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POSTNOTE

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Bioenergy

Bioenergy is the use of renewable natural material for electricity, heat and liquid fuels. Currently, the UK sources approximately 3% of its primary energy from bioenergy feedstocks[1]. This POSTnote considers the opportunities and challenges of producing bioenergy sustainably to meet greenhouse gas reduction targets.

Overview

- Liquid biofuels, solid biomass and biogas could replace the use of petrol, coal and natural gas as renewable fuels. These can be used for heat, power and transport.
- Bioenergy provides opportunities for reductions in greenhouse gas emissions, although savings vary depending on supply chains.
- Sustainable approaches to producing bioenergy on existing cropland include using waste, by-products and dedicated energy crops.
- Intensification of agriculture and changes to forestry practice can also yield the necessary biomass, but may have negative impacts if not appropriately regulated.

Uses of Bioenergy

Any organic matter such as plant material or animal waste (from here on referred to as biomass) can be used for bioenergy. Its relative cost-effectiveness compared with other renewable technologies makes it an attractive option for contributing towards the delivery of renewable energy targets (Box 1). In 2010, biomass sources accounted for 46% of renewable electricity generation in the UK, a third of which was from landfill gas[2]. Heat demand is responsible for nearly half of the UK's greenhouse gas (GHG) emissions[1]. Biomass is expected to play a crucial role in decarbonising the heat sector. It can also be converted into liquid fuels for use in transport, or in the production of bioplastics and other biomaterials (the latter not considered in this briefing). The growth of the bioenergy sector depends on the availability of sustainable biomass resources and government support.

Electricity and Heat

Electricity generated by burning coal or natural gas may be replaced, partially or entirely, by biomass and biogas respectively. Thermal power stations use heat produced by burning such fuels to generate electricity. Up to 45% of this heat is converted to electricity; the rest is usually wasted (dissipated through cooling towers or released into the sea). Combined heat and power (CHP) generation captures some or all of the by-product heat for heating purposes. Using biomass for CHP generation is endorsed by the government in its recent Bioenergy Strategy (Box 1). CHP is most efficient where there is local heat demand, such as for industrial process heating. Many pulp and paper mills, refineries and chemical plants use CHP generation. CHP can also be used for district heating, or for heating individual homes (micro-CHP).

Transport

Liquid fossil fuels power most forms of surface transport and aviation. Blended into fossil fuels in small portions, biofuels can be safely used in today's road vehicles. Within the EU, liquid biofuels have to meet legally-binding sustainability criteria, developed in response to concerns over sustainability of crop-based biofuels (see below). Regulatory and technological constraints currently prevent the use of biofuels in aviation. However, advanced aviation biofuels are being developed as the only future alternative to fossil fuels. Aviation joins the EU Emission Trading System in 2012 (POSTnote 354).

Converting Biomass into Biofuels

The technology required to convert biomass into biofuels depends on the source of biomass and the desired fuel quality (Box 2). Certain processes, such as biomethane produced from food waste by anaerobic digestion (POSTnote 387), already have a market share of the industry, whilst others are still being developed. A metric for assessing the maturity of evolving technologies is available (Box 3).

Box 1. Major Policy Drivers For Bioenergy

EU Directives

- *The Renewable Energy Directive* (EU RED, 2009/28/EC) requires that by 2020 15% of all energy and 10% of surface transport fuel delivered to UK consumers comes from renewable sources.
- *The Fuel Quality Directive* (2009/30/EC) requires fuel suppliers to reduce the GHG emissions of transport fuels by 6% by 2020 compared to the EU-average level of emissions from fossil fuels in 2010. Biofuels can be blended with fossil fuels to achieve this reduction, as long as they meet sustainability criteria (Box 4) included in the Directive (mirrored by the EU RED).

UK policies that support achievement of EU RED targets include:

- *The Renewable Heat Incentive* (RHI) provides financial assistance to producers of renewable heat. It is designed to encourage the take-up of biomass-fired domestic heating, biomass CHP and other technologies to reduce GHG emissions from heat production.
- *The Renewables Obligation* (RO) requires electricity suppliers to source a proportion of electricity from renewable generators. Eligible generators are awarded certificates for each unit of electricity they produce, and suppliers buy these to demonstrate that they have met their obligation. Generators thus receive extra revenue on top of selling electricity. In the future, under the government's plans for Electricity Market Reform, renewable generators will be supported by long-term contracts providing a guaranteed level of payment ('Feed-in Tariffs' with 'Contracts for Difference').
- The *Renewable Transport Fuels Obligation* (RTFO) requires fuel suppliers to source a percentage of fuel from renewable sources. Similar to the RO, suppliers demonstrate this by purchasing certificates from biofuel producers, which are awarded for each litre of biofuel that meets the EU RED sustainability criteria (Box 4).

UK Bioenergy Strategy

Released in April 2012 by DECC, DfT and Defra, the strategy outlines a framework for the use of bioenergy in the UK in 2020 and up to 2050. It is based on 4 principles that will guide policies. According to the strategy, policies should aim to deliver genuine carbon reductions in the most cost-effective way, while avoiding adverse effects on the wider economy. Without targets and rules, this principles-based system is designed to be flexible enough to remain valid in the face of evolving evidence and technological innovation. It advocates periodic revisions to bioenergy policy at regular 5-yearly intervals.

Liquid biofuels are commonly separated into "generations" according to their level of development and the feedstocks they use. *First generation* biofuels are made from conventional crops using mature technologies, such as bioethanol produced from corn or sugarbeet. *Second generation* biofuels are made either from novel non-food crops (such as elephant grass or algae) using conventional technologies, or from materials rich in lignocelluloses (i.e. fibrous biomass such as straw and wood) using advanced processing and conversion technologies. The development of second generation fuels is encouraged through biofuel policies (Box 1).

Addressing Sustainability Concerns

Biomass for bioenergy can either be harvested from land currently under production (agriculture and forestry), or from previously unmanaged land converted expressly for the purpose. Sustainability criteria (Box 4) are used to identify sources of biomass that are suitable for bioenergy production. If these criteria are not employed, there may be undesirable outcomes. For example, WWF and Friends of the Earth argue that areas of special conservation value (such as rainforests) may be cleared to make room for new or displaced agriculture, due to an increased demand for biomass. Equally, there are "win-win" scenarios, such as the use of agricultural residues for biofuel production.

Box 2. Technologies for Producing Liquid and Gas Biofuels

Making Liquid Biofuels

Harvested biomass contains sugars and oils that can be turned into biofuels. In the case of woody biomass and crop residues, pre-treatment is required prior to conversion to release the sugar or oil.

- Fermentation turns sugars into bioethanol that can be blended directly with petrol. Brazil leads in the production of bioethanol from sugar cane.
- Esterification is the process by which biodiesel is produced from extracted vegetable oil.
- Pyrolysis is the thermal decomposition of organic material at very high temperature, in the absence of oxygen, to produce low quality "bio-oils". These can be upgraded to synthetic diesel.

Making Biogas

- Anaerobic Digestion (AD) uses microbes to breakdown organic material in a controlled environment to produce biomethane, which can be blended with natural gas in the existing network.
- Gasification produces "syngas" (a mixture of hydrogen, carbon monoxide, CO_2 and a range of hydrocarbons) when solid biomass is heated with little or no oxygen. The syngas can be catalytically converted into liquid fuels.

Biorefineries

A biorefinery is a facility that uses multiple biomass conversion processes and equipment to produce fuels, power, heat and chemicals from biomass. A biorefinery takes advantage of the various stages of biomass processing and intermediate products, therefore maximising the value derived from biomass feedstocks.

Reducing GHG Emissions

The rationale for supporting bioenergy relies largely on the assumption that it can deliver genuine GHG emissions savings. Under current international accounting mechanisms (Box 5), burning biomass is considered to be *"carbon neutral*" because the carbon accumulated during biomass growth is released during burning. This is an oversimplification. In practice, throughout the biomass' lifecycle, fossil fuels are used for harvesting, processing and transport, resulting in net carbon emissions. Additional energy (with associated GHG emissions) is required to convert the biomass into fuel. Sustainability criteria for biomass and biofuels do not treat all biomass as carbon neutral and include a minimum threshold for 'lifecycle GHG savings' compared to fossil fuels (Box 4).

Box 3. Technology Readiness Levels

The trajectory of a technology from research and development through to commercialisation can be marked by Technology Readiness Levels (TRLs), originally introduced by NASA. TRLs of:

- 1-3 denote technologies that are undergoing laboratory feasibility studies
- 3-5 are assigned to technologies in development
- 5-7 to those in demonstration
- 7-9 pilot scale use and commercialisation

Bioethanol produced from woody material has a TRL ~4, while anaerobic digestion of organic waste has a TRL ~9.

Direct and Indirect Land Use Change

Changing land use may be a 'source' or a 'sink' of GHG emissions. For instance, GHGs may be released from soils during agricultural practices, such as ploughing. Certain soil types are particularly sensitive; for example converting carbon-rich peatland for agriculture has a large carbon footprint. Where the effects are local and traceable, they are referred to as *"direct*". In comparison, *indirect land use change* (iLUC) emissions result when the demand for agricultural products displaces existing economic activity to new land, with associated emissions.

For example, previously unmanaged grasslands in the Ukraine may be used to produce food-grade rapeseed oil, due to increased demand for European biodiesel made from rapeseed[4]. There is no consensus on how to incorporate emissions from iLUC into carbon accounting (Box 4). Against this background, the Nuffield Council on Bioethics argues that penalising only bioenergy production for iLUC, when other economic activities such as the conversion of land for building homes do not have to account for carbon, amounts to an unfair disadvantage[5].

Box 4. Sustainability Criteria

Sustainability can be defined as the long term maintenance and enhancement of human well-being within finite planetary resources (POSTnote 408). Sustainability criteria for bioenergy include a requirement for a reduction in GHG missions without depleting global resources or forcing people into poverty and hunger.

Environmental Sustainability

There are mandatory environmental sustainability criteria under the EU RED for liquid biofuels, and a voluntary framework for solid biomass and biogas. These impose restrictions on using materials sourced from land with high biodiversity value (e.g. rainforests), or high carbon stock (e.g. peatlands). There are minimum requirements for lifecycle GHG savings compared with fossil fuels. Although emissions from cultivation, processing and transport have to be accounted for, there is no agreed method of accounting for emissions from indirect land use change. A penalty for use of certain crops based on their "*indirect land use change risk factor*" may be introduced. Within the UK, sustainability criteria are mandatory for bioenergy used for electricity generation, transport and heat production. There are difficulties in ensuring sustainability standards are maintained internationally, especially in countries not signed up to the Kyoto Protocol (Box 5).

Social Sustainability

Bioenergy production should not infringe on human rights, including the rights for just reward (labour rights) and land[5]. Issues over land rights occur in many developing countries with communities who exercise Native Customary Rights to the land, relying on it for a source of food, medicines and construction materials. The Global Bioenergy Partnership (a body of the UN Food and Agriculture Organisation) is developing a set of sustainability indicators to forge a consensus among a broad range of national governments and international institutions on sustainability. These include indicators for social sustainability alongside environmental and economic ones.[3]

Ethics of Using Food Crops

For many bioenergy feedstocks, either the crops or the land on which they are grown could otherwise be used for food. This is the basis of the *"food vs. fuel"* debate. In particular, demand for first generation biofuels has been blamed for contributing to increasing food prices[6]. However, a cross-Whitehall analysis of the agricultural price spikes of 2007/2008 concluded that biofuels had a relatively small contribution, particularly as far as wheat price was concerned. Nevertheless, the report also concluded that the additional global demand for biofuels will put upward pressure on the prices for those agricultural commodities used in biofuels production[7].

A report to the G20 Agriculture Ministers[8] by contributors from ten international governance organisations recommended governments to introduce policies that adjust biofuel production and consumption at times when global markets are under pressure and food supplies are endangered. Furthermore, it is possible to decrease demand for land by running agricultural practices more efficiently, using material residues from harvesting and processing. For example, in Saltend (UK) a joint venture between BP, AB Sugar and Dupont has invested in a first generation technology that produces both bioethanol and animal feed from wheat. The sugar component of the wheat is fermented, leaving the protein meal to be processed into animal feed.

Box 5. International GHG Accounting

Countries that have signed up to the Kyoto Protocol are required to account for emissions from bioenergy in the land use, land-use change and forestry (LULUCF) sector. Since biomass absorbs CO_2 during its growth, which is eventually released when the biomass is used for bioenergy, the process is thought to be *"carbon neutral"*. To avoid double accounting, the IPCC has developed guidelines for national inventories, in which the carbon released is recorded when biomass is harvested, but not when it is used. It is therefore credited as "*zero carbon*" in the energy sector, as the emissions should have already been accounted for before use as a biofuel. A fundamental problem is that any biomass sourced from countries not signed up to the Kyoto Protocol, such as the US, Canada and some developing countries will never be accounted for in the global inventory and when used will still be considered "*zero carbon*".

Energy Crops

Dedicated energy crops, such as *Miscanthus* (elephant grass) and switchgrass, or poplar and willow grown as short rotation coppice (SRC), can provide sustainable feedstocks for bioenergy. They yield more energy per hectare than food crops and may be grown on poorer quality land. It may be possible to increase food production on best quality land through intensification, while using less optimal land for energy crops, thereby increasing overall land productivity. Rothamsted Research, a centre for dedicated energy crops research, are breeding energy crops that can grow on lower quality agricultural land, or abandoned and waste land. It has demonstrated that SRC willow has multiple environmental benefits, including enhancing biodiversity[9].

Production of dedicated energy crops is currently supported in England under the Energy Crops Scheme and encouraged by the Bioenergy Strategy. The scheme offered grants to farmers for establishing energy crops both for their own energy use or to supply power stations. However, energy crop plantings in the UK remain small. The potential to expand is restricted by UK planting and harvesting capacity, acceptance of energy crops by growers, economics, technology compatibility and social resistance related to concerns around long-term land use change[1].

Algae

Algae (grown in water) are a potential biofuel feedstock. Many are rich in oils suitable for biodiesel production, or sugars that can be turned into bioethanol. Under the right conditions, algae grow faster than land-based biofuel crops so, in theory, less land is required to achieve similar biomass yields. Some species grow in sea water, or can use waste water, avoiding competition with food crops entirely (see POSTnote 384). However, algal-based biofuels are far from commercialisation (TRL~2, Box 3)[10]. The Nuffield Council on Bioethics considers there is significant potential for ethical and sustainable algal biofuels to be produced and calls for their innovation trajectory (Box 3) to be supported.

Sustainable Use of Forestry

Trees or residues from forest management may be used as feedstocks for energy production. Forests cover approximately 12% of UK land, a small fraction compared with the 75% used for arable land and pasture. Around 40% of privately owned woodland in the UK is not actively managed. Forestry Commission England are working to bring more woods into management – both to provide biomass for the renewable heat market (RHI - Box 1) and to enhance woodland biodiversity, which relies on habitats created by managing trees. A recent study, based on lifecycle methodology, showed that managing UK forests for wood and bioenergy to displace non-wood products and fossil fuels would result in lower total GHG emissions than leaving the wood unharvested[11]. Optimal approaches generally involved use of forest for the production of both material products and bioenergy, with re-use and recycling wherever possible. The Wood Panel Federation argues that although this would provide forest owners with more income, many users would experience higher prices.

Demand for biomass from the renewable heat and electricity markets could not be met domestically. The UK currently imports 80% of all the wood it consumes, a figure likely to increase with the growth of bioenergy. Drax Power (the largest electricity generator in the UK, supplying 7% of electricity demand) is moving towards co-firing biomass with coal. In 2010, Drax secured contracts from a wide range of sources including wood pellets from Canada, the USA and South Africa.

Turning Waste into Bioenergy

Municipal and food waste produces methane gas in landfill sites, a process that can be sped up and harnessed using AD (Box 4). There are mature technologies for generating fuels from sewage (POSTnote 282) either using AD or direct incineration. Waste cooking oil can be used either directly in internal combustion engines or upgraded to biodiesel, which currently contributes ~50% of UK biodiesel supplies[12].

The Future of Bioenergy

Biomass and biofuels are commodities traded on an international market. Growth of bioenergy both in the UK and abroad will depend on how much affordable, sustainably-sourced biomass is available. The International Energy Agency predicts a contribution for bioenergy of up to 21% of the global primary energy demands by 2050 compared with 2% in 2008[13]. The latter is within the range predicted by the UK Energy Research Centre's estimate of roughly 25%[14]. For the UK, the Committee on Climate Change (CCC) predicts that bioenergy could sustainably contribute up to 10% of the UK's primary energy by 2050[13]. The estimate was arrived at by excluding agricultural land used for food production as a potential source of biomass, on ethical grounds. Under similar assumptions, DECC predicts that bioenergy could sustainably provide between 10% and 14% of UK's primary energy demand in 2030[1].

Allocating Biomass Resources

If the global demand for bioenergy outstrips sustainable biomass supply, it will be necessary to allocate biomass to "best uses". Domestic policies can support certain uses over others and determine allocation. One definition of "best uses" is the cheapest ways of meeting the GHG reductions targets by 2050. Computational analyses of alternative scenarios can identify such options.

In a recent CCC analysis[15], the conclusions were determined by whether carbon capture and storage (CCS) technologies (POSTnote 335) were available. Applying CCS to biomass electricity generation (Box 6) and using biomass for hydrogen production (Box 2) offers the opportunity for substantial GHG savings. In a scenario without CCS, appropriate bioenergy use was primarily limited to heat generation for heavy industry, as well as producing aviation biofuels. Other organisations (such as the UK consultancy E4tech) argue that biomass will probably find a more diverse range of energy uses, including for road transport fuel, depending on the relative economics of different options and the evolution of transport and energy infrastructure.

Box 6. Biomass Power with Carbon Capture and Storage

When biomass power is coupled to carbon capture and storage, CO_2 captured during combustion is stored underground resulting in net removal of CO_2 from the atmosphere (POSTnote 335). The Energy Technologies Institute predicts that meeting the 80% reduction in CO_2 emissions by 2050 without the use of bioenergy and CCS, would cost the UK an extra £44 billion and £42 billion respectively. These are the highest opportunity costs in their analysis. As a comparison, the omission of nuclear would require an additional £4 billion of investment into renewables. However, although producing power from biomass is a mature technology, the safety, efficacy and economic viability of CCS have yet to be demonstrated.

Endnotes

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POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. POST is grateful to Elena Kazamia for researching this briefing, to the Natural Environment Research Council for funding her parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Dr Jonathan Wentworth.