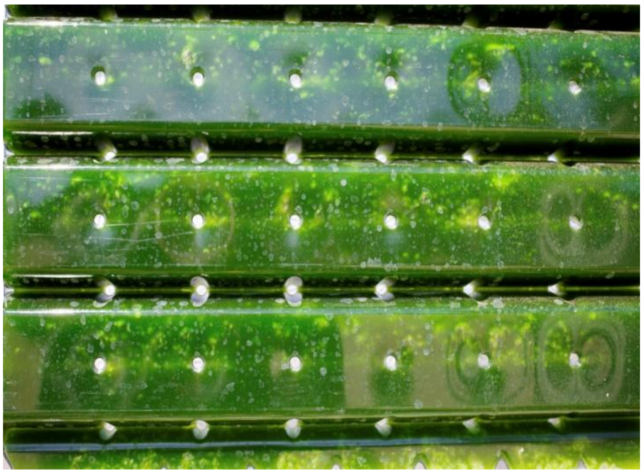
HOUSES OF PARLIAMENT
PARLIAMENTARY OFFICE OF SCIENCE & TECHNOLOGY

POSTNOTE

Number 384 July 2011

Biofuels from Algae



Algae, including seaweed, are a potential source of renewable fuel, food and chemicals. This POSTnote examines the technical, economic and environmental issues around algal biofuels and their relevance to UK and EU policy targets.

Overview

- Algae can provide a variety of fuels for transport, heating or electricity generation, including biodiesel, aviation fuel and biogas.
- Algal biofuels are at an experimental stage and are more expensive than fossil fuels.
- Algal biofuels could be made more cost-effective by extracting other valuable products from algae or incorporating their production into waste water treatment.
- Commercial production of biodiesel from algae is unlikely before 2020.
- The use of seaweed for energy is being explored in the UK, particularly in Scotland.
- Research efforts are currently focused on decreasing the cost of production, reducing greenhouse gas emissions and investigating the potential to grow algae in the UK.

Background

Biofuels (POSTnote 293) are renewable fuels made from organic matter (biomass), which can be used in place of, or blended with, fossil fuels. Most biofuels currently used in the UK are imported and are derived from land crops, including sugar cane, maize and vegetable oil. These are referred to as "first-generation" biofuels. Some first-generation biofuels have come under criticism for competing with food production for land and water resources, motivating the search for alternatives.[1,2] These include "second generation" biofuels from wood, wastes, grasses and agricultural residues, and biofuels from algae.

A major motivation for the use of biofuels comes from the transport sector. Transport in the UK currently relies almost entirely upon fossil fuels and contributes around 19% to the UK's total greenhouse gas (GHG) emissions. Increased use of renewables and a reduction in GHG emissions are key priorities in EU and UK energy and transport policy.

Biofuels in Surface Transport

The EU has set a target, reflected in UK government policy, for 10% of the energy used in road and rail transport to be derived from renewable sources by 2020. In 2009, around 2.4% of the UK's surface transport energy was obtained from biofuels.[3] The Committee on Climate Change, which advises the UK government on setting and meeting climate change targets, forecast in 2010 that biofuels could provide a 6.6% reduction in CO_2 emissions from surface transport by 2020.[4] In addition to biofuels, low-carbon and renewable options for surface transport include hydrogen fuel cells and electric vehicles (POSTnote 365).

Biofuels in Aviation

By contrast with surface transport, air transport is expected to continue to rely upon liquid fuels. This is because electrification and fuel cells are considered unsuitable, mainly on weight grounds. Aviation is due to be included in the EU Emissions Trading System, which sets a cap on CO_2 emissions in the EU, from 2012 (POSTnote 354, Global Carbon Trading). This is expected to encourage the use of alternative fuels.

As a result of these factors, the aviation sector is increasingly interested in biofuels as 'drop-in' replacements for fossil fuel. Some in the aviation industry believe that biofuels should be reserved for air travel, given the absence of alternatives for the sector. The International Air Transport Association (IATA) states that 6% of aviation fuel could be obtained from renewable sources by 2020. In 2011 the international standards body ASTM International approved a standard for aviation biofuels, allowing biofuels to be used in commercial flights.

Algae for Fuel

Algae are a diverse group of aquatic and marine organisms. Like plants, algae carry out photosynthesis, using sunlight to convert carbon dioxide, water and nutrients to oxygen and biomass (carbohydrates, oils and proteins). Some can also grow in the dark, by consuming sugars.

Single celled algae, known as microalgae, are usually grown in open ponds or in enclosed systems known as photobioreactors. Larger species of algae, including seaweed, are known as macroalgae, and can be grown at sea or in tanks.

The range of fuels that can be produced from algae are summarised in Box 1. Currently, the fuels of most interest for transport are biodiesel and bioethanol. Biogas can be used for electricity, heating or transport.

Box 1. Fuels from Algae

The types of fuel that can be derived from algae depend on the species of algae and the part of it that is used.

- **Biodiesel** is produced from the oil (lipid) content of microalgae by chemical processing to give biodiesel (fatty acid methyl ester; FAME) and glycerol, used in chemical manufacturing. Blends with up to 5% FAME are common. Current EU specifications allow up to 7% FAME.
- **Bioethanol** is used as a substitute for petrol, and is produced by fermentation of the carbohydrate content of algae by microbes or yeasts. Most cars can use fuel containing up to 10% ethanol, while flexible-fuel vehicles can use blends with up to 85% ethanol.
- **Biobutanol** is produced by fermentation of the carbohydrates in either micro- or macroalgae. It contains more energy per molecule than ethanol and is less corrosive to internal combustion engines.
- **Hydrocarbons** can be produced by treating unprocessed algae with high pressures and temperatures or by chemical conversion of microalgal oil. Some species of algae produce hydrocarbons directly. Hydrocarbons are used as aviation fuel.
- **Biogas** is produced from microalgae and macroalgae by bacteria, in a process known as anaerobic digestion. It can be burned directly for heat and electricity generation, or purified to give biomethane, which is used as an alternative to natural gas in electricity generation, heating or transport. Biogas can be produced from unprocessed algae, or from residues left after other products have been extracted.
- **Hydrogen (**POSTnote 186) is produced from water by some species of algae and bacteria in the absence of oxygen.

Prospects for Algal Biofuels

Microalgae

It is widely reported that microalgae have advantages over first-generation biofuel crops, including higher yields, faster growth and lower requirements for land. Significant investment has been made in the development of algal biofuels, particularly within the energy and aviation sectors (examples include Airbus, ExxonMobil and the US Navy). However, to date algal biofuels have been demonstrated only on a small scale, and no suppliers are currently operating commercially. Many researchers estimate that production of microalgal biodiesel on a commercial scale is at least ten years away. The existing microalgae industry (strongest in the USA, Australia and Israel) produces around 10,000 tonnes of dry algae per year,[5] mainly for dyes, fish feed and dietary supplements. With an oil yield of 25%, typical for many algae species,[6] this international industry would need to be scaled up at least 300 times to produce 5% of the diesel used in the UK in 2009.[3]

The high cost of growing, harvesting and processing microalgae presents a large barrier to commercialisation. Cost estimates depend upon the type of fuel and the production pathway. An influential 1989 pilot study indicated a cost of more than US$6 per litre of biodiesel, more than ten times higher than petroleum.[6] With currently available technology, the production cost is around US$3 per litre.[7] Algal biofuels could become more competitive as fossil fuel prices increase, although this would also increase the cost of algal fuel production through increases in the cost of building materials, energy or nutrients.

Macroalgae

Macroalgae are currently used mainly for food. Seaweed cultivation for bioethanol and biogas is being explored in Asia, Europe and South America, while biobutanol from macroalgae is attracting research interest and investment in the USA. The cost of production is high – recent estimates suggest that biogas from seaweed could be 7-15 times more expensive than natural gas.[8]

For both macro and microalgae, extracting other valuable chemicals (Box 2) is seen as a key way to increase revenue and reduce the net cost of fuel production.

Box 2. High Value Products from Algae

Algae can contain other substances with a higher market value than fuel. If these can be extracted along with fuel, and markets for the co-products exist, the income generated can reduce the net cost of biofuel production. Examples of these co-products include:

- **animal and fish feed.** These already provide markets for algae, and could be produced from algal residues left after oil extraction.
- **food and food additives,** including carrageenan (a thickener) and Omega-3 oil, used to fortify foods or as a dietary supplement.
- **chemical feedstocks**, such as dyes and ‘building block’ chemicals for manufacturing including hydrocarbons, alcohols and sugars.
- **health and beauty products,** including cosmetics and sunscreens.
- **pharmaceuticals.** Substances in algae are being screened for medical applications and include antibiotics and antiviral or antifungal extracts.

A ‘biorefinery’, where oil and other useful products are extracted, the remaining biomass converted to bioethanol or biogas, and nutrients and water recycled, could be an efficient way to maximise revenue from algae cultivation. Biorefineries are the subject of ongoing research.

The net cost of fuel production could also be decreased by growing algae for biofuel as part of a waste water treatment process. Waste water may contain nitrate and phosphate, which are essential nutrients for algae. They can be harmful if released into water courses by promoting the growth of ‘algal blooms’, large and potentially toxic accumulations of algae in rivers and lakes. Using biofuel-producing algae to absorb these nutrients could decrease the cost of algae cultivation, as well as providing revenue from the water treatment process.

Growing Algae in the UK

Microalgae

80% of biofuels currently used in the UK are imported.[9] It is widely believed that any significant supply of biofuels from microalgae in the UK would also rely upon imports. This is because most existing approaches to growing microalgae require high sunlight levels and consistent temperatures for high productivity throughout the year. Producing algal biofuels in the UK climate would require the discovery of algal strains that can grow at low temperatures and light levels (as well as protecting cultures from frost) and integrating production with waste treatment or high-value products to bring down the cost.

Macroalgae
Most of the estimated 10 million tonnes of wild seaweed in the UK is found in Scotland. It is thought that around 130,000 to 180,000 tonnes could be sustainably harvested each year, similar to the amount currently harvested in Norway.[10] Cultivation could increase this amount dramatically. The Crown Estate, the owner of the UK seabed, estimates that up to 1.5% of the seabed area could be used for macroalgae cultivation.[11] This could give an annual biogas yield equivalent to around 5% of the natural gas consumed in the UK in 2009.[3,10] In practice, the amount of seaweed biomass available for conversion to biogas is expected to be substantially lower, since high value products would also need to be extracted and marketed, given the high cost of production.

At a small scale, macroalgae are proposed as a means to supply biogas in remote coastal areas such as the Western Isles of Scotland, where grid connections are poor and existing gas supplies expensive.

Box 3 highlights selected areas of UK algal research.

Box 3.Algal Biofuel Research in the UK
Algal biofuels research in the UK covers many aspects of the production process, including:
- **selecting algae strains** for fuel or high-value chemicals. For example. the BioMara project, involving researchers in Scotland, Northern Ireland and Ireland is studying algae strains and identifying the specific genes that play a role in oil production.
- **improving production methods** for growing microalgae in warm climates (the objective of the Carbon Trust's Algae Biofuels Challenge which ran from 2008-11) or in northern Europe (the focus of an EU project, 'Energetic Algae', involving scientists in the UK, Ireland and four other countries).
- **pilot scale studies**, proposed as part of several EU-funded projects including Energetic Algae and BioMara. Researchers at Cranfield University, in collaboration with aviation sector members including Airbus, British Airways and Rolls-Royce, intend to grow microalgae at sea for conversion to jet fuel.
- **renewable chemicals,** such as a collaboration between Plymouth Marine Laboratory and the healthcare manufacturer Boots.
- **analysis and modelling** of algal biology (Swansea and Glasgow Universities), economics and carbon dioxide emissions (University of Cambridge, Imperial College London).
- **links between industry and academia**, supported by initiatives including a Knowledge Transfer Centre funded by the Welsh Assembly Government and based at Swansea University, an Algal Bioenergy Special Interest Group supported by the Natural Environment Research Council and Technology Strategy Board and a proposed Algal Innovation Centre in East Anglia.

Policy Drivers
The key EU legislation driving the use of renewable energy in all sectors is the Renewable Energy Directive (RED). This requires that 15% of energy delivered to consumers in the UK be obtained from renewable sources by 2020.

Transport
Under the RED, 10% of the energy used in surface transport in the UK must be obtained from renewable sources by 2020. This target is scheduled for review in 2014. Any renewables used in aviation or shipping can also be counted towards the target. If advanced biofuels and biofuels from waste are used, they are considered to make twice the contribution of first-generation biofuels towards the 10% target. This is intended to give additional support to biofuels which do not compete with food production, and which cause lower GHG emissions. Some criticise this policy as unfairly penalising farmers of first-generation biofuel crops. The European Commission has not yet confirmed whether algae will be eligible for this additional support.

Regulations on biofuel sustainability are included in the RED. These require that biofuels are not grown on land of high biodiversity or on land such as forest or peatland, where converting the land for growing biofuel crops would cause high CO_2 emissions. The total GHG emissions of biofuels must also be 35% lower than the fossil fuels they replace (rising to 50% in 2017). In addition, the EU Fuel Quality Directive requires a 6% reduction in life cycle GHG emissions from all transport fuel by 2020.

At a UK level, the Renewable Transport Fuels Obligation (RTFO), scheduled to run until 2014, mandates that an annually increasing percentage of the UK's transport fuel be obtained from biofuel (currently the target is 3.5%, rising to 5% in 2014). The sustainability criteria in the RED are due to be implemented in the RTFO in late 2011.

Electricity and Heating
In order to meet the 15% overall target set by the RED, analysis by the Department of Energy and Climate Change has suggested that 12% of the energy used in heating, and 30% of electricity, could be derived from renewable sources by 2020. Biogas from algae would be eligible for financial support under a range of measures aimed at meeting this target. For electricity generation, these include the Feed-In Tariff and the Renewables Obligation. From mid-2011, the Renewable Heat Incentive (POSTnote 353) will support biogas used in heating or supplied to the National Grid.

Sustainability Issues
Greenhouse Gas Emissions
As with all biofuels, algae take up carbon dioxide while growing and release it again when the fuel is burned. They do not reduce atmospheric CO_2 in isolation, but can reduce emissions where they displace fossil fuels. To estimate the total 'carbon footprint' of a fuel, all emissions from production to end use must be considered. Sources of emissions include:
- building materials, construction and the effect of land use change;
- providing fertiliser, stirring or pumping the algae to ensure access to nutrients and light, or providing artificial lighting;
- harvesting, drying and processing;
- transport, supply to consumers and the use of the fuel.

Since there is no clear consensus on the optimum production pathway, and emissions data for commercial scale production are lacking, calculations of carbon footprints rely on estimates and vary considerably, depending on the production process used. For microalgal biodiesel, reports present a range of estimates, from GHG emissions 80% lower than fossil diesel, to emissions 300% higher. Many of the lower estimates assume that CO_2 is supplied by flue gas (Box 4) and nutrients by waste water.

For macroalgae, emissions estimates are scarce. Some estimates suggest that emissions could be between 40 and almost 90% lower than natural gas.[8]

Box 4. Carbon Dioxide from Flue Gas

Most microalgae grow by absorbing CO_2, which is usually pumped into the pond or tank in which the algae grow. Researchers suggest that CO_2 could be supplied by power station or industrial flue gas, 'recycling' the emitted CO_2 by converting it to fuel. Although the CO_2 is released again when the fuel is burned, growing algae in this way could decrease the amount of 'new CO_2' released into the atmosphere, provided more CO_2 is absorbed than is emitted during other production stages.

- It has been suggested that algae grown using CO_2 from flue gas should be eligible for support as a CO_2 mitigation technology (POSTnote 354). However, the European Commission and UN do not consider it eligible, because the CO_2 absorbed by the algae is released when the resulting fuel is burned.
- Some groups (including the National Non-Food Crops Centre, NNFCC) consider algae grown using this 'fossil CO_2' to fall outside the definition of a renewable energy source or biofuel. Current policy does not distinguish between types of biomass based on the source of CO_2.
- The potential scale of algal growth using flue gas is constrained by the availability of vacant land near emitting sources, and the amount of available CO_2. The latter would decrease with the decarbonisation of electricity generation or as long term carbon capture and storage (CCS, POSTnote 238) technologies become available.

Land Use

Studies suggest that algae make more efficient use of land than traditional biofuel crops,[12] and one of their advantages over these crops is that they do not require arable land. However, even with a productivity of 40 tonnes of biodiesel per hectare per year – the aim of several EU-funded pilot projects, though current yields are half this – algae could require an area of land of more than half a million hectares (one quarter the size of Wales) to meet the UK's demand for diesel.[3] Campaigners including Friends of the Earth are concerned that high-volume production of algal biofuels could put pressure on arable land, and warn that even land defined as non-arable or degraded may have social or economic importance to local communities.

When grown at sea, macroalgae or microalgae (Box 3) do not compete for land with food production. However, the scale and location of wild harvests or cultivation will need to minimise impacts on biodiversity, other marine uses such as fishing and shipping, and other uses of the algae (for example the use of seaweed for food). In the UK, commercial seaweed farms would require a licence under licensing provisions in the Marine and Coastal Access Act 2011.

Water and Fertiliser Resources

Many algae species being evaluated for biofuels grow in salty or brackish water. However, fresh water may be required for some aspects of production including cooling, replacing water lost by evaporation, and processing. If saline or waste water (Box 4) is not used for cultivation, the fresh water requirement for algae can be higher than for other crops.[12,13] The requirement for fertiliser can also increase costs and GHG emissions associated with algal biofuels, and could put pressure on global fertiliser resources. Recycling of nutrients during production and the use of waste water are two strategies to address this.

If grown inland or in arid areas, water may need to be imported, requiring infrastructure such as pipes or canals, or extracted from underground aquifers, which could be unsustainable in the long term. Moving seawater inland may also affect the local salinity of groundwater.

Air Quality

A recent study[14] indicated that at blending levels of up to 15%, first-generation biofuels reduce most atmospheric pollutants compared with fossil fuels (for biodiesel, oxides of nitrogen, NO_x, increased slightly). For fuel blends with high ethanol content, some US studies indicate increased levels of formaldehyde and ozone. The air quality impacts of algal biofuels are not well understood, and are complicated by the wide range of algae strains, giving a range of chemical compounds in the resulting fuel. There are some indications that algal biofuels could produce lower levels of air pollution than fossil fuels. For example, a 2010 test flight using algal jet fuel showed reductions in hydrocarbons, NO_x and sulphur dioxide compared with the fossil fuel equivalent.

Environmental and Product Regulation

Effluent from algal biofuel production must meet water quality standards, and producers require permits under conditions set out in the Environmental Permitting Regulations 2010 (EPR). Possible adverse environmental impacts include algal blooms or contamination by heavy metals. These may be accumulated by algae if they are present in seawater, waste water or flue gas.

The conditions under which the algae are grown could also affect the regulation of the fuel or chemicals produced. Fuels from algae grown using waste water might also be classed as a waste product unless producers can show they are identical to algae grown on non-waste water. Fuels from waste are subject to tighter regulation than other fuels, for example biogas from waste is only allowed into the National Grid with special permission from the Environment Agency.

Genetic Modification

Some approaches to algal biofuel production involve genetically modified organisms (GMOs) or synthetic biology (POSTnote 298) to increase product yields or provide resistance to herbicides. Campaigners have expressed concern that GMOs may have negative environmental impacts if released. Regulations on GMOs in the UK and EU require full scientific assessments to be made before GMOs can be released to the environment. It is expected that genetically modified algae would be preferentially employed in closed systems rather than outdoor ponds.

Endnotes

1 Environmental Audit Committee Session 2007-8 *Are Biofuels Sustainable?*
2 Nuffield Council on Bioethics, 2011, *Biofuels: Ethical Issues*
3 DECC, 2010, *Digest of UK Energy Statistics*
4 The Committee on Climate Change, 2010, *Fourth Carbon Budget*
5 Lundquist et al, 2010, *A Realistic Technology and Engineering Assessment of Algae Biofuel Production*, Energy Biosciences Institute
6 Darzins et al, 2010, *Current Status and Potential for Algal Biofuels Production*, International Energy Agency
7 Williams and Laurens, 2010, *Energy and Environmental Science*, **3**, 554–590
8 Ecofys, 2008, Worldwide Potential of Aquatic Biomass
9 Department for Transport, 2011, RTFO Quarterly Report 11
10 Kelly and Dworjanyn. 2008. *The potential of marine biomass for anaerobic biogas production,* The Crown Estate
11 Professor M Cowling, The Crown Estate, *pers comm*
12 Clarens et al, 2011, *Environmental Science and Technology*, **44**, 1813-1819
13 Yang *et al*, 2011, *Bioresource Technology*, **102**, 159-165
14 Air Quality Expert Group, 2011, *Road Transport Biofuels: Impact on UK Air Quality* http://www.defra.gov.uk/publications/files/pb13464-road-transport-biofuels-110228.pdf

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 Clare Dyer-Smith for researching this briefing, to the Royal Society of Chemistry for funding her parliamentary fellowship, and to all contributors and reviewers. For further information please contact the co-author, Dr Stephen Allen, on allens@parliament.uk. Front page image source: http://goo.gl/T5HZG