The potential contribution of bioenergy to Scotland's energy system

Report for ClimateXChange
IQ11-2018

ED 11677 | Issue Number 5 | Date 27/02/2019

Customer:

ClimateXChange

Customer reference:

IQ11-2018

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27 February 2019

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Ref: ED11677- Issue Number 5

Executive summary

The Scottish Energy Strategy, published in December 2017, sets out the Scottish Government's vision for a flourishing, competitive energy sector, delivering secure, affordable, clean energy for Scotland's households, communities and businesses. The Strategy was ambitious about what can be achieved in Scotland, stating that 50% of all energy consumed in Scotland is to come from renewable sources by 2030, and set out a range of actions to be taken forward to achieve this. One of these was a commitment to developing a bioenergy action plan.

This study forms one of the first steps in the development of the bioenergy action plan, setting out an evidence base on the nature and quantities of biological resources within Scotland that could be used for bioenergy, and the conversion technologies that could be deployed to utilise them. The study is based on the best available data from the literature at the time the study was carried out and information from consultation with a number of key stakeholders.

The focus of the report is on Scottish rather than imported biomass resources, as use of the former will generally bring additional economic benefits due to the added value delivered through development of local fuel supply chains. The timescale of the report is to 2030 to reflect the focus within the Energy Strategy on near term actions.

Bioenergy already contributes to energy supply in Scotland, meeting an estimated 4.4% of final energy demand in 2016. This was achieved through a number of bioenergy conversion technologies utilising a range of bioresources. These included dedicated biomass power plants, combined heat and power plants and boilers using bioresources such as wood, straw, poultry litter, and anaerobic digestion (AD) plant. These digest food wastes, wastes and by products from the food and drink industry, together with animal wastes and energy crops, to produce biogas which is then converted to electricity and heat, or biomethane for injection to the grid. The addition of biofuels (biodiesel and bioethanol) to petrol and diesel supplied to road transport in Scotland also contributed to this overall supply. While some of this bioenergy production utilised domestic bioresources, there were also some imports, for example wood pellets and bioethanol, which are not produced in Scotland.

Increasing the contribution that bioenergy makes by 2030 would require additional bioenergy plant to be built and deployed within the next decade. A high level assessment of bioenergy technologies that could be suitable for use in Scotland suggests that the available domestic bioresource in 2030 should be sufficient to support most types of conversion plant which are already commercially deployed, such as biomass boilers, biomass combined heat and power plant, and anaerobic digestion plant. Although for technologies which are of a medium or large scale (e.g. energy from waste, dedicated biomass plant) there may only be enough resources to support only a few plant.

Based on typical capital, operating and feedstock costs, all of the bioenergy conversion technologies considered produce energy or fuel at a price that is higher than that produced by conventional technologies, based on current fossil fuel prices. Therefore, as has historically been the case, bioenergy is unlikely to be viable commercially without some form of financial support. The exception is Energy from Waste, where the gate fee for waste is a significant income stream, which reduces the cost of power produced.

While the estimates of domestic bioresources suggest that several additional anaerobic digestion plant are technically feasible, utilising the resource fully is likely to require the use of a mixture of feedstocks in some plant. This can potentially be a barrier to development, particularly for smaller schemes, as regulatory compliance becomes more complex and onerous. In the case of biomass

boilers, there are concerns over the impact on air quality in urban areas from their deployment. The impact can be minimised by utilising larger scale boilers (e.g. for district heating) which can include pollution abatement equipment to minimise emissions of particulate matter. There is less of a concern in rural areas, where small scale boilers could be deployed without such a significant impact on air quality.

In addition to those technologies already commercially deployed, there are a number of more advanced conversion technologies such as gasification for power or to produce synthetic natural gas and advanced biofuels production. These technologies could be commercially proven by 2030. These more advanced plant are typically fairly large scale (greater than 15 MW capacity) and so a single plant has quite large investment and feedstock requirements.

In terms of feedstocks for new bioenergy plant, this study suggests that bioresources equivalent to 6.7 TWh per year (in primary energy terms)[1] are currently used for bioenergy purposes. Just over three-quarters of this is wood, mainly from the forestry sector either as small roundwood, or processing residues from sawmills, but also waste wood and wood from the management of trees outside of the forest sector (e.g. in parks). More minor resources include tallow, food waste, poultry litter, used cooking oil, sewage sludge, animal manures and by-products/wastes from the whisky and dairy industry.

Looking at the overall availability of the bioresources, it is estimated that after allowing for competing uses of some bioresources in other sectors of the economy, there is another 5.3 TWh per year (of primary energy), that is currently not collected or is disposed of as waste, that could potentially be utilised for bioenergy. The main bioresources where current information suggests that there is scope for further use for bioenergy are straw, animal manures, forestry brash (the tops and branches of felled trees) residual waste, waste wood, food waste, sewage sludge, and by-products/waste from the whisky industry. The estimate of 5.3 TWh relates to the quantities of resource potentially available, and although some are available at relatively low cost, it is also necessary to take into account the cost of suitable conversion technologies when assessing whether it is desirable to use these resources for bioenergy The amount of energy that can be delivered from these additional bioenergy resources will depend on the conversion technologies used to utilise them, and the efficiency with which they convert the bioresource to heat, electricity or fuel.

Looking to the future, it is estimated that by 2030, further bioresources equivalent to 2 TWh per year (of primary energy) could be available. This is mainly due to increases in production from forestry as current forests mature, which leads to an increase in the availability of processing residues from sawmills as well as an increase in the availability of small diameter timber from the forest. The remainder (0.7 TWh per year) comes almost entirely from the cultivation of perennial energy crops such as willow, grown as short rotation coppice, and Miscanthus a woody grass.

[1] For context this is 4.7 % of **final** energy consumption in Scotland in 2016.

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1 Introduction

The Scottish Energy Strategy, published in December 2017, sets out the Scottish Government's vision for a flourishing, competitive energy sector, delivering secure, affordable, clean energy for Scotland's households, communities and businesses. It describes the ways in which the Scottish Government will take a whole systems approach across heat, transport and electricity. There was also an emphasis on the ability to strengthen the development of local energy, protect and empower consumers, and support Scotland's climate change ambitions while tackling poor energy provision.

The Strategy was ambitious about what can be achieved in Scotland, stating that 50% of all energy consumed in Scotland is to come from renewable sources by 2030. Importantly it also set out the social, environmental, economic and commercial benefits for Scotland of decarbonising the energy system.

The Strategy established six strategic priorities, which place a focus on the areas which the Scottish Government is able to affect:

1. **Consumer engagement and protection:** working to protect consumers from excessive and avoidable costs
2. **Champion Scotland's renewable energy and low carbon potential** by continuing to explore the potential of Scotland's huge renewable energy resource
3. **Improve the energy efficiency** of Scotland's homes, buildings, industrial processes and manufacturing through actions to improve the use and management of energy
4. **Support oil and gas industry strengths** – supporting innovation and diversification in these sectors
5. **Maintain secure, resilient and flexible energy supplies** to all homes and businesses throughout the energy transition
6. **Empower communities** by supporting innovative local energy systems and networks

The focus in the Strategy is on the near term, in part due to the pace of technological change within the energy system, and sets out a range of actions to be taken forward. One of these was a commitment to developing a bioenergy action plan. Bioenergy already contributes to energy supply in Scotland and has the potential to play an important role in low carbon energy systems in the longer term. However, it is important to ensure that use of biological resources for the production of energy does not have other adverse environmental impacts or harmful impacts on other sectors of the economy. The Energy Strategy sets out the following guiding principles for the Scottish Governments approach towards bioenergy:

- Policies to support bioenergy are consistent with the ambitions laid out in the Strategy, and with Scotland's Climate Change Plan and land use strategy.
- Bioenergy schemes deliver greenhouse gas emission reductions that help meet Scotland's climate change targets.
- Bioenergy schemes represent good value for money, deliver benefits for communities, and help tackle fuel poverty.
- Biomass is produced and managed in a sustainable way, and should be used in heat-only or combined heat and power schemes to exploit available heat and local supply.
- Demands on land for food, energy crops and other non-food crops are managed equitably.

This study forms one of the first steps in the development of the bioenergy action plan, setting out an evidence base on the nature and quantities of biological resources within Scotland that could be used for bioenergy, and the conversion technologies that could be deployed to utilise them. Information for this study has been drawn from both a literature review and consultation with a range of key stakeholders (Appendix 1).

The focus of the report is on domestic Scottish, rather than imported, biomass resources, as use of the former will generally bring additional economic benefits due to the added value delivered through development of local fuel supply chains. The timescale of the report is to 2030 to reflect the focus on near term actions.

The report first examines the current contribution of bioenergy to the energy consumed in Scotland, and the future trends in energy consumption (**Section 2**). It then goes on to assess the range of bioresources in Scotland that could potentially be used for bioenergy, looking at their availability both now and in 2030, and taking into account demands for the resource by other sectors of the economy **Section 3**). This section also gives a high level assessment of the suitability of the resources for use for bioenergy taking into account other factors such as costs, logistics environmental considerations and impact on carbon emissions. A more detailed analysis of carbon emissions and environmental issues is given in **Section** Error! Reference source not found.. Finally, **Section 5** contains a high level assessment of key bioenergy conversion technologies which could potentially be deployed in Scotland to 2030.

More detailed supporting information on bioresources and bioenergy conversion technologies are contained in Appendices 2 and 3 respectively.

2 Contributing to energy consumption

2.1 Current bioenergy use

2.1.1 Electricity generation

Electricity is currently generated from a number of bioresources (Table 2.1):

- Combustion of biomass in dedicated biomass plant generated about two-thirds (67%) of electricity from bioresources in Scotland in 2017. This was predominantly from the combustion of wood, although other materials such as municipal waste, draff (a by-product from the whisky industry) and poultry litter were also burnt.
- Combustion of landfill gas accounted for about 20% of electricity from bioresources in Scotland in 2017. Landfill gas is produced as waste degrades in landfill and can be captured and burnt in gas engines at the landfill site. Generation from landfill gas is declining as the quantities of waste sent to landfill have declined over recent years, reducing the amount of landfill gas that is produced. It will continue to decline further due to the forthcoming ban (in 2021) on disposal of biodegradable waste to landfill[2].
- Combustion of biogas produced in anaerobic digestion (AD) plant accounted for about 10% of accounted for about 20% of electricity from bioresources in Scotland in 2017. AD plant use a variety of feedstocks ranging from food waste, to distillery wastes and energy crops grown specifically for AD (e.g. rye or maize). A small amount of electricity (2%) was produced from biogas produced by the anaerobic digestion of sewage sludge

Generation from bioenergy in Scotland grew significantly between 2016 and 2017, due to increases in the number and capacity of AD plant and biomass combustion plant.

Table 2.1 Electricity generation from bioresources in Scotland

Technology	No. of sites		Generation Capacity (MW)		Electricity generated (GWh)	
	2016	2017	2016	2017	2016	2017
Biomass	37	61	226	251	1234	1485
of which						
Plant biomass			*196*	*221*		
Energy from waste			*18*	*18*		
Animal by-products			*13*	*13*		
Landfill gas	46	49	116	116	493	445
Anaerobic digestion	47	54	40	45	167	220
Sewage sludge	8	8	7	7	32	36
Total	138	172	390	419	1925	2187
Increase 2016 to 2017		25%		7%		14%

Sources: BEIS Regional Renewable Statistics and BEIS Energy Trends[3]

[2] Waste (Scotland) Regulations 2012

[3] https://www.gov.uk/government/statistics/regional-renewable-statistics and https://www.gov.uk/government/collections/energy-trends. Accessed 21/11/2018

Electricity generation from bioresources has historically been supported through the Renewables Obligation (Scotland) (ROS), which is now closed to new applicants, and for smaller plant (AD schemes only up to 5 MW), Feed-in-Tariffs (FiT), These will close to new applicants in March 2019. A successor scheme, Contracts for Difference (CfD) for generation over 5MW opened for applications in 2014. The CfD includes two groups of technologies, established (pot 1) and less established (pot 2). Several bioenergy technologies are included in each pot. The draft budget for the third allocation round has recently been announced and will be for pot 2 only; including for bioenergy advanced conversion technologies, anaerobic digestion over 5 MW and dedicated biomass with combined heat and power. Under the CfD a generator receives payments for the difference between a 'strike price' - a price for electricity reflecting the cost of investing in a particular technology - and a 'reference price' a measure of the average market price for electricity in the market. The auction process uses competitive bidding between different technologies, so the strike prices offered by generators need to be competitive.

2.1.2 Heat Production

The main source of heat from bioresources is from biomass boilers, predominately utilising wood pellets, chips or logs, although some operate on other fuels such as straw. There are an estimated 6,666 boilers in Scotland, the majority of which these (over 90%) are smaller boilers in the domestic and commercial sector. However, the majority of the heat output (81%) comes from a more limited number of larger boilers in the commercial and industrial sectors[4].

Table 2.2 Heat production from bioresources in Scotland (2016)

Heat technology	Capacity MW	% of total capacity	Heat produced GWh	% of heat output
Biomass boiler	1,030	68%	2,504	73.6%
Biomass combined heat and power	401	27%	555	16.3%
Anaerobic Digestion*	65	4%	272	8.0%
Energy from waste	13	1%	67	2.0%
Landfill gas	1	0.1%	2	0.1%
Total	**1,510**		**3,400**	

* Includes heat from biogas combined heat and power plants and biomethane produced by upgrading biogas, which is injected into the natural gas grid

Source: Energy Saving Trust, 2017: "Renewable Heat in Scotland, 2016"

The production of heat from biomass has increased significantly over the last few years, due mainly to the introduction of the Renewable Heat Incentive in 2011 for non-domestic buildings and 2014 for domestic buildings. This provides a payment to the operator for each unit of renewable heat generated, or biomethane injected to the grid, for seven years for domestic installations and twenty years for non-domestic installations. This has led to the biomass boiler and CHP capacity in Scotland more than tripling between 2012 and 2016[5].The UK government has allocated funding to the scheme until March 2021, so it is likely that installations of bioenergy heating schemes will continue to increase until that time.

[4] Woodfuel Demand and Usage in Scotland: 1st Jan 2016 – 31st Dec 2016, Report produced for Forestry Commission Scotland by Energy Saving Trust

[5] Based on data from Energy Saving Trust, 2017: "Renewable Heat in Scotland, 2016" and Energy Saving Trust, 2014: Renewable Heat in Scotland, 2013.

2.1.3 Transport Fuels

The use of renewable transport fuels in Scotland is driven by the obligations at a UK level (the Renewable Transport Fuels Obligation, RTFO), which require fuel suppliers above a certain size to ensure that a specified proportion of their supply (by volume) comes from biofuels. In 2016/17, 3% of fuels used for road and non-road mobile machinery fuel by volume came from biofuels. As biofuels have a lower energy density than fossil fuels this was equivalent to 2.5% in energy terms. The fuels supplied were mainly bioethanol, which was added to the petrol supply and biodiesel FAME[6] added to the diesel supply, with small volumes of biomethanol, off-road biodiesel, hydrotreated vegetable oils (HVO) and biomethane (Table 2.3). Only 27% (by volume) of biofuels consumed were supplied from the UK, with the remainder supplied mainly from Europe and the US. Scotland has a biodiesel production plant producing biodiesel FAME from tallow, used cooking oil and other waste oils and greases, but there is no bioethanol production in Scotland. The capacity of the Scottish biodiesel plant is roughly equivalent to the estimated current consumption of FAME in Scotland.

Table 2.3 Biofuels supply in 2016/17

	UK		Scotland[a]		Percentage of supply	
	million litres	GWh	million litres	GWh	Volume basis	Energy basis
Biodiesel FAME[b]	721	6606	61.1	560.5	47%	58%
Biodiesel HVO[b]	1	12	0.1	1.0	0.1%	0.1%
Bioethanol	758	4421	64.3	375.1	49%	39%
Biogas	1	9	0.1	0.8	0.0%	0.1%
Biomethanol	57	254	4.9	21.6	4%	2%
Off road biodiesel	3	23	0.2	2.0	0.2%	0.2%
Total	1540	11324	131	961	100%	100%

Notes:
[a] Estimated consumption in Scotland based on data from sub-national energy statistics that road transport in Scotland accounts for 8.5% of UK road transport fuel consumption
[b] FAME is Fatty Acid Methyl Ester and as it has slightly different properties to conventional diesel can only be added to diesel at up to 7% by volume without affecting the vehicle warranties. HVO is hydrotreated vegetable oil, which has similar properties to conventional diesel and can be used as direct replacement i.e. there are no blending limits

Source: RTFO Year 9 Report 6

2.1.4 Overall contribution of bioenergy in Scotland

Based on the data above it is estimated that bioenergy supplied 4.4% of final energy needs in Scotland in 2016 (Table 2.4).

Table 2.4 Overview of bioenergy use in Scotland in 2016

	GWh	Equivalent to:
Electricity generated	1,925	9.4% of electricity consumed
Heat produced	3,400	5.0% of fuels consumed for heating (excluding electricity)
Biofuels for transport	961	2.5% of transport fuels (excluding electricity)
Total	**6,286**	**4.4% of final energy consumption (including electricity)**

[6] FAME is Fatty Acid Methyl Ester and as it has slightly different properties to conventional diesel can only be added to diesel at up to 7% by volume without affecting the vehicle warranties.

2.2 What role could bioenergy have in the energy system in 2030

In identifying where bioenergy might effectively be used in the future energy system to help reduce carbon emissions, it is instructive to consider the trend of future energy demand, to capture future trends, both in the overall demand for energy, and in changes in the types of energy required. For example, moves toward the electrification of vehicles will increase demand for electricity and reduce demand for liquid transport fuels. Over a similar timeframe the use of heat pumps to heat homes and businesses will also increase demand for electricity while reducing demand for other heating fuels such as gas and oil. Given that the lifetime of most bioenergy plant will be at least 15 years and possibly as much as 30 years for some larger plant, it is important to look not only at changes in energy trends to 2030, but to also consider the longer term.

Overall demand for energy will also be affected by the extent to which consumers can use energy more efficiently, and businesses can improve the productivity of their processes to squeeze out more activity from every unit of energy used. Scotland has a target to reduce total final energy consumption by 12% from a 2005-2007 baseline and achieved this target six years early; by 2016 the target had been significantly exceeded, with a 15.4% reduction from the baseline[7]. More recently the Energy Strategy set a new target of increasing the productivity of energy use across the Scottish Economy by 30% by 2030. In May this year, the Scottish Government published its route map for the Energy Efficient Scotland programme, which set out the detail on how the domestic and non-domestic sectors will become more energy efficient.

2.2.1 Future electricity and heat demand

The scale of energy demand change to 2030 remains subject to some uncertainty. For example, National Grid have developed four Future Energy Scenarios, reflecting differing degrees of ambition regarding decarbonisation of the economy, and the level of decentralisation of renewables, which are intended to illustrate a range of possible outcomes for the energy system8. These highlight that overall electricity and gas demand could reduce by between 9 and 29 per cent between now and 2030, with modest changes in electricity demand (Figure 2.1), and more substantial movements in the demand for gas (Figure 2.2). In the longer term (to 2050) electricity demand rises as electrification of the vehicle fleet and heat progresses, and gas demand continues to fall due to the rise of other low carbon generation technologies and electrification of heating. However even in the most ambitious decarbonisation scenarios (Two Degrees and Community Renewables) there is still a role for other fuels in the provision of heat (Figure 2.3) and in the transport sector.

‘

[7] Energy Statistics for Scotland Q2 Figures, September 2018. Available at https://www2.gov.scot/Resource/0054/00541525.pdf; accessed 21/11/208

[8] See http://fes.nationalgrid.com/

Figure 2.1 Future electricity demand under National Grid's Future Energy Scenarios

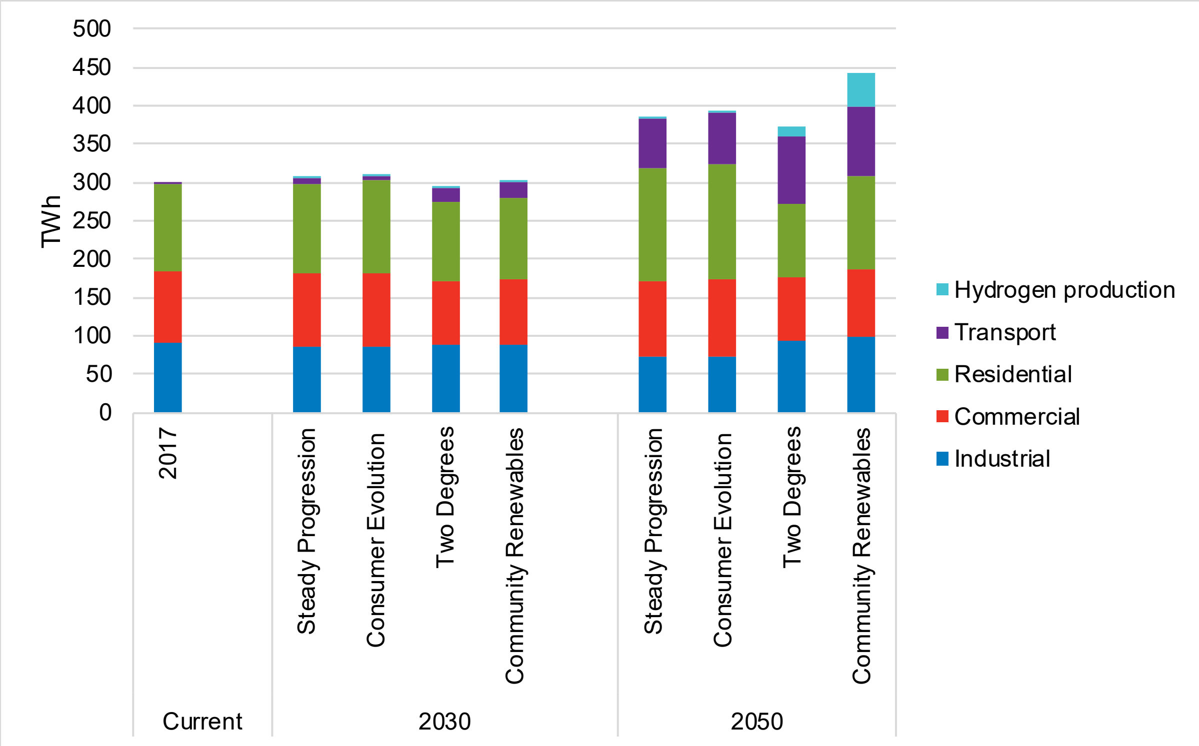


Figure 2.2 Future gas demand in the National Grid's Future Energy Scenarios

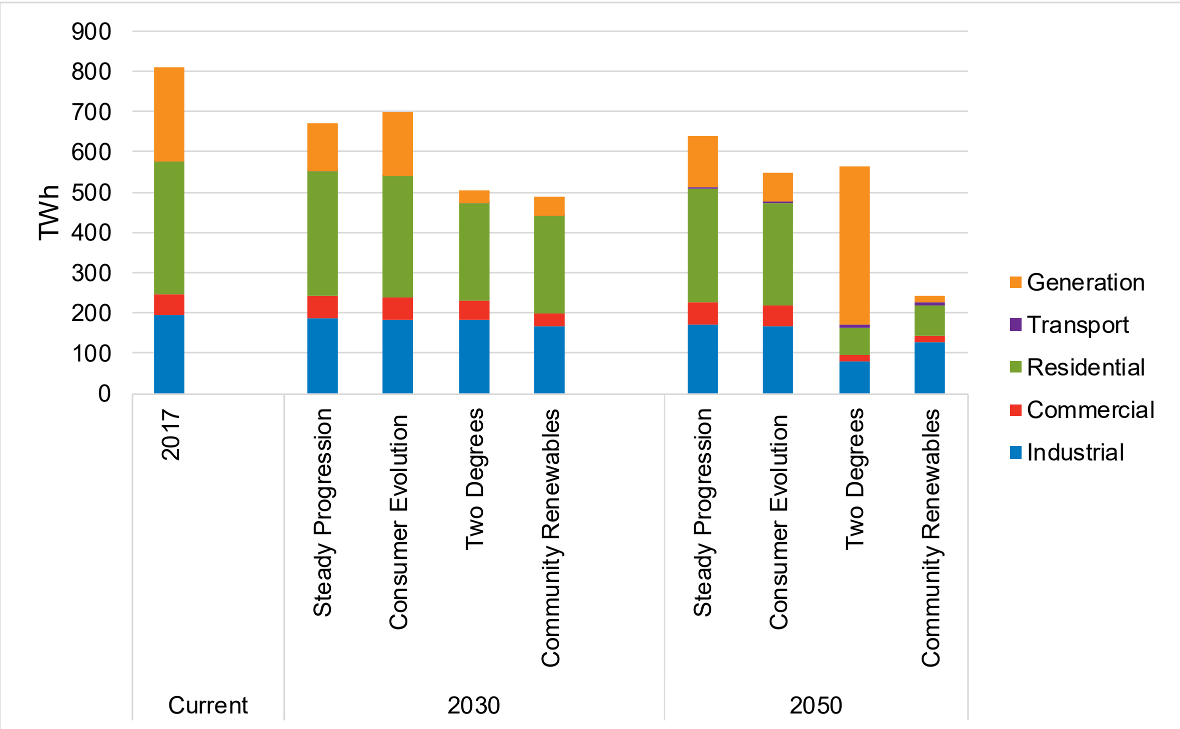
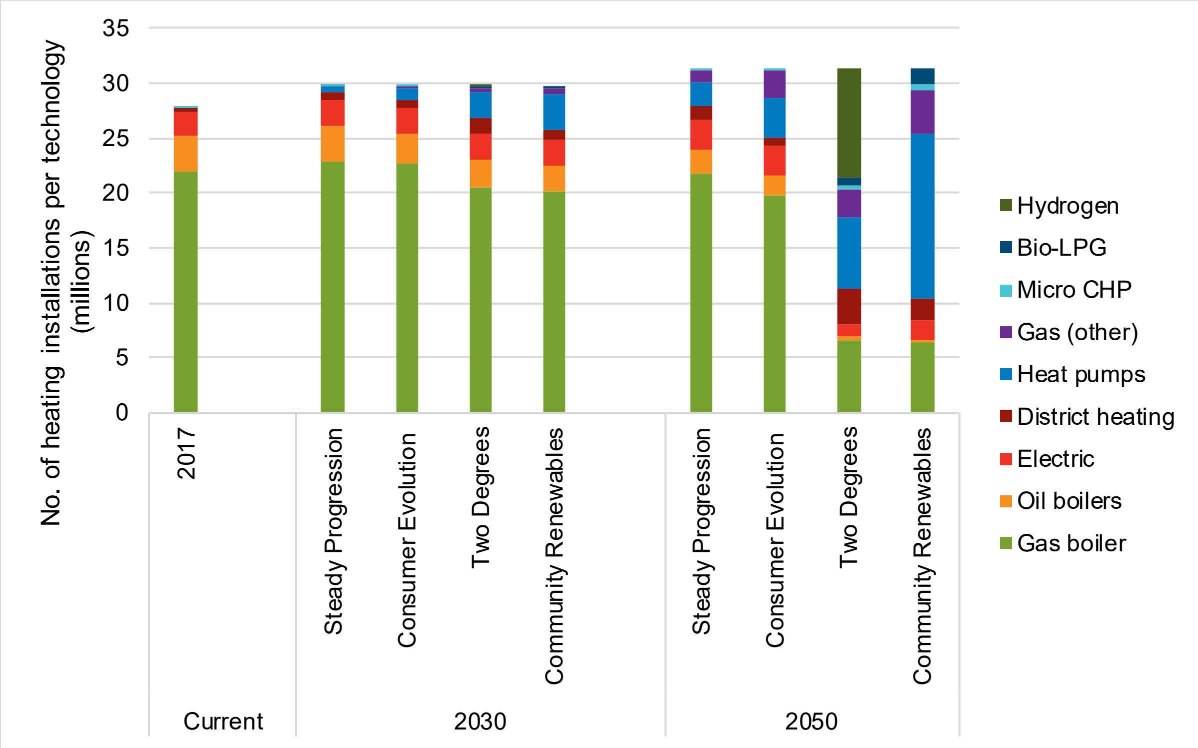


Figure 2.3 Deployment of heating technologies in the National Grid's Future Energy Scenarios



Where there is continued use of gas, the injection of biomethane into the gas grid (from either the upgrading of biogas produced from anaerobic digestion or a gasification route) provides a potential way of decarbonising this supply, and of decarbonising heat supply for those on the gas grid. Scotland however has a higher proportion of users who are off the gas grid than other parts of the UK, with about 20% of households - half a million residential properties - i.e. off the grid[9]. Bioenergy could potentially play a role in decarbonising heat supply in those off-grid properties and businesses for which heat pumps are not suitable, through the use of biomass boilers, biokerosene, a replacement for heating oil, or bioLPG, a replacement for LPG. Both bioLPG and biokerosene would probably be needed to be imported into Scotland (see Section 3.1.2). While bioLPG is a direct replacement for LPG so that LPG boilers do not require conversion to use it, biokerosene has slightly different properties to conventional kerosene, so existing oil boilers require conversion to use it[10].

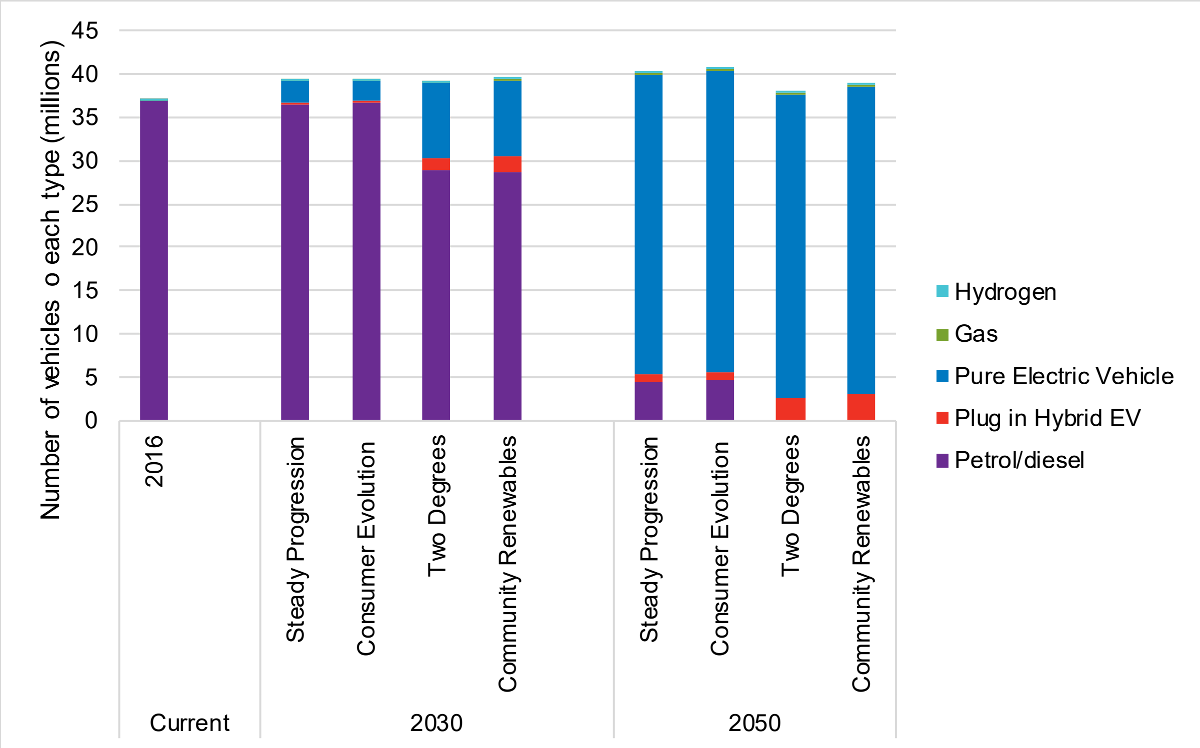
2.2.2 Future transport demand

In the transport sector the target date for phasing out the need for new petrol and diesel cars in Scotland is 2032, eight years before the target for the rest of the UK. Meeting this target will require more rapid electrification of the fleet. There will still be a substantial demand for liquid fuels in 2030, both for older petrol and diesel cars but more importantly for the freight sector, where electrification is a more technically challenging option for larger vehicles. Options include the supply of advanced biofuels which are a direct replacement for conventional diesel; biomethane supplied in compressed or liquified form; or the FAME biodiesel currently supplied. A key driver for demand for biofuels will be the future targets set under the Renewable Transport Fuels Obligation (RTFO) which require 12.4% of total fuel supply by volume to come from biofuels by 2032, with advanced biofuels forming at least 1.4% by volume of total fuel supply.

[9] Energy Statistics for Scotland Q2 Figures, September 2018. Available at https://www2.gov.scot/Resource/0054/00541525.pdf; accessed 21/11/208

[10] Some components and flexible oil lines need to be replaced and in some cases the oil storage tank. The estimated the cost of conversion is between £1500 and £3500 per boiler; see https://www.oftec.org.uk/consumers/faqs-on-bioliquids-for-heat

Figure 2.4 Deployment of vehicle types in the National Grid's Future Energy Scenarios



3 Bioenergy resources

3.1 Availability of bioenergy resources

Scotland has a wide range of biological resources (bioresources) which could be used for bioenergy (Table 3.1). Information for this review has been drawn from both a literature review and consultation with a range of key stakeholders (Appendix 1). Aspects which were considered for each resource, were the availability of the resource both currently and in 2030, its existing use for bioenergy, other competing uses for the resources, other potential constraints on its use for bioenergy and potential environmental impacts associated with its use. This information is reported in detail for each resource in Appendix 2. It represents the best available assessment of the resource potential given the information available during the course of the study, but it should be noted that future developments in industries generating these bioresources, or in industries which utilise these resources for other purposes, could alter these estimates. In assessing the potential of waste bioresources, care has been taken to respect Scotland's aim to move towards a circular economy[11] and the waste hierarchy which encourages prevention, reuse and recycling above recovering energy from the resource.

The main focus of this assessment is on Scottish rather than imported bioresources, as use of the former will generally bring additional economic benefits due to the added value delivered through development of local fuel supply chains. A brief discussion on imported bioresources is however included in Section 3.1.2. Domestic bioresources which were not assessed were landfill gas and oil and starch crops for production of 'first generation' biofuels. Landfill gas was excluded as the resource is already declining, and will decline further once the ban on disposal of biodegradable waste to landfill comes into force in 2021. Oil and starch crops were excluded, due to a recent UK policy decision, to limit the use of crop-based biofuels in transport fuels due to sustainability concerns[12]. There may also be other by-products, particularly from the food and drink industry, which could be utilised for bioenergy (e.g. culms from the malting process), but which are not included here as data on the resource was not available.

Table 3.1 Domestic bioresources suitable for bioenergy

Feedstock	Description
'Dry' solid feedstocks suitable for combustion	
Forestry - small round wood (SRW)	Small roundwood (SRW) which is removed from the forest to thin plantations, to allow larger diameter trees to flourish (i.e. thinnings) and smaller size material which is produced when the forest is finally harvested and is unsuitable for use as sawlogs. SRW has typically been considered as wood with a diameter <16cm.
Forestry - residues from harvest (brash)	Residues from final harvest operations comprise the tops and branches of felled trees (often termed brash). Residues can also include unmarketable wood, such as diseased wood.
Short rotation forestry (SRF)	SRF uses fast growing species of trees on rotations of 8 to 20 years, depending on species and site. SRF plantations can be established on marginal agricultural land, permanent grassland and rough grazing.

[11] Making Things Last: a circular economy strategy for Scotland. Scottish Government, 2016.
[12] Under the Renewable Transport Fuel Obligation, there will be a maximum limit on the use of crop-derived biofuels will be allowed to meet a supplier's obligation up to a maximum limit. This cap will begin at 4% of a supplier's total relevant fuel supply for 2018/19, The level will decrease year-on-year from 2021 to reach 3% by 2026 and 2% by 2032. See Renewable Transport Fuel Obligation Guidance Part One Process Guidance Year 11: 15/4/18 to 31/12/18,

Feedstock	Description
Sawmill residues	When harvested timber is processed to sawn timber in a sawmill, wood chips, sawdust and bark are produced as co-products. These are collectively known as sawmill residues. Panel board mills may also produce bark and sawdust residues.
Arboricultural arisings	Arboricultural arisings come from the management of trees and shrubs from public and private (non-forest) land, such as gardens, park land, utility land, and road sides.
Waste wood	Waste wood arises from several sources and varies in quality, depending on its source. 'Clean' waste wood comes from packaging, pallets, joinery residues etc. 'Dirtier' grades include wood waste from construction and demolition, wood extracted from waste steams (e.g. at Civic amenity sites). Wood classed as hazardous waste includes fencing, railway sleepers and transmission poles.
Perennial energy crops: Short rotation coppice (SRC) and *Miscanthus*	SRC refers to willow (or poplar) grown using a short rotation coppice (SRC) technique. Once planted the crop takes up to four years to reach maturity, after which it is harvested at regular intervals - typically four years for willow SRC. After about 20 to 25 years the crop is removed and replanted, and then the harvesting cycle begins. *Miscanthus* is a woody grass, which after it has matured, is harvested every year.
Cereal straws	Straw is a by-product from the production of commercial crops such as wheat, barley and oats.
Residual municipal solid waste (MSW) and residual commercial waste	Residual waste is the waste left after the recyclable fraction and food waste have been removed. This residual fraction will still contain some material of organic origin. This is regarded as a "biogenic fraction" and represents the content of the waste that is used to generate renewable energy. In some cases residual waste can be processed into a refuse derived fuel (RDF), or if it meets specifications outlined in guidance, as a solid recovered fuel (SRF).
Poultry litter	Poultry litter is essentially chicken manure from broilers hens (i.e. those raised for meat production) mixed with the soft wood shavings or straw used as bedding for the poultry.
Wetter and liquid feedstocks	
Domestic and commercial food waste	Food waste from the domestic and commercial sector separated at source
Draff	A by-product of the whisky industry. Draff s spent grain left in the mash-tun after the liquor has been drawn off and has a high moisture content.
Pot ale	A by-product of the whisky industry. The liquor left in the wash still after the first distillation in the pot still process. It's very low solids content (of about 4%) means it is a very dilute source of biogenic matter.
Spent lees/wash	A by-product of the whisky industry. The residue in the Spirit Still after the distillation of the foreshots, potable spirits, and feints. Similar in properties to pot ale, but more dilute.
Distillers dark grains (DDG)	Draff and condensed pot ale are combined to produce distiller dark grains, an animal feed that is drier, has a higher nutritional value and is easier to transport than draff.
Spent grain	A by-product from brewing. The composition of spent grain makes it suitable for use as an animal feed.

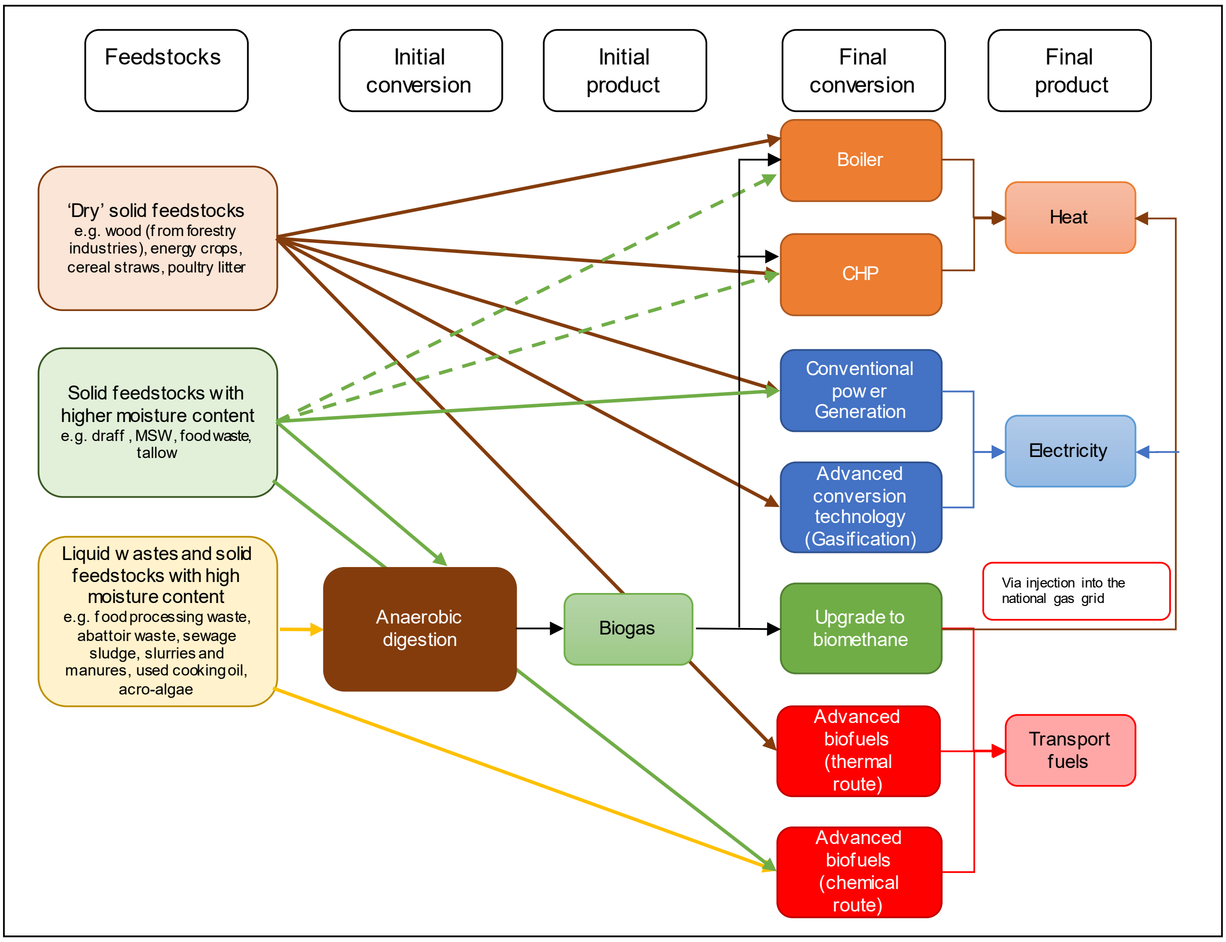
Feedstock	Description
Spent hops	A by-product from brewing. Hops are mixed with the wort and boiled, after which the solids are removed as trub and spent hops. Spent hops can be used as a mulch or soil conditioner, with or without composting.
Spent yeast	A by-product from brewing. Some spent yeast is reused in the brewing process. The remainder yeast is produced in a liquid form and can be disposed of with other liquid wastes to the sewage system.
Whey	Whey is the liquid remaining after milk has been curdled and strained. It is a by-product of the manufacture of cheese or casein.
Fish processing waste	Waste produced during fish processing operations can be solid or liquid, and includes skin, trimmings, bones, viscera. These may be made into fish paste, fishmeal or sold as a product.
Shell fish waste	Discarded shellfish (under-utilised, undersized or non-quota species) and parts of the shellfish that are not usually used for human consumption.
Animal by products: (ABP) Abattoir waste and fat	Blood and bones (excludes hide and skin as not suitable for use as energy resource). This can be rendered into blood and bone meal for fertiliser or blood meal for animal feed. Some of the abattoir waste produced is a fat.
Tallow	Tallow is a by-product of meat processing, produced when offal and carcass/ butcher's wastes are processed at rendering plants. Depending on the production method, some can be used in products such as soaps and cosmetics but other can only be used for industrial applications or burnt.
Sewage sludge	Sewage sludge from waste water treatment plants.
Dairy, beef and pig slurry	Slurry is excreta produced by livestock while in a yard or building, including excreta mixed with bedding, rainwater and washings. It has a consistency that allows it to be pumped or discharged by gravity.
Dairy, beef and pig farm yard manure	Farmyard manures (FYM) are livestock excreta mixed with bedding material (such as straw) and has a higher dry matter content (>10%) than slurries.
Used cooking oil	UCO comes from catering premises, food factories and households.
Macro-algae	Macro-algae (seaweed) which may be wild-harvested or farmed.

There are numerous routes to convert the bioresources identified into energy (Figure 3.1). The more solid forms of biomass are suitable for combustion in boilers to produce heat, or in power plant or combined heat and power plant to produce electricity and/or heat. They can also be gasified to produced syngas which, after cleaning, can be converted to biomethane for use as a vehicle fuel or injection into the gas grid, or further processed into liquid fuels. Wetter wastes and by-products are generally more suitable for anaerobic digestion to produce biogas which can then be combusted to produce heat and/or power, or upgraded to biomethane. Some solid biomass as well as wetter biomass may also be suitable for use in advanced biofuels processes based on chemical routes.

3.1.1 Availability of domestic bioresources

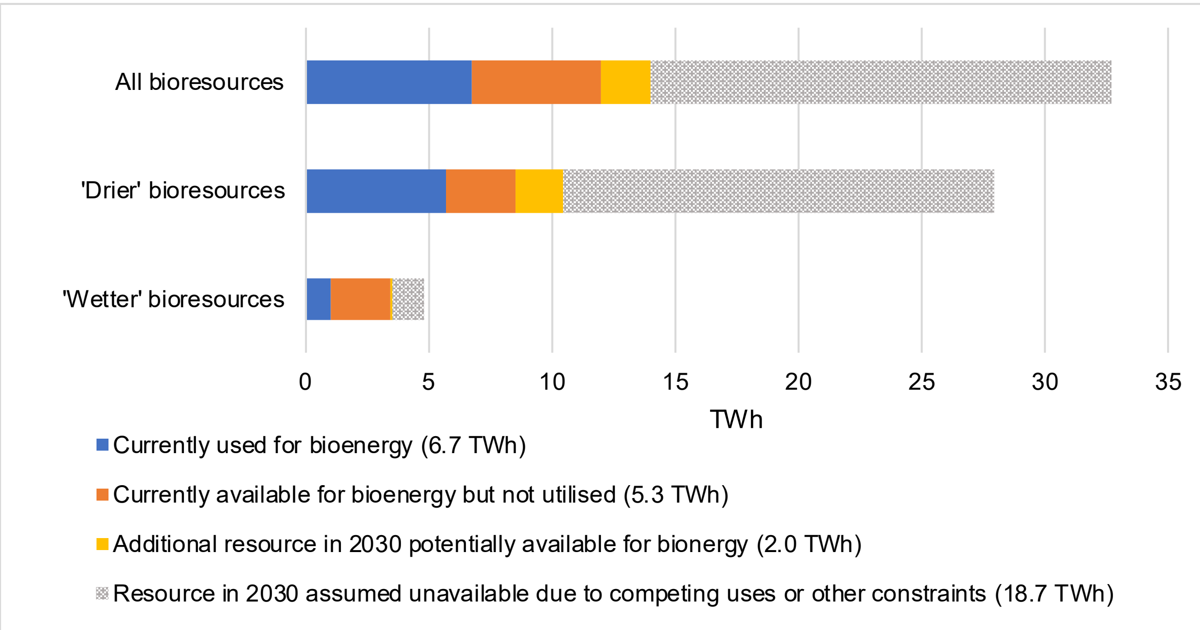
The overall availability of domestic bioresources currently and in 2030 is summarised in Figure 3.2. Further detail is given for bioresources which are relatively dry and are suitable for combustion in Figure 3.3, and in Figure 3.4 for bioresources which are wetter and may be more suitable for processes such as anaerobic digestion. In total, an estimated 6.73 TWh per year of biomass (5.67 TWh of dry biomass and 1.06 TWh of 'wetter' bioresources) is currently used for bioenergy purposes (shown in blue in the Figures). Derivation of the data for each resource is given in Appendix 2.

Figure 3.1 Possible route for conversion of bioresources to bioenergy



Note: dotted lines indicated that route may not be suitable for all feedstocks in category

Figure 3.2 Availability of bioresources for bioenergy use



The study has also looked at what bioresources are available that are currently not being used for bioenergy but could be (shown in orange in the Figures). In doing so it has allowed for:

- use of some bioresources for other purposes (e.g. forestry products for particle board, by-products and wastes from the food and drink industry used for animal feed),
- implementation of the waste hierarchy and achievement of recycling targets, so estimates of residual waste allow for the recycling of materials such as paper
- the impracticality of collecting all of some widely dispersed resources for use for bioenergy.

These competing uses and resources which are not available due to practical constraints are shown in grey in the Figures.

In total, even after allowing for these constraints, it is estimated that a further 5.3 TWh per year of resources could be available for use for bioenergy currently. By 2030, as production in the forestry sector grows, and if perennial energy crops such as short rotation coppice and *Miscanthus* are established, a further 2 TWh per year could be available (shown in yellow in the graphs). This means that potentially the use of biomass for bioenergy could more than double from the current value of 6.7 TWh per year to 14 TWh per year, an increase of 7.3 TWh per year by 2030.

Figure 3.3 Availability of solid feedstocks suitable for combustion

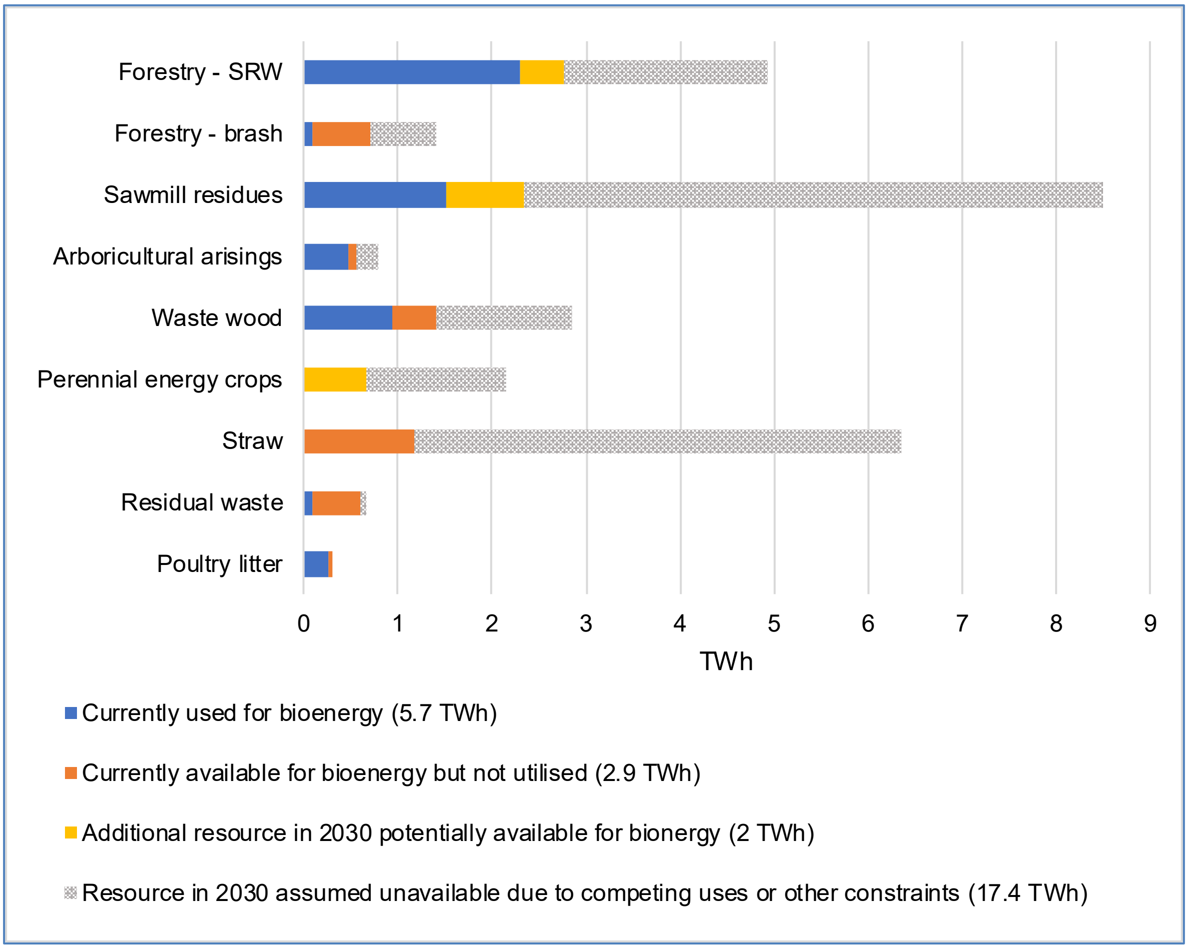
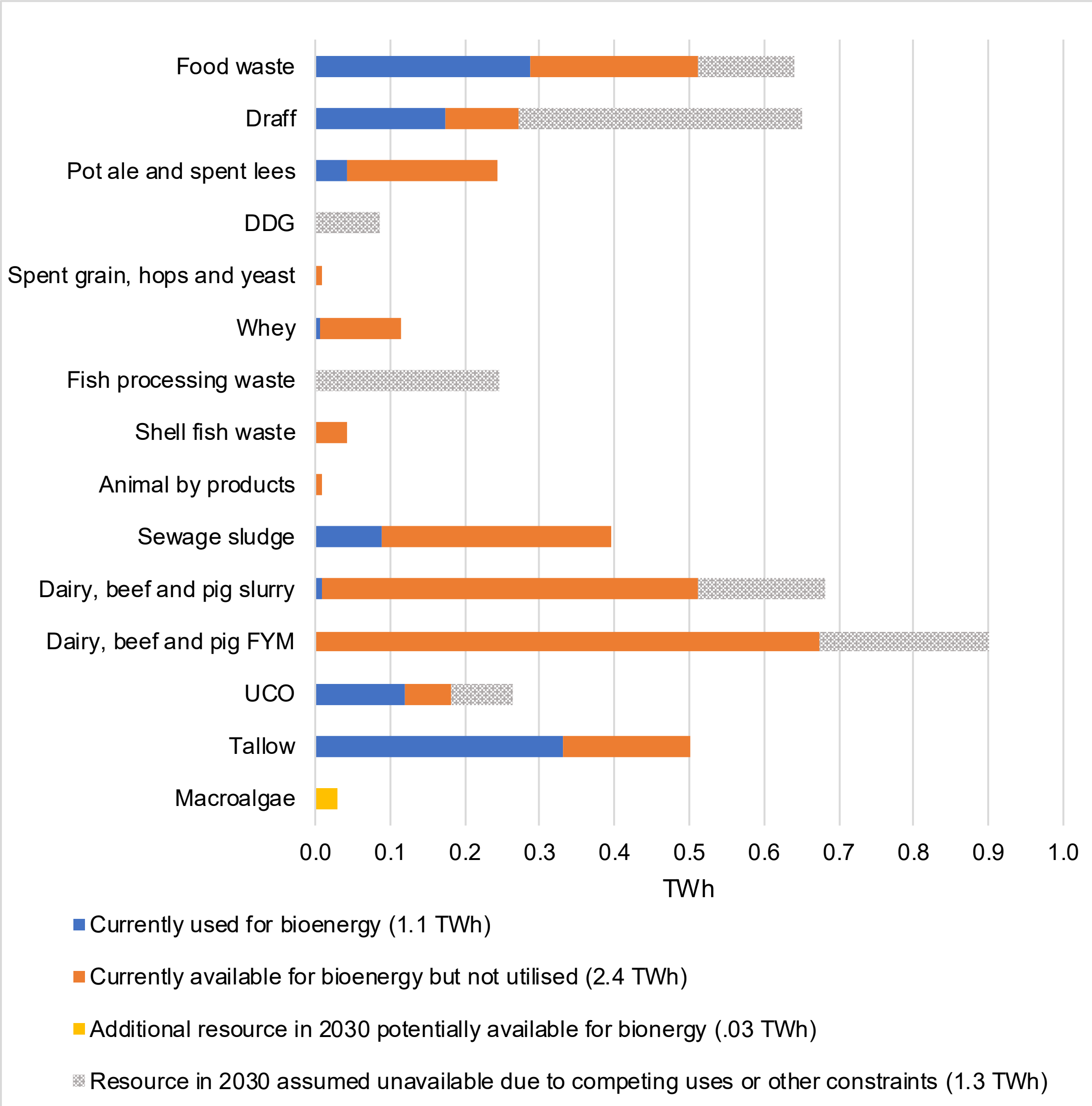


Figure 3.4 Availability of wetter feedstocks more suitable for processes such as AD



3.1.2 Non-domestic bioresources

Imports of bioresources for energy into Scotland are believed to currently include wood and waste wood from the UK, wood pellets from outside the UK and biofuels from outside the UK. Data on quantities of imports is only available at the UK level. In 2017, the UK imported about 7 million tonnes of wood (equivalent to 35.3 TWh) for bioenergy, almost all (98%) in the form of wood pellets. These came predominantly from the US (60%), Canada (21%) and the Baltic States (14%)[13]; large quantities go to co-firing in power stations (e.g. Drax), but pellets are also used in smaller biomass CHP plant and in biomass boilers. To set this into context, total consumption of wood (excluding waste wood) and other plant biomass for bioenergy in the UK in 2017 was about 87 TWh[14], so imported wood accounts for about 40% of this. It is likely that imported wood will remain an important bioenergy resource for the UK, although it will become increasingly important to ensure that these imported supplies are produced sustainably.

[13] Digest of UK Energy Statistics, Table G.6: Imports and exports of wood pellets and other wood 2008-2017
[14] Digest of UK Energy Statistics, Table 6.1 Commodity Balances 2017.

As discussed in Section 2.1.3, only 27% (by volume) of biofuels consumed in the UK in 2017 were supplied from the UK, with the remainder supplied mainly from Europe and the US. Scotland has a biodiesel production plant producing biodiesel FAME from tallow, used cooking oil and other waste oils and greases, but there is no bioethanol production in Scotland. There are bioethanol plants in England, although these are currently not producing as the price for bioethanol does not make it viable to do so.

A bioresource which the UK is beginning to import is a biologically based Liquid Petroleum Gas replacement (BioLPG). BioLPG is produced as a co-product in Neste’s Hydrotreated Vegetable Oil (HVO) production facility at Rotterdam. Feedstocks for HVO production are vegetable and waste oils, meaning that the BioLPG can be considered a renewable fuel, although as fossil based hydrogen is used in the production plant, and as some of the hydrogen in the BioLPG is derived from water, only 93.2% of BioLPG can be considered to be of biological and renewable origin[15]. Calor UK are now offering BioLPG from this production facility to customers and are hoping to source additional BioLPG from the UK in the future. As the chemical structure of BioLPG is exactly the same as conventional LPG it is a simple drop in replacement, and can be used in all existing appliances with no impact on performance. As it has an identical structure, it can also be blended with LPG, so companies such as Calor UK are currently offering domestic customers a blend of 40% BioLPG/60% conventional LPG. The cost of producing bioLPG is higher than that of producing conventional LPG due to the additional treatment processes and fuel upgrade processes involved, but as price information for BioLPG is not in the public domain, it is not clear what the premium is likely to be. One study considering the use of BioLPG in Ireland estimated that for commercial customers BioLPG might be offered at a 20% premium[16].

At the moment biokerosene for use in boilers is not supplied commercially in the UK, as there is no demand for it. Biokerosene for use in boilers can be a pure bioliquid based on 100% FAME - the biodiesel produced from vegetables oil, used cooking oil or tallow that is added at low concentrations to diesel transport fuel. However, it is more likely that FAME would be blended with conventional kerosene in the ratio of 30% FAME and 70% kerosene to produce a heating oil B30K that is partially renewable. As discussed earlier the capacity of the existing FAME biodiesel production plant in Scotland is believed to be roughly equal to current consumption of FAME in Scotland, so any FAME used in biokerosene in Scotland would be likely to be imported, unless FAME production capacity was expanded and additional domestic bioresources were available to support that additional capacity.

3.1.3 Assessment of domestic bioresources

Identification of the available bioenergy resource is only the first step in developing a bioenergy strategy. To ensure that the development of bioenergy is done in a sustainable and cost-effective way it is also important to consider other aspects. These include, most importantly:

- cost
- the ease with which resources can be collected and transported to the point of use
- the pressure that use for bioenergy may put on other market sectors which utilise the resource
- any environmental impacts from developing or utilising the resource, and;
- carbon impacts.

[15] Copy of letter from UK DfT to Calor of 23 June 2015, provided to Ricardo Energy & Environment by Calor.

[16] Element Energy and Ricardo Energy & Environment, 2017.Interface analysis and report for incorporation and alignment of data from biomethane study into RHI workstream. Final report for SEAI. Available at https://www.seai.ie/resources/publications/Tab-F-Renewable-Gas-Interface-Report-(Jan-2017).pdf

These aspects are each considered in detail for each feedstock in Appendix 2. In order to allow the development of a broad overview, a set of criteria was also developed for each of these aspects (as set out in Table 3.1) to allow each resource to be ranked against each aspect. The criteria are set out in Table 3.2

Table 3.2 Criteria used for scoring of Scottish bioenergy resources

Criteria	Red	Amber	Green
Availability in 2030 for bioenergy use (additional to current use for bioenergy	<0.1 TWh	0.1 to 0.5 TWh	>0.5 TWh
Competing uses or other constraints to use for bioenergy (compared to availability for bioenergy use)	>50%	10 to 50%	<10%
Ease to collect/logistics	'Wet' waste so not economic to transport far (typically 10 km) OR more energy dense resources, but very dispersed so even though transport is viable, logistics are difficult	Transport feasible but not very energy dense so likely to be limited say 10 to 50 km	Energy dense - economic to transport 50km or more OR Occurs in relatively large quantities at point source, or in smaller sources which are in close proximity
Cost per MWh	>£20/MWh	£5 to £20/MWh	< £5/MWh
Environmental considerations	Negative impacts which it may be difficult to ameliorate	No positive benefits identified and potential for some negative impacts unless best practice followed carefully OR some positive impacts but offset by some negative impacts	Potential for positive environmental impacts (or reduced negative impacts due to better management of wastes and no significant environmental impacts which cannot be easily avoided through ensuring best practice
Carbon emissions	Marginal carbon savings (<30%) compared to fossil fuel it replaces	Lower carbon emissions (30 to 80%) in territory than fossil fuel it replaces	Significantly lower (>80%) emissions (in territory) than fossil fuel it would replace

Table 3.3 shows the results of the assessment. It suggests that there are a number of bioresources, including a large number of wastes or by-products without existing competing uses which could be suitable for bioenergy. Utilisation of them may however present a challenge as many occur in relatively small quantities and are not easily transported, so require utilisation at the local level.

Table 3.3 Overview of assessment of domestic bioenergy resources

		Additional availability	Competing uses/other constraints	Ease to collect/ logistics	Cost	Environmental impacts	Carbon emissions
Solid/'dry' feedstocks suitable for combustion							
Forestry products	Small round wood	Amber	Red	Amber	Amber	Green	Green
Forestry residues	Branches and tops	Green	Green	Amber	Amber	Amber	Green
Short rotation forestry		None by 2030		Amber	Amber	Amber	Green
Sawmill residues		Green	Red	Green	Green	Green	Green
Arboricultural arisings		Red	Amber	Amber	Green	Green	Green
Waste wood		Amber	Red	Green	Green	Green	Green
Energy crops		Green	Green	Amber	Amber	Green	Green
Cereal straw		Green	Red	Amber	Amber	Green	Green
Municipal solid waste		Green	Green	Green	Green	Green	Green
Poultry Litter		Red	Green	Green	Green	Green	Green
Wetter feedstocks mores suitable for AD and biofuels							
Food waste	Food waste	Amber	Amber	Amber	Green	Green	Green
By-products from whisky industry	Draff*	Amber	Variable*	Green	Green	Green	Green
	Pot ale	Amber	Green	Green	Green	Green	Green
	Spent lees/wash	Red	Green	Amber	Green	Green	Green
	DDGS	Red	Green	Green	Red	Green	Green
By-products from brewery industry	Spent grain (beer)	Red	Green	Green	Green	Green	Green
	Spent hops (beer)	Red	Green	Green	Green	Green	Green
	Spent yeast (beer)	Red	Green	Green	Green	Green	Green
Dairy by-product	Whey	Amber	Green	Green	Green	Green	Green
Waste from fish processing	Fish process waste	Red	Red	Amber	Green	Green	Green
	Shell fish waste	Red	Green	Amber	Green	Green	Green
Abattoir waste	Blood and bones	Red	Green	Amber	Green	Green	Green
	Fat	Red	Green	Amber	Green	Green	Green
Sewage sludge	Sewage sludge	Amber	Green	Green	Green	Green	Green
Animal manures	Dairy and beef slurry	Amber	Green	Green	Green	Green	Green
	Dairy and Beef FYM	Green	Green	Green	Green	Green	Green
	Pig Slurry	Red	Green	Green	Green	Green	Green
	Pig FYM	Red	Green	Green	Green	Green	Green
Used cooking oil	Used cooking oil	Red	Green	Green	Amber	Green	Green
Tallow	Tallow	Amber	Green	Green	Amber	Green	Green
Macro-algae		Red	Green	Green	Red	Amber	Green

* the main competing use for draff is as animal feed, however the quantities going to animal feed vary year on year due to changes in both the supply of draff and the demand for draff as feed[17]. Supply varies as levels of whisky production vary and demand for draff as feed varies depending on levels of production of other animal fodder which is affected by weather and prices of alternative feeds.

[17] SRUC, 2018. Distillery by-products, livestock feed and bio-energy use in Scotland. To be published9

Table 3.4 Carbon savings associated with bioenergy feedstocks on a lifecycle basis

	Electricity	Heat	Natural gas	Transport fuel
Fossil fuel comparator based on	UK grid in 2016	Heat from gas boiler	Natural gas in grid	Value in RED II
Fossil fuel comparator (g CO_2/kWh)	325	259	233	338
	Carbon saving against comparator			
Wood chips - UK	91%	97%		
Wood chips - N America	48%	79%		
Wood chips - UK SRC	90%	96%		
Wood pellets - UK	63%	85%		
Wood pellets - N America	29%	72%		
Wood pellets - UK SRC	60%	84%		
Anaerobic digestion of slurry	73%	87%	65%	76%
Anaerobic digestion of silage grass	7%	55%	32%	53%
Biomethane (gasification of wood)			86%	91%
Bioethanol (average for current supply)				69%
Bioethanol (2G – straw)				90%
Biodiesel (average for current supply)				85%
Biodiesel (2G - forestry)				82%
	Sustainability criteria set in legislation			
Legislation	**Renewables Obligation**	**Renewable Heat Incentive**	**Renewable Heat Incentive**	**RED II (for new plant post 2021)**
Sustainability criteria (g CO_2/kWh)	55.6 (post 2020) 50.0 (post 2025)	34.8	34.8	32.9
Carbon saving against fossil fuel comparator specified above	38% (post 2020) 45% (post 2025)	52%	46%	65%

Source: Calculations by Ricardo Energy & Environment using B2C2 carbon calculator tool[18] and values for advanced biofuels supplied in RED II

The main area of concern is the impact on health of emissions of particulates, particularly of very fine particulates $PM_{2.5}$. from smaller biomass boilers in urban areas. An Air Quality Expert Group study on $PM_{2.5}$ indicated that although most of $PM_{2.5}$ in ambient air is a secondary pollutant (formed from reactions in the atmosphere), there is a significant increase in urban areas from residential heating and cooking, which it is important to reduce if the exposure of the population to this pollutant is to be reduced.

[18] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/

A regional inventory of sources is not available for $PM_{2.5}$, but the regional inventory for PM_{10} indicates that bioenergy in Scotland accounts for 26 % of PM_{10}, of which the majority (80%) is from 'other combustion'. Within this category open fires and wood burners are the main emitters but wood boilers also contribute.

For small boilers (used in domestic situations and commercial premises) there are currently no regulations on particulate emissions. However, if the boiler is to receive funding under the Renewable Heat Incentive then it must meet emissions criteria for particulate matter of 30 g/GJ net heat input. Biomass boilers (under 500kW) which come onto the market from January 2020 will have to meet the requirements set in the Ecodesign Regulations[19], which are more stringent for automatic boilers (19 g/GJ[20]). Larger biomass boilers between 1 and 50 MW are regulated via the EU Directive on Medium Combustion Plant (which is implemented by SEPA) which has a similar emission limit for particulates (in force for new boilers from December 2018). Some form of abatement to reduce particulate emissions is normally installed on larger boilers (of about 250 kW or above); the simplest is cyclones, with more sophisticated equipment - ceramic or fabric filters or Electrostatic Precipitators (ESP), typically installed on boilers of 500 kW or above.

The air quality standards which specify permitted concentrations of pollutants are more stringent for PM10 and PM2.5 than other parts of the UK and consequently available 'headroom' for biomass development in urban areas within Scotland may be more limited. Guidance from Scottish Government to Scottish Local Authorities[21] highlighted concerns about potential conflicts between using biomass to meet 2020 targets for Renewable Energy and air quality. It suggested that conflict might be avoided through use of high quality, low emission plant and an expectation that biomass heat deployment would be less common in urban areas and larger, cleaner biomass units to be more prevalent. This advice has been adopted in local air quality management policy for some urban areas (e.g. Glasgow[22]). This approach, of favouring a smaller number of larger biomass boilers, where it will be easier to reduce particulate emissions, over a larger number of smaller boilers would seem to be appropriate for urban areas.

3.2 Other environmental issues

3.2.1 Digestate

Digestate from anaerobic digestion (AD) plant can have a useful role as a soil conditioner and as a fertiliser providing it is of suitable quality. Standards do exist for digestate, but there are emerging concerns about the presence of microplastics in digestate (e.g. from fragments of plastic packaging contained in food waste) and the presence of antibiotics in slurries. A better understanding of these potential impacts could be useful before there is an expansion of AD. In addition to this, stakeholders consulted during the study raised concerns about whether there are enough areas of suitable land to receive increased quantities of digestate. However, Scotland has a relatively limited arable area suitable for taking higher quality digestate, and land for taking lower quality digestate (e.g. for land reclamation) is becoming more limited. Due to the cost of transporting digestate (which will have a high moisture content making it bulky to transport even if it is in a solid form), disposal or utilisation generally needs to be relatively close to the AD plant[23]. Ensuring that AD plant are located suitably,

[19] EU Regulation 2015/1189 for solid fuel boilers

[20] Emissions limits are 40 mg/Nm3 40 mg/Nm3 (automatic boiler) and 60 mg/Nm3 (manual boiler). This is pollutant concentrations at 10% O_2, dry and STP (0°C, 101.3 kPa), and has been converted to g/GJ on a net energy input basis using stoichiometric flue gas volumes contained in Conversion of biomass boiler emission concentration data for comparison with Renewable Heat Incentive emission criteria produced by AEA Technology for Defra 2012.

[21] Letter from Scottish Government Minister for Environment and Climate Change to COSLA and copied to Scottish Local Authorities available here http://www.scottishairquality.co.uk/assets/documents/news/letter.pdf

[22] Glasgow https://www.glasgow.gov.uk/CHttpHandler.ashx?id=3140&p=0 and Highlands & Islands

[23] Some studies have suggested that land for spreading digestate may need to be within a radius of only 10 to 12 miles of the plant (e.g. Zero Waste Scotland, 2010: Digestate Market Development in Scotland)

from a perspective of land suitable for receiving digestate as well as feedstock availability and suitable end users or energy infrastructure, is therefore important,

3.2.2 Energy crops

Cultivation of perennial energy crops - *Miscanthus*, a perennial grass and Short Rotation Coppice (SRC) (willow or poplar grown using a coppicing technique) - on arable land could lead to a number of positive environmental impacts.

Compared to arable crops, perennial energy crops convey significant benefits on soil quality[24] and can increase soil carbon. This is due to the characteristics of the energy crops. They are generally in the ground for 20 to 25 years and have deep root systems providing increased below ground biomass carbon stocks, and high litter input (where there is leaf fall).

The management practices used for cultivation of energy crops, which include long harvesting cycles (every four years typically for SRC), limited fertiliser inputs and fewer routine operations, also lead to positive environmental impacts. Compared to intensive agricultural cultivation, perennial energy crops can provide refuge from agrochemicals and a less disturbed environment, which is more beneficial to insects and birds, and leads to more diversity of flora/fauna. Crops such as SRC willow allow the development of understorey flora, significantly enhancing habitat creation compared to normal food crops, and leading to improved biodiversity such as increased insect populations. The scale of planting also determines impacts. Whereas small scale energy crop production (at perhaps 5 to 10% of farm area) can provide diversity in the landscape and provide wildlife corridors between fragmented habitats, large scale production can reduce diversity within the landscape.

Miscanthus, and SRC can have high water use during the growing season. This can have a negative impact in water stressed areas, particularly if a large area is planted in the same river catchment. However, the high water use and long growing season of the crops can be a positive feature in flood prone areas, where SRC in particular can help to reduce flooding by a mix of land drying, soil stabilisation and physical slowing of water flows. When planted on agricultural land, many perennial energy crops (e.g. SRC, *Miscanthus*) have positive effects on water quality. This is due to the low level of fertilisation required for these crops, reducing nitrate leaching. The perennial nature of the crops also leads to soil stabilisation and reduces erosion and river turbidity and sedimentation.

3.2.3 Forestry residues

Forest residues are tips and branches typically left in the forest when trees are harvested for saw logs or pre-commercial thinnings. The impacts on soils from the removal of these forest residues can vary widely and are dependent on the amount and type of residues removed, site characteristics, species and harvesting methods. Potential impacts typically occur when too high a proportion of residues are removed. These can include:

- Soil disturbance and compaction and soil erosion.
- Reduced levels of soil organic matter (SOM) and soil carbon storage.
- Changes in the soil and microclimate which can have an impact on microorganisms in the soil.

[24] Holland R.A., Eigenbrod F., Muggeridge A., Brown G., Clarke D., and Taylor G (2015) A synthesis of the ecosystem services impact of second generation bioenergy crop production Renewable and Sustainable Energy Reviews 46 30-40 and Milner S., Holland R. A., Lovett A., Sunnenberg G., Hastings A., Smith P., Wang S. and Taylor G (2016) Potential impacts on ecosystem services of land use transitions to second-generation bioenergy crops in GB. GCB Bioenergy (2016) 8, 317–333, doi: 10.1111/gcbb.12263.

- Reduced soil nutrients and depletion of calcium, magnesium, potassium and sodium ions in the soil, resulting in soil acidity.
- Decreased water retention.

Mitigation of these impacts is best achieved from understanding site specific impacts and creating specific sustainable forest management plans that prevent the removal of too many residues. The UK Forestry Standard highlights the importance of considering all impacts before harvesting forest residues. It is widely acknowledged that residues have a significant role in the ecology of the forest, productivity, soil nutrients, the soil's physical properties and soil carbon[25].

However, the impact of the removal of residues is variable and site dependent, suggesting that management of residues needs to be flexible and evidence based. Removal of too much residue can reduce the amount of deadwood needed for the survival of some species, remove niche habitats and lead to proliferation of invasive species, as well as leading to loss of nutrients reducing diversity. On the other hand, in some circumstances large quantities of residues can negatively impact forest health and productivity by increasing risks of wildfire, pests, and disease, while impeding forest regeneration.

[25] Vance E.D., Prisley S P., Schilling E.B., Tatum V.L., Wigley T.B., Lucier A.A. and van Deusen P.C. (2018) Environmental implications of harvesting lower-value biomass in forests Forest Ecology and Management 407 47-56 and Roach J and Berch S.M. 2014 A Compilation of Forest Biomass Harvesting and Related Policy in Canada. Prov. B.C., Victoria, B.C. Tech. Rep. 081. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr081.htm

4 Conversion of biomass to bioenergy

There are numerous routes to convert the biomass resources identified in Section 3 to energy. The more solid forms of biomass are suitable for combustion in boilers to produce heat, or in power plant or combined heat and power plant to produce electricity and/or heat. For relatively 'clean' forms of biomass such as wood from forestry, sawmills, or clean waste wood this can be burnt in dedicated biomass plant. More contaminated waste wood will need to be burnt in plant that have additional pollutant abatement systems, while residual waste from the municipal waste stream will typically be burnt in dedicated Energy from Waste (EfW) plant. More advanced conversion technology can be used to gasify biomass to produce syngas. This can be combusted for power, or after cleaning, can be converted to biomethane for use as a vehicle fuel or injection into the gas grid, or can be converted to liquid fuels via the Fischer-Tropsch process using catalysts.

Wetter wastes are generally more suitable for anaerobic digestion to produce biogas which can then be combusted to produce heat and/or power, or upgraded to biomethane for use as a vehicle fuel or injection into the grid. Some solid biomass as well as wetter biomass may also be suitable for use in advanced biofuels processes based on chemical routes.

An overview of the key bioenergy conversion technologies is given in Appendix 3.

In considering which conversion technologies might be most suitable for development in Scotland to 2030, a number of high level factors are important to consider:

- Scale and feedstock availability: what are typical sizes for the technologies and is there enough domestic feedstock to supply a plant, or would substantial imports of feedstocks be required? If enough feedstock is available now, how much certainty is there that it will continue to be available over the lifetime of the plant?
- Final energy vector: what energy vector does the technology produce (electricity, heat, gaseous fuels or liquid transport fuels) and will there still be significant demand for this fuel in 2030?
- Conversion efficiency: how effectively does the plant convert the energy contained in the bioresource into the final energy vector?
- State of development: is the conversion technology commercially proven now, or likely to be by 2030?
- What scale of investment is required for the plant; more advanced technologies, particularly those which need to be built at a large scale, can require high levels of investment, which can be difficult to raise if the technology is not proven?
- What is the cost of energy produced and how does this compare to energy produced in other ways?

Table 4.1 shows how criteria were defined to allow key conversion technologies to be compared against each of these criteria.

Table 4.1 Criteria used for assessment of conversion technologies

Criteria	Rating		
Conversion efficiency	High (>50%)	Medium (25 to 50%)	Low (<25%)
Scale	Large >15 MW	Medium (1 to 15 MW)	Small (<1MW)
RAG rating	**Red**	**Amber**	**Green**
Status	Unlikely to be commercial by 2030	Likely to be commercial by 2030	Commercial now
Scale of investment required	More than £100m per plant	£15m to £100m per plant	Less than £15m per plant
Cost compared to non-biomass alternative	More than 30% higher than energy produced from conventional technology	Less than 30% more than energy produced from conventional technology	Less than or equivalent to energy produced from conventional technology
Availability of domestic feedstock	Enough to support only one plant or may utilise a high proportion of total resource in 2030	Enough feedstock to support 2 to 10 new typically sized plant in 2030	Enough feedstock to support more than 10 new plant in 2030

The results of the assessment are shown in Table 5.2. These are intended to give a broad overview of each of the technologies and are based on published data on typical costs and efficiencies for each plant, together with typical costs for the bioresource used as a feedstock[26]. They should be considered as indicative only, and any individual plant considered for deployment would require a more detailed assessment, particularly for costs. More details of the cost analysis carried out are given in Appendix 4.

Assessment of individual plant would also need to consider other operational aspects such as the amount of residual material (for example, ashes from combustion plant or digestate from AD plant) and routes for disposal or utilisation, and the geographical distribution of the available feedstocks in relation to the plant locations and associated transport logistics. The latter is particularly important for technologies utilising less energy dense feedstocks (e.g. some of the wastes used for anaerobic digestion, where their high moisture content means that transporting them over longer distances will have high costs.

[26] Key sources used include BEIS, 2016: Electricity Generation Costs; E4Tech, 2017, Ramp up of lignocellulosic ethanol in Europe to 2030, and DECC, 2014, RHI Biomethane Injection to Grid Tariff Review.

Table 4.2 Assessment of bioenergy conversion technologies

	Energy vector				Size			Conversion efficiency			Assessment criteria			
	Heat	Electricity	Gaseous	Liquid fuel	Small	Medium	Large	Low	Medium	High	Technology status in 2030	Scale of investment required for single	Cost compared to non-biomass	Availability of domestic feedstock
Biomass boilers	●				●	●				●	Green	Green	Amber * / Red *	Green
Dedicated biomass plant		●				● (grey)	●	● (grey)	●		Green	Amber	Amber	Amber
Biomass CHP	●	●				●	● (grey)		●	●	Green	Amber	Amber	Green
Energy from waste		●				●	● (grey)	● (grey)	●		Green	Red	Green	Amber
Energy from waste (CHP)	●	●				●	● (grey)		●	●	Green	Red	Red	Amber
Gasification of waste for power		●				●	● (grey)		●		Amber	Amber	Red	Green
Gasification biomass to SNG			●			● (grey)	●			●	Amber	Red	Red	Amber
Gasification biomass to diesel				●			●			●	Red	Red	Red	Red
Advanced biofuels (chemical route)				●			●		●		Red	Red	Red	Amber
AD (waste) for electricity		●			●	●			●		Green	Green	Red	Green
AD (waste) for CHP	●	●	●		●	●			●		Green	Green	Red	Green
AD (waste) for biomethane			●			●				●	Green	Green	Red	Green

* Amber for larger boilers with high heat loads (e.g. providing district heating or process heat), red for smaller scale domestic boilers.

The financial assessment, which is based on typical capital, operating and feedstock costs, indicates that energy or fuel from all of the bioenergy technologies (apart from energy from waste) is likely to be more expensive than conventional energy sources. In the case of energy from waste the gate fee received for the waste is a significant income stream for the plant, and allows it to produce power at a lower cost. As discussed in Section 2, the higher cost of bioenergy has led to a number of schemes to subsidise or incentivise its production and help to reduce territorial carbon emissions and decarbonise the energy sector (e.g. Contract for Differences for electricity, Renewable Heat Incentive for heat and biomethane and the Renewable Transport Fuel Obligation for transport fuels). The assessment above indicates that new bioenergy conversion plant are unlikely to be competitive unless they receive some form of financial support.

The domestic bioresource which is estimated to be available in 2030 should be sufficient to support most types of conversion plant, although for technologies which are of a medium or large scale (e.g. energy from waste, gasification, dedicated biomass plant) there may only be enough resources to support a few plant. For combustion type plant, the assessment of feedstock availability is based on availability of all types of wood (including waste wood), straw and energy crops, but it should be noted that plant may not be able to take all types of feedstocks as they require a more uniform feedstock. Similarly, advanced biofuels plant using chemical conversion routes, may not be able to take a wide variety of feedstocks, and there may not be enough of any one particular type of feedstock within Scotland, or within a radius of the plant that it is viable to transport feedstocks. As advanced biofuels plant using a gasification plant typically need to be built at large scale, it is likely that such a plant would need to utilise imported feedstock in addition to domestic bioresources. Long term certainty over feedstock supply can be an important consideration in determining commercial viability of a plant.

Conversion technologies where the assessment suggests that domestic resources could support several additional plant, are AD and biomass boilers. However in the case of the former, as the assessment in this study has been done at the Scottish level, the assessment of the number of plant that could be built does not fully take into account of the geographical distribution of feedstocks. For AD plant, where it is not economic to transport many of the suitable feedstocks more than a short distance due to their liquid nature or high moisture content, this means that in some cases schemes would need to use a mixture of feedstocks available within the immediate geographical location. Co-digestion of a variety of feedstocks is technically feasible, and indeed can be desirable as it allows feedstocks with low biogas yields to be mixed with higher biogas yield feedstocks improving overall profitability. However, stakeholders pointed out that different regulatory regimes can apply for different types of feedstocks. For example, digestion of wastes and animal slurries are subject to different regulatory regimes. This can potentially be a barrier to development, particularly for smaller schemes, as regulatory compliance becomes more complex and onerous.

In the case of biomass boilers, as discussed in Section **Error! Reference source not found.** on **Error! Reference source not found.**, impacts on air quality in urban areas from deployment of these boilers is best minimised by utilising larger scale boilers (e.g. for district heating) which can include pollution abatement equipment to minimise emissions of particulate matter. This is less of a concern in rural areas, where small scale boilers could be deployed without such a significant impact on air quality.

As discussed in Section 3 and 4 of the report, use of the bioresources in the bioenergy conversion technologies would lead to a reduction in territorial carbon emissions compared to utilisation of fossil fuels, although electricity from bioenergy could have higher emissions than some other low carbon sources of electricity such as wind.

The carbon footprint of bioenergy technologies can be reduced further however through the addition of carbon capture and utilisation (CCU) and carbon capture and storage (CCS). These technologies have not been assessed here as Biomass with CCS is unlikely to be fully commercial and operational by 2030, but their utilisation with bioenergy is widely recognised internationally to be likely to be an important component of climate change mitigation strategies. Within the UK, the UK government's clean growth strategy set out a new approach to CCU and CCS with the aim of being able to deploy it at scale during the 2030s, subject to its cost coming down[27]. This could lead to significant carbon reductions. For example, the UK Committee on Climate Change has suggested that by 2050 between 20 and 65 $MtCO_2e$/yr could be sequestered through Bioenergy CCS in the UK (equivalent to up to around 15% of current UK carbon emissions)[28].

[27] https://www.gov.uk/guidance/uk-carbon-capture-and-storage-government-funding-and-support
[28] Committee on Climate Change, 2018. Biomass in a low-carbon economy.

Appendices

Appendix 1: Stakeholders Consulted

Appendix 2: Bioenergy Resources

Appendix 3: Conversion Technologies

Appendix 4 Costs for Conversion Technologies

Appendix 1 – Stakeholders Consulted

The following stakeholders were consulted during the course of the study and their insights and information provided are gratefully acknowledged

- Bioenergy Group, Energy Technology Partnership
- CNG Services
- Energy Technologies Institute
- Forestry Commission Scotland
- Scotia Gas Networks
- Scottish Association for Marine Science
- Scottish Environment Protection Agency
- Scottish Tenant Farmers Association
- Scottish Water
- UK Forestry Products Association
- University of Aberdeen
- Wood Panel Industries Federation
- Zero Waste Scotland

The Scottish Government also held a dissemination event to discuss the findings of this report (in Perth on 12th December 2018) and provided an opportunity for further stakeholder feedback on the final draft report.

Appendix 2 – Bioenergy Resources

<table>
<tr><td>Resource</td><td>Forestry - small round wood</td><td>Cost</td><td colspan="8">Low to Medium</td></tr>
<tr><td>Description</td><td colspan="8">Small roundwood (SRW) which is removed from the forest to thin plantations to allow larger diameter trees to flourish (i.e. thinnings) and smaller size material which is produced when the forest is finally harvested and is unsuitable for use as sawlogs. SRW has typically been considered as wood with a diameter <16cm.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Coniferous SRW production is currently about 2.24 Mt/y, but as the current forests mature will decline to about 2.14 Mt/y by 2030 (and further thereafter). [1]. Data on broadleaf forests is at UK level only; these are typically small and scattered and in Scotland 85% are in private ownership. Current harvesting levels estimated to be only 10% of biological potential [1].</td><td>5.164</td><td>4.934</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">For coniferous roundwood, data from [1] suggests about 1Mt/y of coniferous round wood is being used for energy (either directly or as a supply to wood pelleting plants). In addition, it is possible that around 100,000 t of hard wood from small broadleaved forests may be being utilised.</td><td>2.306</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">Other main uses are for roundwood fencing, and the panel board industry. There are two panel board manufacturers in Scotland, Norbord and Egger and the former has plans to expand production.</td><td>2.859</td><td>2.167</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">In the UK as a whole, production of SRW and demand for SRW are currently finely balanced. As production is forecast to decline in the future, and demand to increase, due mainly to additional demand for wood energy demand, there is likely to be a shortage of SRW. A demand and production balance forecast for SRW is not available specifically for Scotland but given that SRW production in Scotland is forecast to decline, it is likely that this shortage will also be experienced in Scotland. This pressure on SRW could lead to larger diameter logs, which typically go to saw logs, being used for SRW applications, although in some local authorities, including southern Scotland, [1] suggests that the balance between availably and demand is tight for all sizes of timber.</td><td>0.000</td><td>0.461</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">The coniferous resource is fairly evenly distributed across Southern and Central Scotland, with each containing just over a third of the resource; forest cover is less in Northern Scotland, which accounts for 28% of current production.
Broadleaved woodland areas tend to be smaller and more widely dispersed.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td>✓</td><td>Power generation</td><td>✓</td><td>Biogas for heat and power</td><td></td><td>Advanced biofuels (thermal route)</td><td>✓</td></tr>
<tr><td>CHP</td><td>✓</td><td>Gasification</td><td>✓</td><td>Biomethane</td><td></td><td>Advanced biofuels (chemical route)</td><td></td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2">Discussion with stakeholders suggested that it might be possible to optimise harvesting operations by ensuring that markets were identified for all potential products and this might increase SRW availability. However this approach needed to be further explored in order to be validated. While there may be potential for more production from broadleaved forests, there are several barriers to overcome, such as the fragmented nature of broadleaf forests and their smaller scale, the fact that they may be managed for many objectives, (or indeed be left unmanaged). They can also be important for biodiversity and harvesting needs at an appropriate scale to make sure it has no negative impacts.</td><td>Typical carbon emissions</td><td colspan="8">7 kg CO_2/MWh of feedstock (as wood chips)
30 kg CO_2/MWh of feedstock (as wood pellets)
28 kg CO_2/MWh electricity if used as chips
120 kg CO_2/MWh electricity if used as pellets</td></tr>
<tr><td>Assumptions</td><td colspan="8">Quantities in tonnes assumed to be at 50% moisture with a net calorific value (NCV) of 2.3 MWh/tonne at 50% moisture. Carbon emissions estimated using [2] assuming pellets produced using biomass as heat source for drying and generating efficiency of 25%</td></tr>
</table>

Environmental impacts	Providing forests are sustainably managed to preserve long term carbon stocks, management is to appropriate standards (e.g. Forest Stewardship Council), and harvesting is carried out appropriately there should be no adverse environmental impacts.	References	[1] John Clegg Consulting, 2016. Wood Fibre Availability & Demand in Britain 2013-2035. Report for CONFOR, Forestry Commission, UKFPA and WPIF [2] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/

Resource	**Forestry - residues from harvest**	Cost	Residues from harvesting are commonly called “brash”. This is a by-product of forestry harvesting and there are costs associated with extracting it. This means that costs may be medium in short term, but could fall to low as harvesting and extraction techniques improve.

Description	Residues from final harvest operations comprise the tops and branches of felled trees (often termed brash). Residues can also include unmarketable wood, such as diseased wood. A proportion of this brash has to remain in the forest, for environmental reasons (such as protection of soil, nutrient retention and prevention of erosion), which is dependent on the site conditions	Current (TWh /yr)	2030 (TWh /yr)
Total quantity of resource	Allowing only for residues extracted in an environmentally friendly way and excluding foliage and stumps, the resource is estimated to be 282,000 oven dried tonnes (odt)/y[29][1]. This includes both conifer and broadleaf brash from public and private estates. This resource could increase to 2030 as final harvesting of forests is forecast to increase by then.	1.410	1.410
Current use for bioenergy	Currently about 20,000 odt/y is used in large scale boilers [2]	0.100	
Competing uses / current disposal routes	There are no other competing uses. As indicated above some brash must be left in forest for environmental and operational reasons, but this was not included in the resource estimate.	0.705	0.705
Additional resource potentially available for bioenergy	In theory an additional 262,000 odt/y could be potentially available, but part of this resource may be difficult to access economically, due to terrain conditions, remote locations and the cost of transport.	0.6056	0.605

Geographical distribution	Forest residues will be distributed in same locations as mature forests, as described in the SRW resource	Resource suitable for use in	Boiler	✓	Power generation	✓	Biogas for heat and power		Advanced biofuels (thermal route)	✓
			CHP	✓	Gasification	✓	Biomethane		Advanced biofuels (chemical route)	

Other considerations in utilisation for bioenergy	Brash is bulky to transport in comparison with saw logs and small round wood. In general the fraction that it will be feasible to extract is assumed to be 50% of total resource.	Typical carbon emissions	8 kg CO_2/MWh of feedstock (as wood chips) 28 kg CO_2/MWh of feedstock (as wood pellets) 32 kg CO_2/MWh electricity if used as chips 111 kg CO_2/MWh electricity if used as pellets
		Assumptions	Quantities in tonnes have been assumed to be at 0% moisture when dried with an NCV of 5.0 MWh/odt. Carbon emissions have been estimated using [3] assuming that pellets are produced using biomass as a heat source for drying and the generating efficiency is 25%.

[29] Oven dried tonnes(odt) represents wood with no moisture content. In reality harvested wood does contain water, but odt is used as a standard measure to enable comparison between different types of wood.

Environmental impacts	It is important to ensure that enough brash is left in the forest to protect the ground from compaction by harvesting machinery and protect soil fertility. This is likely to need to be assessed on a site by site basis, depending on terrain and climate.	References	[1] John Clegg Consulting, 2016. Wood Fibre Availability & Demand in Britain 2013-2035. Report for CONFOR, Forestry Commission, UKFPA and WPIF [2] Wood Fuel Task Force, 2011. The supply of wood for renewable energy production in Scotland [3] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/

Resource	**Short rotation forestry (SRF)**	Cost	Unknown at present.
Description	SRF uses fast growing species of trees on rotations of 8 to 20 years, depending on species and site. SRF plantations can be established on marginal agricultural land, permanent grassland and rough grazing.	Current (TWh /yr)	2030 (TWh /yr)
Total quantity of resource	FCS have commenced trials in Scotland to assess survival and yield and commercial viability of SRF. Significant areas are unlikely to be planted before these are completed, so given the rotation length (likely to be at least 10 years and more likely longer) no resource could be expected by 2030. FCS have suggested that up to 170,000 ha of permanent improved grassland in Scotland could be converted to forestry, some of which could be SRF, and SNIFFER also suggest there is significant potential. [2] suggested up to 90,000 ha could be converted to SRF, which would yield (when all matured) about 0.5 million odt/y (about 10 PJ), (assuming a yield of 90 odt/ha and a 15 year rotation).	0.000	0.000
Current use for bioenergy	None as resource will not have matured by 2030	0.000	
Competing uses / current disposal routes	It is envisaged that such plantations would be planted for dedicated energy use	0.000	0.000
Additional resource potentially available for bioenergy	None as resource will not have matured by 2030	0.000	0.000

Geographical distribution	SRF is likely to be established predominantly in areas of upland grazing and permanent grass land in north west Scotland [3]	Resource suitable for use (when available) in	Boiler	✓	Power generation	✓	Biogas for heat and power		Advanced biofuels (thermal route)	✓
			CHP	✓	Gasification	✓	Biomethane		Advanced biofuels (chemical route)	
Other considerations in utilisation for bioenergy	Stakeholders commented that the barriers for conversion to SRF include the need to obtain planning permission, as it is a change of use from agriculture to forestry. Associated with this are concerns that it will not be possible to return the land to agricultural use in the future, as deforesting these areas would be difficult both legally and socially.	Typical carbon emissions	8 kg CO_2/MWh of feedstock (as wood chips) 32 kg CO_2/MWh of feedstock (as wood pellets) 32 kg CO_2/MWh electricity if used as chips 130 kg CO_2/MWh electricity if used as pellets							
		Assumptions	Carbon emissions estimated using [1], assuming pellets are produced using biomass as heat source for drying and that the generating efficiency is25%							
Environmental impacts	Environmental impacts will depend on the land use that is displaced. If permanent grassland is used then the carbon impacts from loss of soil organic carbon will be more than if arable crops are displaced.	References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] Wood Fuel Task Force, 2011. The supply of wood for renewable energy production in Scotland [3] AEA, 2010. UK and Global Bioenergy Resources and Prices							

Resource	**Sawmill residues**	Cost	The cost is generally low, although competition from other uses will be strong at this low price point

		Current (TWh /yr)	2030 (TWh /yr)
Description	When harvested timber is processed to sawn timber in a sawmill, wood chips, sawdust and bark are produced as co-products. These are collectively known as sawmill residues. Panel board mills may also produce bark and sawdust residues, if they debark small roundwood to produce wood chips for manufacture of panel board on site.		
Total quantity of resource	The total resource is estimated as 2 Mt/y in 2016, rising by about 20% by 2030 due to increasing throughput at saw mills [1]	6.668	8.488
Current use for bioenergy	These residues can be used for energy, by combustion in an appropriate plant to generate heat and/or power. The sawmill industry and panel board industry may use residues on site for their own heat and power. Wood chips and sawdust can also be processed into wood pellets, which are more easily handled and transported that the raw residues, or briquettes. It is estimated that about a quarter of current sawmill residues are used for energy.	1.505	
Competing uses / current disposal routes	The main competing uses of sawmill residues are as a raw material for panel board manufacture (which currently uses about half of sawmill residues produced), agriculture (e.g. for animal bedding) and horticulture, which together currently account for about 20% of sawmill residues produced in Scotland. A small proportion of sawmill residues are exported outside of Scotland. These competing uses are likely to be price dependent.	5.163	6.143
Additional resource potentially available for bioenergy	As sawmill throughput increases in the future then a small additional amount of residues will become available for use.	0.000	0.840

Geographical distribution	Sawmills are located across Scotland: just over half of the resource arises in Southern Scotland, and just under a quarter in each of northern Scotland and central Scotland.	Resource suitable for use in	Boiler	✓	Power generation	✓	Biogas for heat and power		Advanced biofuels (thermal route)	✓
			CHP	✓	Gasification	✓	Biomethane		Advanced biofuels (chemical route)	

Other considerations in utilisation for bioenergy	This resource is relatively easily utilised, as it arises at a point source, and is 'clean' uncontaminated wood, which is relatively dry, such that combustion is straightforward. The main constraint on use for bioenergy is demand in competing markets.	Typical carbon emissions	8 kg CO_2/MWh of feedstock (as wood chips) 28 kg CO_2/MWh of feedstock (as wood pellets) 32 kg CO_2/MWh electricity if used as chips 111 kg CO_2/MWh electricity if used as pellets
		Assumptions	Quantities in tonnes have been assumed to be at 50% moisture with an NCV of 3.5 MWh/t assuming 30% moisture. Carbon emissions estimated using [2] assuming this to be similar to forestry residues and pellets produced using biomass as heat source for drying and generating efficiency of 25%
Environmental impacts	As this is a by-product, there should be no harmful environmental impacts associated with its production. If use for energy avoids disposal as a waste product then there may be environmental benefits	References	[1] John Clegg Consulting, 2016. Wood Fibre Availability & Demand in Britain 2013-2035. Report for CONFOR, Forestry Commission, UKFPA and WPIF [2] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp /

Resource	**Arboricultural arisings**	Cost	Generally low

Description	Arboricultural arisings come from the management of trees and shrubs from public and private (non-forest) land, such as gardens, park land, utility land (railways, reservoirs etc), business estates, roads and other public land. They comprise all parts of the woody material collected and include material collected by councils, contractors and from utility work.	Current (TWh /yr)	2030 (TWh /yr)
Total quantity of resource	A total of 712,000 t/y are estimated to be produced, of which 166,000 t/y is roundwood, suitable for use as fuel, and 310,000 t/y are brash, which would be more difficult to use. The remainder is foliage, which would not be suitable for energy use [2]	0.784	0.784
Current use for bioenergy	70,600 t/y are estimated to be sold as wood firewood and 28,400 t/y are estimated to be chipped for use as wood fuel, representing a total of 99,000 t/y.	0.468	
Competing uses / current disposal routes	Other routes for disposal include landfill, burning, composting, shredding for use in landscaping, simply leaving on site, and some use of animal bedding, bespoke furniture manufacture, or use in paper mill or panel board. The main competition for roundwood is likely to be animal bedding, wood manufacture and panel board plants, which currently account for about 49,000 tonnes.	0.231	0.231
Additional resource potentially available for bioenergy	If it is assumed that all roundwood can be used for fuel, then the total resource is 166,000 t of which 99,000 is already utilised. Of this additional resource (67,000t) about 49,000 t may be taken by competing markets, leaving an additional 18,000 t for bioenergy use. It is also possible that some brash could be utilised for energy although it might require more processing as it may be more contaminated with soils and stones. The impending ban on landfill of biodegradable material could also provide an incentive to improve management of materials.	0.085	0.085

Geographical distribution	Arboricultural arisings are concentrated around urban areas and widely distributed across Scotland. The best resource in terms of quantity and availability for fuel use is probably in the central Scotland urban conurbations.	Resource suitable for use in	Boiler	✓	Power generation	✓	Biogas for heat and power		Advanced biofuels (thermal route)	✓
			CHP	✓	Gasification	✓	Biomethane		Advanced biofuels (chemical route)	

Other considerations in utilisation for bioenergy	Factors that will influence the use of these resources for fuel include transport costs, the need for chipping equipment and the need to gather the arisings together for processing and distribution at a central hub.	Typical carbon emissions	8 kg CO_2/MWh of feedstock (as wood chips) 28 kg CO_2/MWh of feedstock (as wood pellets) 32 kg CO_2/MWh electricity if used as chips 111 kg CO_2/MWh electricity if used as pellets
		Assumptions	Quantities in tonnes assumed to be at 0% moisture when dried with an NCV of 4.7 MWh/odt. Carbon emissions estimated using [1] assuming this to be similar to forestry residues and pellets produced using biomass as heat source for drying with a generating efficiency of 25%.
Environmental impacts	As arboricultural arisings are essentially a waste, there should be no harmful environmental impacts associated with its production and use for energy. If use for energy avoids disposal as a waste product then there may be environmental benefits.	References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] International Synergies Ltd, 2010. Arboricultural Arisings Scotland Study. Report for Regional Biomass Advice Network Scotland

Resource	**Waste wood**	Cost	Generally low
Description	Waste wood arises from several sources and varies in quality, depending on its source. The quality of the wood determines the application it can be used for, which in turn influences its price. 'Clean' waste wood from packaging, pallets, joinery residues etc is termed Grade A, and is not subject to emissions requirements under the Industrial Emissions Directive. Construction and demolition waste wood is considered as predominantly Grade B, wood extracted from waste steams (e.g. at Civic amenity sites) is classed as Grade C and hazardous waste wood (including fencing, railway sleepers and transmission pole contractor waste) is classed as Grade D.	Current (TWh /yr)	2030 (TWh /yr)
Total quantity of resource	Total waste wood arisings are estimated as 602,000 odt [2]	2.843	2.843
Current use for bioenergy	The Markinch combined heat and power (CHP) biomass plant at the old Tullis Russel site near Fife is designed to burn 360,000t/y of waste wood (and 40,000 t/y of virgin wood). This waste wood demand is equivalent to about 250,000 to 290,000 odt/y. A substantial proportion of this is likely to be supplied from Scotland.	0.944	
Competing uses / current disposal routes	The main competing use for Grade A and B waste wood is panel board production, but clean waste wood can also be used for animal bedding, which is a high value product. Around 310,000 odt/y are estimated to be used in panel board production in Scotland [2]	1.444	1.444
Additional resource potentially available for bioenergy	It is assumed that all waste wood apart from that currently committed to the panel board industry or sold for animal bedding could be available for bioenergy use i.e. around 300,000 odt/y	0.454	0.454

Geographical distribution	This resource is concentrated around urban areas and widely distributed across Scotland as a result. A network of reprocessors exist that reprocess the waste wood to various fractions, including chip for waste wood energy plants.	Resource suitable for use in	Boiler ✓ Power generation ✓ Biogas for heat and power Advanced biofuels (thermal route) ✓ CHP ✓ Gasification ✓ Biomethane Advanced biofuels (chemical route)
Other considerations in utilisation for bioenergy	Transport costs might be significant for energy plant that are distant from the production area. The specification (Grade of the waste wood) determines the amount available and the cost. Waste wood can also contain contaminants such as metals and coatings, which tend to be concentrated in the fines fraction of the reprocessed waste wood. This tends to be available at the lowest price, but smaller scale plant may not be able to deal with these more contaminated waste streams.	Typical carbon emissions Assumptions	8 kg CO_2/MWh of feedstock (as wood chips) 28 kg CO_2/MWh of feedstock (as wood pellets) 32 kg CO_2/MWh electricity if used as chips 111 kg CO_2/MWh electricity if used as pellets Quantities in tonnes assumed to be at 0% moisture when dried with an NCV of 4.7 MWh/odt. Carbon emissions estimated using [1] assuming this to be similar to forestry residues and pellets produced using biomass as heat source for drying and with a generating efficiency of 25%
Environmental impacts	As this is essentially a waste, there should be no harmful environmental impacts associated with its production. If waste wood used for energy avoids disposal as a waste product, then there may be environmental benefits.	References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] Wood Fuel Task Force, 2011. The supply of wood for renewable energy production in Scotland

Resource	**Short rotation coppice (SRC) and Miscanthus**	Cost	Prices may need to be in the range of £80 to £100/odt (about £4 to £6/GJ) to be attractive for farmers [2], although recent work on Miscanthus has suggested that Miscanthus production could be economic at current commercial prices [3].

		Current (TWh /yr)	2030 (TWh /yr)
Description	SRC and Miscanthus are perennial crops that can be used for energy. The energy crops most suitable for cultivation in Scotland are willow (or poplar) grown using a short rotation coppice (SRC) technique and, in some regions, Miscanthus (a woody rhizomatous grass). These crops can be grown on arable land and temporary grassland or reasonable quality permanent pasture, although the latter may be undesirable as it may result in poor carbon savings. The planting, cultivation and harvesting of these crops requires specialised equipment, techniques and planting material. Establishment requires intensive effort and some agrochemical input, but thereafter perennial crops require less input in agrochemicals and labour than annual crops. Once planted they take up to four years to reach maturity, after which they are harvested at regular intervals - typically every year for Miscanthus and every four years for willow SRC. After about 20 to 25 years the crop is removed and replanted, and then the harvesting cycle begins again.		
Total quantity of resource	Only very small quantities of SRC are grown commercially in Scotland at present (we estimate that around 250 ha are planted, yielding about 2000 odt/y), and there are no commercial plots of Miscanthus. About 1 Mha of arable and temporary grassland in Scotland might be suitable for perennial energy crops, and if 5% (55,000 ha) were utilised then potentially 430,000 odt/y could be produced.	0.010	2.150
Current use for bioenergy	250 ha equates to about 2,000 odt which is assumed to be used for energy purposes.	0.00	
Competing uses / current disposal routes	No competing uses as would be grown specifically for energy use. Miscanthus can also be used for animal bedding	0.000	1.490
Additional resource potentially available for bioenergy	The development of additional energy crop resource will depend on overcoming barriers and persuading farmers to plant crop. To achieve increased production propagation of planting material is vital. In addition, energy crops require specialist planting and harvesting machinery, which is also in short supply at present. Together these factors limit the rate at which planted areas can be expanded (we have adopted the assumption that the increase in area could be around 20% p.a., which is the rate used in the BEIS UK and Global biomass resource model[30]). If it was assumed that 1000 ha could be planted in 2020 in Scotland, then this this rate of increase would result in 32,150 ha planted by 2030. As it takes four years for energy crops to reach maturity, the mature portion of this planted area would produce a resource of 132,000 odt (rising to 257,000 odt/y by 2034).	0.010	0.660

Geographical distribution	Energy crops are most suitable for the arable belt along the Eastern Scottish coast	Resource suitable for use in	Boiler	✓	Power generation	✓	Biogas for heat and power		Advanced biofuels (thermal route)	✓
			CHP	✓	Gasification	✓	Biomethane		Advanced biofuels (chemical route)	

Other considerations in utilisation for bioenergy	The lack of production of energy crops by farmers to date reflects a number of barriers - the lack of a perceived stable market for energy crops, lack of experience with crops, perception of risk and uncertainty, and requirements for up-front investment and cash flow issues in early years. Farmers can also be reluctant to commit land to long term production of one crop. Energy crops also need to be an attractive financial investment compared to alternative land uses	Typical carbon emissions	8 kg CO_2/MWh of feedstock (as wood chips) 32 kg CO_2/MWh of feedstock (as wood pellets) 32 kg CO_2/MWh electricity if used as chips 130 kg CO_2/MWh electricity if used as pellets
		Assumptions	Quantities in tonnes assumed to be at 0% moisture when dried with an NCV of 5. MWh/odt. Carbon emissions estimated using [1] assuming pellets are produced using biomass as heat source for drying and with a generating efficiency of 25%

[30] See: https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model

Environmental impacts	Growing perennial energy crops on land previously used for arable crops can lead to improved biodiversity, help with flood mitigation, and result in an increase in soil carbon.	References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] Hastings et al, A, 2017. Economic and Environmental Assessment of Seed and Rhizome Propagated Miscanthus in the UK. Frontiers in Plant Science, vol 8, Article 1058 [3] P Alexander et al, 2014. Estimating UK perennial energy crop supply using farm-scale models with spatially disaggregated data. GCB Bioenergy, 2014. pp 142-155

Resource	**Cereal straws**	Cost	The price at farm gate typically ranges from £40/t to £60/t (£2.6 to £4/GJ) but in some years (such as 2017) where less straw is produced, prices have been known to increase to £100/t or more (£6.8/GJ). Transport costs of around £25 for delivery to a power plant add £1.7/GJ.

		Current (TWh /yr)	2030 (TWh /yr)
Description	Straw is a by-product from the production of commercial crops such as wheat, barley and oats. It can be combusted to generate electricity and/ or heat. Straw bales can be burnt whole but are more efficient when prised open and either chopped or shredded or fed in sections into the combustion plant; straw can also be pelletised. In the future, the development of gasification and pyrolysis techniques could allow more efficient combustion and advanced biofuel conversion technologies could allow the production of bioethanol from straw.		
Total quantity of resource	The estimated potential production of straw in 2017 was 1.62 Mt [2]. However, straw production varies annually, due to fluctuations in the area of cereals planted, and the cereal yields achieved, which are dependent on factors like weather. For example, the wet weather in 2017 resulted in low straw yields (reflected to the low estimate of resource above) and production has been higher in other years (as much as 1.9 Mt/y) [1].	6.345	6.345
Current use for bioenergy	There are some straw boilers in Scotland, but quantity used is unknown.	0.000	
Competing uses / current disposal routes	The main competing use of straw is animal bedding in North and West Scotland (representing 0.82 Mt) and feed (0.33 Mt) (in 2015). There is also some use for cover for carrots (0.17Mt), giving a total use of about 1.32 Mt/y.	5.170	5.170
Additional resource potentially available for bioenergy	In 2017, this resulted in a potential quantity of 0.3Mt straw which could be available for bioenergy if it is harvested and baled. The impact of the weather in 2017 raises the issue of climate change and the potential impact it might have on crops and crop residues in future years.	1.175	1.175

Geographical distribution	The straw resource is predominantly produced in the arable east; and these regions have a surplus of straw, some of which is used to supply demand in the west of Scotland where there is insufficient supply.	Resource suitable for use in	Boiler	✓	Power generation	✓	Biogas for heat and power		Advanced biofuels (thermal route)	✓
			CHP	✓	Gasification	✓	Biomethane		Advanced biofuels (chemical route)	✓

Other considerations in utilisation for bioenergy	Straw is bulky to transport so transport costs are high. For example, it can cost £25/t to transport straw from East to South West Scotland. The potential resource estimated here is that available if all straw is harvested and baled. However, straw can be chopped and reincorporated for a number of reasons e.g. wet weather at the time of harvest, potentially limiting availability, so the estimate represents a maximum availability.	Typical carbon emissions	18 kg CO_2/MWh of feedstock 74 kg CO_2/MWh electricity
		Assumptions	Quantities in tonnes assumed to be at 15% moisture with an NCV of 3.9 MWh/t. Carbon emissions estimated using [1] assuming a generation efficiency of 25%
Environmental impacts	Some incorporation of straw can be required in order to maintain soil quality but as long as these limits are not exceeded there should be no damaging impacts	References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] SRUC, 2018. Straw and Forage Study

<table>
<tr><td>Resource</td><td>Residual municipal solid waste (MSW) and commercial waste - Biogenic component only</td><td>Cost</td><td colspan="9">Typically gate fee can be charged for waste, so that the feedstock becomes an income stream for energy plant, rather than cost. The gate fee depends on alternative options for waste disposal, but gate fees have risen in response to the landfill tax.</td></tr>
<tr><td>Description</td><td colspan="8">Residual waste is the waste left after the recyclable fraction and food waste have been removed. This residual fraction will still contain some material of organic origin. This is regarded as a "biogenic fraction" and represents the content of the waste that is used to generate renewable energy. In some cases, residual waste is referred to as a refuse derived fuel (RDF), or if it meets specifications outlined in guidance as a solid recovered fuel.</td><td>Current (TWh /yr)</td><td colspan="2">2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Data from Zero Waste Scotland's (ZWS) residual waste model suggest that total residual waste in 2016 was 2.91 Mt (of which MSW accounted for 0.9 Mt and commercial and industrial waste is 1.7 Mt) including 0.4 Mt of food waste. Future targets for Reuse, Recycling and Composting of 70% mean that by 2030, total residual waste is forecast to fall to 1.6 Mt (0.7 Mt of residual waste and 0.9 of C&I waste), including 0.2 Mt of food waste. However only a proportion of residual waste is biogenic. Excluding food waste, which is evaluated separately below, and using the assumptions in the ZWS residual waste model the total biogenic component of residual waste excluding food waste was 0.62 Mt in 2016 and will be 0.22 Mt in 2030.</td><td>1.891</td><td colspan="2">0.660</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">Scotland currently has two energy from waste plant utilising waste. These are a large plant at Baldovie taking 150,000 t/y waste and a small one at Shetland (26,000 t/y). Further energy from waste plant are planned for Scotland, as evidenced in the media, but these may not all go ahead[31].</td><td>0.084</td><td colspan="2"></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">Landfill of biodegradable MSW will be banned from 2021, meaning that other treatment methods will need to be found - these could include incineration with energy recovery, or use of other techniques such as mechanical biological treatment (MBT) to reduce the biodegradability of waste before landfilling it.</td><td>0.189</td><td colspan="2">0.066</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">Some waste occurring in more rural locations might be better treated by other methods, although production of RDF for transport to a larger scale central facility might be feasible. It is assumed that perhaps 90% of the resource could be captured.</td><td>0.510</td><td colspan="2">0.510</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Waste is mainly concentrated in urban areas and the Scottish central belt.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td>✓</td><td>Power generation</td><td>✓</td><td>Biogas for heat and power</td><td></td><td colspan="2">Advanced biofuels (thermal route)</td><td>✓</td></tr>
<tr><td>CHP</td><td>✓</td><td>Gasification</td><td>✓</td><td>Biomethane</td><td></td><td colspan="2">Advanced biofuels (chemical route)</td><td></td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2">Waste disposal is governed by the principles of the waste hierarchy in which prevention, reuse, and recycling come above disposal. It is policy in Scotland to ensure that the waste hierarchy is in place and that higher value uses are waste are promoted before energy recovery. This will impact on the amount of waste available for energy recovery and on its characteristics (e.g. biogenic content).</td><td>Typical carbon emissions</td><td colspan="9"></td></tr>
<tr><td>Assumptions</td><td colspan="9">Assumed to be an NCV of 3.1 MWh/t as received at the energy recovery plant gate.</td></tr>
</table>

[31] See, for example, https://www.endswasteandbioenergy.com/article/1466050/uk-plans-88m-scottish-efw-plant-advance and https://www.endswasteandbioenergy.com/article/1448222/plans-22mwe-efw-plant-approved

Environmental impacts	As long as waste is not diverted to energy from other higher value management options further up the waste hierarchy then provision of the feedstock does not of itself generate environmental impacts. Permitting and monitoring to meet the Industrial Emissions Directive should ensure that environmental emissions are minimised.	References	

<table>
<tr><td>Resource</td><td>Poultry litter</td><td>Cost</td><td colspan="8">Low</td></tr>
<tr><td>Description</td><td colspan="8">Poultry litter than can be used for energy is essentially chicken manure mixed with soft wood shavings or straw from broilers hens (i.e. those raised for meat production).</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">The estimated production of chicken litter in Scotland is 133,834 tonnes. [2].</td><td>0.294</td><td>0.294</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">120,000 tonnes used at dedicated poultry litter power station (Westfield) near Fife</td><td>0.263</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">Chick litter is disposal to land because of its high fertiliser value. However, in areas where poultry plants are concentrated this causes an odour nuisance.</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">We have assumed remaining resource available for energy (although this assumes intensive poultry farm operations)</td><td>0.030</td><td>0.030</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Quantities of poultry litter produced throughout Scotland with higher concentrations in south, central and north-east Scotland.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td>✓</td><td>Power generation</td><td>✓</td><td>Biogas for heat and power</td><td></td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td>✓</td><td>Gasification</td><td>✓</td><td>Biomethane</td><td></td><td>Advanced biofuels (chemical route)</td><td></td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2">Ash from poultry litter plants was used as a fertiliser so that the fertiliser value was not lost. However, poultry litter plants are now classified as waste plants and are subject to Industrial Emissions Directive. The ash may now be regarded as a waste, which will mean that its disposal may be regulated, and its use as a fertiliser not allowed.</td><td>Typical carbon emissions</td><td colspan="8">18 kg CO_2/MWh of feedstock
74 kg CO_2/MWh electricity</td></tr>
<tr><td>Assumptions</td><td colspan="8">Quantities in tonnes assumed to be at 50% moisture with an NCV of 2.2 MWh/t. Carbon emissions estimated using [1] assuming emissions similar to straw, and generating efficiency of 25%</td></tr>
<tr><td>Environmental impacts</td><td>As this is a waste, there may be environmental benefits from utilising for energy compared to other disposal routes.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
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<table>
<tr><td>Resource</td><td>Domestic and commercial food waste</td><td>Cost</td><td colspan="8">Historically anaerobic digestion (AD) plants have been able to charge a gate fee for food waste; however anecdotal evidence is that a shortage of food waste, due to an increase in the capacity of AD plant in Scotland, and an increase in comingled food waste collections means that for unpackaged food waste (e.g. from householders), the gate fee has significantly lowered as plants seek to attract feedstock</td></tr>
<tr><td>Description</td><td colspan="8">Food waste produced from the domestic and commercial sector.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Total food waste from household waste and commercial and industrial waste is currently about 582,242 t/y of which 183,980t/y is collected separately, and 398,262 t/y still goes to residual waste and is disposed of to landfill or energy recovery. Legislation to encourage source separate collection of food waste means that the quantities collected separately should increase to about 210,000 t/y in 2030.</td><td>0.640</td><td>0.640</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">Of the food waste that is collected separately, some can be used as a feedstock for an AD plant. However, some is collected comingled with garden waste, in which case it cannot go to AD but instead goes to In-Vessel Composting (IVC). The amount of waste split between these two methods of collection is not known. There are 5 operational AD plants taking solely food waste in Scotland. These have an estimated combined capacity of 267,000 t/y of food waste. This is greater than the estimate of source separate collected food waste, suggesting that feedstocks may be supplemented with food waste from industrial food processing sites.</td><td>0.286</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">Alternative disposal routes are IVC for waste that has been collected separately or landfill or energy recovery for food waste in the residual waste stream.</td><td>0.128</td><td>0.128</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">Full separation of food waste from the residual waste stream is unlikely, but higher rates than are currently achieved should be possible. For this study we have assumed that 80% of food waste can be separated at source based on best practice.</td><td>0.226</td><td>0.226</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Waste is mainly concentrated in urban areas and the central belt.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2">The type of collection for food waste is determined by the Local Authority. While comingled collection of garden and food waste may be preferred by Local Authorities for a number of operational and financial reasons, this type of collection precludes use of that food waste in AD, for a number of reasons (in part because it makes it more difficult to use the digestate). In more rural areas, quantities of waste may be too small to sustain a viable AD plant, unless bulked up by co-digestion with other materials.</td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 1.1 MWh biogas/t. Carbon emissions estimated using [1] assumed emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td>As this is a waste, there may be environmental benefits from utilising for energy compared to other disposal routes.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/</td></tr>
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Resource	**By-products from whisky industry - Draff**	Cost	low

Description	Spent grain left in the mash-tun after the liquor, wort, has been drawn off. Draff has a high moisture content (about 77%). This material is rich in protein, carbohydrates and fibre.	Current (TWh /yr)	2030 (TWh /yr)
Total quantity of resource	Estimated production 684,000 tonnes. [2] Production varies year on year as whiskey production varies.	0.65	0.65
Current use for bioenergy	Publicly available data suggests that the only CHP plant combusting draff is the Rothes CoRDe plant, located in Speyside. This is using 115,000 t/y of wet draff annually, together with 60,000 tons of wood chips. Some draff is also co-digested with pot ale at AD plant located at distilleries, and there may be some transport to other AD plant although this is likely to be limited due to the high moisture content of draff which means that it is unlikely to be economical to transport it far. Data on the quantities of draff used in AD are not publicly available but based on information of the capacity of AD plant in distilleries, and assuming that feedstocks are draff and pot ale in the proportions that they are produced, then an estimated 140,000 t/y of wet draff are used in AD plant.	0.17	
Competing uses / current disposal routes	The remainder (about 429,000 t) is currently used as animal feed.	0.38	0.380
Additional resource potentially available for bioenergy	Some draff is used as animal feed could potentially be used for bioenergy. We have estimated a constrained resource based on assumption that 50% could be available. Pot ale is also being considered as a feedstock for an advanced biofuels production process to produce biobutanol and bioethanol. This process would still produce an animal feed as a by-product.	0.10	0.10

Geographical distribution	Concentrated around the north east and Highlands. A considerable amount is also produced in the west and east coastal regions. 6 local authorities make up 80% of production.	Resource suitable for use in	Boiler	✓	Power generation		Biogas for heat and power	✓	Advanced biofuels (thermal route)	
			CHP	✓	Gasification		Biomethane	✓	Advanced biofuels (chemical route)	✓

Other considerations in utilisation for bioenergy	There are concerns from the farming community about removal of a low-cost animal feed.	Typical carbon emissions	30 kg CO_2/MWh of feedstock (to electricity) 87 kg CO_2/MWh electricity 82 kg CO_2/MWh biomethane to grid
		Assumptions	Quantities in tonnes assumed to have an NCV of 1.1 MWh/tonne at 70% moisture. Carbon emissions estimated using [1] assuming emissions similar to wet manure and generating efficiency of 35% for electricity and 35% for biomethane
Environmental impacts		References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] ZWS Biorefining potential model

<table>
<tr><td>Resource</td><td colspan="2">By-products from whisky industry - Pot ale</td><td>Cost</td><td colspan="8">low</td></tr>
<tr><td>Description</td><td colspan="7">Pot ale is the liquor left in the wash still after the first distillation in the pot still process. It has a very low solids content (of about 4%) meaning that it is a very dilute source of biogenic matter. This liquid is produced in very large quantities: about 8 litres of pot ale generated per litre of alcohol in the whisky.</td><td colspan="2">Current (TWh /yr)</td><td colspan="2">2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="7">The estimated production of pot ale is 2,048,000 t/y. [2]</td><td colspan="2">0.243</td><td colspan="2">0.243</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="7">Information on AD plant located at distilleries suggests that about 560,000 t/y of pot ale, spent lees and draff may already be going to AD for generation of biogas for CHP or upgrading to biomethane. We have assumed that this 560,000 t is made up of the three by-products in the proportions that they are produced, meaning that an estimated 360,000 t/y of pot ale are going to AD plant.</td><td colspan="2">0.042</td><td colspan="2"></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="7">A very small amount (only 1.5%) is converted to a thicker pot ale syrup, which may then be disposed of, or can be used as an animal food, or may be used as a feedstock for AD plant not located close to distilleries; pot ale not used for AD will be disposed of as waste water to treatment plant prior to discharge to local seas and rivers.</td><td colspan="2">0.000</td><td colspan="2">0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="7">We have assumed that the total resource is available for bioenergy via AD. The viability of this at smaller distilleries will need further assessment. Pot ale is also being considered as a feedstock for an advanced biofuels production process to produce biobutanol and bioethanol.</td><td colspan="2">0.201</td><td colspan="2">0.201</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2" colspan="2">Pot ale is concentrated around the north east and Highlands. A considerable amount is also produced in the west and east coastal regions. 6 local authorities make up 80% of production.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2" colspan="2">Unlikely to be economic to transport long distances due to liquid nature. Concentrating to pot ale syrup will help to reduce transport requirements but has an energy penalty</td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of NCV of 0.1 MWh biogas/tonne. Carbon emissions estimated using [1], assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td colspan="2">In cases where pot-ale is disposed of to seas or rivers, there may be environmental benefits from utilising for energy.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

<table>
<tr><td>Resource</td><td>By-products from whisky industry - Spent lees/wash</td><td>Cost</td><td colspan="8">low</td></tr>
<tr><td>Description</td><td colspan="7">Spent lees are the residue in the Spirit Still after the distillation of the foreshoots, potable spirits, and feints. They are usually treated and run to waste. Similar in properties to pot ale, but more dilute.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="7">The estimated production of spent lees is 361,000 t/y. [2]</td><td>0.0011</td><td>0.0011</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="7">Information on AD plant located at distilleries suggests that about 560,000 t/y of pot ale, spent lees and draff may already be going to AD for generation of biogas for CHP or upgrading to biomethane. We have assumed that this 560,000 t is made up of the three by-products in the proportions that they are produced, meaning that an estimated 63,000 t/y of pot ale are going to AD plant.</td><td>0.0002</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="7">Spent lees not used for AD will be disposed of as waste water to seas and rivers</td><td>0.0000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="7">We have assumed that the total resource is available for bioenergy using AD.</td><td>0.0009</td><td>0.0009</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Spent lees are concentrated around the north east and Highlands of Scotland in association with the whisky industry. There is also a considerable amount produced in the west and east coastal regions. 6 of Scotland's local authority regions make up 80% of production.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2">It is unlikely to be economic to transport spent lees long distances due to its high liquid content. Concentrating to pot ale syrup will help to reduce transport requirements but there is an associated energy penalty to doing this, which will need to be considered.</td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.003 MWh biogas/tonne. Carbon emissions were estimated using [1], assuming emissions are similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td>Spent lees are typically treated on the distillery site utilising conventional aerobic biological treatment before being discharged to local water courses [3]. Utilising for bioenergy may therefore deliver some environmental benefits.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model
[3] Akunna J C and Walker G M (2017) Co-products from malt whisky production and their utilisation, chapter 34 in Anaerobic waste water treatment and biogas plants: a practical guide ed. Akunna J C (2018)</td></tr>
</table>

<table>
<tr><td>Resource</td><td>By-products from whisky industry – Distilllers Dark Grains (DDG)</td><td>Cost</td><td colspan="8">DDG has a value as animal feed, and attracts prices similar to that of grain used for animal feed [3].</td></tr>
<tr><td>Description</td><td colspan="8">Larger distilleries or clusters of distilleries in Scotland have invested in technology to process draff and pot ale into a drier and more concentrated animal feed, dark grains. This is a high energy process due to the heat needed to evaporate the pot ale, however DDG has a higher nutritional value than raw draff and can be economically transported greater distances.</td><td>Current (TWh/yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">The estimated production is 254,000 t/y. [2]</td><td>0.085</td><td>0.085</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">None</td><td>0.000</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">DDG is currently produced from draff and pot ale solely for use as animal feed.</td><td>0.085</td><td>0.085</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">It is assumed that DDG continues to be used as animal feed, and that production at current levels continues.</td><td>0.00</td><td>0.00</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">DDG is concentrated around the north east and Highlands, associated with whisky production. A considerable amount is also produced in the west and east coastal regions. 6 of the Scottish local authority regions make up 80% of production. An estimated 40% of dark grains from Scottish distilleries are sold to farmers in northern England, with the rest used throughout Scotland31.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2">With both draff and dark grains, there is often a strong and well established commercial relationship between the distilleries and the animal feed companies or the farmers, which has the potential to be a barrier to developing new uses for these materials [3].</td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.3 MWh biogas/tonne. Carbon emissions estimated using [1] assuming emissions similar to wet manure and generating efficiency of 35% for electricity and 35% for biomethane</td></tr>
<tr><td>Environmental impacts</td><td></td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model
[3] ZWS Sector Study on Beer Whisky and Fish</td></tr>
</table>

<table>
<tr><td>Resource</td><td>By-products from brewery industry - Spent grain (Beer)</td><td>Cost</td><td colspan="8">Spent grain has a value as animal feed</td></tr>
<tr><td>Description</td><td colspan="8">Spent grains contain cellulose, hemicelluloses, lignin, sugars and amino acids, making them suitable for use as a feed for cattle and other ruminants. Spent grains are predominantly used for local animal feed, directly or via feed merchants who sell it as a 'moist feed'. Spent grains are a good source of protein (~25% on a dry matter basis), fibre and energy suitable for cattle and other ruminants.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Estimated production 48,700 t/y. [2]</td><td>0.007</td><td>0.007</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">None</td><td>0.000</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">Spent grain is currently used in animal feed</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">Likely to remain used as an animal feed.</td><td>0.007</td><td>0.007</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Over 60% is produced within Glasgow (30,000 t/y), with smaller amounts found in the surrounding regions.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2"></td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.1 MWh biogas/tonne. Carbon emissions were estimated using [1] assuming that the emissions are similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td></td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

Resource	**By-products from brewery industry - Spent hops (Beer)**	Cost	Spent hops have a value as fertiliser or compost but is too bitter for animal feed applications.

		Current (TWh /yr)	2030 (TWh /yr)
Description	Hops are mixed with the wort and boiled, after which the solids are removed as trub and spent hops, in some cases separately and others mixed. Spent hops can be used as a mulch or soil conditioner, with or without composting.		
Total quantity of resource	Estimated production 428 t/y. [2]	0.000	0.000
Current use for bioenergy	None	0.000	
Competing uses / current disposal routes	Currently spread to land	0.000	0.000
Additional resource potentially available for bioenergy	These products have been used as feedstocks for AD plant in other parts of the UK and overseas	0.000	0.000

Geographical distribution	Over 82% is produced within Glasgow, with smaller amounts found in the surrounding regions.	Resource suitable for use in	Boiler		Power generation		Biogas for heat and power	✓	Advanced biofuels (thermal route)	
			CHP		Gasification		Biomethane	✓	Advanced biofuels (chemical route)	✓

Other considerations in utilisation for bioenergy		Typical carbon emissions	30 kg CO_2/MWh of feedstock (to electricity) 87 kg CO_2/MWh electricity 82 kg CO_2/MWh biomethane to grid
		Assumptions	Biogas yield of 0.1 MWh biogas/tonne. Carbon emissions estimated using [1] assuming emissions similar to wet manure and generating efficiency of 35% for electricity and 35% for biomethane
Environmental impacts		References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] ZWS Biorefining potential model

<table>
<tr><td>Resource</td><td>By-products from brewery industry - Spent yeast (Beer)</td><td>Cost</td><td colspan="8">low</td></tr>
<tr><td>Description</td><td colspan="8">The brewery fermentation process produces a surplus of yeast, some of which is reused in the brewing process. The remaining spent yeast is produced in a liquid form and can be disposed of with other liquid wastes to the sewage system, with or without on-site aerobic pre-treatment.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Estimated production 3,653 t/y. [2]</td><td>0.001</td><td>0.001</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">None</td><td>0.000</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">Spent yeast is currently disposed of as wastewater i.e. to local sea/rivers after treatment</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">These products have been used as feedstocks for AD plant in other parts of the UK and overseas</td><td>0.001</td><td>0.001</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Over 82% is produced within Glasgow, with smaller amounts found in the surrounding regions.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2"></td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.1 MWh biogas/tonne. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane</td></tr>
<tr><td>Environmental impacts</td><td>Where treated spent yeast is disposed of to water courses, there may be environmental benefits from utilising for energy.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

<table>
<tr><td>Resource</td><td>By-product from dairy industry - Whey</td><td>Cost</td><td colspan="8">low</td></tr>
<tr><td>Description</td><td colspan="8">Whey is the liquid remaining after milk has been curdled and strained. It is a by-product of the manufacture of cheese or casein and there are therefore a relatively small number of point sources.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Estimated production 505,486 t/y. [2]</td><td>0.115</td><td>0.115</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">25,500 tonnes in Argyll and Bute (5% of arisings) is going for anaerobic digestion</td><td>0.006</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">The largest source in Dumfries and Galloway, which accounts for 92.5% of arisings, is currently mainly used as animal feed. In Argyll and Bute (where 5% of arisings are produced) it is going for anaerobic digestion and the remainder (2.5% of arisings) in the Orkney Islands and North Ayrshire is being disposed of to sea/rivers.</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">We have assumed that all of the resource could potentially be used for AD</td><td>0.109</td><td>0.109</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Over 90% in Dumfries and Galloway, with the remaining in 3 other local authority areas.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2"></td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.2 MWh biogas/tonne. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td>There may be environmental benefits from utilising for energy compared to disposal to water courses.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

<table>
<tr><td>Resource</td><td>Waste from fish processing - Fish process waste</td><td>Cost</td><td colspan="8">Has a value as animal feed</td></tr>
<tr><td>Description</td><td colspan="8">Waste produced during fish processing operations can be solid or liquid, and includes skin, trimmings, bones, viscera. These may be made into fish paste, fishmeal or sold as a product.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Estimated production 160,250 t/y. [2]</td><td>0.247</td><td>0.247</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">n/a</td><td>0.000</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">Fish was is generally reprocessed into products such as fish meal, fish paste and oils, which are then used for animal feed, fish feed or pet food</td><td>0.247</td><td>0.247</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">There may be potential for some whole fish waste</td><td>0.000</td><td>0.000</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Fish waste is concentrated around Aberdeenshire, Highlands and Islands.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2"></td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 1.5 MWh biogas/tonne. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td></td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

<table>
<tr><td>Resource</td><td colspan="2">Waste from fish processing - Shell fish waste</td><td>Cost</td><td colspan="8">low</td></tr>
<tr><td>Description</td><td colspan="9">Shell fish waste is captured and discarded shellfish, comprising under-utilised / undersized / non-quota species and parts of the shellfish that are not usually used directly for human consumption. It can include shell, viscera, heads and legs.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="9">The estimated production is 27,211 t/y. [2]. Only small are quantities generated, mostly in rural areas, as shell fish tend to be exported whole.</td><td>0.042</td><td>0.042</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="9">n/a</td><td>0.000</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="9">The current disposal method is not clear, but is likely to involve local disposal as there are relatively small pockets of waste in rural areas. here is a derogation that allows shells from crustaceans with soft tissue and flesh attached, which do not show any signs of disease communicable to humans or animals, to be applied to land as organic fertilisers/soil improvers without additional processing or treatment, so it is possible that some waste is disposed of in this way</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="9">It is assumed that all of the waste could potentially be used for bioenergy</td><td>0.042</td><td>0.042</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2" colspan="2">Shell fish waste is concentrated around Aberdeenshire, Highlands and Islands.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2" colspan="2"></td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 1.5 MWh biogas/tonne. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane</td></tr>
<tr><td>Environmental impacts</td><td colspan="2">There may be environmental benefits from utilising for energy compared to other waste disposal routes.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

<table>
<tr><td>Resource</td><td>Abattoir waste - Animal by products</td><td>Cost</td><td colspan="8">low</td></tr>
<tr><td>Description</td><td colspan="8">Blood and bones (excludes hide and skin as not suitable for use as energy resource). This can be rendered into blood and bone meal for fertiliser or blood meal for animal feed.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Estimated production 30,713 t/y. [2]</td><td>0.008</td><td>0.008</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">n/a</td><td>0.000</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">Rendered into a bone meal fertiliser or blood meal animal feed.</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8"></td><td>0.008</td><td>0.008</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Quantities of abattoir waste by product are produced throughout Scotland, with higher concentrations in the east coast.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2"></td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.2 MWh biogas/tonne. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td>If any of this by-product is disposed of as a waste rather than going into alternative uses, then there may be environmental benefits from using it for energy.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

<table>
<tr><td>Resource</td><td>Abattoir waste - Animal by products</td><td>Cost</td><td colspan="8">low</td></tr>
<tr><td>Description</td><td colspan="8">Fat produced as a waste at abattoirs. This can be made into tallow.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Estimated production 7,110 t/y. [2]</td><td>0.002</td><td>0.002</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">n/a</td><td>0.000</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8"></td><td>0.000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8"></td><td>0.002</td><td>0.002</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Quantities of waste by product produced throughout Scotland with higher concentrations in the east coast.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2"></td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.2 MWh biogas/t. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td>If any of this by-product is disposed of as a waste rather than going into alternative uses, then there may be environmental benefits from using it for energy.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

<table>
<tr><td>Resource</td><td>Sewage sludge</td><td>Cost</td><td colspan="8">low</td></tr>
<tr><td>Description</td><td colspan="7">Sewage sludge from waste water treatment plants</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="7">The estimated production is 123,476 t/y of dry solids. [2]. Of this about 89% was produced at waste water treatment plants servicing larger urban areas that are run by private companies under a public private partnership (PPP).</td><td>0.394</td><td>0.394</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="7">46,254 t/y in Glasgow is currently undergoing drying with the sludge then used for incineration in a cement kiln. AD plant are installed or being considered at some PPP sites. Renewable energy statistics suggest that there are 8 sites, producing 32 GWh (in 2016), which suggests around 350,000 to 420,000 t of sludge treated in AD plants in 2016.</td><td>0.089</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="7">The remainder that is not used in AD plants or incineration is spread to land</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="7">It should be feasible to use sewage sludge at the larger waste water treatment sites for bioenergy. The quantities at smaller sites in rural areas may not be sufficient to sustain an AD plant but could be considered for co-digestion with other resources in the area.</td><td>0.305</td><td>0.305</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Quantities of waste by product are produced throughout Scotland, with high quantities concentrated in areas of higher population.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2"></td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.3 MWh biogas/tonne. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td>As this is a waste, there may be environmental benefits from utilising for energy compared to other waste disposal routes.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] Scottish Water Annual Return Information Requirements Table A3 (2017)</td></tr>
</table>

<table>
<tr><td>Resource</td><td>Slurries - Dairy and beef slurry</td><td>Cost</td><td colspan="8">Zero cost for resource: may be transport costs</td></tr>
<tr><td>Description</td><td colspan="8">Slurry from farms that keep dairy and beef cattle. Slurry is excreta produced by livestock while in a yard or building, including excreta mixed with bedding, rainwater and washings, and that have a consistency that allows them to be pumped or discharged by gravity.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">The Estimated production of dairy and beef slurry is 5,562,766 t/y. [2]</td><td>0.660</td><td>0.660</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">There is some use of slurries in farm-based AD systems, but in almost all cases slurries are co-digested with other materials - predominantly energy crops, but also food wastes and distillery wastes. This is because slurry digestion on its own produces low yields, but co-digestion increases these yields significantly. Slurry only systems in operation have an intake of 36,500t/y. The slurry component of other systems is not known.</td><td>0.009</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">Unless the slurry is used for AD, it is spread on land</td><td>0.165</td><td>0.165</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">Much more of the resource could be utilised for AD, although there is likely to be a minimum size of farm below which AD will not be feasible, even with co-digestion of other wastes. This could reduce resource somewhat. It is not known how much of the slurry resource could be used in AD, but this will depend on economics and the size of the slurry resource produced on a farm. To take this uncertainty into account we have assumed that 75% of resource could be utilised.</td><td>0.486</td><td>0.486</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Quantities of dairy and beef slurry are produced throughout Scotland with higher concentrations in the South of Scotland (Ayrshire, Dumfries and Galloway, Borders and South Lanarkshire.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2">The economics of slurry digestion can be poor unless the slurry is co-digested with other feedstocks. This has led to little utilisation of this resource to date in Scotland. The distributed nature of the resource and the lack of a connection to the gas grid or electricity grid can also be barriers. There are concepts for creating a 'virtual pipeline' by upgrading to biomethane, which is then stored in pressurised containers prior to being transported by road to an end user or for injection into the grid at an appropriate location, which could help with utilisation of resources in more remote locations.</td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.1 MWh biogas/tonne. Carbon emissions estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.</td></tr>
<tr><td>Environmental impacts</td><td>As this is a waste, there may be environmental benefits from utilising for energy compared to other waste disposal routes.</td><td>References</td><td colspan="8">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

Resource	**Slurries - Dairy and Beef FYM**	Cost	Zero cost for resource: may be transport costs

Description	Farmyard manures (FYM) refer to livestock excreta mixed with bedding material (such as straw). In general, FYM has a dry matter content of more than 10%.	Current (TWh /yr)	2030 (TWh /yr)
Total quantity of resource	Estimated production 7,387,154 t/y. [2]	0.876	0.876
Current use for bioenergy	There is some use of slurries in farm-based AD systems, but in almost all cases slurries are co-digested with other materials - predominantly energy crops, but also food wastes and distillery wastes. Slurry only systems which are operational have an intake of 36,500t/y. The slurry component of other systems is not known and is likely to vary depending on the slurry production on farm and the availability of substrates for co-digestion.	0.000	
Competing uses / current disposal routes	Unless the slurry is used for AD, it is stored in lagoons and spread on land [3].	0.219	0.219
Additional resource potentially available for bioenergy	Much more of the resource could be utilised for AD, although there is likely to be a minimum size of farm below which AD will not be feasible, even with co-digestion of other wastes, which could reduce resource somewhat. We have assumed that 75% of resource could be utilised	0.657	0.657

Geographical distribution	Quantities of waste by product produced throughout Scotland with higher concentrations in Ayrshire, Dumfries and Galloway, Borders, Aberdeenshire and South Lanarkshire.	Resource suitable for use in	Boiler		Power generation		Biogas for heat and power	✓	Advanced biofuels (thermal route)	
			CHP		Gasification		Biomethane	✓	Advanced biofuels (chemical route)	✓

Other considerations in utilisation for bioenergy	The economics of slurry digestion can be poor unless it is codigested with other feedstocks. This is because yields are poor without co-digestion. This has led to little utilisation of this resource to date in Scotland. The distributed nature of the slurry resource and the lack of a connection to gas grid or electricity grid can also be barriers. There are concepts for creating a 'virtual pipeline' by upgrading to biomethane, which is stored in pressurised containers prior to being transported by road to an end user or for injection into the grid at an appropriate location could help with utilisation of resources in more remote locations.	Typical carbon emissions	30 kg CO_2/MWh of feedstock (to electricity) 87 kg CO_2/MWh electricity 82 kg CO_2/MWh biomethane to grid
		Assumptions	Quantities in tonnes assumed to be at 90% moisture with an NCV of 0.1 MWh biogas/tonne. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane.
Environmental impacts	As this is a waste, there may be environmental benefits from utilising for energy compared to other waste disposal routes.	References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] ZWS Biorefining potential model [3] Ricardo Energy & Environment, 2017 Slurry Storage on Scottish Farms – a feasibility study. https://www.climatexchange.org.uk/media/2971/slurry-storage-on-scottish-farms.pdf

<table>
<tr><td>Resource</td><td colspan="3">Slurries - Pig Slurry</td><td>Cost</td><td colspan="9">Zero cost for resource, but there may be transport costs</td></tr>
<tr><td>Description</td><td colspan="11">Slurry from farms that rear pigs. Slurry is excreta produced by livestock while in a yard or building, including excreta mixed with bedding, rainwater and washings, and that have a consistency that allows them to be pumped or discharged by gravity.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="11">The estimated production of pig slurry is 357,426 t/y. [2]</td><td>0.022</td><td>0.022</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="11">There is some use of slurries in farm-based AD systems, but in almost all cases slurries are co-digested with other materials - predominantly energy crops but also food wastes and distillery wastes. Current operational slurry only systems have an intake of 36,500t/y. The slurry component of other systems is not known and is likely to vary depending on the slurry production on farm and the availability of substrates for co-digestion.</td><td>0.000</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="11">Unless the pig slurry is used for AD, it is spread on land</td><td>0.006</td><td>0.006</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="11">Much more of the resource could be utilised for AD, although there is likely to be a minimum size of farm below which AD will not be feasible, even with co-digestion of other wastes, which could reduce resource somewhat. Consequently we have assumed that 75% of resource could be utilised.</td><td>0.017</td><td>0.017</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2" colspan="3">Pig slurry is concentrated in only 20% of the regions in Scotland, with the largest amounts in Aberdeenshire, Borders and East Lothian.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td colspan="2">Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td colspan="2">Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2" colspan="3">The economics of slurry digestion are poor, unless it is co-digested with other feedstocks. This is because yields of biogas are poor without co-digestion. This has led to little utilisation of this resource to date in Scotland. The distributed nature of the slurry resource and the lack of a connection to gas grid or electricity grid can also be barriers to AD of pig slurry. There are concepts for creating a 'virtual pipeline' by upgrading to biomethane, which is stored in pressurised containers prior to being transported away by road to an end user or for injection into the grid at an appropriate location could help with utilisation of resources in more remote locations.</td><td>Typical carbon emissions</td><td colspan="9">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="9">Biogas yield of 0.1 MWh biogas/tonne. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane</td></tr>
<tr><td>Environmental impacts</td><td colspan="3">As this is a waste, there may be environmental benefits from utilising for energy compared to other waste disposal routes.</td><td>References</td><td colspan="9">[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/
[2] ZWS Biorefining potential model</td></tr>
</table>

Resource	**Slurries - Pig FYM**	Cost	Zero cost for resource: may be transport costs

		Current (TWh /yr)	2030 (TWh /yr)
Description	Farmyard manures (FYM) refer to livestock excreta mixed with bedding material (such as straw). FYM have a dry matter content of more than 10%.		
Total quantity of resource	The estimated production of pig FYM is 378,652 t/y. [2]	0.024	0.024
Current use for bioenergy	There is some use of slurries in farm-based AD systems, but in almost all cases slurries are co-digested with other materials - predominantly energy crops but also food wastes and distillery wastes. Slurry only systems which are operational have an intake of 36,500t/y. The slurry component of other systems not known and is likely to vary depending on the slurry production on farm and the availability of substrates for co-digestion.	0.000	
Competing uses / current disposal routes	Unless used for AD, pig FYM is spread to land.	0.006	0.006
Additional resource potentially available for bioenergy	Much more of the resource could be utilised for AD, although there is likely to be a minimum size of farm below which AD will not be feasible, even with co-digestion of other wastes, which could reduce resource somewhat. We have consequently assumed that 75% of resource could be utilised.	0.018	0.018

Geographical distribution	Over 72% of pig FYM is produced within Aberdeenshire, with smaller amounts found in Borders (23%) and Midlothian (4%).	Resource suitable for use in	Boiler		Power generation		Biogas for heat and power	✓	Advanced biofuels (thermal route)	
			CHP		Gasification		Biomethane	✓	Advanced biofuels (chemical route)	✓
Other considerations in utilisation for bioenergy	The economics of slurry digestion can be poor unless it is co-digested with other feedstocks. This has led to little utilisation of this resource to date in Scotland. The distributed nature of resource can also be a barrier to its use, as can a lack of a connection to the gas grid or electricity grid. There are concepts such as creating a 'virtual pipeline' by upgrading to biomethane which is then stored in pressurised containers to be transported by road to an end user or for injection into the grid at an appropriate location that could help with utilisation of resources in remote locations.	Typical carbon emissions	30 kg CO_2/MWh of feedstock (to electricity) 87 kg CO_2/MWh electricity 82 kg CO_2/MWh biomethane to grid							
		Assumptions	AD of pig FYM on its own results in a biogas yield of 0.1 MWh biogas/t. Carbon emissions were estimated using [1] assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane							
Environmental impacts	As this is a waste, there may be environmental benefits from utilising for energy compared to other waste disposal routes.	References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] ZWS Biorefining potential model							

<table>
<tr><td>Resource</td><td>Used cooking oil (UCO)</td><td>Cost</td><td colspan="8">low</td></tr>
<tr><td>Description</td><td colspan="8">The main sources of UCO are catering premises, food factories and households. These can be recycled for use as lubricants, in industrial burners and as an additive to manufactured products.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">It is estimated that 26,000 t/y are generated of which 18,000 t/y can be recovered for energy use [1].</td><td>0.263</td><td>0.263</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">UCO can be collected, filtered and used as a feedstock in production of biodiesel. The biodiesel plant at Motherwell utilises UCO, tallow and brown grease and sewer grease. It is estimated that the plant, which has a capacity of 45 kt/y of biodiesel would require 47 kt of UCO or 54 kt of tallow per year. In 2010, The plant sourced all of its UCO from the UK and Ireland and therefore had the capacity to utilise a large proportion of the UCO and tallow resource which is available in Scotland. The quantities actually used by the plant that are sourced in Scotland are not known. Given the existence of the biodiesel plant in Scotland which will create a market for UCO, it is estimated that two-thirds of the resource suitable for recovery.</td><td>0.12</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">UCO that is not recovered is likely to go to sewer (where it can cause problems with creation of 'fat bergs' in the sewer or at the waste water treatment plant).</td><td>0.081</td><td>0.081</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">A number of local authorities in Europe have established collection points in schools and other public places, which have resulted in higher collection in urban areas. Some local authorities in the UK now offer separate collection of used cooking oil as part of recycling collections. It is assumed that the full 18,000 t/year identified above could be utilised for energy meaning that there is an additional resource available of about 6,000 tonnes.</td><td>0.062</td><td>0.062</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">The production of the utilisable resource of UCO will be concentrated around urban areas.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2"></td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biodiesel yield of 10.1 MWh of biodiesel/ tonne.</td></tr>
<tr><td>Environmental impacts</td><td>As this is a waste, there may be environmental benefits from utilising for energy compared to other waste disposal routes.</td><td>References</td><td colspan="8">[1] Ricardo-AEA, 2013. Biofuels. Report for Scottish Enterprise
[2] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/</td></tr>
</table>

Resource	**Tallow**	Cost	Higher grades of tallow have a value in the oleochemical industry (see categories below), which will increase their value and hence cost.

Description	Tallow is a by-product of meat processing, produced when offal and carcass/butcher's wastes are processed at rendering plants. Depending on the production method, it is classified into three categories, dictated by the Animal By-products Regulations: • Category 1 can only be used for burning or fuel production • Category 2 can be used for industrial applications • Category 3 can be used for human contact (e.g. in soaps and cosmetics).	Current (TWh /yr)	2030 (TWh /yr)
Total quantity of resource	The estimated production of category 1 tallow is 55,000 t/y [1]	0.500	0.500
Current use for bioenergy	An estimated two-thirds of tallow produced are currently used for bioenergy	0.330	
Competing uses / current disposal routes	Category 3 tallow can be used in the oleochemical industry, but this is taken into account in the resource estimate, which only relates to category 1.	0.000	0.000
Additional resource potentially available for bioenergy	It is estimated that the remaining one-third of tallow could also be used for bioenergy.	0.170	0.170

Geographical distribution	Large abattoirs with which tallow production should be associated are situated in Scotland's central belt, Argyll and Bute and in the Borders [2].	Resource suitable for use in	Boiler		Power generation		Biogas for heat and power	✓	Advanced biofuels (thermal route)	
			CHP		Gasification		Biomethane	✓	Advanced biofuels (chemical route)	✓

Other considerations in utilisation for bioenergy		Typical carbon emissions	30 kg CO_2/MWh of feedstock (to electricity) 87 kg CO_2/MWh electricity 82 kg CO_2/MWh biomethane to grid
		Assumptions	Biodiesel yield of 9.1 MWh of biodiesel/tonne tallow
Environmental impacts		References	[1] UK Solid and Gaseous Biomass Carbon Calculator v2.0 (build 36). Available at: http://www.e4tech.com/b2c2temp/ [2] Sustainable Food Trust (2018) A good life and a good death: re-localising farm animal slaughter. http://sustainablefoodtrust.org/wp-content/uploads/2013/04/Re-localising-farm-animal-slaughter-low-res.pdf

Resource	**Macro-algae (seaweed)**	Cost	The costs of harvesting seaweed in Scotland are £10 to £25 per wet tonne, transport costs are £10 to £54 per wet tonne.

<table>
<tr><td>Description</td><td colspan="8">Macro-algae (seaweed) have been wild-harvested and used for food, feed and as fertiliser in coastal communities for centuries, and their commercial use for food and feed products and specialty chemicals and fertilisers, albeit on a small scale, are well established. Macro-algae, or indeed the cellulosic residues from the processing of macro-algae for other higher value uses such as chemicals, could be used as a feedstock in AD or to produce bioethanol or biobutanol.</td><td>Current (TWh /yr)</td><td>2030 (TWh /yr)</td></tr>
<tr><td>Total quantity of resource</td><td colspan="8">Estimates of standing stocks of seaweed in Scotland are around 40-50 Mt, with an annual sustainable harvest of about 8 to 10 Mt [2]. Presently around 3,000 to 4,000 wet tonnes of natural seaweed are harvested each year, compared to 130,000 to 180,000 t/y in Norway. It is thought that similar levels could be sustainably harvested in Scotland, although this would require expansion of the areas currently harvested [1]. The resource could be expanded by 'farming' seaweed on long ropes out at sea. However, unless this process could be mechanised, the labour involved could mean that harvesting costs would be very high. In addition, storms would provide challenges to the stability of seaweed farms.</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Current use for bioenergy</td><td colspan="8">None</td><td>0.000</td><td></td></tr>
<tr><td>Competing uses / current disposal routes</td><td colspan="8">A number of speciality products can also be obtained from seaweed, and it seems likely that the most cost-effective exploitation of the resource will involve a 'biorefinery' concept where higher value products are extracted first.</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Additional resource potentially available for bioenergy</td><td colspan="8">150,000 t/y, assuming that wild harvesting can be raised to levels seen in Norway.</td><td>0.000</td><td>0.028</td></tr>
<tr><td rowspan="2">Geographical distribution</td><td rowspan="2">Coastal areas. The Highlands and Islands Enterprise are carrying out a mapping exercise.</td><td rowspan="2">Resource suitable for use in</td><td>Boiler</td><td></td><td>Power generation</td><td></td><td>Biogas for heat and power</td><td>✓</td><td>Advanced biofuels (thermal route)</td><td></td></tr>
<tr><td>CHP</td><td></td><td>Gasification</td><td></td><td>Biomethane</td><td>✓</td><td>Advanced biofuels (chemical route)</td><td>✓</td></tr>
<tr><td rowspan="2">Other considerations in utilisation for bioenergy</td><td rowspan="2">There are potential synergies between seaweed cultivation and other sea uses such as salmon farms, but potential conflicts with other sea uses (such as fishing and shipping), and any development of harvesting or farming would need to be done in a phased way. Seasonality of supply could pose some operational challenges in delivering energy to markets and would need appropriate storage facilities to be developed. Due to high transport costs energy generation from seaweed would need to be done relatively locally (as is the case for many 'wet' AD feedstocks).</td><td>Typical carbon emissions</td><td colspan="8">30 kg CO_2/MWh of feedstock (to electricity)
87 kg CO_2/MWh electricity
82 kg CO_2/MWh biomethane to grid</td></tr>
<tr><td>Assumptions</td><td colspan="8">Biogas yield of 0.2 MWh biogas/wet tonne. Carbon emissions were estimated using [1], assuming emissions similar to wet manure and a generation efficiency of 35% for electricity and 35% for biomethane</td></tr>
<tr><td>Environmental impacts</td><td></td><td>References</td><td colspan="8">[1] ZWS Biorefining potential model</td></tr>
</table>

Appendix 3 – Conversion Technologies

In the following section the TRL definition is as follows:

Technology Readiness Level (TRL)	Definition
1	Basic Research
2	Technology formulation
3	Applied research
4	Small scale prototype
5	Large scale prototype
6	Prototype system
7	Demonstration system
8	First-of-a-kind commercial system
9	Full commercial application

<table>
<tr><td>Technology</td><td>Power generation</td><td>Output</td><td colspan="2">Electricity</td></tr>
<tr><td>Potential feedstocks</td><td>Typically, dry biomass fuels, such as wood chips or pellets, straw, Miscanthus, poultry litter and dry food processing residues. Size of local resource will dictate the size of medium scale plants (<50MW). For large plants (>100 MW) economies of scale allow import of fuels such as wood and waste wood. Waste fuels, such as waste wood require permit under The Industrial Emissions Directive (IED).</td><td>Technology Readiness level</td><td colspan="2">9 – Full commercial application [1]</td></tr>
<tr><td rowspan="3">Commentary</td><td rowspan="3">Technology well proven and commercial now. Fluidised bed plants also available for large scale, but it is important to use biomass fuels that can be pre-processed to the right particle size for these plants. For most plants it is important to provide biomass to the correct specification to ensure efficient combustion, minimise downtime and minimise emissions.</td><td colspan="3">Scale</td></tr>
<tr><td>Typical</td><td colspan="2">Range</td></tr>
<tr><td>10MWe (Scotland)</td><td colspan="2">Small: 1-5MWe
Medium: 10-50 MWe
Large: up to 300 MWe</td></tr>
<tr><td colspan="2">Feedstock required for typical plant</td><td colspan="3">Conversion efficiency</td></tr>
<tr><td colspan="2">Around 86,500 t/y for 10MWe plant
Assumes 30% moisture content,
97% load factor and
30% efficiency</td><td colspan="3">30% (typical range 27-33%) [2]</td></tr>
<tr><td>Commentary</td><td colspan="4">The Scottish Renewables Order (SRO) includes a 10MW cap on dedicated biomass electricity generation. This was introduced to encourage the use of local Scottish biomass and in response to concerns about biomass availability and competition for the resource.</td></tr>
<tr><td colspan="2">Currently installed in Scotland</td><td colspan="3">Under development in Scotland</td></tr>
<tr><td colspan="2">2 power only plants at Westfield (chicken litter) and Lockerbie (Steven's Croft, wood)</td><td colspan="3">None listed</td></tr>
<tr><td>Potential for additional new plant in Scotland (initial view)</td><td colspan="4">Most new plants are CHP. There is no mechanism to support new dedicated biomass electricity only plants that are not CHP or ACT</td></tr>
</table>

References

[1] Arup (2016) Review of Renewable Electricity Generation Cost and Technical Assumptions

[2] BASIS (2015) Report on conversion efficiency of biomass (http://www.basisbioenergy.eu/fileadmin/BASIS/D3.5_Report_on_conversion_efficiency_of_biomass.pdf)

<table>
<tr><td>Technology</td><td>Biomass CHP</td><td>Output</td><td>Heat and electricity</td></tr>
<tr><td>Potential feedstocks</td><td>Wood fuels, straw, poultry litter, food and drink processing residues</td><td>Technology Readiness Level</td><td>9 – Full commercial application [1]</td></tr>
<tr><td rowspan="3">Commentary</td><td rowspan="3">Small scale CHP (<750kWe) is feasible but the electrical efficiency is very poor (1-3% in some systems). 750kWe is probably the smallest scale that can achieve 80% overall efficiency at present for the good quality CHP scheme.</td><td colspan="2">Scale</td></tr>
<tr><td>Typical</td><td>Range</td></tr>
<tr><td>Commercial/ Industrial: 5MWe</td><td>750 kWth- 50 MWth
Markinch is 53MWe;
Cowie is 15MWe;
UPM Caleonian is 26MWe.</td></tr>
<tr><td colspan="2">Feedstock required for typical plant</td><td colspan="2">Conversion efficiency</td></tr>
<tr><td colspan="2">A 5 MWe plant will require around 65,000t/y
Assumes 20% efficiency, 97% availability and 30% moisture content</td><td colspan="2">For CHPQA and RHI need to be 20% electrical efficiency. Most medium size plants are around 27% electricity efficiency. Requirement is for >80% overall efficiency (heat and power). Most small scale plants cannot achieve this overall efficiency.</td></tr>
<tr><td>Commentary</td><td colspan="3">This looks at solid biomass boilers, not energy from waste or AD</td></tr>
<tr><td colspan="2">Currently installed in Scotland</td><td colspan="2">Under development in Scotland</td></tr>
<tr><td colspan="2">In addition to the 3 plants in Column G, there are also:
Rothes (8.3MWe); Speyside (12.3 MWe); Sustainable Power Research Campus (6.5MWe); Invergordon (5MWe)
Total capacity: 126MWe.</td><td colspan="2">There are four with planning approval: 1 MW and 5MWe (both wood based); the 85MWe Grangemouth plant that has a CfD contract; and Rosyth (120MWe). Of these the first three are most likely to go ahead (91MWe)</td></tr>
<tr><td>Potential for additional new plant in Scotland (initial view)</td><td colspan="3">Biomass CHP plants supported under RHI; could be potential for more plant if can be located in areas where there is a heat demand and feedstock is available.</td></tr>
</table>

References

[1] Arup (2016) Review of Renewable Electricity Generation Cost and Technical Assumptions

<table>
<tr><td>Technology</td><td>Energy from waste (incineration)</td><td>Output</td><td>Electricity and CHP</td></tr>
<tr><td>Potential feedstocks</td><td>Residue from recycled waste, solid recovered fuels</td><td>Technology Readiness level</td><td>9 – Full Commercial application</td></tr>
<tr><td rowspan="3">Commentary</td><td rowspan="3">Technology well-proven for standard mass burn grate and fluidised bed. RDF fuels are likely to be less efficient and produce relatively high ash. Note: In Scotland incinerators tend to be small (6-10MWe). There are only two operational EfW plants in Scotland. In England they are typically 10-50MWe, but there is a trend to large scale: 65MW and 100MWe recently.</td><td colspan="2">Scale</td></tr>
<tr><td>Typical</td><td>Range</td></tr>
<tr><td>6-40MWe</td><td>6-40MWe</td></tr>
<tr><td colspan="2">Feedstock required for typical plant</td><td colspan="2">Conversion efficiency</td></tr>
<tr><td colspan="2">Between 6000 and 20,000t/MW capacity. Most plants are 8000 - 16,000t/MW capacity. The current 8 MW plant at Dundee uses 150,000t waste/y (18750t/MW capacity); it's Baldovie replacement will use 2756t/MWth capacity</td><td colspan="2">Average: 22-30% (electrical efficiency). CHP tend to be ~68% efficient overall, but can achieve 76-80% for FGR (Flue gas recirculation)</td></tr>
<tr><td>Commentary</td><td colspan="3">Dundee is district heating.</td></tr>
<tr><td colspan="2">Currently installed in Scotland</td><td colspan="2">Under development in Scotland</td></tr>
<tr><td colspan="2">2 plants installed in Dundee and Shetland (MW); Dundee plant nearing retirement</td><td colspan="2">MVV Baldovie plant in construction - will replace DERL</td></tr>
<tr><td>Potential for additional new plant in Scotland (initial view)</td><td colspan="3">When all of the gasification plants are confirmed to have failed, then there will be spare RDF capacity that will need to be disposed of. Shetland is examining whether it wants to replace its waste district heating plant.</td></tr>
</table>

Technology	**Gasification - power: biomass**	Output	Electricity (and heat)
Potential feedstocks	Woody biomass (chips and pellets), agricultural crop residues (straw, poultry manure), seeds, husks, shells.	Technology Readiness level	Small scale 9 – Full commercial application/ Medium and large scale 8-9 - First of a kind commercial system – full commercial application (depending on feedstock and design)
Commentary	Technology proven at small scale on homogeneous feedstocks such as clean wood (often pellets or wood chips) for CHP (<700kWe). Some larger scale plants operating on well specified feedstock.	Scale	
		Typical	Range
		Small: 200 kWe; Medium: 2 MWe; Large: 30 MWe	Small: 100-700 kWe. Medium: 1-9MWe; Large: 10-50 MWe
Feedstock required for typical plant		Conversion efficiency	
Wood, straw or manure: around 4-6kt/y for medium scale (0.6-2 MWe) e.g. 2.5t/h for 1.5 MWe (12,500t/y) 0.9t/h for 1MWe plant (4,500t/y)		Electrical efficiency: 26-35%; heat and power - 70-90%, depending on plant configuration	
Commentary	Small scale plants are most successful commercially. There are a number of designs and the selection of design depends on the type of fuel and whether or not the operator can handle complex operation. Most available plants (particularly small scale) are fixed bed, which are simple to operate but not flexible. Updraft gasifiers require extensive clean-up of syngas; down draft gasifiers have relatively clean syngas. More flexibility for a range of fuels is offered by fluidised bed gasification systems, which also produce cleaner syngas, but these are more complex and tend to be used in larger operation. Few plants operate continuously for more than 5000 h/y.		
Currently installed in Scotland		Under development in Scotland	
None operational		None	
Potential for additional new plant in Scotland (initial view)	There is good potential for biomass plants, if sufficient feedstock of the right quality is available.		

Technology	**Gasification - power: Waste**	Output	Electricity (and heat)
Potential feedstocks	Solid recovered fuel or refuse derived fuel. The waste needs to be treated to ensure that contaminants and large objects are removed first.	Technology Readiness level	6-9 - Prototype system to full commercial application (depending on feedstock and design): many waste RDF plants are demonstration and not commercial scale.
Commentary	No small scale waste plants. Some medium scale plants operating on waste wood. Waste plants tend to be large scale plants. One waste (solid recovered fuel) gasifier operating successfully in Finland.	Scale	
		Typical	Range
		Medium: 2 MWe; Large: 30 MWe	No small scale. Medium: 1-7MWe; Large: 10-50 MWe but some can be much larger e.g. Kymijarvi (in Finland) is 160MWe
Feedstock required for typical plant		Conversion efficiency	
Wood, straw or manure: around 4-6kt/y for medium scale (0.6-2 MWe); 100,000t/y for 10MWe RDF plant. 250,000t/y for 50MWe (Lahtii II)		Electrical efficiency: 26-35%; heat and power - 70-90%, depending on plant configuration	
Commentary	Few plants operate continuously for more than 5000 h/y. For larger scale plant there are problems in operation, mainly due to feedstock problems, which affect the efficiency of operation. Note that Outotec has three contracts to build, operate and maintain waste to energy gasification plants in the UK, each processing over 100,000t/RDF a year (over 10MWe) and a medium scale 3.65MWe plant (44,700t RDF/y).		
Currently installed in Scotland		Under development in Scotland	
None operational		There are two proposed, total capacity 40MWe, but not certain that they will be developed.	
Potential for additional new plant in Scotland (initial view)	Waste gasification has been difficult to demonstrate commercially. However, there are waste wood plants in operation in the UK and a few waste gasification elsewhere. We believe that this technology is generally pre-commercial and there will be more reliable commercial plants operating on good quality RDF in the next 5-10 years.		

<table>
<tr><td>Technology</td><td>Gasification - SNG - methane</td><td>Output</td><td>Biomethane</td></tr>
<tr><td>Potential feedstocks</td><td>Wood; RDF</td><td>Technology Readiness level</td><td>6 to 8 – Prototype system – first of a kind commercial system [5]</td></tr>
<tr><td rowspan="3">Commentary</td><td rowspan="3">Wood plant based on GoBiGas; RDF on the Syngas Products Avonmouth and Compact Power plants</td><td colspan="2">Scale</td></tr>
<tr><td>Typical</td><td>Range</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Feedstock required for typical plant</td><td colspan="2">Conversion efficiency</td></tr>
<tr><td colspan="2">The GobiGas plant which is a demonstration scale plant is 20 MW, and has a requirement of about 80.000 tonnes of wood chip (at 30% moisture). A full scale plant might be 100 MW.</td><td colspan="2">63% [7]</td></tr>
<tr><td>Commentary</td><td colspan="3">Plants are likely to need to be at least medium scale. The planned expansion of the GoBiGas demonstration is not going to happen and the demonstration plant is up for sale.</td></tr>
<tr><td colspan="2">Currently installed in Scotland</td><td colspan="2">Under development in Scotland</td></tr>
<tr><td colspan="2">None</td><td colspan="2">None</td></tr>
<tr><td>Potential for additional new plant in Scotland (initial view)</td><td colspan="3">None</td></tr>
</table>

References

[5] E4Tech and Ricardo Energy & Environment (2017) Future Fuels for Flight and Freight Competition – Feasibility Study

[7] Ricardo-AEA, 2014. Waste and Gaseous Fuels in Transport. Report for DfT

<table>
<tr><td>Technology</td><td colspan="2">Gasification – Synthetic Natural Gas (SNG) – Fischer Tropsch (FT) diesel</td><td>Output</td><td>Renewable diesel or aviation fuel</td></tr>
<tr><td>Potential feedstocks</td><td colspan="2">Wood, waste, agricultural residues</td><td>Technology Readiness level</td><td>5-6 - large scale prototype to prototype system [5]</td></tr>
<tr><td rowspan="3">Commentary</td><td colspan="2" rowspan="3">Proven on coal, so FT processing is regarded as proven, but only demonstrated on biomass at pilot scale, no commercial plants available. Some first-of-a-kind commercial and demonstration scale projects are planned for 2017 onwards [5].</td><td colspan="2">Scale</td></tr>
<tr><td>Typical</td><td>Range</td></tr>
<tr><td>At least 100,000 tonnes of fuel per year</td><td></td></tr>
<tr><td colspan="3">Feedstock required for typical plant</td><td colspan="2">Conversion efficiency</td></tr>
<tr><td colspan="3">A typical size plant would require about 650,000 tonnes of wood chip (at 30% moisture) per year</td><td colspan="2">56% of energy goes into fuel; but process is exothermic and if electricity is produced and exported and a use can be found for waste heat, then overall efficiency can be 80%</td></tr>
<tr><td>Commentary</td><td colspan="4">Plant typically need to be large to take advantage of economies of scale – perhaps 100,000 tonnes of diesel. As technology develops, plants likely to increase in size providing feedstock is available</td></tr>
<tr><td colspan="3">Currently installed in Scotland</td><td colspan="2">Under development in Scotland</td></tr>
<tr><td colspan="3">None</td><td colspan="2">[5] considered this route to be unlikely to happen in UK in near future</td></tr>
<tr><td>Potential for additional new plant in Scotland (initial view)</td><td colspan="4">Unlikely before 2030</td></tr>
</table>

References

[5] E4Tech and Ricardo Energy & Environment (2017) Future Fuels for Flight and Freight Competition – Feasibility Study

<table>
<tr><td>Technology</td><td>Anaerobic digestion - biogas to CHP</td><td>Output</td><td>Electricity and heat</td></tr>
<tr><td>Potential feedstocks</td><td>Wide range of potential feedstocks, ranging from liquid wastes e.g. from distilleries and dairy industry, and slurries, to food waste from households, commercial premises, and industrial food processing and purpose grown energy crops such as beet and rye, and wastes such as sewage sludge.</td><td>Technology Readiness level</td><td>9 – Full commercial application</td></tr>
<tr><td rowspan="3">Commentary</td><td rowspan="3">Farm based units can be quite small down to 50kWe although a more typical size is 250 to 500 kWe; plant taking large quantities of energy crops and /or food waste or processing waste tend to be larger from 500 kWe up to 5 MWe. Within Scotland the range of existing plant is 25 to 950 kWe for farm based plants and 305 kWe to 5.5 MWe for waste based plants</td><td colspan="2">Scale</td></tr>
<tr><td>Typical</td><td>Range</td></tr>
<tr><td>Farm based 250 to 500kWe; Waste based 500 kWe to 2MWe</td><td>Farm based: 50-100 kWe up to 5MWe
Waste based 200 to 5MWe+</td></tr>
<tr><td colspan="2">Feedstock required for typical plant</td><td colspan="2">Conversion efficiency</td></tr>
<tr><td colspan="2">Very dependent on type of feedstock; a 500 kW plant taking a mixture of slurry and energy crops or silage might use between 10,000 and 20,000t depending on proportions of each, a larger energy crop fed plant might be 30,000t. For food waste plants, depending on size typically upwards of 30,000 tonne per year although can be as high as 60-70,000 t.</td><td colspan="2">35 to 40 % for electricity and 50% to 65% for heat</td></tr>
<tr><td>Commentary</td><td colspan="3">It can be difficult to find a use from heat from the CHP, in which case the overall efficiency will be lower. For some types of feedstock (e.g. slurries) quite a high proportion of the heat will be needed to warm the digesters (maybe 20 to 30%) but for less liquid feedstocks can be much less. Location of schemes can be an issue for finding an appropriate heat use (e.g. there may be limited opportunities on farm) and for merchant waste plants, although may be located in closer proximity to potential users, cost of infrastructure to deliver heat can be a barrier. Best opportunities for heat use are probably within food and drinks industry, where there are likely to be heat uses on site if wastes digested on site.</td></tr>
<tr><td colspan="2">Currently installed in Scotland</td><td colspan="2">Under development in Scotland</td></tr>
<tr><td colspan="2">A reported 38 sites in Scotland (excluding those at sewage treatment plants); 16 waste fed and 22 farm fed. Reported capacity 30.8 MWe utilising 866 kt of feedstocks. Note some of the farm fed plant may no longer be operational</td><td colspan="2">Three sites listed as awaiting construction or under construction in Renewable Planning Database</td></tr>
<tr><td>Potential for additional new plant in Scotland (initial view)</td><td colspan="3">Additional feedstocks are potentially available so potential for new plant</td></tr>
</table>

<table>
<tr><td>Technology</td><td>Anaerobic digestion - biogas to biomethane injected to grid</td><td>Output</td><td>Biomethane</td></tr>
<tr><td>Potential feedstocks</td><td>Wide range of potential feedstocks, ranging from liquid wastes e.g. from distilleries and dairy industry, and slurries, to food waste from households, commercial premises, and industrial food processing and purpose grown energy crops such as beet and rye, and wastes such as sewage sludge.</td><td>Technology Readiness level</td><td>9 – Full commercial application</td></tr>
<tr><td rowspan="3">Commentary</td><td rowspan="3">These plant tend to be larger due to the economies of scale needed to cover the cost of upgrading cost of the gas grid connection</td><td colspan="2">Scale</td></tr>
<tr><td>Typical</td><td>Range</td></tr>
<tr><td>550 Nm3/hr of biogas which is equivalent to biomethane output of 3MW</td><td>1.2 to 6MW</td></tr>
<tr><td colspan="2">Feedstock required for typical plant</td><td colspan="2">Conversion efficiency</td></tr>
<tr><td colspan="2">As FOR AD with CHP - dependent on type of feedstock. For a typical 3 MW plant, could be about 35,000 tonnes of food waste or between 20,000 to 35,000 tonnes of energy crops</td><td colspan="2">Overall conversion efficiency will depend on how the biomethane is used, but apart from energy required for upgrading, all of the energy in the biogas produced will end up in the biomethane</td></tr>
<tr><td>Commentary</td><td colspan="3">Once injected to grid then biomethane can be utilised for any use that natural gas would be put to: electricity use, heat or as a vehicle fuel. The limited gas grid in Scotland does limit the location of these types of plant, and in addition, there are some areas where summer gas flows are so low that it is not possible to inject biomethane.</td></tr>
<tr><td colspan="2">Currently installed in Scotland</td><td colspan="2">Under development in Scotland</td></tr>
<tr><td colspan="2">A reported 12 sites: 2 waste fed and 10 farm fed, utilising 761,000 t of feedstock to produce 188 MW gas</td><td colspan="2">Unknown</td></tr>
<tr><td>Potential for additional new plant in Scotland (initial view)</td><td colspan="3">Additional feedstocks are potentially available so potential for new plant</td></tr>
</table>

<table>
<tr><td>Technology</td><td>Anaerobic digestion - biogas to biomethane transported to grid or other end uses such as vehicle fuel</td><td>Output</td><td>Biomethane (as fuel for heat or as transport fuel)</td></tr>
<tr><td>Potential feedstocks</td><td>Wide range of potential feedstocks, ranging from liquid wastes e.g. from distilleries and dairy industry, and slurries, to food waste from households, commercial premises, and industrial food processing and purpose grown energy crops such as beet and rye, and wastes such as sewage sludge.</td><td>Technology Readiness level</td><td>8 – first of a kind commercial system</td></tr>
<tr><td rowspan="3">Commentary</td><td rowspan="3">For sites which are not near the gas grid, where distances are too great or there are restrictions on injection because of low summer flow, then it is possible to upgrade the biogas and store the biomethane in pressurised containers on site. These can then be transported away by road for injection at a central point, or direct to sites which are off gas grid to use as a gas supply or to vehicle fuelling systems. For sites such as water treatment plant, or some food processing sites, where that are a large number of vehicle movements then the fuel could be used on site. The concept of transport to a central point for injection has been proven in England,</td><td colspan="2">Scale</td></tr>
<tr><td>Typical</td><td>Range</td></tr>
<tr><td>Could be smaller than typical plant injecting to grid, perhaps 1.5 to 2 MW</td><td></td></tr>
<tr><td colspan="2">Feedstock required for typical plant</td><td colspan="2">Conversion efficiency</td></tr>
<tr><td colspan="2">As for AD with CHP - dependent on type of feedstock. For a 1.5 MW plant, could be about 17,500 tonnes of food waste or between 10,000 to 17,500 tonnes of energy crops</td><td colspan="2">Overall conversion efficiency will depend on how the biomethane is used, but apart from energy required for upgrading, all of the energy in the biogas produced will end up in the biomethane</td></tr>
<tr><td>Commentary</td><td colspan="3">Feasibility study being undertaken on whether this might be an option for some rural farms with large beef or dairy herds. There is a large slurry and manure resource in Scotland; although the economics of digestion of slurry on its own are poor, if it could be combined with other feedstocks with a higher biogas yield such as some wastes or energy crops then on-farm AD plant where the gas is tinkered away could be a way to utilise this resource</td></tr>
<tr><td colspan="2">Currently installed in Scotland</td><td colspan="2">Under development in Scotland</td></tr>
<tr><td colspan="2">None</td><td colspan="2">None</td></tr>
<tr><td>Potential for additional new plant in Scotland (initial view)</td><td colspan="3">Additional feedstocks are potentially available so potential for new plant</td></tr>
</table>

Appendix 4 – Costs for Conversion Technologies

Costs for Conversion Technologies

The values in the table below are intended to be representative of costs for typical plant and are presented to allow a comparison of relative costs, scales and efficiencies between different types of conversion plant. They should not be taken as an accurate indication of the cost of new plant.

Technology	Size (MW)	Efficiency (%)	Capex (£k/MW)	Fixed O&M (£k/MW /year)	Variable O&M (£k/MW /year)	Typical feed-stock costs (£/MWh)	Level-ised cost (£/MWh)	Ref
AD	2	40%	4,390	145	48	Gate fee of £15/t	171	1
AD CHP*	2	32%	4,990	199	561		169	1
AD for biomethane	6	100%	2,403	490	561		91	2
Biomass boiler (domestic)	0.02	94%	155	15	0	48	91	3
Biomass boiler (commercial)	0.18	85%	808	20	0	56	100	3
Biomass boiler (process heat)	0.5	81%	514	20	0	56	154	3
Biomass boiler (district heating)	0.2	73%	702	20	0	48	61	3
Dedicated biomass	23	29%	2,927	90	59	10	96	1
Biomass CHP *	14	23%	5,234	305	57	10	195	1
EfW	30	28%	8,383	180	77	-31	40	1
EfW CHP*	24	22%	13,456	246	170	-31	117	1
Gasification for power	9	25%	7,166	244	145	-12	147	2
Gasification CHP *	1	24%	10,110	244	276	-12	174	1
Advanced bioethanol plant	42	31%	3,633	inc in variable	276	11	103	4

* for CHP plant, total represents LCOE for electricity and includes an allowance for revenue from steam

Sources for data:

[1] BEIS (2016) Electricity generation costs. Available at https://www.gov.uk/government/publications/beis-electricity-generation-costs-november-2016

[2] DECC (2014) RHI Biomethane Injection Grid Tariff Review

[3] Ricardo own data as used in development of Renewable Heat Calculator for Scottish Enterprise

[4] E4Tech (2017) Ramp up of lignocellulosic ethanol in Europe to 2030.

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