid injection (http://www.greenwisebusiness.co.uk/news/new-certification-scheme-for-green-gas-2163.aspx).

streams, meaning it does not address techniques and issues relating to energy from source segregated food waste and agricultural residues.

The guide highlights some potential biofuel production pathways based on the waste streams considered and claims that the use of fuel from such waste to power a vehicle directly may be more efficient than combustion of fuel to produce steam to drive turbines for electricity production (Defra, 2013a)[10]. However, the guide does acknowledge that the 'parasitic load' (energy requirement) needed for biofuel production may also significantly affect the well to wheel (WTW) energy balance. The extent of this 'parasitic' energy requirement will depend on several factors, including the specific feedstock and production pathway chosen (see section 6.1).

2.2 Sources of biofuels in the UK

The Department for Transport (DfT) publishes detailed data on biofuel supply in the UK on a quarterly basis (based on unverified data from suppliers) as well as yearly reports covering the past fiscal year (based on verified data)[11]. As can be seen from Figure 2, the relative importance of different feedstocks in the total supply has changed significantly in the last three years (Year 3 to Year 5 of the RTFO).

For Years 3 and 4, biodiesel was the predominant form of renewable fuel supplied in the UK. However, there has been a major shift towards bioethanol, which increased in share from 43 per cent in year 4 to 55 per cent of the total biofuel mix for the first three quarters of Year 5.

In terms of biofuel feedstocks, corn (maize) has remained the predominant feedstock for bioethanol throughout the period, as shown in Figure 2. Its market dominance has increased, with the US being the most important country of origin. This may have been due to large subsidies for US corn ethanol exports to the EU, making it the cheapest large scale source of bioethanol for the UK. This US export subsidy has now been challenged by the EU on anti-dumping grounds, with the planned imposition of a 9.6 per cent import duty on US bioethanol imports (Europolitics, 2012; Reuters, 2013). This tariff, if imposed, could significantly reduce bioethanol imports from the US to the EU.

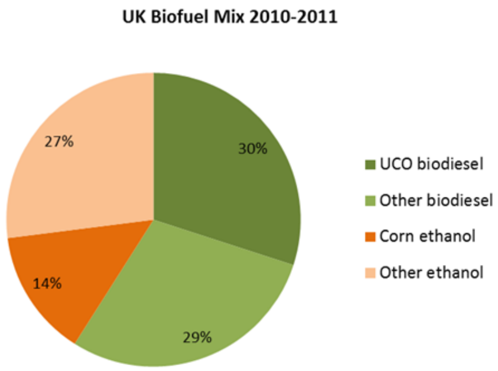
The biodiesel mix has also changed over time, largely due to the pattern of fiscal incentives. In 2010, due to a 20p per litre duty differential between used cooking oil (UCO) and diesel, UCO gained a competitive advantage over other biofuel feedstocks. UCO consequently dominated the UK biodiesel market and indeed the total biofuel market, its share climbing to 50 per cent of all biofuel consumed in the UK in 2011/12 (see Figure 2). Then, the favourable tax treatment ended in 2012, leading to a decline in UCO derived biodiesel consumption, down to nine per cent in the first three quarters of 2012. However, as the unverified figures for 2012 do not quantify the extent of UCO brought in from outside the UK, it is hard to determine to what extent the overall market share of UCO has been

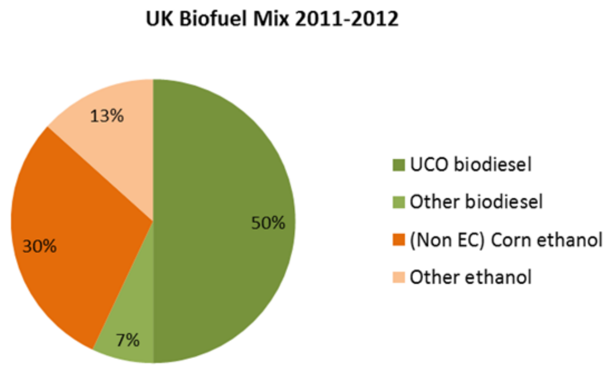
[10] However, this does not take into account the inefficiency of current vehicle engines, typically under 20 per cent for internal combustion engines and under 25 per cent efficiency in the case of diesel engines (WBGU, 2008).

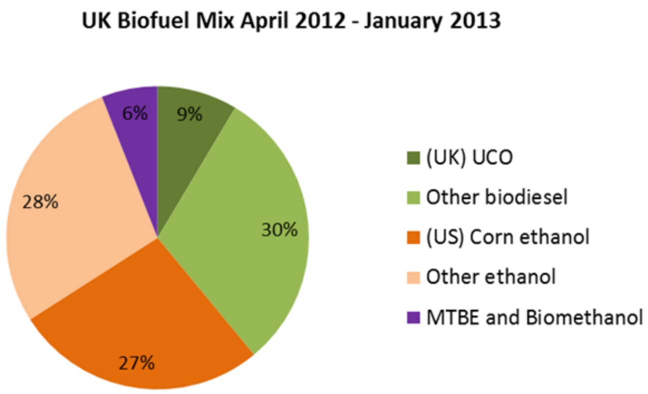
[11] The most up to date report on verified data available is for Year 4 of the RTFO, ie 2011/12. Unverified data for the first two quarters of Year 5 (2012/13) is also available.

affected. UCO is currently the major significant source of biofuel that falls into the wastes and residues category. Furthermore, tallow is used to produce biodiesel in the UK and a very small share of the market is from waste derived biomethane. The remaining use of biofuels is reliant on arable crops. This situation requires a policy response both in order to broaden the feedstock mix and to shift away from food and feed crops and thereby reduce the environmental and social footprint of national biofuel consumption.

Figure 2: The sources of feedstocks for biofuels consumed in the UK 2010 - 2013







Quantity of UCO supplied in the UK in past years

Obligation Period	Year	UCO supply (million litres)
2008/09	1	40
2009/10	2	43
2010/11	3	459
2011/12	4	800.4

Chart sources: 2010/2011 data: RTFO Year 3 Verified Report: 15 April 2010 - 14 April 2011; 2011/2012 data: Renewable Transport Fuel Obligation statistics: obligation period 4, 2011/12, report 6; 2012/2013 data: Renewable Transport Fuel Obligation statistics: obligation period 5, 2012/13, report 3. **Table sources:** 2008/2009 figure: RFA (Renewable Fuels Agency) Quarterly Report 4:15 April 2008 - 14 April 2009, Verified data set; 2009/10 figure: RFA Quarterly Report 8: 15 April 2009 - 14 April 2010, Verified data set; 2010/2011 figure: 'Year 3 Verified Report: 15 April 2010 - 14 April 2011; 2011/12 figure: Renewable Transport Fuel Obligation statistics: obligation period 4, 2011/12, report 6. **Notes:** Biomethanol can be produced from biomass by gasification. MTBE (methyl tertiary butyl ether) is formed by a chemical reaction between methanol and isobutylene. Both MTBE and Biomethanol are used as a petrol additive.

3 ENVIRONMENTALLY SUSTAINABLE WASTES AND RESIDUE STREAMS

This section discusses the relative sustainability within Europe of certain feedstocks, mainly waste and residue streams (Annex 1), which would qualify for special incentives in future if the European Commission's proposal on ILUC is adopted. In particular, the Commission proposed to count advanced biofuels from these feedstocks at a level of two or four times their energy content towards the RED 10 per cent target. We stress the need for the introduction of safeguards to make these truly sustainable alternatives.

3.1 Sustainability – a first assessment

The Commission's proposal leaves several unanswered questions. One concerns the exact definition of the feedstocks listed and another the existing uses from which these materials might be diverted and the resulting environmental, social or economic impacts. A rather more detailed examination and assessment of each feedstock, including definitions can be found in a recent Institute report (Kretschmer *et al,* 2013). Table 2 summarises this assessment but should be read as simply as the result of an initial screening exercise and in conjunction with the report from which it derives.

The assessment takes into consideration the principal known existing uses and predominantly the environmental risks of diverting resources away from those and towards biofuel production. Other considerations were outside the scope of this report. For example, it did not consider the most appropriate prioritisation of certain biomass sources against different energy (transport fuel or heat and electricity generation) and non-energy (eg bio-chemicals and bio-plastics) uses. This, of course, is an important issue.

We have grouped feedstocks into the categories:

- '**potentially sustainable (contingent on safeguards)**', meaning that the resource could be considered sustainable if certain, in this case mainly environmental risks , are mitigated by appropriate safeguards;
- '**likely unsustainable**' given considerable environmental risks that will be difficult to mitigate by safeguards; however, limited volumes may still be mobilised at the local level; and
- '**unclear**' since a more definitive assessment could not be made based on the information available.

The inclusion of the majority of feedstocks within the 'potentially sustainable' category is striking and highlights the considerable uncertainties surrounding the Commission's list[12]. An important challenge impeding a clearer assessment is the lack of reliable and comprehensive data on existing uses of the waste and residue feedstocks in particular. Equally important is the role of local and regional conditions in determining the levels of wastes and residues that may be sourced sustainably. Variability in the sustainability of supply in different parts of Europe may arise due to differences in the prevailing uses of materials at present as well as different climatic and biophysical conditions. A 'bottom up' type of assessment of the biomass sources available on a more local scale would be useful.

[12] The proposal sets out a list, but does not provide more detailed information on the content of the list, for example as part of the impact assessment accompanying the proposal.

Even the national level hides major regional differences – a point to emphasise in considering the UK as a whole later in the report.

Table 2: Summary of a first sustainability assessment of the Commission's feedstock list

Sustainability assessment	Feedstock
Potentially sustainable (contingent on safeguards)	Tall oil pitch (4x)
	Nut shells (4x)
	Algae (4x)
	Biomass fraction of mixed municipal waste (4x)
	Biomass fraction of industrial waste (4x)
	Straw (4x)
	Animal manure and sewage sludge (4x)
	Palm oil mill effluent and empty palm fruit bunches (4x)
	Bagasse (4x)
	Grape marc and wine lees (4x)
	Husks (4x)
	Cobs (4x)
	Used cooking oil (2x)
	Animal fats (Category 1 and 2) (2x)
Likely unsustainable	Bark, branches, leaves, saw dust and cutter shavings (4x)
	Non-food cellulosic material (2x)
	Ligno-cellulosic material except saw logs and veneer logs (2x)
Unclear	Crude Glycerine (4x)

Source: Kretschmer *et al* (2013)

3.2 Safeguards to prevent perverse outcomes

Safeguards will be required to prevent perverse outcomes arising from a new set of incentives to use these diverse materials for biofuels on a much larger scale. Some safeguards would need to be feedstock-specific, but a range of more general safeguards also are needed, as suggested in the Institute report:

- **Ensure clear definitions**: The European Commission's ILUC proposal in its current form lacks clear definitions for several feedstocks. These are important: first to establish more precisely the materials involved and ensure the policy is workable; second to allow potential risks and appropriate mitigating safeguards to be identified; and third, to improve the consistency of definitions across the EU-27 Member States. The latter is necessary to ensure that the same advanced biofuels are eligible for multiple (double or quadruple) counting across the EU and that appropriate safeguards are enforced EU-wide.

- **Adhere to the waste hierarchy**: As discussed in Section 2, this means that only non-recyclable and non-compostable waste should be utilised for energy recovery, unless energy recovery can be justified for reasons of technical feasibility, economic viability or environmental protection. It has been demonstrated, for example, that anaerobic digestion of food waste generally is superior to composting in terms of GHG savings (ERM, 2006; DECC and Defra, 2011). In other words, incentives to use wastes and residues as biofuel feedstock must not counter ongoing efforts to reduce waste and increase recycling rates.

- **Consider GHG emissions that arise from wastes and residues over the complete lifecycle**: Accurate, up-to-date information and use of appropriate accounting protocols are both important. While the methodology for accounting for GHG emissions set out in EU legislation accounts for transport and processing emissions other, potentially significant, emission sources are neglected. In particular, the RED and FQD methodology considers wastes and agricultural residues to be 'zero emission' up to the point of their collection. This ignores the impacts on soil carbon stocks that can occur as the extraction of residues increases. The system boundaries of the methodology should be extended by taking into account changes in soil carbon stock from agricultural or forestry residue extraction.

- **Assess current uses of feedstocks and evaluate the indirect environmental, social and economic impacts of diverting residues towards biofuel production**: The list of feedstocks eligible for multiple counting (or any other support measures) needs to be kept under review in light of continuing research and analysis. The availability of low-carbon alternatives for different applications needs to be taken into account. The economic value added that can be generated per unit of biomass input is also relevant. The 'built in' market mechanism usually would be expected to result in higher feedstock prices being paid by industries producing higher-value products like bio-chemicals. However, this would very likely be distorted by new incentives in the energy sector, thereby affecting previously more high value uses. At the same time, a use associated with a higher economic added value does not necessarily lead to greater environmental benefits or GHG savings. There is a strong public interest to be pursued alongside market considerations.

- **Mitigate the environmental impacts of certain advanced conversion pathways:** The processing of biomass into biofuels via advanced biochemical or thermochemical conversion pathways can require relatively high energy inputs. These are addressed in the GHG methodology. However, other environmental impacts resulting from the processing of biomass through advanced conversion technologies, such as water consumption in processing, should be investigated and if necessary be addressed by safeguards.

- **Consider impacts outside the EU:** The incentives provided for the use of particular wastes and residues under the RED should not lead to the increased import of wastes and residues, or indeed other feedstocks, where this will cause environmental, social or economic impacts in countries outside the EU.

Preferably, safeguards of this kind would be put in place at the European level. However, it is uncertain how far this will occur in the coming years. In their absence, sustainability criteria need to be built into national measures to incentivise a new generation of biofuel feedstocks.

4 SUSTAINABLE DOMESTIC WASTES AND RESIDUES OF RELEVANCE FOR TRANSPORT IN THE UK

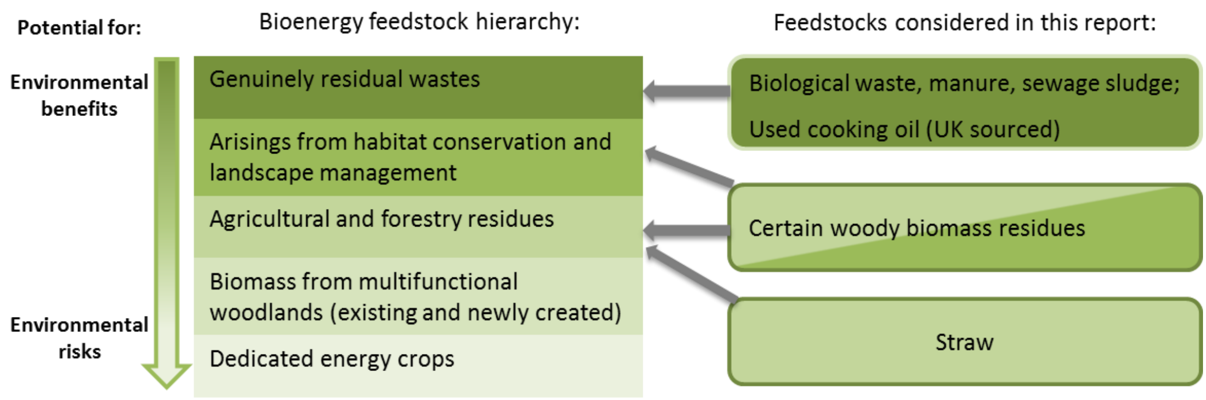
Turning to domestic waste and residues in the UK, no study seems to have been published so far about the potential sustainability of the different categories of feedstock being proposed as advanced transport biofuels by the European Commission. Most, if not all, of the general principles set out in the previous section apply equally at the national level.

Taking into account those feedstocks which appear more plentiful in the UK and more likely to be sustainable on the basis of the pan-European analysis, we have selected five categories of feedstock for further investigation. These are:

- Biological waste, including source-segregated waste such as food and green waste as well as the biological fraction of non-segregated municipal solid waste (MSW);
- Manure and sewage sludge;
- Used cooking oil (UCO) sourced in the UK;
- Certain woody biomass residues (as further set out below);
- Straw.

There is published work available which helps to identify which of the various wastes and residue feedstocks might be the most sustainable source for biofuels in the UK. While this focuses primarily on bioenergy feedstocks as a whole, rather than those intended specifically for biofuels, most of the same general principles apply. In particular, we have built on a study by RSPB (Gove *et al*, 2010), subsequently developed by IEEP (Kretschmer *et al*, 2011) which resulted in a hierarchy of different categories of biomass feedstock according to the level of our environmental benefit or risk associated with them. This hierarchy is shown in Figure 3 below which also indicates where the five categories considered here fit on the hierarchy.

Figure 3: Bioenergy feedstocks hierarchy and focus of this report



Source: Own compilation. The bioenergy feedstock hierarchy on the left hand side is adopted in modified form from Gove *et al* (2010) and taken from Kretschmer *et al* (2011).

The hierarchy incorporates a number of different environmental considerations. Particularly important are the GHG emissions associated with use of the feedstock for bioenergy, drawing on different biomass sources and use pathways as discussed by the Environment Agency (2009a; b) and impacts on biodiversity. In this respect, account has been taken of the potential for meeting UK biodiversity policy goals, such as those set out in the Biodiversity Action Plan[13]. Following this exercise a second group of feedstocks are not considered further in this report. Some of the reasons behind this are set out in Box 2.

Box 2: Why certain feedstocks are not considered further

Short rotation coppice, short rotation forestry or other dedicated energy crops: In the UK this is a small but growing sector, amounting to about 20,000 ha of dedicated crops, larger than in most other EU countries[14]. It consists mostly of Miscanthus and short rotation coppice (such as willow). However, while these are not food crops, they do occupy land, most of which is actually or potentially agricultural (excepting short rotation forestry); new crops grown on this land will displace other land uses. Consequently, there will be ILUC effects and therefore serious questions about the extent of any reductions in GHG emissions. Wider environmental impacts, such as on water and biodiversity, depend on the previous land use (Kretschmer *et al,* 2011). Perennial crops may provide benefits for biodiversity and soil structure when replacing annual crops but negative impacts are likely to result from the conversion of permanent grasslands and semi-natural habitats. The promotion of certain perennial crops for the purpose of SRC could lead to the introduction of non-native species or genetically modified varieties, for example in the case of eucalyptus, which is reported to have negative impacts on hydrological conditions[15].

Waste wood and secondary forestry processing residues such as saw dust and cutter shavings: Smith (2011) presents figures on the wood waste balance in the UK, noting that available supply is largely taken up by existing uses, notably fibre board production and combustion. At the same time, it is estimated that availability up to 2020 will increase due to increasing rates of waste wood recycling, potentially giving room for new uses such as advanced biofuels without displacing current uses. At the same time, however, particle board production may respond to the increase in supply and offer a more favourable processing route in carbon terms in that it would lock in carbon for a considerable period. It is worth monitoring and revisiting projections on waste wood recycling rates and on demand from the board industry to re-assess the suitability of waste wood as a sustainable energy source. Forestry processing residues such as saw dust and cutter shavings have similar existing uses including in the particle board industry, as well as for combustion and animal bedding (for example as an alternative to straw). So, while there are some available supplies, the volumes do not seem likely to be large.

Roundwood: The use of roundwood for energy purposes is highly controversial. Studies suggest that on a large-scale level it is unlikely to generate GHG emission savings compared to the fossil fuels replaced over many decades to come (Bowyer *et al*, 2012). A better environmental outcome generally would follow from using roundwood in construction, furniture or (in case of smaller diameters not suitable as saw logs) paper making, these uses are more sensible from an economic point of view also, as they generate higher value added. The UK has a substantial trade deficit in wood and wood-based products (Forestry Commission, 2012a); therefore, any additional harvest should be used to benefit the UK wood-processing industries first. However, we do consider biomass from currently undermanaged woodland and from habitat management as part of this report, because some of this resource can be expected to be of too low quality for uses other than energy generation.

Tallow: Tallow is produced in the UK in similar quantities as used cooking oil. Tallow can be used in a range of

[13] http://jncc.defra.gov.uk/page-5155

[14] See Elbersen *et al* (2012) for an overview of cultivation of these crops in the EU. The cultivated area in England is 2010/2011 was around nine thousand hectares of Miscanthus and three thousand hectares of short rotation coppice (Defra, 2013b). The planted area in 2009 for the whole UK was estimated at around 12.7 thousand hectares for Miscanthus and 6.4 thousand hectares for short rotation coppice (Defra, 2009).

[15] John Vidal wrote in the Guardian of 15 November 2012 about 'GM tree plantations bred to satisfy the world's energy needs', http://www.guardian.co.uk/environment/2012/nov/15/gm-trees-bred-world-energy. Recently, reports emerged evidencing negative health impacts through air pollutants from growing crops such as poplar, willow or eucalyptus (Alister Doyle writing for Reuters on 7 January 2013 on 'Biofuels cause pollution, not as green as thought - study', http://www.reuters.com/article/2013/01/07/us-climate-biofuels-idUSBRE90601A20130107.

applications, depending upon the origin of the tallow. Tallow derived from material which is safe for the food chain can be used in a range of high value, human contact applications such as oleochemicals[16]. We do not consider the use of this material in this report, because it has a strong demand from other sectors (Smith, 2011) but also because there is risk from displacing tallow from existing uses and a risk of importing palm oil as the closest substitute with associated risks for deforestation, peatland drainage and social impact. Tallow material which carries a disease risk can only be used in energy and fuel applications. The Commission's ILUC proposal considers only this material as eligible for extra incentivisation. It is generally used as a fuel for the rendering process but Argent Energy in Motherwell, Scotland, currently use some tallow in the production of biodiesel. While a potentially sustainable resource for biofuels, we do not consider tallow further in this report because it would require substitution of fuels for the rendering process. It is therefore not a true waste.

Source: Own compilation

The five types of feedstock which are potentially more promising for biofuel production are considered in the following section.

4.1 Food waste, green waste, non-segregated MSW, manure and sewage sludge

All these waste streams can be classified as waste products in the sense that they are not easily avoidable, with the exception of food waste, where the priority should be to reduce the high current levels of waste generated (see Box 3).

There are different sources for food waste, including agricultural produce that is not marketed due to quality standards, wastes from manufacturing, food from supermarkets that is not sold, as well as wastes and leftovers from households and the food services industry. Green waste includes garden waste as well as grass clippings. We cover cuttings from trees and bushes from gardens, parks, etc, that typically have higher lignin content in section 4.3, given their different processing needs. Common to food waste, green waste, manure and sewage sludge is that they are fit for energy recovery via anaerobic digestion (AD). Alternatively, food and green waste can be composted although, some restrictions apply, for example cooked kitchen waste is not suitable for windrow composting[17]. According to the waste hierarchy, composting should take priority over (energy) recovery. However, one fairly recent study found that anaerobic digestion can provide higher net carbon savings than composting, a justification for preferring energy recovery over composting (ERM, 2006). UK Government documents reiterate that AD is generally the preferred waste treatment option for food waste; the production of both renewable energy and bio-fertiliser (digestates) offers the highest GHG saving potential (Defra, 2011; DECC and Defra, 2011).

The biological fraction of non-segregated municipal solid waste includes other types of wastes, for example old paper and clothes inappropriately discarded via the collection infrastructure, that are not suitable for AD. They can be processed through thermochemical conversion (see section 6.1).

[16] Oleochemical processes use chemicals derived from plant and animal fats as opposed to using petroleum derived chemicals as part of the petrochemical industry.
[17] Windrow composting refers to a practice in agriculture whereby compostable material is placed in long narrow piles or 'wind-rows' that are regularly turned, see for example: http://www.fao.org/docrep/007/y5104e/y5104e07.htm.

Box 3: Food waste

The UK produces the largest amount of food waste in absolute terms in the EU, around 16 million tonnes of post-farm gate waste (Defra, 2011), and is among the highest 'producers' on a per capita basis, with 236 kg per capita per year compared to an EU average of 179 kg (based on European Commission, 2010). Total household food waste alone amounts to 7.2 million tonnes according to the latest WRAP figures (2011). Apart from avoiding waste, for example by raising awareness among consumers and through changes to the food date labelling system by retailers, another option higher up the hierarchy is to 're-use' some of this material. Charitable food distributors collect food 'waste' accruing in supermarkets, ie food that is still fit for human consumption but passed the 'sell by' date, and redistribute this to people in poverty. There are some concerns that if incentives are introduced, food will be diverted from charitable food distribution to energy supply, also contradicting the waste hierarchy.

Source: Own compilation

Both animal manure and sewage sludge are used as organic fertilisers, with significant benefits to soil organic matter and fertility. However, although beneficial when applied to fields in the correct concentrations and using appropriate techniques, there are situations where the density of livestock production is such that animal manure and slurry is produced in excess. This can be particularly problematic in livestock dominated areas of the UK and where manure and slurry volumes exceed that which can be applied back to the land without risking water pollution, for example from nitrates in Nitrate Vulnerable Zones. Traditional manure management should not be diverted to an extent that would lead to a decline in soil organic matter. The AD process yields digestates as a by-product that can be applied as a fertiliser; reliance on on-farm AD with parallel use of the digestates should be promoted over complete removal of sludge and manure from the farming system.

The use of wastes and residues in AD bears the risk of increasing the cultivation of a substrate crop, grown to co-feed anaerobic digesters, most notably maize. Past experience in Germany has shown that maize cultivation increased significantly as a result of incentives set by renewable energy policy with corresponding reductions in pasture and ILUC effects (see also Kretschmer *et al*, 2011, for discussion of this issue in the UK context).

Necessary environmental safeguards to make *food waste, manure and sewage sludge* sustainable alternatives:

Safeguards are required to ensure that the use of the **biological fraction of waste streams** is in line with the waste hierarchy. This requires cooperation between policy makers from different departments (notably Defra and DECC) in order to prevent conflicts between the objectives of energy and waste policies.

Traditional **manure** management should not be diverted to an extent that would lead to a decline in soil organic matter. The use of AD on farms has real potential and can give rise to a by-product suitable as a fertiliser. In most circumstances, it should be promoted over complete removal of sludge and manure from the farming system. Sustainability at the farm level will depend on adequate measures to protect soils, particularly soil organic matter. These could include appropriate cross compliance measures attached to the payments farmers receive under the CAP.

To counter the risk of maize cultivation being expanded significantly: requirement for a more diverse feedstock basis in AD generation eg via incentives to use more environmentally friendly feedstock combined with a cap on maize or other cereal grain inputs. For example, the 2012 German Renewable Energy Sources Act (EEG) caps the input of maize or other cereal grain in electricity from biogas production to 60 per cent and pays bonuses for the use of certain wastes and residues and other biomass, eg landscape management material, catch crops etc[18]. The most important risk to mitigate is the depletion of soil carbon and nutrients, eg by requiring biorefinery operators to investigate the local humus balances in regions where manufacturing plants are to be installed and commit to only sourcing agricultural residues where these are not depleting soil organic carbon or other soil nutrients.

4.2 Used cooking oil (UCO) sourced in the UK

UCO is typically collected from catering establishments, including fish and chip shops, and industrial food processors as a waste material. It may also be collected from domestic households where the infrastructure exists, but this remains very limited at present. The UK Sustainable Bio-Diesel Alliance (2011) estimates that less than five per cent of the UCO available from households is currently collected. The rest is typically landfilled or disposed of through the drain, causing considerable costs to water companies to clear sewers. Another environmental concern are GHG emissions from uncontrolled decomposition.

Already, UCO from non-household sources represents an important source of biodiesel in the UK, as evidenced by the figures in Section 2.2. The use of UCO has been scaled up due to the duty incentive, in place until March 2012 and the granting of two RTFO certificates for supplying UCO-based biodiesel. The latter is in line with the double counting mechanism permitted in EU legislation – the RED (Article 21.2). The biofuel industry is the most important outlet for UCO supply; other uses are in the oleochemicals industry, for energy generation and animal feed (Smith, 2011).

Necessary environmental safeguards to make *used cooking oil* a sustainable alternative:

The utilisation of used cooking oil for biofuels is sustainable in principle and scaling up collection from households in particular would have benefits in terms of avoiding costs associated with cleaning drainage and sewers and reducing GHG emissions from uncontrolled decomposition. However, there is a real concern that fraud can occur on a systematic basis in the sense that virgin oil is diluted by small quantities of UCO or even heated up solely for the purpose of making it qualify for incentives. Such concerns tend to be based on anecdotal evidence, making it difficult to obtain a realistic sense of the scale of the problem.

Given this risk, safeguards, for example in the form of a rigorous tracking system[19] that makes the whole UCO supply chain accountable, need to be introduced in order to ensure that oils are not simply fried without food only to make them 'used'.

[18] Biomass ordinance 2012, Annex 3 on 'Substances for substance tariff class II and their energy yield': http://erneuerbare-energien.de/files/english/pdf/application/pdf/biomasse_verordnung_en_bf.pdf

[19] Such tracking systems are being developed, however their effectiveness remains yet to be proven in practice: Trace your claim (http://trace-your-claim.com) and Register of Biofuels Origination (http://www.biofuelsregister.eu/).

4.3 Certain woody biomass residues

This category includes a wide variety of vegetative material produced by the management of domestic landscapes, green space and more natural habitats, primarily for environmental purposes in a broad sense. The type of habitat management activities that would fall under this category and the mobilisation of which would provide environmental benefits include the removal of conifers from planted ancient woodland sites (PAWS), removal of invasive alien species from woodlands and water courses, scrub removal and grassland mowing.

Another suitable source of woodfuel may arise through the re-instatement of management in currently undermanaged woodlands. According to Natural England, around 60 per cent of Britain's ancient semi-natural and other semi-natural woodlands are undermanaged currently[20]. However, the implications of using certain types of woody materials for biofuels are not all straightforward. The use of certain forms of woody biomass in particular poses challenges with regard to life cycle GHG emissions, as explained in Bowyer *et al* (2012). The use of woody material arising from habitat management, the removal of which would contribute to a thriving forest or woodland system, stands a better chance of ensuring an overall reduction in GHG emissions over the relevant timeframe than the extraction of material that otherwise would be used for timber and other products.

Necessary environmental safeguards to make *certain woody biomass residues* a sustainable alternative:

It is challenging to determine very clear safeguards for woody residues. The European Commission is mandated to make a proposal on EU sustainability standards for solid biomass more generally but has yet to do so. To be effective these standards would need to include a GHG accounting framework that takes into consideration soil carbon stock changes that result from the extraction of forest residues. At a generic level, the following issues need to be addressed: additional management of forests needs to be sustainable, including sustainable residue extraction rates; where woody biomass residues are already being put to good use by other industries, such as in the fibre board and paper pulp industries but also in the compost industry and soil mulch processing and for animal bedding (for example as an alternative to straw), use in the energy sector should not erode the resource base of appropriate established uses.

More specifically, both the concept and the practical implementation of sustainable residue extraction are dependent on a rigorous approach to the sustainable management of forests and other woodlands. The UK Woodland Assurance Standard (UKWAS) functions as an independent certification standard for verifying sustainable woodland management, in line with the requirements under the Government's Forestry Standard, the UK's 'reference standard on sustainable forest management' (UKFS) (UKWAS, 2012). Recent updates to the UKWAS standard guidelines (version 3.1) include reference to the Woodland Carbon Code (Forestry Commission, 2012b). This sets out requirements for voluntary carbon sequestration projects that incorporate core principles of good carbon management as part of modern sustainable forest management. One of these requirements is to maintain the woodland as a permanent carbon sink and clearly this has a bearing on the harvesting of timber and extraction of residues.

[20] Rob Green, Natural England, *pers comm*, 2011.

4.4 Straw

Straw is a by-product of harvesting cereals but the term can be defined more broadly to include straw from oilseed rape and ‘stover’ from maize cultivation. A range of traditional uses exist, both within and outside the agricultural sector. Important applications in the UK include the large scale use as a soil improver (by ploughing crop residues back in) and for animal bedding and as well as a fodder supplement. Straw is also used in mushroom production and horticulture. Outside the agricultural sector straw is used as thatching and more generally as a building material as well as for heat and electricity generation through direct combustion. In other parts of the world straw is being used in a variety of additional ways that are not currently foreseen (to 2020) within the EU. One such example is the use of straw to produce paper, something which is taking place currently in China, India and the US.

The sustainability of straw as a biofuel feedstock is closely related to the scale and location of its extraction and the extent of diversion from existing uses, which will give use to consequences of their own. Kretschmer *et al* (2012) discuss the potential for using straw on a European scale but also the negative impacts of excessive straw diversion towards energy use including: depleted soil functionality, most importantly through a reduction of soil organic matter and therefore nutrients; potential longer term impacts on fauna resulting from modifications to stubble heights and straw management; and animal welfare impacts when no suitable alternatives for bedding (such as sawdust or wood chippings) and roughage are readily available.

Soil management issues are a particularly important element of sustainability. The acceptable level of straw extraction will vary depending on a number of factors such as the level of straw incorporation[21] in previous years and the relative nutrient balance, which varies considerably between different soils, of which there is quite a range in the UK. Excessive incorporation of straw can lead to detrimental impacts on the soil carbon to nitrogen ratio so reducing fertility as well as exacerbating pest problems such as slugs. Therefore, before incentives for utilising straw for biofuels are increased, a national programme of detailed soil analysis be carried out on farms and for specific fields in order that the appropriate level of straw incorporation (and thus extraction) can be determined and guidelines produced. These will of course need to be intelligently interpreted and the close involvement of both farmers and soil scientists in the process will be helpful. In very general terms, straw can be ploughed back into fields one year in three, suggesting around two thirds of the total straw resource in a three year period will be available for other uses in many conditions. However, the overall sustainable extraction, once existing uses are considered, is much lower. For example, anecdotal evidence suggests that England’s pig farmers alone utilise around 350,000 tonnes of straw per year as bedding material. Such competing uses have led to the National Farmers Union (NFU) setting up a straw supply working group[22] to increase the volume of straw available as a resource, identify what barriers there are to developing straw supply chains and consider issues such as wastage and efficiency, usage and best practice.

[21] Where straw is ploughed back into the soil to improve structure, organic matter and fertility.
[22] Involving both straw producers and users within the agriculture sector.

Necessary environmental safeguards to make *straw* a sustainable alternative:

The most important risk to mitigate is the depletion of soil carbon and other nutrients, eg by requiring biorefinery operators to investigate the local soil nutrient and carbon balances in regions where manufacturing plants are to be installed and commit to only sourcing agricultural residues where these are not depleting soil organic carbon or other soil nutrients. Key recommended safeguards:

- Strengthening environmental safeguards on farmland, for example through cross compliance on farmers' direct payments under the CAP in the form of specific requirements regarding soil organic matter
- Providing advice and support to farmers on sustainable straw use
- Including soil carbon in the GHG accounting framework (in the RED).

5 VOLUMES OF DOMESTIC WASTES AND RESIDUES AVAILABLE TO THE UK BIOFUEL FOR TRANSPORT INDUSTRY

The potential volumes of domestic waste and residue materials that could be used as feedstocks for sustainable biofuel production need to be established in order to derive a better picture of the significance of the resource as well as its sustainability. In this section potential availability is discussed for the five main categories of feedstock identified in section 4 (for the purpose of this section we group together those feedstocks suitable for AD, see section 5.1). The section concludes with a brief overview of the most significant resources and sets out the question of whether these are best used specifically for biofuel production or for other forms of bioenergy, with a variety of trade offs involved between the choices.

Several studies have estimated overall biomass availability for the UK. The Government published its Bioenergy Strategy in 2012 (DECC, Defra and DfT, 2012), including estimates of the scale of domestic and imported biomass resources and assessing the potential for a UK bioenergy industry. An important input on the potential sources of supply was provided by a study by AEA and others for DECC (Howes *et al*, 2011). The NNFCC has prepared a series of studies assessing the potential for an advanced biofuels industry in the UK in particular (Nattrass *et al*, 2011). The analysis presented here draws primarily from the latter study complemented with additional information for some of the specific biomass sources.

Estimates of the potential quantity or energy value of available material are reported in different units in different studies. To make the figures comparable, we report them in the energy unit of peta joules (PJ), wherever available. To illustrate the volumes involved more explicitly and for the purposes of estimating the potential size of the industry (section 6.3), we also report available estimates in million (oven dry) tonnes.

5.1 Food waste, green waste, non-segregated MSW, manure and sewage sludge

Reporting on the potential quantity of various biomass feedstocks is complicated by the fact that the different categories of biomass are defined differently in different studies. This is apparent in the reported estimates of the potential of different waste categories. Smith (2011) reports potential ranges of food waste availability of between 10.3 and 38 PJ by 2020 and of green waste availability at between 6.5 and 10 PJ by 2020. The estimated range of total biological waste, including commercial, industrial municipal waste streams, amounts to 34 to 342 PJ by 2020. This latter range includes waste wood (eg from the demolition of houses and wood furniture), which is not part of the focus of this report, as well as ‘arisings’ from mowing and pruning in parks and transport corridors, which are categorised in some studies as arboricultural arisings or as landscape care wood (see section 5.3 below). Table 3 includes estimates by Howes *et al* (2011) and shows how they compare to the ranges that Smith (2011) presents as likely estimates. It is apparent that Howes *et al*’s food waste estimate is rather on the high side. Overall, the large uncertainty about the total waste availability is striking. An important determinant is how waste prevention, reuse and recycling efforts progress and whether barriers to mobilising residual waste streams are overcome. Figures from the Government’s Review of Waste Policies (Defra, 2011) complement the table. Annex 2 includes a detailed illustration of the different sources of wastes suitable for AD processing in England.

Table 3: Summary of UK estimates of potential for biological waste streams

	Howes *et al* (2011)	Smith (2011)	Defra (2011)
	2020 estimates		*Current*
	PJ	PJ	Mt
Sewage sludge	12.4		1.7 (dry)
Livestock manures	16.4		90-100
Renewable fraction of wastes	43.7		
Food waste	46.9	10.3 to 38	16
Green waste		6.5 to 10	
Total	**119.5**	**34 to 342**	
Main uncertainties			
Howes *et al* (2011) and Smith (2011) mention as barriers to sourcing waste for biofuels the fact that local authorities award long-term contracts for waste management which are not very flexible. Over time, the available volumes should diminish with enhanced efforts by local authorities to meet recycling targets and reduced food waste at source.			

Sources: As indicated. **Note**: The Howes *et al* (2011) total figure given in the table should not be interpreted as their estimated total waste potential, as we deliberately excluded waste wood (as well as arboricultural arisings). Howes *et al* (2011) model a range of possible scenarios that differ according to the biomass feedstock price level assumed (£4, £6 or £10 per GJ) and the extent to which a set of postulated constraints (market conditions, policy and regulations, as well as technical and infrastructure limitations) is overcome. The estimates reported here (and in the following tables) are from a scenario assuming easy and medium constraints are overcome and a price level of £6/GJ (considered a 'realistic estimate' for the short to medium term). The total waste figure from Smith (2011) includes many categories other than food and green waste as explained in the main text.

5.2 Used cooking oil (UCO) sources in the UK

Domestic production of UCO in 2008 was around 10.27 PJ (0.258 Mt) in the UK. Significant quantities are already being used for biofuel production (Table 4), amounting to 3.26 PJ or 0.082 Mt. Market conditions are tight with demand commonly outstripping available supply. However, only around half of UCO produced is actually currently being used; the remainder of 5.37 PJ (0.135 Mt) in principle could be mobilised, but the need for new collection infrastructure and quality issues represent significant challenges. Based on different estimates, the NNFCC expects that a realistic range for additional UCO supplies would be 4.0 to 6.4 PJ or 0.1 to 0.18 Mt (Smith, 2011). Adding to this the current use for biofuels yields an estimated range of potential of between 7.26 to 9.66 PJ or 0.18 to 0.26 Mt.

Table 4: Summary of UK UCO potential

Estimates of overall potential	Existing uses	Estimated potential for biofuels
10.27 PJ (0.258 Mt) in 2008	Biofuels: 3.26 PJ (0.082 Mt) Oleochemicals: 0.99 PJ (0.025 Mt) Incineration: 0.4 PJ (0.01 Mt) Animal feed: 0.8 PJ (0.02Mt)	7.26 to 9.66 PJ (0.18 to 0.26 Mt) including current biofuel use
Main uncertainties		
Market conditions are tight with demand commonly outstripping available supply despite only around half of UCO being used. The extent to which this surplus 'production' can be mobilised represents the main uncertainty factor, as described above.		

Source: Own compilation based on Smith (2011)

5.3 Certain woody biomass residues

The greater use of forestry and other woody residues in the UK to produce biofuels would be dependent to a large degree on increasing woodland management. Smith (2011) notes that much of the current UK forestry materials from public forestry (roundwood and residues) are absorbed by sawmills and the panelboard industry. However, given the large share of (mainly private) undermanaged woodlands in the UK, there is potential to increase the supply of residues significantly, with some material available as a feedstock for the energy sector. This could have beneficial side effects, such as creating local jobs and in many cases could lead to improvements in the woodland environment (see Box 4). Increasing the supply of forestry residues through enhanced management is one of the stated objectives of existing UK forest policy and strategies, most notably the Forestry Commission's *Woodfuel Strategy for England* (2007) and the subsequent *Woodfuel Implementation Plan 2011–2014* (Forestry Commission, 2011). These pursue the goal of delivering an additional two million green tonnes of woody biomass (both residues and timber) annually by 2020 by:

- Setting standards for a competitive and sustainable woodfuel supply chain;
- Capacity building by developing markets and removing barriers to woodland management;
- Providing access to expert information to contribute to market development in close cooperation with the Biomass Energy Centre (BEC).

The two million tonnes figure represents a large proportion of current biomass output and combines both roundwood and some forestry residues. It corresponds to roughly 50 per cent of the unharvested timber increment (annual additional growth) from England's woodlands in 2001. However, this target does not represent purely woodfuel and would include potential sources of construction timber and other products. It is unclear precisely the volume of forestry residues that would result from increased management, but clearly they would be only a fraction of the two million tonne figure. In 2012, the Independent Panel on Forestry[23] published its final report on the future of woodlands in England supporting the use of wood fuel (and woody residues) in energy generation, but within a broader framework of more considered wood use, as depicted in Figure 4. The increased harvesting of UK timber, particularly from undermanaged woodlands, could help to increase the supply of forestry residues as well as contributing towards the use of UK timber for medium and long term products.

Figure 4: Favoured wood use in England

Source: Independent Panel on Forestry (2012)

[23] The Independent Panel on Forestry was created in March 2011 following a fierce public debate over the future of the public forest estate in England.

The Woodfuel Implementation Plan lists the potential availability of arboricultural arisings from felling, pruning and safety operations carried out on trees in built up areas and along transport corridors. In total 396,000 tonnes are produced annually with only 32 per cent of this having a current market. Therefore a total potential resource of 269,280 tonnes could be made available annually for energy generation.

Other studies have also reviewed estimates of potential future supply. Focusing on the types of woody biomass identified in section 4.3, Howes *et al* (2011) estimate arboricultural arisings to amount to 46 PJ in 2020, an estimate that includes arisings from transport networks such as the perimeter of railway lines and urban green space[24]. They estimate forestry residues at 8.3 PJ. Smith (2011) does not distinguish between different sources of wood biomass resources, such as virgin wood and residues, but only suggests an aggregate range based on a set of studies reviewed of around 0.4 to 4.2 Modt or 8 to 79.8 PJ in 2020.

Box 4: The 'Woodfuel East' project

More than seven per cent of the East of England is covered with woodland. Of these 140,000 hectares almost half is under-managed or not managed at all, which means that at least 200,000 tonnes of timber (including some residues) is unutilised every year.

Although every wood is different, and each needs to be assessed on its own merits, all regional woodland would benefit from active management. The benefits of management for woodfuel include:

- Timber harvested brings a new and diversified income stream to woodland owners
- The harvesting and processing of woodfuel provides much needed rural employment.
- Removal of poorer quality trees for woodfuel improves the quality of the remaining crop opening opportunities for other markets such as sustainable construction
- Thinning and coppicing increase the light available on the woodland floor, which has excellent benefits for biodiversity encouraging plants, insects, birds and mammals.
- The replacement of fossils fuels in the 'Woodfuel East' project aims to save up to 90,000 tonnes of carbon dioxide emissions per annum, equivalent to 12,500 homes supplied with energy. More than 100 jobs will be created.

Source: http://www.woodfueleast.org.uk/Content.aspx?ID=21

The forestry biomass potential for the whole EU has been estimated recently as part of the 'EUwood' study[25] (Mantau *et al*, 2010). Table 5 presents the results for the UK for those woody biomass categories of interest in the context of this study and for the year 2020. It compares them to results by Howes *et al* (2011) for similar categories. While the two studies define categories differently (for example landscape care wood, LCW) in Mantau *et al* includes prunings and garden waste) and yield very different results, these differences

[24] The figure on arboricultural arisings seems high when compared to Smith's (2011) estimate of green waste of 6.5 to 10 PJ, which seems to cover similar sources ('garden waste from municipal sources and from landscape maintenance of public parks, verges etc', p27). This lower range can be explained by more cautious assumptions in Smith (2011) about the amounts that are expected to be collected.

[25] Study produced for the European Commission to assess different scenarios of future wood supply available for energy use and meeting EU renewable energy targets.

balance out in the total figure with Mantau *et al* giving an estimate that is only 9 per cent higher than the one derived from Howes *et al*.

Table 5: Woody biomass residue estimates for the UK (in 2020)

Howes *et al* (2011)		**Mantau *et al* (2010)**		
	PJ		**million m^3**	**PJ**
Forestry residues	8.3	Forest residues	2.2	19.2
Arboricultural arisings	46	LCW (use)	4.1	35.8
		Bark	0.5	4.4
Total	**54.3**	**Total**	**6.8**	**59.3**
Main uncertainties				
Both studies account for uncertainty by modelling 'low-medium-high' type of scenarios. Estimates reported here are taken from the medium range for both studies. As noted above, a much increased supply of woody residues for biofuels could be achieved only by much larger scale active management of currently undermanaged woodlands.				

Source: As indicated. **Notes**: The Mantau *et al* estimates are for the *medium mobilisation scenario*. In the case of landscape care wood (LCW), 'use' refers to 'potential that is or will be used', determined again according to a high, medium and low scenario, but this time accounting for different demand levels with constant supply. Under neither of the scenarios does the full LCW potential become utilised due to high 'procurement costs' associated with small volumes of biomass from scattered locations and of low density (Mantau *et al*, 2010, Chapter 5). Howes *et al* figures as per notes to Table 3.

In its recent Bioenergy Strategy, the Government evaluates the contribution that UK forestry resources could make to supply the renewable energy sector, but referring specifically to heat and electricity generation. It is estimated that the role played by domestic resources will remain relatively limited and focused on smaller-scale applications particularly for renewable heat supply. Given the market situation for forestry biomass in the UK, it is unlikely that supply levels will be sufficient to provide the high volumes required by typical commercial electricity generating plants (DECC, Defra and DfT, 2012). This finding is relevant to the advanced biofuel sector to some extent, given the large requirements of commercial biorefineries, unless a mix of feedstocks can be used (as is the case in thermochemical conversion routes, see section 6.1). If residues are not concentrated in reasonable volumes within a 30-50 mile radius of plants the collections costs become a major barrier to commercial operation.

5.4 Straw

The availability of straw for biofuel feedstock purposes is closely linked to the supply of the crops from which it derives, most importantly cereals and, to a lesser extent, rapeseed. Just as yields of crops vary from year to year, so does straw availability. Apart from this uncertainty, the availability of straw for biofuel production depends on the volumes available once other worthwhile uses have been satisfied with price a consideration, too. Smith (2011) compiled figures on the volumes used for livestock bedding, which amount to more than half of total production in the UK. Combustion for heat and power generation is growing whilst use in mushroom cultivation (and thatching etc) remains a niche application. This leaves a potential surplus of 91.8 PJ (4.83 Modt) according to Smith (2011). However, the quantities that need to be reserved for the essential use of straw as a soil improver and the more limited use in animal feed are difficult to quantify and only a portion of the theoretical 'surplus' will be available for bioenergy.

Several studies have estimated straw supply and demand for different uses for the year 2020. Results vary widely, the challenge of taking into account regional differences being one potential explanation. Based on existing studies, Smith (2011) suggests a range of 18 to 132 PJ (0.94 to 6.99 Modt) of straw could be available for UK advanced biofuels production in 2020. A European study offering estimates for individual countries gives a UK straw potential of 88.5 PJ (Elbersen *et al*, 2012).

Table 6: Summary of UK straw potential

Estimates of production	Existing uses	Estimated potential for biofuels in 2020
Around 209 PJ (11 Modt) current yearly production (cereal and oilseed straw)	Livestock bedding: 129.2 PJ (6.8 Modt) Combustion + mushroom production: <5.7 PJ (0.3 Mt)	18 to 132 PJ (0.94 to 6.99 Modt) Elbersen *et al* (2012): 88.5 PJ
Main uncertainties		
While Smith (2011) compiles figures for some existing uses, such information is neither available for the amounts of straw ploughed in to benefit soil fertility nor for the amounts used as animal feed and bedding. The main uncertainty relates to the locally specific sustainable level of straw extraction which depends on soil as well as climatic and bio-physical conditions.		

Source: Own compilation based on Smith (2011) as the source for all figures, and Kretschmer *et al* (2012).

The relatively low energy density of straw represents an additional challenge, constraining viable transport distances to around a 30-50 mile radius at most (see Smith, 2011 and Kretschmer *et al*, 2012).

5.5 Summary – discussing preferable uses for domestic wastes and residues

There is potential to increase the mobilisation of the wastes and residues reviewed here, for some feedstocks more than for others, and to overcome different sets of barriers, notably with regard to collection infrastructure.

Despite the need to retain a certain amount of straw in soils, and other uses of this material there appears to be ample potential to increase mobilisation of **straw** for use in the energy sector. This also holds for **food waste and green waste and non-segregated MSW**, though the volumes of at least food waste and non-segregated MSW should be gradually reduced by ongoing efforts to prevent waste. There is more limited scope to increase the amount of **used cooking oil** available for energy uses, mostly from households. At the same time, mobilising UCO from households is particularly challenging in terms of collection arrangements, with rather small amounts of UCO accruing from many dispersed sources. There is ample scope to increase the mobilisation of **woody biomass residues**. However, this can be done only with a substantive change in woodland management requiring action by a large number of actors which is unlikely on a sizeable scale without new incentives. Estimates of potential are particularly uncertain.

Aside from biofuels, the feedstocks mobilised from such sources could be used for other forms of energy supply. Straw, woody biomass residues and UCO can also be combusted to generate heat and electricity and reduce the GHG intensity of the UK electricity mix (and so indirectly to fuel electric vehicles). Similarly, biogas can be used for heat and electricity generation, either used on-site or fed into the electricity grid. Biogas may also be upgraded to biomethane that can be fed into the natural gas grid or directly power dedicated fleets of vehicles where own-fuelling infrastructure is available. To determine whether the resources reviewed here should be used for advanced biofuel production or for alternative energy (or indeed non-energy) uses is beyond the scope of this report.

This decision will have to be taken based on available alternatives for low-carbon energy generation in the UK in the totality of the heat, electricity and transport sectors. Given that fewer alternatives are currently readily available for decarbonising the transport sector, there might be a case for some resources to be earmarked especially for that sector (as was concluded by the CCC, 2011, see section 2.1.1). Nevertheless, this should not reduce efforts to increase the use of those alternatives that are available, especially for road transport such as electric vehicles (see also Skinner, 2013). Some of the merits of different conversion routes are discussed further in section 6.1, which also touches on the environmental implications of adopting certain options.

The following Tables 7 and 8 summarise the evidence presented in this section in quantitative terms and indicate the scale of the UK waste and residue resource potentially available for the transport sector. The two tables follow the two main sources used, with estimates compiled in different ways. Table 7 summarises estimates by Smith (2011) that offer *ranges that are likely to be available for the transport sector* for some of the wastes and residues we consider. Table 8 summarises estimates by Howes *et al* (2011), specifically 'medium range' estimates (as explained in the notes to Table 3). Howes *et al* did not focus on biomass availability for liquid biofuels but rather at the *overall 'UK biomass for energy' resource*. Therefore, we apply different 'factors' to their estimates to show what quantity might be available for biofuels if we assumed that ten, 20 or 30 per cent of the resource would be available for the transport sector. This is to reflect the fact that the majority of the resource would more likely end up in heat and power generation, either through AD or by direct combustion, both of which are established technologies. Shares of 20 or 30 per cent ending up in the transport sector by 2020 are probably on the high side. Even ten per cent may turn out to be unrealistically high on the timescale unless some determined policy interventions occur.

Table 7: Summary of UK waste and residue potentials

Feedstock	Min PJ	Max PJ
Food waste	10.3	38
Green waste	6.5	10
Used cooking oil	7.26	9.66
Straw	18	132
Total PJ	**42**	**190**
Share of 2020 biofuels	23.9%	107.7%
Share of 2020 transport energy	2.4%	10.8%

Source: Own compilation and calculations based on Smith (2011) and UK NREAP

Table 8: Summary of UK waste and residue potentials (continued)

Feedstock	PJ*	10%	20%	30%
Renewable fraction of solid wastes	43.8	4.4	8.8	13.1
Manure	16.1	1.6	3.2	4.8
Sewage sludge	12.6	1.3	2.5	3.8
Forestry residues	8.3	0.8	1.7	2.5
Arboricultural arisings	46	4.6	9.2	13.8
Total PJ	**126.8**	**12.7**	**25.4**	**38.0**
Share of 2020 biofuels		7.2%	14.4%	21.6%
Share of 2020 transport energy		0.7%	1.4%	2.2%

Source: Own compilation and calculations based on Howes *et al* (2011) and UK NREAP. **Note**: We apply different 'factors' to the estimates by Howes *et al* (2011) to show the amount of feedstock available for biofuels if we assumed that ten, 20 or 30 per cent of the resource would be available for the transport sector. This is to reflect the fact that the majority of the resource would more likely end up in heat and power generation (through AD or direct combustion).

These estimates (in PJ) from both tables need to be put in the context of national demand for biofuels and for total energy in road and rail transport in 2020 (as set out in the UK National Renewable Energy Action Plan[26], NREAP, and summarised in Box 5). This gives a sense of the potential contribution that the waste and residue resource might make to the transport sector. Table 9 summarises the outcome, combining the numbers from both previous tables to provide a potential range for advanced biofuels from wastes and residues as a share of both predicted 2020 UK biofuel demand and 2020 demand for energy in road and rail transport. For the lower-end ('min-min') estimates it incorporates the lower-end sum from Table 7 and the sum of estimates scaled by a factor of ten per cent from Table 8 (ie the sum of the percentages in the blue cells in the two Tables).

There are caveats which must be emphasised. First, no attempt has been made to deflate the estimates in Tables 7 and 8 to take account of any practical real world constraints. Second, the maximum range points of Table 7 are per definition high-end figures and unlikely to materialise in 2020. The resulting range suggests that biofuels from the wastes and residues considered here may contribute between 31 and 129 per cent to total UK biofuel demand in 2020; or 3.1 to 13.0 per cent to total UK transport energy demand in 2020 (these percentages are the summation of the blue highlighted estimates for the lower-end figures and of the orange highlighted estimates for the higher-end figures). Comparing the latter range to estimates from Nattrass *et al* (2011) highlights the role of further constraints mentioned above. These mainly relate to the potential speed of investment in biorefineries which would be needed to have in place the processing capacity to convert the biomass resource into biofuels within seven years. Considering a different feedstock mix (including wheat and energy crops but excluding sewage and manure), Nattrass *et al* estimate that advanced biofuels could contribute between 1.3 to 2.6 per cent to total UK road and rail transport energy demand in 2020, below the 3.1 per cent suggested in Table 9.

[26] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47871/25-nat-ren-energy-action-plan.pdf

Box 5: UK biofuel and total energy in road and rail transport demand in 2020

Total (conventional) biofuels in 2020:			
4.21	Mtoe	176.1	PJ
Total energy demand in road and rail transport 2020:			
42	Mtoe	1749	PJ
Conversion to PJ: 1 Mtoe=41.868 PJ			

Source: Own compilation based on UK NREAP. **Note**: According to the NREAP, the Government anticipates only using conventional biofuels in 2020.

Table 9: Extreme ranges for shares of advanced biofuels from wastes and residues

	Min-min	Max-max
Share of 2020 biofuels	31.1%	129%
Share of 2020 transport energy	3.1%	13.0%

Source: Own compilation and calculations based on sources in Table 7 and Table 8. **Note**: Actual volumes of biofuels produced are likely to be lower in practice as constraints for example on the investments in refining capacity, are not considered.

6 OUTLOOK FOR AN ADVANCED BIOFUELS INDUSTRY IN THE UK

6.1 Processing wastes and residues into biogas and advanced biofuels

This section considers potential conversion routes for making biogas and biofuels and addresses some of their implications, for example with regard to the energy input needed for converting biomass to liquid fuels. The evidence on the relative GHG savings and wider environmental impacts associated with different biomass-to-energy conversion routes is examined, although much of it is quite tentative.

6.1.1 Conversion routes

A large number of conversion routes exist to convert biomass to biofuels (Figure 5). They can be broadly classified into three groups:

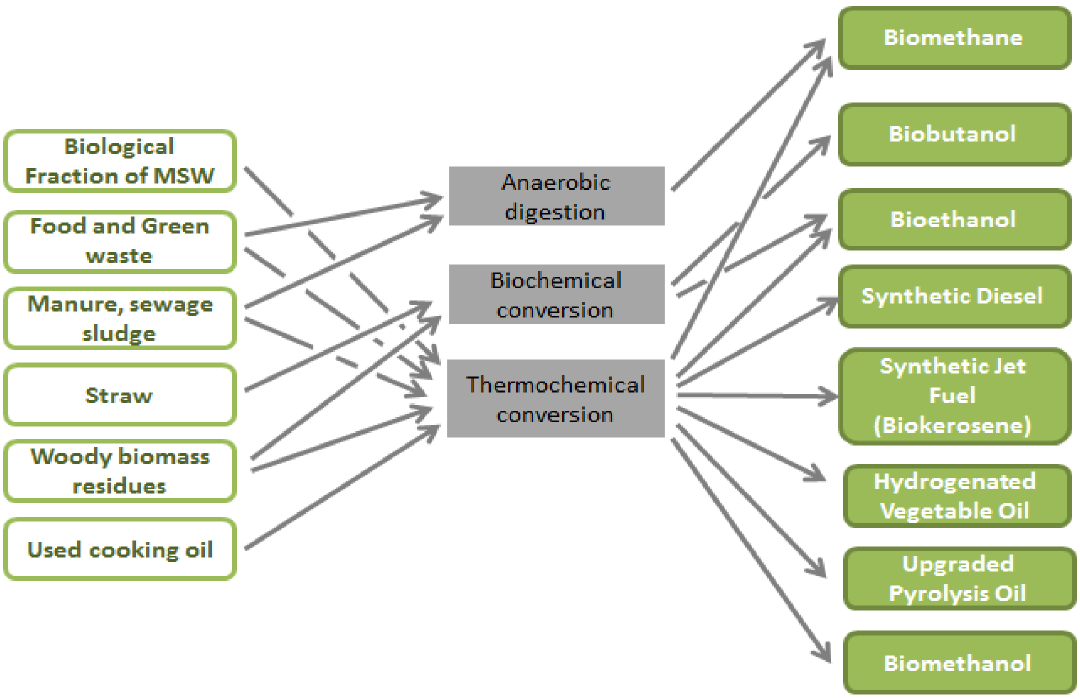
- **Anaerobic digestion (AD).** Anaerobic digestion is a natural, biological process where in the absence of oxygen microorganisms break down a predominantly wet biomass feedstock to biogas (a mixture of biomethane and carbon dioxide) and a digestate material. The biogas can either be burned on-site to produce energy and heat, or upgraded to biomethane and fed into the natural gas grid or used as a transport fuel. There are over 200 anaerobic digestion plants within the UK, at a variety of scales, using mainly food waste, sewage sludge, manure and slurries (see also section 6.3.1)[27].
- **Biochemical approaches.** The principal focus of biochemical based approaches is to utilise the sugars within the biomass to produce gasoline blending materials such as bioethanol and biobutanol. The use of food-based materials (such as sugar cane, sugar beet, maize and wheat) for bioethanol production is commercial throughout the world, with two plants in the UK. The use of the sugars from lignocellulosic biomass materials for biofuels production is also close to commercialisation. While bioethanol production is the only commercial biochemical conversion technology at present, fuels such as bio-butanol and furanics may also offer opportunities in the medium and longer timescales, respectively. Biochemical systems are less energy intensive than thermochemical approaches, but they need a more consistent feedstock.
- **Thermochemical approaches** such as gasification and pyrolysis[28] can use a wide range of lignocellulosic materials including food wastes, forestry residues, dedicated energy crops, straw and even a combination of these. This makes thermochemical approaches particularly attractive for the UK where there is no one principal feedstock. Gasification produces a syngas, which can be used to produce a large number of fuels, energy and

[27] If a biodegradable material fed into an anaerobic digestion plant is a waste, or contains any waste, the digestate produced would normally be classified as waste and be subject to waste regulation controls. However, the Environment Agency has developed a quality protocol which outlines circumstances in which digestate can be regarded as a non-waste product and free from waste regulation. Manure and slurry fed into anaerobic digester plants is a special case, and although the Environment Agency applies waste regulatory controls to this activity, the use of the remaining digestate as a fertiliser on agricultural land in England and Wales will normally be free from such controls (Environment Agency, 2010). The digestate from AD of 'residual waste' is unsuitable for application to agricultural land due to the mixed nature of the material and potential contamination risk. The digestate is still permitted for use in the restoration of landfill sites and for brownfield land application. This limit to the use of the digestate from 'residual waste' may make this a less sustainable pathway for AD than for many other feedstocks.

[28] Pyrolysis is the thermal decomposition of biomass in the absence of oxygen which produces solid, liquid and gaseous components.

chemical products including bioethanol, biomethanol, synthetic diesels, jet fuels (biokerosene), bio-hydrogen and biomethane (known in this context as synthetic natural gas SNG). However, the necessary purification of the syngas, an energy intensive process, remains a significant challenge to its viability (IEA, 2010). Pyrolysis produces a type of oil, which is potentially upgradeable via refining processes, for use as liquid biofuel, whilst hydrogenation processes convert oil feedstocks (including animal fats, waste cooking oils and virgin vegetable oils) to a high quality fuel material which can be used as an aviation or transport biofuel. Several thermochemical conversion approaches are commercial or close to commercial, including the thermochemical conversion of glycerine to methanol in the Netherlands (BioMCN[29]). Thermochemical processes are heat and energy intensive but can potentially convert all of the carbon within the biomass, so are potentially more efficient than biochemical approaches that are able to convert only the sugar component.

Figure 5: Conversion routes from biomass to biofuels



Source: Own compilation

6.1.2 *Environmental impacts of different conversion routes*

The environmental impacts associated with the production of biofuels are highly sensitive to the conversion process used. Differences between apparently similar fuel chains can occur as a result of differences in the cultivation of the biomass feedstock, the exact conversion technology used, the type of process energy used, the end use of the product and the system boundaries. This is especially the case for advanced biofuels production, where, in most cases, biofuel production facilities are either not commercially mature, or are first-of-

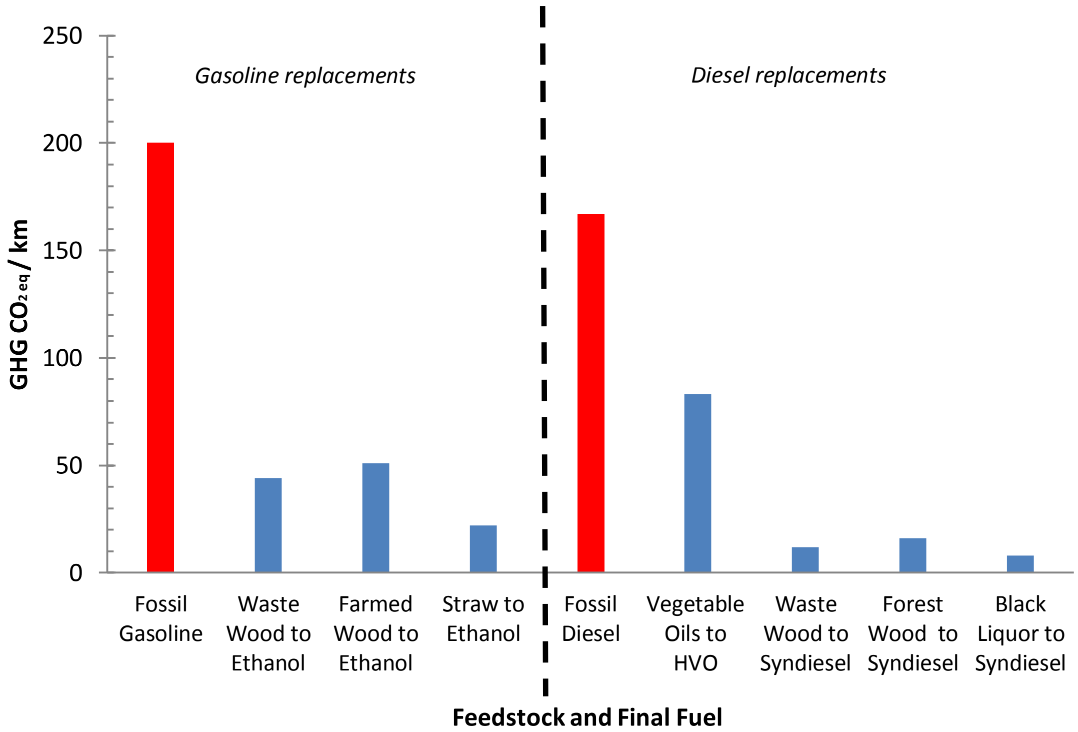
[29] http://www.biomcn.eu/

a-kind[30] plants, from which significant technological development could occur and improve performance in the future.

Energy and GHG impacts

The reduction of GHG emissions is one of the principal drivers for the production and use of biofuels. Biofuels vary significantly in their GHG benefits however and many conventional biofuels produced from food-based crops struggle to meet the GHG savings targets outlined in the RED and the FQD (or will struggle to do so with higher future GHG savings thresholds). The use of advanced technologies, using waste materials, can potentially improve GHG savings significantly compared to conventional fuels. Nevertheless, the feedstock and process technology used can significantly affect the GHG and energy balance of the final biofuel as shown in Figure 6.

Figure 6: Well to Wheels GHG emissions from different feedstocks and biofuels.



Source: Own compilation based on data from Edwards *et al* (2011). **Notes**: HVO – Hydrotreated Vegetable Oil. Red bars represent fossil fuels, whilst blue bars represent biofuels. Information on biofuel GHG emissions per km on the left hand side of the dotted line should be compared with fossil gasoline, similarly information on biofuel GHG emissions per km on the right hand side should be compared with fossil diesel.

Conversion technologies vary in their tolerance of feedstocks to moisture. AD and biochemical conversion routes, for example, can tolerate high moisture contents, whilst other technologies may require a drier biomass, for example many of the thermochemical gasification and pyrolysis routes. Biomass drying (pre conversion) may be necessary for some feedstocks to ensure a quality syngas is produced through gasification, and to ensure high conversion efficiency, although biomass drying is energy intensive and can have detrimental GHG emission impacts depending upon how it is dried.

[30] A first-of-a-kind plant is a commercial scale plant, but the first one from which learning can still occur.

Both biochemical and thermochemical routes are affected by the way process energy is produced and used within biofuel production. This can have large effects on the energy and GHG balance of the final fuel, especially where the energy input is derived from largely fossil resources. Stephenson (2010) modelled the conversion of SRC willow to bioethanol and showed GHG savings of 70 to 90 per cent relative to gasoline, whereas Budsberg (2012), again using willow, demonstrated GHG savings of 120 per cent relative to fossil fuels. Budsberg accounted for the difference between the studies as being a result of the greater use of coal as an energy source in the USA, in the latter study. In this case, the use of residues from the conversion process for energy would displace a greater amount of coal in the grid. Similarly, Hsu (2011) investigated the use of forest residues for pyrolysis, showing 65 per cent lower GHG emissions compared to conventional gasoline. However, as grid electricity and natural gas account for some 81 per cent of emissions, the displacement of these energy sources, either through using biomass in place of fossil fuels to produce process energy or using co-products from the conversion process, would significantly improve the GHG balance of this system (Hsu, 2011).

The active use of co-products and residues from the production process so they are not treated as wastes may significantly improve the GHG savings from both biochemical and thermochemical conversion routes. The production of mixed alcohols through thermochemical approaches can, for example, produce ethanol (which can be used as a fuel) and various other higher alcohol products which can be sold and generate revenue for a biorefinery[31]. These can also displace alcohols derived from natural gas, therefore having beneficial environmental impacts (Mu *et al*, 2010). However, in some cases, the use of co-products and residues may be detrimental to the use of the feedstock for biofuel production. For example, the high efficiency conversion of biomass sugars to bioethanol reduces the amount of residues which can be used as an energy source. Indeed, the greater GHG savings in Budsberg (2012) compared to Stephenson (2010) was partially attributed by Budsberg (2012) as a result of greater amounts of residues produced in the scenarios developed in that paper.

Water and air emissions

The impacts of biofuel production on water quantity and quality and air quality will also vary, depending on the conversion technology, feedstock and also the locations involved. The use of best available technologies should minimise detrimental environmental impacts. Nonetheless, as advanced biofuels are largely immature technologies, the environmental impacts are not completely understood. As a result, there is a need to monitor them closely and improve technologies over time.

Mu *et al* (2010) compared the lifecycle effects associated with the production of bioethanol through biochemical routes and through thermochemical routes using lignocellulosic feedstocks. They noted that although biochemical routes have a better GHG balance and lower fossil fuel usage, they have higher water consumption than thermochemical routes. Even excluding the water used during cultivation (which was assumed to be from rain rather than irrigation), Budsburg (2012) suggested that the lifecycle water use of willow used for lignocellulosic ethanol production was up to 169 per cent greater than the amount of water used in fossil fuel production (0.49 kg water per 1 MJ fuel compared to 0.29 kg water per 1

[31] Mixed alcohols may include significant amounts of higher alcohols with longer chain lengths than ethanol.

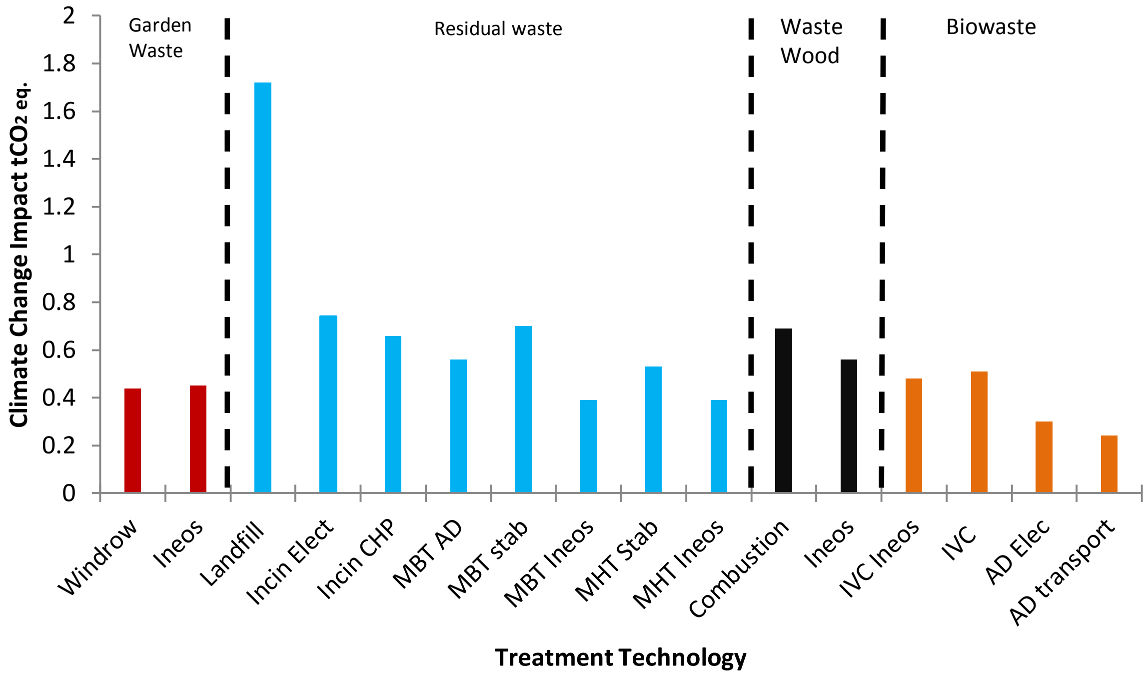
MJ fuel). The conversion process accounted for 43 per cent of this demand; with much of the remainder allocated to water use in the production of chemicals. Indeed, the contribution of lime, nutrients and sulphuric acid used in the biochemical conversion of lignocellulosic materials carries a high water use (Mu *et al*, 2010). Moreover, the IEA (2010) states that the amount of water used in biofuels production is generally only a fraction of that used in feedstock cultivation. However, biofuels from wastes and residues should have a reduced water footprint compared to dedicated crops. Local impacts on water quality and availability should nevertheless be monitored.

In contrast to water impacts, there is relatively little information on the air quality impacts associated with different conversion technologies. The production of biofuels via fermentation-based biochemical approaches produces significant amounts of carbon dioxide. However, this can be captured and used in chemical or in beverage markets. Other air quality impacts are likely to be associated with the chemical inputs used in the conversion process. In thermochemical conversion technologies, some of the gases can be used to power the process, making the process self- sufficient in energy (and hence reducing the need for fossil energy) and mitigating air emissions (Evans, 2007). Although some flue gasses are produced through thermochemical and biochemical routes, the use of abatement technologies should overcome potential detrimental impacts on air quality.

6.1.3 The GHG implications of different biomass uses

As mentioned earlier, it is far from straightforward to determine the most appropriate end-use for different biomass sources, with the options including not only biofuels but also other energy applications (heat and electricity generation), as well as non-energy uses. This section presents some, often tentative, evidence aiming to shed light on the question of appropriate biomass use in relation to climate concerns. A complete environmental impact assessment should consider the alternative uses for different biomass materials compared to biofuels and indeed the different uses that a biofuel may serve, taking account of the feedstock and the conversion route used. For example, in the case of waste biomass, Baddeley *et al* (2010) showed that the gasification of wastes for bioethanol production compared favourably with residual waste processes, especially compared to landfill, and mechanical heat treatment (MHT), as shown in Figure 7. However, the process was less favourable compared to windrow composting and AD, because thermochemical approaches use all of the carbon within the biomass, whilst composting and AD result in residual carbon being added to the soil (Baddeley *et al*, 2010).

Figure 7: Climate change impact of using different waste treatment technologies



Source: Redrawn from Baddeley *et al* (2010). **Notes**: The technologies used to treat different feedstocks are grouped by colour. Incin – Incineration, CHP - combined heat and power, AD – anaerobic digestion, MBT[32] – mechanical biological treatment, MHT[33] – mechanical heat treatment, IVC – in vessel composting, stab – stabilised (ie composted). Ineos refers to the 'INEOS Bio' thermochemical biomass gasification process, producing ethanol as a product.

Biogas can also be used in a number of ways. The most efficient use of biogas is not well established, with different studies quoting different results, likely due to be the result of discrepancies in system boundaries and assumptions. Figure 8, for example, summarises an analysis by Arcadis and Eunomia (2010), which suggests the best environmental impacts, in terms of GHG balance compared to fossil fuel alternatives, in various end markets. This study showed that the greatest GHG benefits from biogas are achieved by using biomethane as a vehicle fuel, followed by use of biogas on-site in a CHP plant or injection of biomethane into the gas grid. The use of biogas fed into the electricity grid gives the least CO_2 savings. However, this contradicts earlier figures produced by National Society for Clean Air and Environmental Protection (2006) and of a German report (WBGU, 2008), which state that the CO_2 replacement benefit for using biogas to generate electricity is likely to be greater than using it as a vehicle fuel. Such differences can be due to assumptions about the choice of which fuel is displaced.

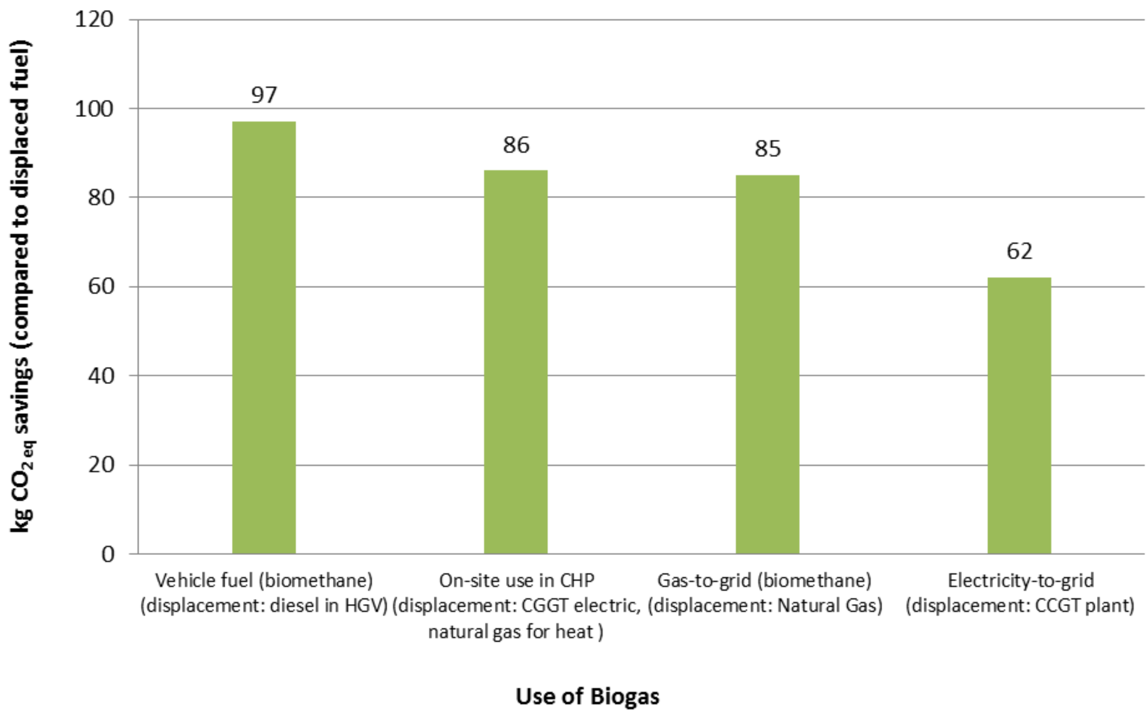
[32] MBT is mechanical biological treatment. This process refers to the mechanical separation of waste, followed by the treatment of the biological component through either AD, composting or biodrying processes.
[33] MHT is mechanical heat treatment. This process is the mechanical separation of waste, followed by the heat treatment, for example, through autoclaving.

The savings indicated in Figure 8 are under the assumption that:

- for electricity generation, generation from a Combined Cycle Gas Turbine (CCGT) plant would be displaced (assumed to be the marginal source of generation in the UK);
- for heat, generation from natural gas would be displaced;
- biomethane injection to the gas grid would displace an equivalent amount of natural gas; and
- bio-methane used as vehicle fuel vehicles would displace the use of diesel in heavy goods vehicles[34].

In conclusion, there is contradictory information, though the more recent study in the UK context points towards the use of biomethane as a transport fuel being superior in terms of emission savings.

Figure 8: GHG savings for different uses of biogas in the UK



Source: Own compilation based on Letsrecylce (2010)[35]

6.2 Production costs of conventional and advanced biofuels

In order to make the case for an advanced biofuels industry, an assessment of the current as well as predicted future production and investment costs is necessary. However, at present the costs of advanced biofuels are currently difficult to quantify as many of the technologies are still at the development or pilot phase and much information is confidential (IEA, 2011). The costs of advanced biofuels are generally higher than those of conventional production[36]

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[34] Ann Ballinger (Eunomia), March 2013, *pers comm*.

[35] These results cited in Letsrecycle (2010) are based on a study by Arcadis and Eunomia (2010) for the European Commission.

[36] Based on distillation and oil extraction

due to the increased complexity of the conversion process, for example the need to break up (ligno-)cellulose into simpler molecules before conversion to ethanol, and as yet limited economies of scale. This leads to capital expenditure (such as for the construction of new plants) becoming a more significant element of the total costs of advanced biofuels, constituting as much as 50 per cent of the overall production costs. This compares with first generation fuels where the supply of feedstock is currently the most significant cost, constituting 45-75 per cent of conventional biofuel production costs (IEA, 2011). The technology involved will also be a major factor in determining capital investment needed, as shown in Table 10. An advanced synthetic biodiesel plant is estimated to have a capital cost more than three times higher than that of a typical advanced bioethanol plant, at 2010 price levels, as well as considerably higher operational expenses and per unit costs (Deloitte, 2011). The extent of markets for co-products from advanced biofuels will also affect the overall net production costs, with naphtha, for example, becoming a major co-product of advanced synthetic biodiesel production (Neste Oil, 2012; Deloitte, 2011)

Table 10: Cost structure and capacity of some advanced biofuel plants

Advanced biofuel process	Annual feedstock input	Fuel output and co-products	Main product (ie fuel) output (tpa)	CAPEX million £ (NPV 2010)	OPEX million £ (NPV 2010)
Thermo/Biochemical ethanol: gasification with subsequent fermentation of syngas to ethanol	1m tonnes Waste	Ethanol + electricity	150,000	185	16
BtL: Gasification and catalytic conversion of syngas	0.5 m tonnes waste	Kerosene + naptha	50,000	300	20
	1.3 m tonnes woodchips	Synthetic diesel + naptha	200,000	600	32
	1.8 million tonnes waste	Synthetic diesel + naptha	200,000	600	32

Source: adapted from Deloitte (2011). **Notes**: BtL = Biomass to liquid, NPV = Net present value (at 2010 prices) tpa = tonnes per annum. The feedstock input refers to the amount required by commercial-scale plants. 'Waste' refers to municipal, or commercial and industrial waste.

6.3 Scaling the industrial potential of the resources

Translating the extent of the available feedstock resource into the potential scale of a future advanced biofuel industry is challenging. Some of the main limitations in making such assessments relate to the varying energy potentials from different biofuel pathways (and thus volumes of feedstock required) and measurement issues including the way in which industry sizes are quoted (such as energy output, volume input, area serviced, or more qualitative descriptions).

The following information is taken from existing literature sources and standardised where possible in order to provide a comparable estimate between biofuel processes and the feedstock base. Figures should be treated as indicative.

6.3.1 Current distribution of biofuel plants in the UK

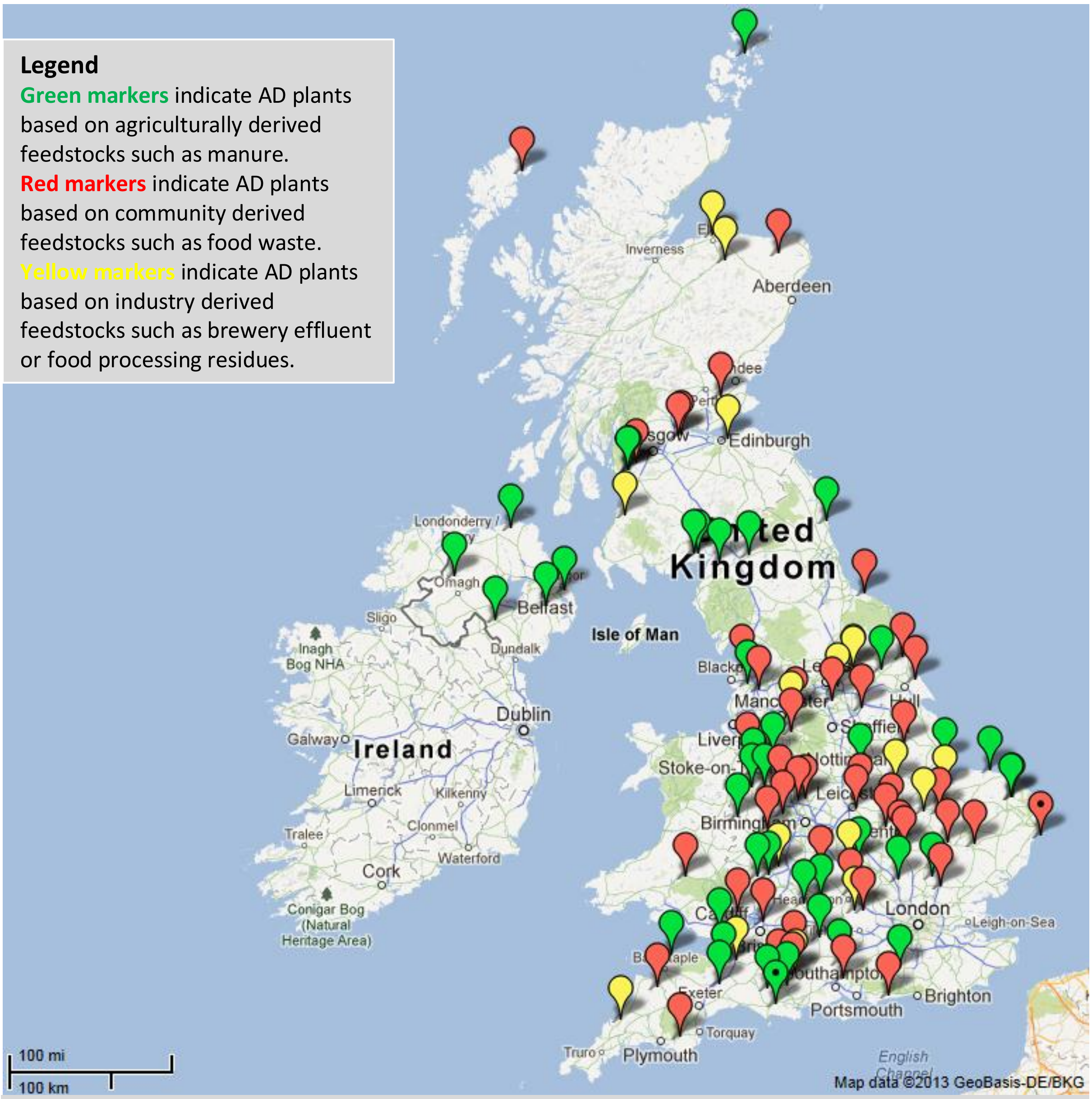
Feedstock availability is one of the major determining factors in the placement of advanced biofuel plants in the UK (see Kretschmer *et al,* 2012). For example one company, EPR energy, currently operates three power plants in the East Anglian region that run almost exclusively on straw and poultry litter generated from the large scale poultry and arable farming in the region. Amongst these is the world's largest straw fired power station (EPR Ely). Currently, the largest UK biorefineries (for bioethanol), the Ensus and Vivergo plants, are located in the North East, another wheat growing region of the country[37]. Another plant using regionally grown sugar beet is the British Sugar Biofuel Plant located in Wissington, Norfolk.

There are around 30 registered medium and large used cooking oil collectors and biodiesel producers in the UK (which may use other wastes, such as tallow, as well), producing fuel for transport as well as heat and power generation. Some of the largest producers include: Argent (Motherwell, Scotland); Harvest (Teeside); Greenergy (Immingham); Agri Energy and Convert2Green (in the North West of England) and Uptown Oil (London) (UK Sustainable Bio-Diesel Alliance, 2011).

AD plants are currently also located in relation to the feedstock involved. The larger purpose grown crop based plants are currently located in the predominantly arable areas, including Norfolk where the main feedstock used for AD is maize. However, several large AD plants are also currently sited at waste water treatment plants around the UK (Figure 9).

[37] However both these plants are currently first generation biorefineries utilising wheat grain as the feedstock.

Figure 9: Current distribution of AD plants in the UK



Only 3 of 106 plants shown are currently upgrading biogas to biomethane and injecting this into the gas grid. The remaining plants utilise biogas to generate heat and power onsite.

Source: Own compilation based on http://biogas-info.co.uk/index.php/ad-map.html

In addition to the 106 plants shown in Figure 9, there are a further 146 sewage treatment AD plants in the UK co-located with sewage treatment works near to large population centres.

The location of agriculturally derived feedstock sources is unlikely to change in the near future (certainly not to 2020) and therefore the distribution of refineries dependant on such feedstocks is likely to remain similar, as are AD facilities located near to major water treatment plants. However, exploitation of other materials on the proposed list of potential advanced biofuel feedstocks set out in the Commission’s ILUC proposal could lead to development of refineries in other locations where such feedstocks are prevalent or where development costs including land price, labour costs and financial incentives are more attractive.

6.3.2 UK biorefinery and biogas potential

UK biorefinery potential using straw

Estimates of the likely scale of advanced biofuel plants are provided in Table 10 as well as in Nattrass *et al* (2011). These suggest that around one million tonnes of raw material will be needed for biochemical or thermochemical conversion plants operating at commercial scale. Based on a UK straw availability of 0.94 to 6.99 million oven dry tonnes per year, between one and seven plants could thus be sustained. Nattrass *et al* (2011), however, judge it to be unlikely that more than one plant per technology pathway would be operational in the UK by 2020. One million tonnes of straw or any other (residue) feedstock is a large quantity of biomass that might be challenging to source in the relative vicinity of a biorefinery plant, ie the 31-50 mile radius suggested above. It also implies significant lorry transport volume in the areas of biorefinery plants and raw material sourcing.

Biogas potential using AD and a mix of feedstocks

As of September 2011, there were 214 AD facilities in the UK with the potential to process around five million tonnes of feedstock material per year[38] (WRAP and NNFCC, 2012). An additional 105 plants[39] had received planning permission at this time with a further 80 awaiting the outcome of planning permission consent. If successful, this would lead to an 86 per cent increase in the number of AD plants operating in the UK[40].

Of the 214 existing facilities 106 are sewage processing facilities with a capacity to process up to 1.1 million tonnes of sewage feedstock per year[41]; 24 are farm based facilities with the ability to process up to 200,000 tonnes of feedstock[42] (two of these are demonstrator facilities with limited processing potential); the remaining facilities are primarily industrial processing sites used to treat waste generated on-site, such as brewery effluent or food processing residues (WRAP and NNFCC, 2012).

Unlike liquid biorefineries, the commercial viability of AD plants varies enormously from small-scale plants utilising between three and five thousand tonnes of feedstock (such as food waste) per year to the Super-AD plants using 120,000 tonnes of commercial and organic food waste per year (see Box 6). Quantifying the scale of a future UK industry is therefore problematic and will depend in part on the feedstock used, the size of the plant infrastructure and whether or not the resulting products are fed into the gas grid or directly used to fuel cars (ie after upgrading to biomethane), or are used for electricity generation fed into the national electricity grid.

Currently only three of the AD plants shown in Figure 9 are converting biogas into biomethane to be fed into the national gas grid and thus generate fuel for gas-fuelled

[38] A total installed generating capacity of over 170 MW of electricity.

[39] 78 waste fed and 27 farm fed (WRAP and NNFCC, 2011)

[40] The ambition for AD uptake in the UK is significant in some sectors, for example in 2008 the National Farmers Union (NFU) proposed that 1000 AD plants should be installed on farms by 2020.

[41] the potential to generate up to 110MW of electricity per year

[42] Cattle slurries and manures; Poultry litter; Pig slurries and manures; Maize silage; Grass silage; Whole crop silage; and Fodder beet.

vehicles. The future potential to include such technology in existing and proposed AD plants would increase the scope for a UK advanced biofuel industry dependant on AD. Given the existing demand for electricity generation, however, it seems unlikely that biomethane production would prove competitive without government intervention. Additional barriers to the upgrading of biogas to biomethane come from the capital and energy costs involved as well as the very specific and stringent requirements regarding the chemical composition of the final gas before grid injection. These barriers are not insurmountable. However, biomethane production is also disadvantaged in the market at present since government financial incentives provided are only through the RHI. Furthermore, there is currently a very limited refuelling infrastructure for biomethane, limiting consumer demand.

Box 6: Small-scale to Super AD, size ranges for AD plant operations in the UK

Small-scale

In 2012, Burdens, a distributor of underground drainage and civil engineering materials, launched the first commercially viable small-scale power heat and biofertiliser AD plant in the UK. Utilising between three and five thousand tonnes of feedstock (food waste) per year the Burdens plant generates around 20 kWe to 150 kWe electricity per year plus heat and up to 100 tonnes of solid biofertiliser. It is the first digester of this size to be compliant with the Animal By Products Regulations (ABPR), which means that it can recycle general food waste, including meat. It also meets compost, soil and land use regulations (PAS100, PAS110). Small-scale plants such as this cost from £750,000 to £2 million to build.

Large-scale and 'super-AD'

In 2011 Biffa, an integrated waste management business opened the largest food waste AD plant of its kind in the UK (and Europe). Utilising up to 120,000 tonnes of feedstock (mainly commercial and industrial food and organic waste) the plant will generate up to six Mw of electricity when running at full capacity and cost an estimated £24 million to build. In 2013, and currently under construction, a 4.2 MW CHP AD plant is being built in Widnes. Once operational, the plant will handle 90,000 tonnes of commercial and domestic food waste generating enough renewable electricity to power 8,000 homes, as well as 4,000kg/hour of steam and hot water. The plant will have cost an estimated £20 million to build.

Source: own compilation

6.4 Job creation potential associated with an advanced biofuels industry

The Renewable Energy Association (REA) estimates that 400,000 renewable energy industry jobs will be required in the UK by 2020 in order to meet the target of 15 per cent of total energy derived from renewable sources (Greene and Wiley, 2012). A proportion of these will be stimulated by a growing biofuels sector but the employment opportunities will be much broader than the biofuel or energy sectors alone (Box 7). For domestic waste and residue feedstocks, collection, distribution and processing will likely form a significant component of the job creation potential, particularly where such facilities do not exist currently.

Quantifying potential employment levels in the biofuels industry is not straightforward due to such issues as the cross-over of work between various industries and the part time or temporary nature of some bioenergy related work (Forestry Commission, 2007). Certain jobs only arise during the construction phase, which may last for two years. Much supply chain work may be equally attributable to other end uses for the feedstock, such as the on-farm employment related to the collection of waste and residue feedstocks or the running of an anaerobic digestion plant used for on-site power generation as well as for transport biofuels. It is therefore difficult to estimate accurately the number of full time jobs attributable specifically to the biofuels industry. Lack of consistency and clarity in terms of methodology and units used in published research is also a source of uncertainty. For example, certain reports project the total number of individual jobs generated while others utilise the concept of 'man years' in order to evaluate part-time, temporary and full-time employment using a consistent unit of measurement (BNEF, 2010, 2012; and Novozymes, undated, are examples of the latter)[43].

Box 7: Biofuel related employment opportunities

For most biofuel production technologies there are many common roles along the various supply-chains, including manual work involved in collection of feedstocks, installation or construction of facilities, as well as employment in ongoing support functions. Examples of such work include labourers; civil works personnel; surveyors; structural engineers; quantity surveyors; electricians; plumbers; roofers; carpenters; heavy equipment operators, sheet metalworkers and security personnel.

Examples of jobs in the general administration and management of biofuel plants include: plant and operations managers, office administrators, health and safety managers, environment officers, general labourers, accountants, purchasers, marketing and logistics personnel.

Where more dedicated skills are required, architects, architectural technicians and planners are common professional roles as well as those involved in building service engineering. Indirect employment opportunities, such as roles dealing specifically with renewables in the financial and insurance industries are also emerging, along with related strategic positions in the public and private sectors.

There is also significant ongoing research and development activity being undertaken, not only within the supply chain, but also in academic institutions throughout the country. The creation of such support function jobs will not only play a key role in the development of advanced biofuel technologies, but will also be essential in ensuring the growth of the sector.

Source: adapted from Greene and Wiley (2012)

Currently, the UK liquid biofuel sector is estimated to provide between 3500 and 5300 jobs, including indirect employment in related sectors (Greene and Wiley, 2012; EurObserv'ER, 2011). This includes figures for jobs in industries for which a substantial source of work (over 20 per cent in the case of the REA figures) is in connection with construction and operation of biofuel plants and production processes. A summary of the job creation potential from different biofuel refinery processes is given in Table 11 at the end of this section.

Several reports have incorporated estimates and future projections for employment levels in the liquid biofuels sector. EurObserv'ER (2011), for example, estimates that there were approximately 150,000 jobs in the biofuel industry across the EU-27 in 2010[44]. However, its projection of one million jobs generated in this sector by 2020 (EU wide) is, by its own estimation, perhaps an 'overly optimistic' figure. It is also noted that this estimation was made prior to the Commission's proposal to cap the contribution of biofuels from food and feed crops to the EU's ten per cent renewable energy in transport target to five per cent.

Other reports have attempted to quantify the employment potential from specific types of advanced biofuel production, as detailed below:

[43] The concept of one 'man year' is equivalent to one year's full time employment for one person.

[44] Based on an assumption of 16 jobs provided per million litres of bioethanol and approximately six jobs per million litres (0.007 jobs per ton) of biodiesel or pure vegetable oil produced. This figure includes agricultural and other supply chain related employment in biofuel production.

Gasification Plants

The NNFCC (Nattrass *et al*, 2011) published estimated employment figures based on three to six operational gasification plants by 2020. These show projections for 180 to 360 full time jobs involved in plant operation, 3,000 to 6,000 jobs in plant construction and 1,060 to 1,830 jobs generated along the supply chains. This represents a total of between 4,240 and 8,190 jobs[45]. These figures are based on an assumption that per plant 60 full time jobs are involved in plant operation and 1,000 to 2,000 jobs in plant construction. These estimates are significantly higher than the figures provided for the Air Products gasification plant currently under construction (see Box 8).

Box 8: Case Study – New gasification plant in the North East

The current construction of a large gasification plant in the North East, claims it will generate 50 full time jobs once the plant is completed, as well as a further 500 to 700 jobs involved in the construction phase (Air Products, 2010). However, this particular plant, although with the potential to produce vehicle fuel, will be used solely for electricity generation in the near term. This will enable the plant to take full advantage of the Renewable Obligation Certificate (ROC) incentive scheme. The existence of such competing incentives to the RTFC scheme will perhaps lower the potential production and hence employment levels linked to advanced biofuels production. In the longer term, the Air Products gasification plant has the potential for production of hydrogen to be used as a vehicle fuel, although the commercial incentive to commence such bio-hydrogen production will be dependent on specific measures being taken to boost its development as a vehicle fuel. The higher job creation potential per plant estimated by the NNFCC could result from further assumed processes for conversion of gasification products to liquid transport fuels. Also, the collection, transportation and distribution steps involved in producing vehicle fuels are not currently relevant to the supply of electricity to the National Grid as anticipated for the Air Products plant.

Cellulosic Bioethanol Plants

The world's first operational commercial scale cellulosic ethanol plant, now in operation in Crescentino, Italy, provides approximately 100 direct full time jobs. The plant's development and operation has also led to indirect employment opportunities in the local economy which have not been quantified[46]. However, this cellulosic bioethanol plant, with a production capacity of over 50 million litres per annum, is currently reliant on a perennial energy crop as its primary feedstock, despite a certain amount of wheat straw and other residues being utilised. Another commercial cellulosic bioethanol plant is due to commence operations later this year in Kansas, utilising similar enzymatic and fermentation technology to the Crescentino plant, but with double its production capacity (100 million litres ethanol per annum). The majority of feedstock will be sourced from arable residues, with corn stover providing 82 per cent of the total in this predominating corn-growing region of the US. According to the plant's operator, 88 jobs were due to be created in the construction phase (Robb, 2009) and once operational, the plant is projected to create a total of 65 full time permanent jobs[47]. The above example of two bioethanol plants illustrates the lack of proportionality between biofuel plant capacity and associated employment level (there should be more proportionality in feedstock collection).

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[45] Figures are quoted for three and six operational plants, respectively.

[46] 'Beta Renewables Cellulosic Ethanol Biorefinery, Crescentino, Italy', http://www.chemicals-technology.com/projects/mg-ethanol/

[47] http://www.abengoabioenergy.com/web/en/acerca_de/oficinas_e_instalaciones/bioetanol/eeuu/kansas/index.html

UCO derived biodiesel
The UK Sustainable Bio-Diesel Alliance (2011) estimates that the UCO based collection and biodiesel production industry employs approximately 1,000 to 1,200 people. For example Convert2Green, the UK's fourth largest biofuel producer, collects and refines and distributes around 10 million litres of UCO a year providing 39 'direct' jobs. Based on the current estimated volume of UCO used for biofuel production (0.082 Mt) this would equate to approximately 363 direct jobs in the present industry. With the potential UCO increases identified in section 5.2 this figure could rise to between 790 and 1,200 'direct jobs' under the same business structure as seen currently.

Biomethane from Anaerobic Digestion (AD) Plants
The AD industry, also relevant to the production of biofuel in the form of biomethane, currently provides an estimated 2,650 full time jobs in the UK and could become an increasingly significant source of employment in the UK should potential industry growth be realised (Greene and Wiley, 2012). The Government estimates that 35,000 new jobs can be created from the growth of the AD Industry alone (DECC and Defra, 2011). This would, however, require a fourteen fold increase in employment, as compared to 2010/2011 levels, according to industry figures (Greene and Wiley, 2012).

Although a proportion of these AD industry jobs will be attributable to the production and supply of biomethane for the transport industry, including for example, the specialised engineering jobs involved in the dual-fuel truck industry, it is likely that much AD capacity will be utilised for on-site heat and energy production for on-farm use as well as electricity generation to be fed into the electricity grid. Currently, 249 out of the total 252 AD plants in the UK are utilised for such non-transport related purposes. Consequently, for AD derived biofuels the job creation figure will likely be much lower than 35,000. The level of potential employment in the transport related areas of the biomethane industry will depend on the development of a refuelling infrastructure and the scale of uptake by road freight vehicle fleets as well as the level of fiscal incentives provided for this specific option for biogas use.

Employment across the biofuel sector
Aside from the number of jobs generated, Deloitte (2011) highlights the benefits to the economy from the high value employment opportunities in this sector with an estimated potential benefit to the economy of up to £176 million (undiscounted) due to the likelihood of higher than average wages in the advanced biofuels sector.

However, the difficulties in estimating such an aggregate effect on the economy are highlighted in a report on the economics of the EU biofuel industry (Charles *et al*, 2013). One challenge is the lack of reliable data particularly for indirect employment relating to biofuels. The report points to the question of *additionality* in employment levels and argues that many of the farm based agricultural jobs relating to biofuel supply chains would still exist without the biofuel industry. It also points to a *substitution effect*, whereby many jobs along the biofuel supply chain are simply displacing jobs in other sectors such as the petro-chemical industry. The report acknowledges that despite this, some net economic and employment benefit can be gained by future development of the biofuel industry but this is likely to be insignificant and will depend on numerous assumptions being realised.

The total employment levels in the UK advanced biofuels industry will therefore depend greatly on the speed and extent to which the industry emerges and the technologies chosen. This will in turn depend on the nature and level of Government subsidies, with the continued existence of competing incentives for electricity production as opposed to the use of bio-resources for vehicle fuels a critical issue. Political decisions on the allocation of the resources either to liquid fuels or to other forms of bioenergy will tip the balance, but there is the opportunity to create new jobs on either pathway. Summed together, the job creation estimates range from in the order of one thousand to more than ten thousand. If there were an active programme to promote advanced biofuels, the total number of jobs in the biofuel sector may more than double.

Table 11: Summary of job creation estimates

Industry	Total Jobs	Timeframe	Comments
Liquid biofuel sector	3,500 – 5,300	Current	Current employment in the UK liquid biofuel sector including indirect employment in related sectors.
Three to six operational gasification plants	4,240 – 8,190	2020	Plant operation, construction and along the supply chain. The majority of jobs (3,000 – 6,000) are in the construction phase.
Anaerobic digestion	Up to 35,000	2020	Not all of these jobs will be in relation to transport fuels. Achieving this figure would require a 14 fold increase in employment compared to 2010/11.
Cellulosic ethanol	100-153	Current - 2020	Direct jobs **per plant**, derived from the two examples of cellulosic ethanol plant discussed in this section. The higher figure includes 88 construction phase jobs (Robb, 2009) in addition to the 65 permanent jobs cited by Abengoa.
UCO related	1,200	2020	Direct jobs in transport fuels. There will be other jobs associated with this part of the sector.
Renewable Energy total	400,000	2020	Estimated by the REA to meet 15% Renewable Energy targets in the UK.

Source: own compilation based on references cited in the above text. **Note**: This table summarises the different estimates available. Some of these are per plant, some related to biofuels directly and others per sector, as explained in the commentary and the main text. Due to their different nature, they cannot be summed up.

7 CONCLUSIONS

The aim of the report is to review the potential to decarbonise the UK transport sector by moving away from conventional biofuels based on food and feed crops towards sustainable alternative biomass sources.

It is clear from the existing body of studies that no 'quick fix solution' will ensure decarbonisation of the transport sector. The capacity of conventional biofuels to deliver substantial GHG savings increasingly is being questioned. The uptake of electric vehicles has been relatively slow and estimated to remain limited up to 2020 and other alternative fuels, such as hydrogen, are not likely to be deployed on a large scale in the short to medium term. Therefore, a mix of responses is required, including reduction in transport demand, improving energy efficiency of vehicles, influencing vehicle use and decarbonising transport fuels.

Sustainable biomass wastes and residues clearly can and should be part of this solution. This report has focused on certain waste streams (food waste, green waste, the non-segregated biological fraction of MSW), manure, sewage sludge, straw, used cooking oil and certain woody biomass residues since they are considered potentially sustainable feedstocks. With a wide range of existing uses for most of these feedstocks, clear environmental safeguards will be needed to prevent perverse environmental and social outcomes.

While the volume of some of these materials could be increased, for others, particularly some wastes, it will fall. Only a portion of the potential flow of these materials should be allocated to biofuel production, given the value of many other uses. For this and other reasons, there are considerable uncertainties over the precise volumes and energy values of the feedstocks that could be deployed sustainably in the UK for biofuel production. Given the pressure to respond to 2020 targets, more work on this is required as a matter of urgency, taking account of economic drivers, competing uses, sustainability imperatives and other factors.

Our own survey of five categories of feedstocks suggests that biofuels from wastes and residues could contribute between 31.1 and 129 per cent to total UK biofuel demand in 2020; or 3 to 13 per cent of total UK transport energy demand in 2020. However, these figures are driven by the feedstock availability estimates; additional constraints that could not be studied in detail here would reduce them. In particular, a realistic gauge of the investment in biorefinery capacity likely to occur over the short time span remaining until the end of 2020 would be needed. Previous work taking into account such projections suggested that advanced biofuels could contribute between 1.3 and 2.6 per cent to total UK road and rail transport energy demand in 2020 (Nattrass *et al*, 2011).

Utilising biomass resources to decarbonise the UK transport sector has significant potential, and the use of sustainable biomass wastes and residues can be part of this solution, both in the direct production of transport fuels (liquid and gaseous) as well as in providing renewable electricity generation potential to decarbonise the UK grid and (indirectly) fuel a future electric vehicle fleet. There is also considerable value in fostering the use of wastes and residues to create jobs within the UK. This is particularly the case for the AD industry where anaerobic digesters are widely distributed across the country, including in rural areas.

There is therefore a case for the UK Government to enhance efforts to ensure sustainable mobilisation of wastes and residues and we suggest a mix of responses including:

- Supporting appropriate changes in EU policy to encourage ***a shift from conventional biofuels towards appropriate advanced biofuels*** from wastes and residues;

- ***Formulating clear safeguards*** to accompany the use of wastes and residues in the transport sector, especially in the absence of safeguards formulated at EU level as part of the current process of amending the Renewable Energy Directive. A key safeguard is to put in place the correct carbon accounting framework for wastes and residues, taking appropriate account of changes in soil carbon stocks (eg in relation to the extraction of straw). The formulation of such safeguards would benefit from cross-departmental coordination to ensure that waste policy goals in particular are not compromised.

- ***Commissioning research to enhance understanding of:***

  - ***priority uses for wastes and residues,*** taking into account the market situation in the UK with regard to domestically available supply and existing (energy and non-energy) uses. This will help to establish more reliable estimates of the amount of wastes and residues that could be available for the transport sector. While we have identified the feedstocks which potentially seem most sustainable, their conversion into biofuels or into biomethane might not constitute the most 'sustainable' use, for instance in terms of overall GHG emissions avoided;

  - ***the sustainable level of straw and woody residue extraction rates.*** Understanding regional, local and even field level conditions is necessary to refine analysis of the available extraction potential and inform policy. Regional level resource assessments appear best suited to assess available resources and existing demand and hence enable a sensible siting of biofuel production capacity;

- ***Cross sectoral advice*** to promote the sustainable sourcing and processing of wastes and residues. Cooperation across Government departments working on sectoral (agriculture, forestry, waste) policies and setting incentives under renewable energy and transport policy is required to ensure policies in different sectors are complementary. This should result in useful advice for the different sectors and actors and trigger cooperation among, for example, farmers, forest owners, waste processors and biofuel or AD plant operators;

- ***Overcoming existing barriers to collection and mobilisation of key resources***. This will require a joint response by actors from multiple sectors and therefore will need to be an important element of both cross sectoral policies and practical operations. Existing expertise in collection and harvesting infrastructure could be drawn upon (for example bailer associations in the case of straw);

- ***Providing investment support*** to promote new technologies in the area of advanced biofuels processing. This is likely to include capital support for new installations as well as support for the development of existing infrastructure. This will help to increase advanced biofuel processing capacity and reap benefits from technological learning in order to reduce the costs of new technologies.

Initiatives in these directions will be necessary not just to support the emergence of an advanced biofuels industry for transport but also to create an appropriate path for the wider biofuels and biomass utilisation industry. There is an opportunity to capture multiple benefits by generating more renewable energy, enhancing technological know-how, and creating economic benefits including a significant number of new jobs by putting currently under-utilised wastes and residue resources to productive uses. Provided that safeguards are implemented, environmental benefits will accrue from moving away from conventional biofuels in decarbonising the UK's transport sector.

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ANNEX 1 LIST OF WASTES AND RESIDUES ELIGIBLE FOR QUADRUPLE AND DOUBLE COUNTING AS PROPOSED IN THE ILUC PROPOSAL

The following is the list of feedstocks eligible for double and quadruple counting as contained in Annex IX of the proposal.

Feedstocks whose contribution to the 10% renewable energy in transport target is proposed to be counted ***four times*** their energy content:

(a) Algae.

(b) Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under Article 11(2)(a) of Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

(c) Biomass fraction of industrial waste.

(d) Straw.

(e) Animal manure and sewage sludge.

(f) Palm oil mill effluent and empty palm fruit bunches.

(g) Tall oil pitch.

(h) Crude glycerine.

(i) Bagasse.

(j) Grape marcs and wine lees.

(k) Nut shells.

(l) Husks.

(m) Cobs

(n) Bark, branches, leaves, saw dust and cutter shavings.

Feedstocks whose contribution to the 10% renewable energy in transport target is proposed to be counted ***twice*** times their energy content:

(a) Used cooking oil.

(b) Animal fats classified as category I and II in accordance with EC/1774/2002 laying down health rules concerning animal by-products not intended for human consumption.

(c) Non-food cellulosic material.

(d) Ligno-cellulosic material except saw logs and veneer logs.

ANNEX 2 DETAILED FIGURES ON THE COMPOSITION OF WASTE IN ENGLAND

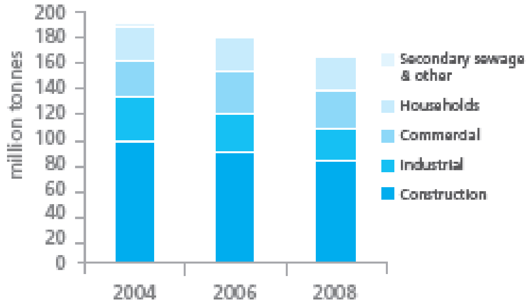
Waste in England

Total waste generation

A total of 165.1 million tonnes of waste were generated in 2008 by households, commercial & industrial businesses and the construction sector. This is a decrease from 191.9Mt in 2004 and 180.5Mt in 2006.

The largest contributing sector was construction, demolition and excavation which generated 81.4Mt of waste.

Source: Defra – Waste Statistics Regulation return to Eurostat, 2004 to 2008



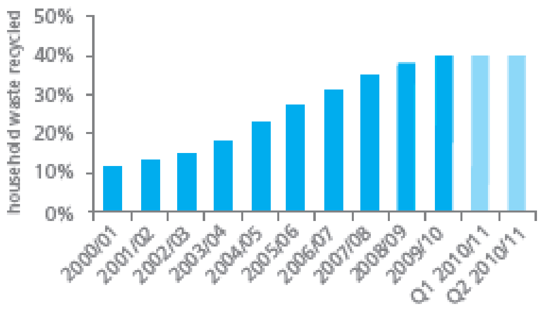
Household waste recycling

A total of 23.4 million tonnes of household waste were generated in the year to September 2010.

Of this, 40.3 per cent was recycled, re-used or composted. This is an increase from 39.7 per cent in 2009/10.

Per person, this equates to 452kg of waste generation per year, of which 182kg was recycled, composted or re-used.

Source: Defra



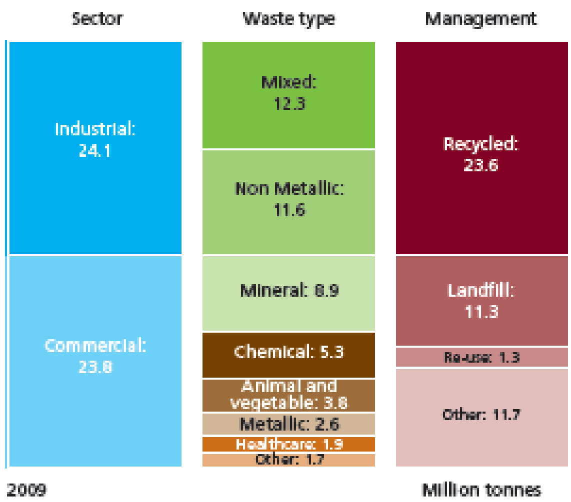
Commercial & Industrial Waste

In 2009, 47.9 million tonnes of waste were generated by businesses. The industrial sector accounted for 24.1Mt and the commercial sector 23.8Mt.

Estimates show that 52 per cent of C&I waste was recycled or re-used and 24 per cent was sent to landfill.

Small enterprises, with between 0 and 49 employees, produced 16.6 million tonnes of C&I waste in 2009, or 35 per cent of total C&I waste.

Source: Defra



These are the most recent waste statistics available. Waste data is compiled from a number of data sources over differing periods, mainly to reflect existing policy measures. Therefore the data in these charts is not strictly comparable, and may show apparent inconsistencies. The latest data is always published at www.defra.gov.uk/statistics/environment/waste.

Source: Defra (2011, p17)