European Academies
easac
Science Advisory Council

The current status of biofuels in the European Union, their environmental impacts and future prospects

EASAC policy report 19

December 2012

ISBN: 978-3-8047-3118-9

This report can be found at
www.easac.eu

building science into EU policy

EASAC

EASAC – the European Academies Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in giving advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard.

Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

EASAC covers all scientific and technical disciplines, and its experts are drawn from all the countries of the European Union. It is funded by the member academies and by contracts with interested bodies. The expert members of EASAC's working groups give their time free of charge. EASAC has no commercial or business sponsors.

EASAC's activities include substantive studies of the scientific aspects of policy issues, reviews and advice about specific policy documents, workshops aimed at identifying current scientific thinking about major policy issues or at briefing policy-makers, and short, timely statements on topical subjects.

The EASAC Council has 28 individual members – highly experienced scientists nominated one each by the national science academies of EU Member States, by the Academia Europaea and by ALLEA. The national science academies of Norway and Switzerland are also represented. The Council is supported by a professional Secretariat based at the Leopoldina, the German National Academy of Sciences, in Halle (Saale) and by a Brussels Office at the Royal Academies for Science and the Arts of Belgium. The Council agrees the initiation of projects, appoints members of working groups, reviews drafts and approves reports for publication.

To find out more about EASAC, visit the website – www.easac.eu – or contact the EASAC Secretariat at secretariat@easac.eu

European Academies

easac

Science Advisory Council

The current status of biofuels in the European Union, their environmental impacts and future prospects

ISBN 978-3-8047-3118-9

EASAC Secretariat
Deutsche Akademie der Naturforscher Leopoldina
German National Academy of Sciences
Jägerberg 1
D-06108 Halle (Saale)
Germany
tel: +49 (0)345 4723 9833
fax: +49 (0)345 4723 9839
email: secretariat@easac.eu
web: www.easac.eu

Cover image: Rain clouds. Cumulus clouds passing over a field of oilseed rape (*Brassica napus*).

Copy-edited and typeset in Frutiger by The Clyvedon Press Ltd, Cardiff, United Kingdom

Printed by DVZ-Daten-Service GmbH, Halle/Saale, Germany

Contents

Foreword

EASAC prepares independent reports and statements on urgent issues of the day. A Working Group of academy-nominated experts in energy production and environmental sciences have produced this report. It summarises our work so far on the scientific evidence about the impacts of biofuels and their environmental sustainability.

Effective action to limit climate change is a high priority for Europe, as for other parts of the world, and is largely focussed on the reduction of the agents of global warming, the greenhouse gases. In Europe, emissions of greenhouse gases from road transport form a large part of the whole, estimated at about a quarter. Action to reduce emissions from road transport therefore has high priority for the European Union (EU) and is a major focus of legislation. A major plank of EU policy is to reduce emissions from individual vehicles by introducing a renewable element to road transport fuel. This has been done by providing a mandatory target for the proportion of renewable energy in the road transport fuel mix. In practice this has meant a rapid development in the use of biofuels derived from biomass in road transport.

However, despite provisions in the EU legislation designed to ensure that biofuel production is environmentally sustainable and produces real savings in greenhouse gas emissions, criticisms persist about the use of biomass for transport, and the use of mandatory targets to incentivise uptake. In particular, there are doubts about whether the current provisions for assuring sustainability take full account of the broader impacts on biodiversity and ecosystem services of providing biomass feedstock, or the full energy costs of biofuel production. There are also, in the case of biofuels produced from edible crops, major questions about the competition for agricultural production between fuel and food.

This is of considerable importance because the EU aims to make real reductions in greenhouse gas emissions and to halt loss of biodiversity and ecosystem services, in the EU and globally. More fundamentally, competition for crops between fuel and food affects us all, but in particular those for whom food is scarce, where price rises driven by this competition are an added burden

Recently, the European Commission responded to criticisms of the provisions of the Renewable Energy Directive (RED) by publishing proposals for amendments (October 2012). It is proposed that the proportion of biofuel derived from edible plant material that counts towards the mandatory target should be limited to about the current level of biofuel production. This is a welcome first step towards addressing our comments about competition between food and biofuels and the consequent food price impacts.

However, we remain concerned that the Commission's proposal fails to address the true level of greenhouse gas savings achieved by biofuels. There are now many credible studies of the full impact of biofuel production including the impacts of indirect land use change (ILUC, which occurs when existing plantations are used for biomass cultivation). Although the estimates of greenhouse gas emissions from ILUC range widely, they are generally significant and should be included in the assessment of which particular biofuels can be counted by EU member states towards the mandatory targets set out in the RED. Leaving out this significant source of greenhouse gas emissions from assessment undermines confidence that the RED will deliver real and major savings in greenhouse gas emissions from transport. I hope therefore that this report will give further impetus to the in-depth review of the current EU policy on biofuels.

I thank the Chairman, Professor Lars Tegnér, and Working Group members, for their hard work in producing this report, the EASAC Environment and Energy Steering Panels for their oversight and critical review of the report, and Dr John Murlis, Secretary, Environment Panel. I also thank Professor Rolf Thauer for his help and the German National Academy of Sciences Leopoldina for permission to use results from the study of biofuels and sustainability recently published by the German National Academy of Sciences Leopoldina.

Sir Brian Heap,
President of EASAC

Summary

As part of its strategy to combat global warming by reducing the emission of greenhouse gases, the European Union (EU), in 2009, agreed the Renewable Energy Directive with ambitious targets for the use of renewable energy. These include targets for renewable energy in the road transport sector. By 2020 10% of the final consumption of energy in transport in the EU and each of its Member States should come from renewable sources. This energy could come from renewable electricity generation or from biomass. However, uptake of electric vehicles and the overall contribution of renewable energy systems to electricity generation in Europe are low, and it is expected that the renewable energy for the 2020 target will come primarily from biomass in the form of biofuels. In 2020 it is expected that the dominant production route for biofuels will still be through the use of edible parts of plants ('first-generation' biofuels).

This Statement arises from concerns about the use of biomass for producing road transport fuels and about the arrangements for ensuring that such fuels provide a real climate benefit while not harming the wider environment. It has been generated as an output of a study by a Working Group of experts on biofuels and biodiversity established by the European Academies Science Advisory Council (EASAC) in 2011.

To ensure that the use of biofuels leads to a real reduction in greenhouse gas emissions, the Renewable Energy Directive contains criteria for those biofuels that are eligible to count towards the target. They must achieve a specified level of greenhouse gas reduction compared with fuels made from crude oil: greenhouse gas savings from biomass of 35% now rising to 60% in 2018. The calculation of the reduction achieved is based on lifecycle analysis, in which greenhouse gas emissions from each stage of biomass cultivation and biofuel production are assessed. Biofuels also do not count towards the target if they are made from biomass grown on protected areas, the Natura 2000 sites for example, and the Directive also prohibits the use of land that has importance because of its biodiversity or because it contains high stocks of carbon.

In a recently reported statement by the European Commission (http://uk.reuters.com/article/2012/09/17/eu-biofuel-idUKL5E8KHA4120120917), it was announced that proposals would be brought forward in the autumn of 2012 for further constraints on eligible biofuels. The use of food-based biofuels would be limited to 5%, about the current consumption level. The remainder of the biofuel required to meet the 10% target would then have to come from wastes and other renewable sources.

The Working Group conclude that the prescribed methods of lifecycle analysis are incomplete, failing to account for some major sources of greenhouse gas emissions, including aspects of carbon storage and the secondary impacts of biomass cultivation known as 'Indirect Land Use Change'. When these sources are taken into account, it appears that the reductions in emissions achieved by first-generation biofuels generally do not meet the 2018 criterion, and in some cases the current criterion too. A revision of the methods of lifecycle analysis to take full account of emissions arising in biomass cultivation is recommended.

The Working Group find that the biodiversity criteria are inadequate in scope, with important areas for conservation of biodiversity left unprotected, and, crucially, that the criteria do not allow fully for the effects of indirect land use change. It is recommended that the criteria for biodiversity protection are revised. To prevent the worst effects of indirect land use change, it is recommended that measures to protect biodiversity should be enacted for all agricultural production, not just for biofuels.

The Working Group consider these issues to be serious, and that the 2020 target in its current form provides a driver for carbon-inefficient and environmentally damaging biofuel production. The Group rejects the claim that the target, inevitably delivered mainly through first-generation biofuels, is necessary to pave the way for second-generation biofuels because different processes and different businesses are involved in the second generation. It recommends that the target should be revisited with the aim of finding a more sustainable target level for 2020, if not abandoning it entirely.

If a target is to be retained, in a revised form, an urgent investigation is required to set an alternative target level/timescale, ensuring that there are appropriate incentives for production of sustainable biofuels without the distortions created by the current target. The European Commission's recently proposed changes to the biofuels targets might provide the opportunity for such an investigation.

Considerations of food security in the context of the increasing demand for food and fodder to meet the needs of a growing global population suggest that there will be continuing pressures on edible plant material, which should exclude its use in biofuel production. The working group recommends that the preferred route for biofuels in the future should be through more advanced (second- and third-generation) technologies. The EU announcement that restrictions would be placed on the eligibility of food-based biofuel to contribute to the

biofuel target is therefore a welcome first step towards its exclusion.

Second-generation biofuels based on inedible parts of plants, including straw, wood and waste streams, and third-generation biofuels, based on algae, show promise. Some second-generation technologies appear to offer much improved reductions in greenhouse gas emissions. However, they will not be in full-scale production before 2020 and the anticipated improvements remain to be demonstrated at the commercial scale, Substantial investment in research and development is still required.

The Working Group note that substantial amounts of food are lost after harvest and that this material constitutes a large compostable resource for the production both of biogas and of solid by-products that could usefully be returned to the soil. It is recommended that the role of biogas in the renewable energy mix should be investigated and that the Renewable Energy Directive should be amended to incorporate provisions for biogas.

1 Introduction

We are living in an age where humanity has become a major factor in the Earth's system, changing the atmosphere and all other natural spheres, and has left only about a quarter of the ice-free land surface of the earth in a natural state (Ellis, 2011). We also live in a world of globalisation and still-increasing population where agriculture, urbanisation and settlement, transport infrastructures, recreation and preservation of wildlife, and ecosystems goods and services compete for land use. A recent study of the Earth's biophysical limits (Rockström et al., 2009) concluded that the sum of human activity is placing an unsustainable pressure on many key aspects of the earth system, including its climate, the biodiversity it supports and the cycling of nutrients required for plant growth, and that the consequences for humanity will be severe.

The Earth benefits from a natural greenhouse effect, which keeps it at a temperature that is conducive for life. Several atmospheric trace gases, including notably carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), act to retain some of the sun's energy, warming the atmosphere, the Earth's surface and the seas. However, since the Agricultural and Industrial Revolutions, the use of fossil fuels as energy sources, together with intensive agriculture and deforestation, have led to an increase in these trace gases. Atmospheric CO_2 and CH_4 levels are now higher than at any time in the past 400,000 years. T he consensus of the world's scientific communities is that this increase is responsible for the major part of the climate change experienced over the past 50 years. In its 4th Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) expresses growing confidence that human activities are impacting the earth's climate system, concluding that 'it is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures at the global scale' and 'there is medium confidence that anthropogenic influences have contributed to intensification of extreme precipitation at the global scale' (IPCC, 2007).

There are also other pressures on the earth system from human activity, noted by Rockström et al.: emissions of air pollutants, including nitrogen oxides (NO_x) and sulphur dioxide (SO_2) from energy conversion, are now higher than natural sources; the extinction rate of living species is at least 100 times higher than normal levels; increase of energy consumption since 1900 is 16-fold; and 40–50% of freshwater is controlled by humans. In addition to their impacts on the earth system, these pressures give rise to many immediate effects, including on human health and wellbeing and all impacts are exacerbated by climate change.

Combating climate change by reducing those greenhouse gas emissions arising from human activities is a top priority for the European Union (EU) and there are many policy initiatives in place, and under development, to ensure that the most severe impacts can be avoided (or minimised). At an international level, the EU has played a leading role in developing agreements under the United Nations Framework Convention on Climate Change aimed at taking all necessary steps to avoid 'dangerous' climate change. The EU aims to ensure that further global warming due to anthropogenic greenhouse gas emissions is limited to no more than 2°C above pre-industrial levels and to about 1.3°C above today's global average temperature. Goals are to halt global increases in greenhouse emissions by 2020, to halve anthropogenic greenhouse gas emissions by the middle of the century and then to ensure that they continue to fall.

The EU has enacted measures to reduce emissions of greenhouse gases from each of the key economic sectors in Europe. Renewable energy is a major part of this and Member States have agreed to measures that aim to ensure that the EU will reach a 20% share of energy from renewable sources by 2020. Transport accounts for about a quarter of total EU emissions of greenhouse gases, making it the second largest sector source, after the electrical supply industry. Although emissions from the electrical supply industry are falling, greenhouse gas emissions from transport continue to rise. Action against transport emissions is therefore a major strand of EU climate strategy and as a part of this, Member States have agreed measures to promote the use of renewable energy in transport, including a mandatory target of 10% share of renewable energy in the sector by 2020. Of all transport sector emissions, road transport contributes about two-thirds, and is a major focus of policy.

In principle, there are many options for reducing the carbon footprint of road transport, including the following:

- traffic reduction measures (for example, investment in public transport infrastructure, improved logistics, and reduction of transportation of goods through local sourcing);
- more efficient use of energy in vehicles (downsizing, light-weighting, improved energy conversion efficiency in engines, and lower speed limits (Berry, 2010));
- new forms of energy such as electrical traction using electricity from renewable sources for passenger cars, or hydrogen as an energy carrier for the future; and
- alternative fuels for the current fleet generated from biomass.

Traffic reduction has proved a considerable challenge and continuing growth shows no sign of faltering. Smaller, lighter passenger vehicles are available but market penetration has been slow. However, the EU has a strategy for introducing more carbon efficient vehicles (http://ec.europa.eu/enterprise/sectors/automotive/competitiveness-cars21/energy-efficient/index_en.htm), including support for research into hydrogen and action on electric vehicles.

In theory, electricity from renewable sources could form a significant part of the mix of energy that contributes to meeting the 10% renewable target for transport by 2020. In practice, however, electric vehicles form only a very small part of the present passenger vehicle fleet, and in most EU countries renewable sources still only account for a modest contribution to overall electricity generation. Nemry and Brons (2010) made a study of the prospects for market penetration of electrically driven vehicles in the EU and concluded that impacts on fuel consumption up to 2020 would be negligible. Beyond this, it is anticipated that the share of electric propulsion in transport will increase and that by 2030 the fuel saving could amount to 6–20% (Nemry and Brons, 2010)

In effect, then, it is expected that the principal means of meeting the 10% renewable target in 2020 will be through fuel derived from biomass.

In addition to the objective of saving greenhouse gas emissions, EU biofuels policy also aims to ensure security of supply and to increase employment. It is noted that the transport sector is currently heavily dependent on imports of crude oil, and that the sources of supply are limited and subject to political instability. However, as noted later in this report, imports currently account for a substantial portion of biofuels used in Europe. The production of biofuels diversifies supply and has the potential to increase employment in rural areas in the EU and in developing economies (Edwards et al., 2008).

Biofuels would help mitigate climate change, provided that they produce real savings in greenhouse gas emissions. But they are also clearly a challenge to land use, placing further pressure on priority uses, including food production, competing both for the land itself and for resources of water and nutrients. Hence, production, distribution and use of biofuels have to be seen as part of a larger system whose sustainability has to be carefully assessed.

The use of biomass for the production of road transport fuel raises many questions about the availability of organic matter from plants, by-products or wastes, and about how such material can best be used. The review of the EU approach to implementing the biofuel target, announced by the European Commission in September 2012, is a recognition that food-based biofuels, in particular are proving problematic.

2 Policy background: what the EU requires

It is envisaged that, for the EU to achieve the aim of 20% of its energy from renewable sources by 2020, a range of alternatives to fossil fuel will be needed. These could include wind, solar, hydro-electric and tidal power as well as geothermal energy and biomass used in a range of economic sectors, including road transport. The risks and benefits associated with these different alternatives have been subject to considerable research (Pimentel, 2008).

In 2003, the EU enacted a Directive for the promotion of biofuels (2003/30/EC), containing a voluntary target of 5.75% share of renewable energy in the transport sector by 2010. Directive 2009/28/EC, on renewable energy, converted this voluntary target into a binding target of 10% for renewable energy content in transport in all EU Member States by 2020. It also improves the legal framework for promoting renewable electricity, requires national action plans that establish pathways for the development of renewable energy sources including bioenergy, creates cooperation mechanisms to help achieve the targets cost effectively and establishes sustainability criteria for biofuels.

The environmental sustainability of biofuels has been recognised from the outset by the EU as an important issue affecting their acceptability to European publics. In consequence, there have been considerable technical and political efforts to develop regimes and rules to ensure that the biofuels that contribute towards the 10% target deliver real greenhouse gas savings and do not impact adversely on biodiversity and ecosystem services. Sustainability requirements, provided initially in the Renewable Energy Directive, were elaborated in a Directive on fuel quality (2009/30/EC), with the aim of ensuring minimum standards of greenhouse gas reduction and the protection of biodiversity.

The first criterion is greenhouse gas reduction. This is designed to ensure that there are real carbon savings from the use of biofuels. The greenhouse gas emission saving from the use of biofuels currently has to be at least 35% to be counted towards achieving the target. In 2017, the saving must rise to 50% and in 2018 to 60% for biofuels produced in installations in which production started in 2017.

Article 19 and Annex V of the Renewable Energy Directive describe how the savings are to be calculated, giving typical values of greenhouse gas emission savings from fuels derived from a range of crops produced in the EU, both for first- and second-generation biofuels.

The aim of the second criterion is to protect biodiversity by prohibiting the use of raw materials taken from land with high biodiversity value. This includes the following:

- primary forest or other wooded land, where native species dominate and are undisturbed;
- areas designated for nature protection, including the EU's Natura 2000 network (18% of EU land at present);
- highly biodiverse grassland; and
- high carbon stock areas such as peat land.

These elements of the biodiversity criterion are designed to prevent conversion of particularly sensitive land to biofuel production. However, a key and important remaining issue is that of indirect land use change (ILUC): the conversion of agricultural land to biofuel production, displacing the agricultural use, possibly to previously uncultivated land. This may compromise that land's contribution to biodiversity and its role as a carbon sink through carbon accumulation in soils, and may increase N_2O emissions.

Other EU policies, designed to promote sustainability within the EU, are also relevant to the development of biofuels use in the EU. Key policy initiatives cover biodiversity and the bio-economy:

- **Natura 2000** is the centrepiece of EU nature and biodiversity policy. It is an EU-wide network of nature protection areas, designed under the 1992 Habitats and 1979 Birds Directives. http://ec.europa.eu/environment/nature/natura2000/index_en.htm
- **EU Biodiversity Strategy** aims to halt the loss of biodiversity and ecosystem services in the EU by 2020. There are six main targets, including better protection of ecosystem services, improved sustainable agriculture practice and forestry management, and a larger EU contribution to averting global biodiversity loss. http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/2020/1_EN_ACT_part1_v7%5b1%5d.pdf
- **EU Strategy for a Sustainable Bioeconomy** aims to shift the European economy towards the use of renewable biological resources. The strategy has the goal of reconciling demands for sustainable agriculture with the most efficient use of renewable biological resources for industrial purposes, whilst ensuring biodiversity and environmental protection. http://ec.europa.eu/research/bioeconomy/pdf/201202_innovating_sustainable_growth.pdf

It is not clear how these and broader EU policies, for example on agriculture, may have influenced the development of the Renewable Energy Directive, nor how some of the specific requirements arose. For example, in the development of the biofuels target itself, there is a paucity of scientific underpinning for the choice of a figure of 10%. A review of the process leading up to the agreement on the 10% target (Sharman and Holmes, 2010) suggests that motivations apart from reduction of greenhouse gas emissions were important. In particular, there were considerations relating to the reform of the sugar regime under the Common Agricultural Policy, given the influence of the farm lobby and its aim of finding a way forward for the EU's sugar-producing capacity as the Common Agricultural Policy subsidies were withdrawn. Sharman and Holmes (2010) suggest that the emerging biofuels industry effectively saw this as an opportunity and aligned itself with the farm lobby in pressing for a specific target.

Following the most recent EU policy development, in October this year (2012), the European Commission published proposals to limit the range of biofuels that can be counted against the 2010 10% target. The aim of the new proposals is to limit the proportion of food-based (primary-crop) biofuels that can contribute towards the target to a maximum of 10%. The remainder of the target, it is expected, would be met by fuels derived from waste or other renewable sources.

The main issue addressed in this Statement are competition with food supply and the compatibility between the EU's biofuels target and its broader aims: achieving real greenhouse gas reductions and halting the reduction of biodiversity with consequent loss of ecosystem services.

3 Biofuels and the use of biomass

Biofuels are fuels derived from current (as distinct from fossil) plant sources (plant biomass), or from such animal products as milk whey, which are used to displace the use of fossil fuels in transport, mainly in road transport, but also in aviation and water transportation, or in stationary applications such as combined heat and power plants: see Annex 1 for definitions of terms.

Owing to the limitations of current technologies, most material that will be used in the near future for conversion to transport fuels will be derived from edible material. For the edible parts of plants, there are clearly qualitatively more important uses of available biomass, notably to provide food for people and animals. For the biomass in general, there are other competing uses. The conversion of sunlight and carbon in plants provides the primary production on which the earth's ecosystems depend, and is vital to maintaining life, including human society, on earth. As well as embedded energy, for food or fuel, the biological systems in plants form complex organic structures that have great value, including as chemicals and pharmaceuticals, materials for building, and wood for products such as furniture and fibres.

A report from the Royal Belgian Academy Council of Applied Sciences (BACAS) suggests a prioritisation of uses of plant biomass in the form of the '5 F cascade' (BACAS, 2011):

(1) Food and feed (for edible parts of plants).

(2) Fine and bulk chemicals and pharmaceuticals.

(3) Fibre and biomaterials.

(4) Fuels and energy.

(5) Fertiliser and soil conditioners (composting).

This ranking implies that the primary use of edible biomass should be for food, then for materials, and only when demand for these is satisfied should the stored energy in the molecular binding be used for energy purposes. For the inedible parts of plants, the provision of chemicals, pharmaceuticals and materials takes precedence over energy. This prioritisation, of course, has to be subject to the availability of viable or desirable alternatives: for many communities worldwide, for example, wood remains a major sources of fuel for cooking and heating.

If, however, there is surplus biomass, then its use in displacing fossil fuels could be of benefit, and substantial investments have been made in biomass-derived fuels both for stationary and mobile applications. Wood products are widely used in combined heat and power plants in the EU, providing of up to 5% of EU consumption of stationary plant fuel. Incentivised by the requirements of the EU's Renewable Energy Directive, biofuel consumption in the EU has risen sharply in recent years.

Biofuels used in road transport are of three main kinds:

- Biodiesel, derived from plant oils (for example palm oil, rape, sunflower, soy), waste oils (cooking oils, animal fats) and from tall oil (a by-product of the Kraft process of wood pulp production, mainly for paper and card).

- Bioethanol, used as a blending agent in gasoline or as an E85 fuel (ethanol fuel blend of up to 85%, by volume, denatured ethanol fuel, together with gasoline or other hydrocarbon), currently derived by fermentation of sugars from carbohydrates (starch from corn, wheat, sago palm, or sugar from beet and sugar cane) and a consecutive fermentation of the sugars to ethanol. Over the next 10 years, it is expected that second-generation technology will be developed to derive bioethanol from cellulosic and ligno-cellulosic biomass (straw and agro-waste, corn cobs, grasses, wood).

- Biogas from fermentation of organic matter, including domestic, farm and food industry waste.

They are commonly divided into technology generations according to the feedstock used. Although there is no common definition, the following is in general use:

- First generation, produced from edible parts of agricultural crops, bioethanol from sugar and starch, biodiesel from oil crops

- Second generation, produced from ligno-cellulosic biomass from non-food crops (grasses, tree plantations or woody waste from forests for example) or the inedible parts of food plants (straw and husks); and

- Third generation, radically new products from biological processes (industrialised production of algae to produce biodiesel, for example, or hydrogen production from biomass gasification).

At present, for the production of liquid fuels, only first-generation biofuels are in commercial production and, despite several pilot-scale second-generation plants (for example, a 1,000 tonne per year ethanol plant in southern Germany: http://www.sud-chemie.com/scwww/web/content.jsp?nodeIdPath=7803&lang=de) and plans for large-scale demonstration plants (see Chapter 7) it is generally recognised that second-generation biofuels are at least 10 years away from commercial-scale production. It seems, therefore, that the major burden of providing biofuels for the EU 10% target in 2020 will fall on first-generation biofuels.

Each of these routes to biofuel has external costs, in the form of land use change, resource use (notably water and fertilisers, including their embedded energy), energy used in production, and impacts on biodiversity and the wider environment. Each is subject to different risks: for example, as first-generation biofuels rely predominately on annual crops, which are less buffered from risk than perennial crops (in particular, wood), they are particularly susceptible to crops failure from drought, late frosts, pests and diseases, and each will require different strategies to ensure a continual supply of feedstock. The viability of these different routes to biofuel depends on the availability of suitable biomass, the overall energy efficiency of production and effective strategies for managing risks and external costs.

4 Current energy requirements and consequences of the 10% target

To put the biomass energy requirement of the Renewable Energy Directive into perspective, it should be seen in the context of overall current demand for primary and final energy, how this demand will change in future, and what climate and environmental costs the use of biomass would have.

The annual world primary energy supply in 2009 has been estimated at 12,150 million tonnes of oil equivalent (Mtoe[1]). Just over one-third (36%) of the energy supply comes from oil. World annual final energy use (accounting for losses during conversion) in 2009 was 8,353 Mtoe, of which transport accounted for about 25% (IEA World Energy Statistics, 2011).

The current annual EU demand for road transport fuel is about 300 Mtoe. To achieve the 10% aims of the Renewable Energy Directive for 2020, assuming that the full burden falls on biofuels and that the contribution of other renewables such as renewable electricity sources in 2020 is still small (see above), about 30 Mtoe of fuel from renewable sources will be required annually by 2020, which is equivalent to an annual biofuel demand of 350 terawatt hours (TWh) (equivalent to 1.26×10^{18} joules (J)).

At present, biofuels contribute about 10 Mtoe to the EU road transport energy mix, of which about 80% is biodiesel, mostly derived from rape seed, and 20% is bioethanol, mostly from wheat, maize, beet and sugar cane. In 2008 about 40% of this was imported into the EU, either as biofuel or feedstocks for manufacture in the EU, mostly from the USA and Brazil.

Land use for current levels of EU biofuel demand is estimated at 7 million hectares (Mha), of which 3.6 Mha is within the EU. To achieve the 10% target, assuming 100% of the required biomass is produced within the EU and using current technologies, about 21 Mha would be needed, which is equivalent to 21% of arable land in the EU (Eurostat 2008 gives the figure of 100 Mha for EU arable land in 2006–7) and represents an additional land area of about 14 Mha, or 14% of arable land (see Table 1). Note, however, that the energy yield from production of liquid biofuels is significantly below the potential yield from crop digestion to produce biogas (Murphy et al, 2011).

At present, the area of cultivated land is decreasing in the EU as a whole and in many of its Member States. The reasons for this are not entirely clear, but economic factors (the relative reduction of farm incomes), changes in soil condition (loss of fertility coupled with the difficulty of sourcing affordable artificial fertilisers) and resource availability (in particular water shortages) are all believed to play a part.

A key question that affects the potential for further biofuel production from EU-grown feedstock is how much of this land can be brought back into use. It is likely that this will depend more on economic factors, including the availability of labour and inputs in the form of the water and fertiliser that would be required to produce satisfactory yields, rather than on the availability of the land itself. Unless the factors that drive the current retraction of land under cultivation can be addressed, this suggests that the availability of suitable land and the necessary resources for intensive further production of biomass for biofuels in the EU will be limited, and that there will be an increasing dependence on imports of biofuel or biomass feedstock.

Imported biofuels tend to have a higher energy yield per hectare than biofuels produced from biomass grown in Europe (Thamsiriroj and Murphy, 2009) so that the area of land required will be less. Reliance on imports remains of concern because more than 30% of the net primary production that is used by people within the EU, including food, fuel and fibres, already comes from imported biomass or biomass products (Haberl et al., 2012). Through added biomass imports, to meet increasing EU demand for biofuels, more of the attendant climate and ecological risks of intensive agriculture would be exported to countries outside the EU.

The resource demands for biofuel production, in terms of water requirement and fertiliser inputs, are significant. For example, the amount of water needed

Table 1 Land use and potential demand for land from biofuel production

	Land use	Proportion of total	Within EU	Outside EU
Available arable land	100 Mha	100%	100 Mha	
Current land used for biofuel	7 Mha	7%	3.6 Mha	3.4 Mha
For 10% target	21 Mha	21%	?	?
Additional land needed for 10% target	14 Mha	14%	?	?

1 1 Mtoe is equivalent to about 42×10^6 gigajoules and 11.7 terawatt hours (TWh).

to grow 1 kilogram of maize biomass is 350 litres. These inputs also have energy embedded in them from water management, production (in the case of fertiliser) and from transport or distribution. Such embedded energy and the nature of its sources have to be taken into account in assessing the overall greenhouse gas reduction achieved.

Many global-level assessments of the potential for energy from biomass and its impacts on food supply and the environment have been published over the past 20 years. Taken together, they give a broad range of estimates of the potential contribution biomass (as distinct from biofuels) could make, from less than 10% of global energy supply to more than 100%. These differences arise from the very different assumptions that have been made in arriving at estimates.

A systematic review of this literature, published by the UK Energy Research Centre (Slade et al., 2011), exposes the assumptions made and the consequences these have for the estimates produced. This review considers the assumptions that give rise to three bands of estimates: those that suggest that up to 20% of global primary energy supply could be provided by biomass; those that suggest between 20% and 50%; and those that suggest over 50%. The review finds the following:

- Estimates of up to 20% of global primary energy supply from biomass and biomass wastes tend to arise from assumptions that there is little extra land available for energy crops, that there will be insignificant further increases in crop yield, that diets worldwide continue on current trends and that primary energy consumption will continue to increase as will the world's population. It is assumed, however, that the proportion of supply from biomass will vary from country to country, being lower in countries with a higher population density and primary energy consumption than the global average. The assumption for countries like Germany is that it will be below 5%.

- Estimates from 20% up to around 50% of global primary supply tend to arise from scenarios where increases in yields of food crops keep pace with increases in food demand driven by a growing world population. Little agricultural land needs to be made available for energy crops, which are grown on areas of deforested, degraded or marginal land varying in size from twice to ten times the size of France. Estimates in this band tend to assume that the world's primary energy consumption will soon plateau.

- Estimates from 50% up to, or just over, current supply tend to assume that increases in yield of food crops outpace increases in demand for food. Large areas, equivalent to about the size of China (more than 1 gigahectare (10^9 ha)) are then available for energy crops. The global primary energy consumption decreases by 50% by 2050.

This analysis of global assessments shows that assumptions about future food consumption are crucial to the demand side of the assessment, and about future yields and the availability of land to the supply side. The analyses, however, do not take account of broad sustainability considerations, including the possible climate and environmental risks associated with intensive agriculture.

A report by the German Advisory Council on Global Change (WBGU, 2008), taking these factors into account, concludes that the sustainable potential of bioenergy is significant, but suggests that the upper limit would be about a quarter of current energy use and less that 10% of the global energy required in 2050.

According to these global analyses, there is likely to be biomass available for energy use. The crucial question is how much of it would be suitable for biofuel production and, given alternative and potentially more efficient means of generating useful energy from biomass, how much should be routed to biofuel production. If it is assumed that about half of the available biomass goes to biofuel production, the EU 10% target would appear to be broadly consistent with even the most conservative estimates of the global potential for use of biomass as fuel.

However, the time horizon associated with this conclusion is crucial. The studies reviewed have, in general, made the assumption that primary energy consumption decreases or at least plateaus and that bioenergy supply comes from first- and second-generation sources combined. Given that energy savings and the large-scale commercialisation of second-generation biofuels are yet to be achieved, the conclusions of this analysis have to be located sometime in the future and beyond the EU 2020 target date. This puts into question the time horizon for achieving the 10% target.

5 Immediate prospects for first-generation biofuels: global and EU perspectives

For the immediate future, and up to the EU target date of 2020, it is likely that first-generation biofuels will play the major part in biofuel supply. This current technology for biofuel production (bioethanol, biodiesel) depends on feedstock derived from the edible fraction of food plants (corn, rapeseed, sugar beet and others). There are therefore concerns about competition between food and fuel. Evidence for this has been found in the form of rising food prices associated with increases in biofuel production (Koh and Ghazoul, 2008). The EU study 'Biofuels Baseline 2008' (Hamelinck et al., 2011) concludes that the impact of EU biofuels consumption was to increase food prices, with modest increases in the case of cereals but with major impact on prices of food oil.

A recent study of the availability of biomass for food and fuel (Johanson and Liljequist, 2009, Johansson et al., 2010) considers this question in terms of the energy requirements for people and for biofuel. The current energy demand for food energy, globally and across the EU, was estimated assuming a world population of 6.7 billion and a daily demand per person of either 2,500 kilocalories (kcal) (about 11,000 kilojoules (kJ)) or, including losses in preparation and cooking, 3,500 kcal (about 15,000 kJ). Johansson and Liljequist then estimate the global annual energy demand for food to be 7,092 TWh (25.5×10^{18} J) to 9,950 TWh (35.8×10^{18} J) according to the assumption they made about daily food energy demand (2,500 or 3,500 kcal). For the EU, the equivalent figures are 526 TWh per year (1.8×10^{18} J per year) to 742 TWh per year (2.67×10^{18} J per year), with the same assumptions about food consumption per person.

The global supply of food energy was estimated from a range of sources, including Food and Agriculture Organization (FAO) food production statistics, with assumption about losses after harvest, for example from moulds, and with the assumptions that rest products from agriculture (for example straw and husks) were or were not recovered and returned to the food chain. Global annual food production was estimated at 7,225 TWh (26×10^{18} J), assuming that by products were not used for food, and 9,265 TWh (33.3×10^{18} J), assuming that they were. For the EU, annual food production was estimated to be 310 TWh (1.1×10^{18} J).

For comparison with world energy supply (12,150 Mtoe in 2009), world food production, according to Johanson and Liljequist, is approximately equivalent to either 620 Mtoe or 795 Mtoe, according to assumptions about losses and the use of by-product. Europe produces food energy equivalent to 26 Mtoe, about 3% of global food production. European demand for food, however, is 7% of global demand so that substantial levels of imports are required.

The conclusions to be drawn from Johanson and Liljequist's work are that, globally, food production just about meets the overall demand at present, but that in the EU the food energy requirement exceeds production so that, according to these estimates, the EU needs to import about 40% to 50% of its food energy requirement. The key question is whether this represents simply a global balance between supply and demand with capacity for supply to respond to changes in demand, or if it shows a system that is at its limits and will struggle to respond to increases in demand. Although the analysis suggests that food supply is broadly adequate at present, ideally there should be surpluses to build stocks against food supply problems arising from price shocks and crop failure. A greater level of supply would improve food security.

At 350 TWh, the energy content of fuel corresponding to the 10% target is roughly equivalent to the energy contained in the EU production of food. In the analysis in Chapter 4 of land requirements for biofuels to meet the target, it was concluded that the 10% target corresponds to a demand for 21% of the EU's arable land. The assumption in this case was that the 'yield' is about 1 Mtoe for each 590 kha, but the actual yield for all agriculture is well below the values obtainable for high yield varieties of grain, beet or oilseed used in biofuel production. This suggests that agriculture is less efficient at making food in general than biofuels but that we need a wide range of different foods. For the EU, food security considerations must place doubt on the wisdom of increasing production of biofuels rather than decreasing dependence on food imports.

Globally, future population growth will require further agricultural production and/or the reduction of losses before and after harvest. In the past, major technological transitions, including the Green Revolution, have enabled agricultural production to keep pace with growing demand. However, there are no similar major advances on the horizon and it seems that availability of edible material for biofuels will become increasingly squeezed. Increases in the quantity of biomass used for biofuel production in future, of the scale suggested in the reports of the UK Energy Research Centre (Slade et al., 2011) or the German Advisory Council on Global Change (WBGU 2008), would have to come principally from non-edible parts of plants or from agricultural waste.

6 Longer-term prospects for biofuels

Future technology for biofuel production is expected to provide flexibility for a wider range of feed stocks, including particularly the use of woody parts of plants (ligno-cellulosic biomass) in second-generation biofuels and, in third-generation biofuels, feed stock such as algae. Other materials, particularly losses after harvest from agriculture, also have potential for conversion to fuel for transport, including through the use of first-generation technologies, and could play a role in the renewable mix.

6.1 First-generation biofuels that do not compete with demand for food

Losses after harvest of the edible parts of plants, in the processing, distribution and consumption of food, account for a significant proportion of agricultural production. This includes food that is lost in the supply chain through damage, moulds and pests, food that is rejected as of unmarketable standard, and wastes from the processing and preparation of food, and from leftovers from food consumption. There are also significant quantities of inedible plant materials and materials from the processing of dairy and meat products. Smil (2000) estimated that about 50% of edible calories harvested globally are lost through waste and through use as animal feed, which is converted to food for humans at a low energy efficiency.

Although it is possible to produce liquid biofuels from these materials, and some, in particular waste oil and by-products of dairy production, are already in use in the production of first-generation biofuels, the greatest potential is considered to come from the production of biogas. Biogas production uses more of the material available and, if the by-products are returned to the soil as fertiliser, has less impact on soil quality (Johansson and Liljequist, 2009).

Biogas, produced by anaerobic digestion and upgraded to commercial standards, has been used, though at low levels, for some time as a transport fuel in the heavy-duty sector, in particular where there are central depots for refuelling. The improved use of biomass-material from current agricultural food practice, post-harvest losses, and inedible products of agriculture alone have an estimated global annual energy potential in the form of biogas of 6000 TWh (21.6×10^{18} J), of which a little bit more than 10% (660 TWh) would be within the EU. In particular, food spoiled annually after harvest (by rotting) is estimated to have the potential to supply 1750 TWh (6.3×10^{18} J) of biogas per year globally and 214 TWh (0.77×10^{18} J) biogas per year within the EU (Johansson and Liljequist, 2009).

This study did not address the question of how much of this potential could be recovered, and there are challenges in the collection of the material and its conversion to biogas, which will reduce the realisable supply. A study of biogas as a road transport fuel in the UK concluded that it could potentially deliver fuel equivalent to 16% of current use, of which half would come from commercial and domestic food waste. The realisable potential, assuming only minimal development of anaerobic digestion for biogas production, was estimated at 1.6% of current road transport fuel but with widespread use of anaerobic digestion for waste treatment; this was estimated to rise to 8% of current road transport fuel (Hitchcock, 2006). This study suggests that investment in advanced waste treatment is the critical factor in realising the potential of biogas. A study of the potential for biogas production from wastes in Ireland (Singh et al. 2010) suggested that the realistic potential from anaerobic digestion is 7.5% of predicted 2020 road transport energy demand.

There is, therefore, significant potential for production without competition with food if these materials can be collected and processed at a reasonable energy, and overall resource, cost.

Another route to increase the productivity of land sustainably is the introduction of mixed crop–livestock agricultural systems. An example of such a system is the integration of sugar cane and cattle (Sparovek et al., 2007). This concept is used in the Brazilian region Ribeirão Preto, where land that was previously used only for extensive cattle farming is now also partly used for sugarcane cultivation. This sugarcane is processed into ethanol fuel. The residues from processing are used as supplementary feed for the cattle. Because there is now a source of cattle feed, less pasture land is required to feed the same stock of cattle, freeing up the land for the sugarcane cultivation.

Examples of this kind are particularly relevant to a future in which imports of materials or products are the major route to increased biofuel consumption in Europe. They illustrate the need for innovation in farming systems to ensure sustainable co-production of biomass and food. They provide further evidence that optimising land use for a single ecosystem service, whether provision of food or biomass, at the expense of other ecosystem services creates a sub-optimum production of ecosystem services taken as a whole (EASAC, 2009).

6.2 Second-generation biofuels

Further biomass fractions from non-food crops are a significant potential source of biofuels, requiring, however, the large-scale realisation of second-generation technology to produce biofuels from ligno-celluloses. There are some promising developments.

Pilot plants are operating in Finland, Germany, Sweden, Malaysia, the Netherlands and other countries. Munich-based speciality chemicals company Süd-Chemie is currently constructing Germany's largest demonstration-scale cellulosic ethanol production plant in Bavaria. The plant will process agricultural residues as feedstock to produce 1,000–2,000 tonnes a year of second-generation bioethanol. The process is expected to provide a yield of 20–30% by weight of the input biomass. The commercial scale plants of the future are estimated to have a production capacity of about 50,000–150,000 tonnes of bioethanol a year (http://www.sud-chemie.com/scmcms/web/binary.jsp?nodeId=7757&binaryId=10757&preview=&disposition=inline&lang=zh).

One such plant is scheduled to start production in 2012 at an annual rate of 55,000 tonnes of ethanol in the USA, using corn crop residues (http://www.biofuelsdigest.com/bdigest/2012/01/24/poet-dsm-form-landmark-cellulosic-ethanol-joint-venture/).

The rapid development of pilot and demonstration plants using second-generation technology to produce bioethanol should ensure that information will increasingly be available about the performance and costs of this form of biofuel production. This will be valuable in informing assessments of the scope for use of agricultural by-products (straws, husks and other kinds of residual material) and energy crops such as *Miscanthus* and willow. There are, however, some basic operational considerations that also have to be taken into account in assessing the overall sustainability of second-generation biofuels.

Energy is needed for biofuel crop cultivation throughout the crop cycle from preparation of land, through energy required for making and distribution fertilisers and for water management, to harvesting and delivery to the conversion plant.

Based on an assumed annual dry matter production in energy plantations of 10 tonnes per hectare (the data for switch-grass in the USA range from 8.7 to 12.9 tonnes per hectare and year; http://esciencenews.com/articles/2010/07/12/yield.projections.switchgrass.a.biofuel.crop) and an ethanol yield of 20–30% (http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html), the plantation area needed to feed one commercial-scale, second-generation bioethanol plant ranges between 250 and 600 km^2, or the area within a circle of 20 km and 27 km, respectively. Therefore, residual materials from agriculture (straw) and forestry (logging residues), which amount to less than 2 tonnes dry matter per hectare per year, cannot alone meet the high demand of such plants without incurring uneconomic transport costs (Leopoldina, 2012).

There are other limits to such use of by-products of forestry and agriculture. Large-scale studies (WBGU, 2008; Leopoldina, 2012) identify land use and competition for ecosystem services, water supply and fertiliser use as major factors constraining biofuel production from energy crops such as *Miscanthus* and willow.

Although there is a considerable quantity of inedible material associated with food production, and in forestry a significant annual outtake of material from forest management, the quantity that can sustainably be removed is limited by its role in maintaining soil quality and in water management (Leopoldina, 2012; Schulze et al., 2012). By-products, in the form of stalks, straw, leaves, bark and small branches, contain substantial amounts of nutrients. Removing these materials from the field or forest removes these valuable nutrients, including micronutrients that cannot easily be replaced by artificial means, requiring substitution with manufactured fertilisers, with the potential release of associated nitrogen oxides and the requirement for energy inputs. If too many of these materials are removed over an extended period, soil quality and water cycling will be reduced, and soil carbon losses will be further exacerbated, beyond a baseline calculated to be about 3% annually in the EU (Leopoldina, 2012).

Most of the valuable meadows and pastures of Europe are already in the Natura 2000 protected area network and therefore cannot be used for biofuel production. If further meadow and pasture land is converted into second-generation biomass plantations, this will not only decrease fodder production but may have serious negative effects on biodiversity and recreational value. Removing biomass by tillage will release carbon bound up in the soil, and reduce the greenhouse gas benefits of biofuel production through this route. Conflicts between land use for biofuel production and grazing are already reported from Germany (http://www.bbc.co.uk/news/world-europe-19413408).

As fertiliser is needed in biofuel plantations, further land use change to biofuel could also impact on ground water quality, putting compliance with the Nitrates Directive at risk. The conversion of meadows and pasture into biofuel plantations also has impacts on ecosystem services in a wider sense, including the cultural value of the landscape, with possible effects on rural communities and tourism; these, too, have to be taken into account in assessing the viability of this route to biofuel production.

There are also limits to the large-scale conversion of conventional forests into biomass plantations, a prerequisite for which is highly mechanised operation. Converting conventionally managed forest into second-generation biomass plantations is only feasible in countries with substantial forest cover because the harvest index (the mass of harvested product as a proportion of the total plant mass) of forests is less than 15% of the net primary production of about 10 tonnes of dry matter per hectare per year (see below).

Modern forestry production in Europe is geared to refining biomass into high-value timber. Since the first half of the 19th century, when most of the forest biomass was used as fuel for trade and industry, the percentage of round-wood sold to the wood industry has increased from less than 20% to nearly 80%. Biomass production for energy use can be highly mechanised on suitable sites and thus is significantly cheaper than conventional forestry. Consequently, depending on changes in costs and values of production, conversion may be profitable for land owners, provided the legal framework is adjusted for this.

Conversion of conventional productive forests with a rotation period (the time a forest stand takes to mature to harvesting) of up to 100 years and more to short-rotation plantations poses economic risks to forest owners if policy changes and/or the market for second-generation feedstock collapses.

There are, however, more general concerns about the use of wood as an energy source for reducing greenhouse gases. For example, in Germany (which has the highest standing wood biomass in Europe) the combustion of the annually harvested sustainable biomass of 60 million cubic metres of wood (approximately 15 million tons of carbon) would only cover 4% of the country's energy demand (Leopoldina, 2012). The argument has been made that wood should be better considered a semi-fossil carbon that should stay where it is, or be used for construction and furniture to replace climate-damaging materials such as concrete, aluminium, steel, plastics, etc.

In addition, the role of forests as carbon sinks is important in mitigating climate warming. The annual CO_2 release that would result from energy use of 'semi-fossil' wood would be as damaging to the climate as the use of fossil carbon. As long as forests are young enough to absorb and store considerable amounts of CO_2 (about 10 tonnes of CO_2 per hectare per year in middle Europe), a case can be made that it would be wise not to use wood as an energy source.

In contrast to wood that can store CO_2 as carbon for decades to hundreds of years, annual or biannual crop sources can be considered true renewable sources for energy use because these sources are prone to natural decay and will release the bulk of absorbed into the atmosphere again if not harvested and used for food or energy production.

There are also operational constraints on some kinds of commercial second-generation biofuel plants. For example, large, wood-based, second-generation plants require a constant flux of feed from the plantation to the plant because woody biomass is much more difficult to store than grains. Piles of wood chips may self-ignite and lose substantial amounts of CO_2 to the atmosphere owing to microbial decay. In regions with winter snow, the supply chain could be difficult and costly to maintain, requiring further investment in higher production rates in the summer months and storage. Increased pest problems are also likely with warmer temperatures and this will add to the operational challenges.

Overall, however, there is the expectation that production of ethanol by second-generation biofuel technologies will grow and that the range of feedstocks will be wide, including wastes, by-products of agriculture and forestry and specially grown energy crops. The quantity that can be produced sustainably will depend on how the issues raised in this section are addressed.

6.3 Third generation biofuels: the potential of algae as a biofuel feedstock

Microalgae have been considered as feed stock for biofuel production since the 1950s (for production of biodiesel, ethanol, biogas and hydrogen, and for biomass combustion, for example). But the negative conclusions of a feasibility study performed by US Department of Energy's National Renewable Energy Laboratory in the framework of the Aquatic Species Program in the 1980s (reviewed by Sheehan et al., 1998) had a strongly negative impact on further research efforts. The early 2000s saw a renewed interest spurred by important advances in photo-bioreactor process technology (mostly from European research efforts). At the same time, the USA has fostered a significant level of private enterprise development in the sector, stimulated through the National Biofuels Technology Road Map (US DOE, 2009). However, very little information on full-scale microalgae production plants is publically available.

Generally two production systems exist, with separate advantages and disadvantages in terms of energy consumption.

In open ponds, although it is often considered that algae production itself consumes little energy, construction of the ponds has a considerable energy input. Lifecycle assessments show that, even in ponds, algal cultivation requires a high energy input (Stephenson et al., 2010) and the harvesting step consumes significant amounts of energy because of the typically low biomass concentrations in the ponds (approximately 0.5 g of dry mass per litre). Developing more energy efficient harvesting methods is one way to address this problem, but currently no generally applicable solutions exist.

Closed photo-bioreactors can produce higher biomass concentrations (5–10 g dry mass per litre) (Morweiser et al., 2010) and are generally more efficient in capturing the energy present in sunlight (about 3% of the light energy is captured compared with a theoretical biological maximum of about 12%), but the biomass production step has a much higher energy consumption mainly related to mixing. Stephenson et al. (2010) report an energy consumption for algal biomass production of biodiesel amounting to six times the energy produced.

Although fully dedicated microalgae biofuel production may still be economically unattractive, biofuel as a side-stream of a multiproduct exploitation of the microalgae biomass is a possible solution. Other potential side-streams include proteins and carbohydrate fractions for food additives, feed and functional chemicals, whereas lipids may be sourced for biodiesel production (Subhadra and Edwards, 2011).

Other possibilities of microalgae, such as nutrient absorption and oxygen production in wastewater treatment, are also being investigated (Zamalloa et al., 2012).

Sustainable microalgae biofuel production is believed to be possible within a development horizon of 10–15 years, but will require multidisciplinary research, encompassing fundamental biology, systems biology, metabolic modelling, strain development, bioprocess engineering, scale-up, biorefineries, integrated production chain and whole-system design, including logistics (Wijffels and Barbosa, 2010).

7 Energy-efficiency criteria

The economics of biofuels, from algae for example, has to be studied with care. Solar energy is more efficiently captured by photovoltaics than algae, so that the cost–benefit balance of this route to advanced biofuels is not obvious, given the alternative of photovoltaic generation of electricity to power road transport by batteries or electrified railways.

Similarly, assuming that there are supplies of biomass from agriculture or forestry, it is not clear that even second-generation biofuel production is the most efficient means of using it for energy. This is partly because of the energy used in production of biofuels and partly because the internal combustion engine is inefficient as a means of converting stored energy to useful work. Direct combustion, in combined heat and power plants, for example, offers potentially greater energy recovery, with the electricity used directly in the light duty parts of the road transport fleet. In a study of the relative merits of bioelectricity and biofuels for road transport, Campbell et al. (2009) found that bioelectricity produces an average of 80% more transport kilometres than biofuel (cellulosic ethanol) per unit of cropland across a range of crops and vehicles. They also found that the greenhouse gas saving for the bioelectricity route was twice that for the biofuel.

However, this is relevant only where there is a substantial electric vehicle fleet. This comes into sharp focus in the case of the heavy-duty fleet where electricity is not an option for the foreseeable future. In the case of heavy-duty transport and the diesel cycle, the only real options are biodiesel and biogas. Although many European countries have extensive distribution networks for gas, biogas for road transport suffers from the disadvantage of a lack of refuelling infrastructure so is likely to remain a niche fuel for centrally fuelled fleets, leaving biodiesel as the most effective short- to mid-term (post-2020) alternative. If suitable refuelling infrastructure can be established, however, biogas would be a strong contender in the market for fuel for heavy duty vehicles.

There are also potential benefits to the EU electricity system in the use of biofuels. The electricity system requires supply and demand to be continuously in balance, and as the anticipated future EU electricity system will rely heavily on variable renewables such as solar power and wind, biofuels can be helpful in achieving this.

8 Sustainability criteria

Sustainability is a fundamental objective of the EU under the Lisbon Treaty. It is therefore entirely appropriate that the major strategies of limiting climate change by reducing greenhouse gases and conserving biodiversity and ecosystem services should be linked, and that sustainability criteria should be applied to the means of implementing these strategies. In the measures for reducing greenhouse gases from transport by setting targets for renewable energy in the transport sector, there are sustainability criteria to ensure real greenhouse reductions are achieved and that renewable energy schemes do not impact on biodiversity or ecosystem services.

8.1 Greenhouse gas emissions reductions

Substantial greenhouse gas emissions can arise from the production of biomass, its harvesting and conversion to biofuel. A particular feedstock can give wildly differing greenhouse gas savings depending on how it is processed (Royal Society 2008). The greenhouse gas criterion set out in the Directive is designed to ensure that there are real emissions savings from the use of biofuel. Assuming that biofuels are used with the same efficiency as conventional fossil fuel, and with a reference value of 87.5 g CO_2 eq/MJ (CO_2 equivalent per megajoule) formed in the production and combustion of fuels from crude oil, the production and combustion of biofuels meeting the carbon reduction criterion would have to be associated with reduced CO_2 equivalent emissions as shown in Table 2 to be counted towards meeting the 10% target:

Table 2 Greenhouse gas reductions and energy equivalents

	Target reduction in carbon emission from biofuel production, relative to reference case	**Equivalent maximum greenhouse gas emission from production, CO_2 equivalent/MJ**
Reference case	—	87.5 g
Present	35%	56.9 g
2017	50%	43.7 g
2018	60%	35.0 g

The assessment of greenhouse gas reduction is made by life cycle assessment using a methodology specified by the Directives, which takes into account inputs required for biomass cultivation, harvesting and processing, and the consequences of direct land use change (for example if the biofuel is grown on previously forested land, the carbon released by the loss of the forest is included).

However, it is the opinion of the EEA Scientific Committee on Greenhouse Gas Accounting (EEA/SCGGA, 2011) that the methodology set out in the Directive for the lifecycle assessments of biofuel impacts requires urgent amendment. At present, the SCGGA argues, the methodology fails to account fully for all changes in the amount of carbon stored in ecosystems and in the uptake and loss of carbon from them that result from the production and use of bioenergy. In particular, the SCGGA notes that there is no allowance for the opportunity cost of direct land use change. They point out, for example, that although the growth of bioenergy crops absorbs carbon, this carbon is then released in production and use of biofuels so that using land in this way comes at the cost of use of the land for absorbing and storing carbon, simply by growing trees. This is described as a fundamental error in greenhouse gas accounting in Haberl et al. (2012). They recommend that accounting standards should include all the carbon and other greenhouse gas releases by the combustion of carbon and offset these with the additional sequestration from reduced decomposition of biomass and additional plant growth to give the net effect of production and use of bioenergy. (It is important, however, to distinguish between land-based crops and algae. Algae do not necessarily displace other land crops, although conversely they do have costs associated with building the growth facilities). A recent statement by the US Union of Concerned Scientists (UCS, 2012) notes the report of the SCGGA and urges the inclusion of impacts due to indirect land use change in the assessment of biofuels.

There are other criticisms of lifecycle assessments in respect of biofuel sustainability:

- Energy demands for inputs tend to be underestimated (energy required for production of nitrogen fertilisers, phosphorus, water supply, etc.).
- Impacts of indirect land use change (ILUC) are not treated explicitly. This is of considerable significance. A recent review of ILUC effects made for the Dutch and UK Governments (Dehue et al., 2011) shows that there are considerable differences between estimates (due mainly to differences in methodology) but that, in general, emissions are significant relative to the fossil fuel reference case.
- Major sensitivities arise from assumptions made about the assignment of energy costs of biomass production to products delivered, including by-products.
- The lifecycle assessments do not consider changes in soil quality and in biodiversity (see below); contamination of ground water, lakes and rivers with nitrates and phosphates, and, in the case of irrigation, negative effects on the water table and salination of the soils (Leopoldina, 2012).

Whenever biofuels are used, their supposed carbon neutrality has to account at least for the following list of factors:

- Other greenhouse gases emitted to produce them (e.g. N_2O released as a result of fertiliser addition is 300 times more potent as a greenhouse gas than CO_2). Up to 4% of the nitrogen incorporated into biomass is emitted as N_2O.
- Other land uses prevented by the production of biofuels (e.g. forest carbon storage as a mitigation process, food production, soil carbon conservation).
- Products such as timber and food imported because of national biofuel production. A piece of land can only be used for one type of product (the land trade-off of biofuel production).
- Principal sustainability issues related to water consumption and the nutrient cycle. Water is a scarce resource, particular in cases where irrigation is used, or when food imports (because of local land use for biofuels) come from agricultural systems that rely on irrigation. Nutrients, in particular micro-nutrients, are hard to replace and should be recycled to the field.
- Costs of advanced biofuel production should be assessed in full to examine the effects of price distortion (in Germany, the rising value of forest biomass caused the timber price to rise several-fold (Leopoldina 2012, supplement 1)). These costs are attributed to other sectors, but need to be 'billed' to biofuels.

Table 3 Greenhouse gas reductions and energy equivalents from lifecycle assessments including effects of ILUC

	Maximum greenhouse gas emission from production, CO_2 equivalent/MJ	Carbon emission from biofuel production, relative to reference case
Reference case	87.5 g	—
First-generation biodiesel	83–105 g	–5 to +20%
First-generation bioethanol	35–43 g	–50 to –60%
Second-generation biofuels (from field-plant material)	20–23 g	–74 to –77%
Second-generation biodiesel and bioethanol from non-land sources	9 g	–90%
Tar sands[2]	107 g	+22%

[2] European Commission reference figure for production of fuels from tar sands.

In the case of second-generation fuels from forest residues, the lifecycle analysis has to take account of the long timescales associated with forest growth. A study of CO_2 emission from wood fuels in Sweden (Wibe, 2012) takes account of the decrease of carbon stored in logging residues owing to its faster transformation to CO_2 (as the fuel is burnt) and the delayed growth of new forest generations when the residues are removed. It concludes that the net result is that wood-based fuels emit as much as 60% of the CO_2 that would have been emitted by fossil fuel. The saving in this case would be 40% and below the level required by the Renewable Energy Directive.

Recent EU data from a full lifetime assessment of biofuel production, including some of the effects of Indirect Land Use Change (http://www.euractiv.com/climate-environment/biodiesels-pollute-crude-oil-lea-news-510437), suggest the values for the energy performance of biofuels shown in Table 3.

According to the information given in Table 3, only second-generation biofuels clearly meet the greenhouse gas saving criterion. Neither first-generation technology (bioethanol or biodiesel) produces biofuels that are compliant with the 2018 criterion. A recent major study of biofuel sustainability (Leopoldina, 2012) concludes that, in most countries, using liquid biofuels instead of fossil fuels does not lead to a net reduction of greenhouse gas emissions. According to some studies, this appears also to be the case for Brazil, where conditions for biofuel production are particularly favourable (Lisboa et al., 2011).

The conclusions from this are the following.

- Lifecycle analysis and evaluation of indirect land use change are highly complex and there is considerable controversy both about methods and results. Methods of lifecycle assessments need further development to ensure that there is full accounting for all climate and environmental costs associated with the production and use of biofuels.
- Full lifecycle assessments of biofuel production and consumption show that the use of biofuels as an energy source is only sustainable under very special conditions of biofuel production, which are difficult to meet.
- Recent EU data from a full lifecycle assessment of biofuel production including ILUC suggest that, whereas second-generation biofuels perform well, biodiesel does not produce a reduction of greenhouse gas emissions relative to the use of diesel produced from crude oil and fi rst-generation bioethanol will fi nd compliance beyond 2017 a challenge.
- A comprehensive and credible programme of research is essential to produce reliable assessment of real greenhouse gas performance of biofuels.

Such results as are available at present raise sufficient concern to question the robustness of the greenhouse gas reductions delivered by the current EU renewable energy policy, in particular the use of targets to drive increased uptake of biofuels for road transport.

8.2 Protection of biodiversity

The aim of this criterion is to protect highly biodiverse land and grassland outside protected areas (which are already excluded from biofuel production) and high carbon stock areas such as peat land.

The provisions of the Renewable Energy Directive and the fuel quality directive 2009/30/EEC specify in detail the land from which raw material for biofuel production cannot be obtained. The provisions apply both to EU Member States and to 'third countries' outside the EU. They include reporting obligations to the Commission, including on social and economic impacts of sources from third countries. Certification schemes are crucial to ensure the compliance of biofuels with the criteria.

There are, however, considerable concerns about the direct impacts of the Directive on biodiversity and ecosystems services (Eickhout et al. 2008). Partly these are about the scope of the restrictions applied, which leaves many important wildlife habitats open to use, for example, scrubland or open woody-savannahs, where fragmentation is a key factor in degradation. Partly they are also about the difficulties of ensuring the correct operation of certification schemes.

A review of studies of impacts of large-scale first-generation liquid biofuel production on biodiversity and ecosystems services (Stromberg et al., 2010) concluded that, although production does provide some ecosystem services over the lifecycle, notably in provisioning and particularly where there is a mixed pattern of farming for food, ethanol and biogas, it compromises others, including water and nutrient cycling. Impacts on biodiversity can be highly negative, and expansion of biofuel production in parts of the world, including Indonesia and Brazil, is considered by many of the reference sources consulted by Stromberg et al. (2010) as one of the main emerging threats to biodiversity. Threats to tropical biodiversity from oil palm seem particularly severe (Koh and Wilcove, 2008, 2009). Oil palm is a relatively small fraction of EU biodiesel but the general point is that clearance of even poor quality forest has repercussion for wildlife, and the need for rigorous sustainability criteria to protect biodiversity is emphasised.

A further concern is the impact of the biofuels target on indirect land use change: the displacement of other agricultural production (mainly food) to make way for cultivation of biofuel feedstock. This can take place on a range of scales, impacting on imports as well as domestic EU production. The concern about this has largely focussed on the impacts this has on carbon emissions, as carbon stored in previously unused land is released in cultivating it for food crops.

However, there are also significant impacts on biodiversity and a range of ecosystem services, including water and nutrient cycling, provisioning of food and timber, and regulation of ecosystem function. Where agricultural land is relocated because of biomass production for biofuels, the new areas of agriculture are not covered by the biodiversity criteria provided in the Renewable Energy Directive and there is the potential for harm to biodiversity and ecosystem services. A recent report of the Institute for European Environmental Policy noted this potentially perverse effect of the Renewable Energy Directive and argues that the debate about indirect land use change should be the opportunity for 'an extended and general debate on various agricultural activities impacting on land use' (Kretschmer, 2011). It is the view of the EASAC Working Group that the application of the Renewable Energy Directive target without the general application of biodiversity conservation criteria to land use change will create further distortions in land use with a high potential for degradation of biodiverse land in Europe and worldwide.

However, management practices for farmland vary, for example in the quantities of chemical input, so that the biodiversity impacts of conversion to biomass production for biofuels can vary too. Biodiversity can also be of benefit to biomass production in high-intensity farmlands, through biological control of pests; and because market pressure to produce 'aesthetically perfect' crops is absent, it makes it possible to use reduced amounts of agricultural chemicals compared with what would be needed for production of food crops. Such farmlands are, however, also profitable for agriculture, so the competition for land use is high. On extensive farmlands, however, where there is a farming system that is designed to allow the existence of high biodiversity, for example in some mixed farming systems, conversion to biomass production for biofuels can very easily lead to biodiversity loss (Dauber et al., 2010; Meehan et al., 2010; Riffell et al., 2011).

There is also the danger that conversion from a high-intensity farmland to intensive biomass cultivation for biofuels may not in practice prove feasible for the long term. Soils of the intensively used farmland will be largely degraded, and biofuel farmers may try to speed up production by intensifying chemical inputs. A system of subsidies may prevent this in the early stages, but once they are withdrawn, farmers may revert to intensive use of chemical inputs.

There are also commercial considerations. Without sustainability criteria associated with protection of biodiversity for all kinds of agricultural uses of land, demand for land for biofuels would create a distortion as areas where it is relatively straightforward to provide proof that sustainability criteria are met could be taken for biofuels, and food production may be moved to areas where it might be more difficult to demonstrate conformity.

Large-scale biomass production will cause large-scale land use change. This has various impacts on rural society and economies, and on ecosystems. Ecosystem services, and the biodiversity running them, are seriously degraded under intensive farming. If biomass production is carefully designed, and environmental consequences are monitored, then it can be a win–win situation for protecting and even restoring some biodiversity, while avoiding land abandonment.

Imminent changes in the Common Agricultural Policy will have significant influences on the agricultural landscape in Europe. In particular, the removal of the milk quota in 2015 and growing concerns about food security are prompting a return to agricultural intensification. This might further undermine the commercial viability of biofuels in many Member States.

The Working Group concludes that:

- Criteria for protection of biodiversity are complex, very often lacking clear definition, as in the case of highly biodiverse grasslands or degraded land, and lack transparency.
- High dependence on imports increases risk of regulatory failure.
- Studies are required to assess actual impacts of biofuel production on biodiversity, arising from indirect land use change.
- Sustainability criteria should be extended to all kinds of biomass including agriculture for food production.
- There is, however, potential for sustainable co-production of food and biomass for liquid biofuel or biogas in mixed farming systems on a local scale.

8.3 Quality standards for biofuels

To ensure sustainability of bioenergy sources, in particular of those imported from other countries, framework standards for environmental and social bioenergy criteria are required. To be credible, these should be at least partly based on existing commodity roundtables and certification schemes. In the context of ambitious bioenergy targets, precisely defined standards are needed in which countries and producers of sustainable bioenergy (refiners, fuel retailers) have to fulfil a set of key performance indicators (based on international norms as set out below and agreed through stakeholder consultations) for the main environmental and social issues associated with bioenergy feedstock growing, processing/refining, transport and greenhouse gas balance. In practice, for example, fuel suppliers wishing to import ethanol from Brazil are required to notify the quantities of biofuels to their national authorities. To show that these imports are sustainable according to the Directive, they can join a voluntary scheme. Biofuels that are not covered by certification can still be imported but do not count towards national targets and are not eligible for fiscal incentives.

The fuel supplier has to make sure that throughout the production chain all records are kept, by the trader from whom they buy the biofuels, by the ethanol plant from which the trader buys the ethanol, and by the farmer who supplies the ethanol plant with sugar cane or other feedstock. This control is done before the company joins the scheme and at least once a year thereafter.

The auditing is done as in the financial sector: the auditor is responsible for checking all documents and inspects a sample of farmers, mills and traders. The auditor should also check whether the land where the feedstock for the ethanol is produced has previously been farm land: not, for example, tropical forest. Certification schemes recognised by the EU are given in http://ec.europa.eu/energy/renewables/biofuels/sustainability_schemes_en.htm/; this includes six schemes, four of which are also recognised by environmental non-governmental organisations.

For a listing of the certification schemes for fuels that meet the requirements of the Directives, see Annex 2.

Such certification schemes are designed to ensure conformity with the Directive and reflect the methodology laid down in the it for assessing sustainability.

In an evaluation of biofuel certification schemes, van Dam et al. (2008) note that, although there is general agreement between the groups behind the schemes on broad principles, there are considerable differences in their overall scope and stringency. They also note that the proliferation of standards causes loss of efficiency and credibility. However, there is the opportunity to learn from the practical application of different standards.

The need for an international approach to standards was highlighted by Scarlat and Dallemand (2011). They suggest that the inclusion of ILUC impacts should be an integral part of standards and point out the potential of monitoring using remote-sensing technologies.

These studies, among others, suggest that certification schemes are a key to credibility and environmental sustainability of biofuels. Convergence on fewer, more international standards, taking advantages of the opportunities presented by remote sensing to monitor land use, would ensure that this potential is realised.

9 Summary of findings

This Statement contains a critique of the current EU policy for reducing greenhouse gas emission from the transport sector by increasing the use of biofuels. Although the overall strategy includes incentives for general energy efficiency in the sector and for alternative fuels, the main thrust of the policy has been to provide a legal framework for the introduction of renewable energy through the requirements of the Renewable Energy Directive, specifically through a 10% target for renewable energy in road transport by 2020. Although there are other possible routes to the renewable energy target, including the widespread use of electricity from renewable sources in the transport sector, in practice the main burden of achieving the 2020 target appears to have fallen on biofuels (transport fuels derived from biomass).

There are reasons to be concerned about the use of biomass to produce transport fuel. First-generation biofuels, the only real option for 2020, are derived from the edible parts of plants, competing with food. Second-generation biofuels, derived from the inedible or woody parts of plants have potential, but are limited by the amount of material that can be supplied sustainably as feedstock and by demand for material, for example straw, as fodder. Third-generation biofuels, using advanced biotechnology, for example to produce algae as feedstock, are a still longer-term prospect and there is much research to be done before they become viable.

There are questions arising from a range of studies about the methods used to assess the overall energy performance of first-generation biofuels. Once all the energy from agricultural and industrial production is taken into account, it appears that in many cases the methods do not deliver the level of greenhouse gas reduction required by the Directive and in some cases no reduction at all.

Furthermore, it appears that there are significant impacts of high levels of demand for biofuel feedstock on the natural environment, and that criteria to protect biodiversity may have the perverse effect of diverting land of high biodiversity value to food production.

The Working Group has therefore concluded that the 10% target has incentivised first-generation fuels that do not meet carbon efficiency criteria and that carry unacceptable environmental costs. It is also not clear that incentives for first-generation biofuels will necessarily help by promoting the development of second-generation biofuels, as the processes are quite different and involve different sectors of industry and agriculture.

10 Conclusions and recommendations

The Working Group concludes that:

- The EU 2020 target of 10% renewable energy in road transport fuels is likely to come almost entirely from first-generation liquid biofuels, made mainly from edible parts of plants. Restricting the proportion of the 10% target that can be met with biofuels produced from edible plant material will create a gap that must be filled with waste-derived biofuels or second-generation biofuels.

- Current first-generation biofuels appear to provide little or no greenhouse gas reduction once all impacts of biomass cultivation, including ILUC, and fuel production are taken into account. Despite the development of criteria for protection of biodiversity and ecosystem services and certification schemes, there are serious concerns about sustainability of biofuel production and its impacts on the natural environment.

- In future, availability of edible material for biofuels at a global scale will become increasingly squeezed as demand increases for food to provide greater food security and to feed the growing global population and satisfy the growing consumption of protein-rich diet. Hence, increases in the quantity of biomass used for biofuel production of any significant scale would have to come principally from non-edible parts of plants, or from agricultural waste. There may also be a role for biomass crops such as switch grass or wood, although these compete with food for arable land and require significant inputs, including water and fertilisers.

- The EU is already dependent on food imports. At present the area of land under cultivation is decreasing. Further analysis is needed to evaluate whether any increase in cultivated land area would be better used for offsetting imports of food, thereby improving food security, or for biomass production for biofuels. If such analysis shows that food production is the better option, then the increased biomass production required for the EU 2020 target will come mainly from imports, with the consequence that environmental risks will be exported.

- There is potential for using municipal organic waste and agricultural wastes and residues from forestry and agriculture for production of liquid biofuels or biogas (second-generation biofuels). However, significant investment in waste treatment by anaerobic digestion will be required for biogas, and second-generation biofuels are not expected to play a major role in bioenergy until after 2020.

- There is reason to be cautious about the contribution that second-generation biofuels from agricultural waste and forestry will make, largely because these materials have important ecosystem functions that limit how much can be extracted. Some agricultural wastes are important sources of fodder. It is, furthermore, doubtful whether it is meaningful to change land use from the production of timber, a high value, multi-use raw material, to the production of raw biomass with inherently low added value.

- The current low level of uptake of electric vehicles is disappointing. Electrical traction may offer a more efficient use of biomass, possibly with up to twice the greenhouse gas saving of biofuels and with considerably less use of land per unit of distance travelled.

The Working Group recommends that:

- The EU Renewable Energy Directive sustainability criteria should be revised to ensure that lifecycle assessments reflect the real-world performance of biofuel production and include all impacts of cultivation and production, direct and indirect.

- The sustainability criteria in the EU Renewable Energy Directive should be extended to take full account of the impacts of biofuel production on water, soil and air requirements, particularly where there are water scarcity/quality problems inside the EU and in regions outside the EU.

- The EU Renewable Energy Directive should be widened specifically to include gaseous biofuel.

- To remove the incentive for indirect land use change, measures to protect biodiversity should be enacted for all agricultural production and not exclusively for biofuels. Sustainability criteria should be mandatory for all kinds of biomass production, including the food and feed sector and the agrochemical industry.

- Until these issues can be addressed, the 2020 target of 10% biofuel provides a driver for carbon-inefficient and environmentally damaging biofuel production and should be revisited with the aim of finding a sustainable percentage, if not abandoning it entirely. The recently announced review of the eligibility of food-based biofuel for contributions towards the target provides a welcome opportunity and should be extended to include a revision of the 10% target.

- If a target is to be retained, in a revised form, an urgent investigation is required to set an alternative target level/timescale, ensuring that there are incentives for sustainable biofuels without the distortions created by the current target.

- If priority is given to improving EU food security by reducing dependence on food imports, food production should be prioritised over biofuel production in expansion of agricultural land in the EU. A European policy on land use will be required to ensure this is achieved, and further increase in EU production of biodiesel, bioethanol and biogas from the edible fraction of plants (first-generation biofuels) should be avoided until EU policy on the balance of domestic production of food and feed, and imports, has been decided.

- Research is urgently required to assess, and realise the potential of, second- and third-generation biofuels (for example, from non-edible crops, forest by-products and algae) and of energy carriers such as electricity and hydrogen, taking account of the function of agricultural by-products in providing ecosystem services including retaining nutrients and water cycle regulation.

- Further studies are needed to compare systematically the environmental and energy performance of biofuels and electric vehicles, taking a full lifecycle approach.

References

Belgian Academy Council of Applied Sciences (2011). *Industrial Biomass: Source of Chemicals, Materials and Energy!*

Berry I (2010). *The effects of driving style and vehicle performance on the real-world fuel consumption of U.S. light-duty vehicles*. Massachusetts Institute of Technology. http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/IreneBerry_Thesis_February2010.pdf

Campbell J E, Lobell DB & Field CB (2009). *Greater transportation energy and GHG offsets from bioelectricity than ethanol.* Science **324**, 1055–1057

Dauber J, Jones MB & Stout JC (2010). *The impact of biomass crop cultivation on temperate biodiversity*. GCB Bioenergy **2**, 289–309

Dehue B, Cornelissen S & Peters D (2011). Indirect effects of biofuel production: overview prepared for GBEP. Ecofys, the Netherlands.

EASAC (2009) *Ecosystem services and biodiversity in Europe*. EASAC policy report 09. http://www.easac.eu/fileadmin/PDF_s/reports_statements/Ecosystems.pdf

Edwards R, Szekeres S, Neuwahl F & Mahieu V (2008). *Biofuels in the European Context: Facts and Uncertainties*, EC/JRC44464 (ed. DeSanti G)

EEA/SCGGA (2011). Opinion of the EEA Scientific Committee on Greenhouse Gas Accounting in Relation to Bioenergy. http://www.eea.europa.eu/about-us/governance/scientific-committee/sc-opinions/opinions-on-scientific-issues/sc-opinion-on-greenhouse-gas/view EEA Scientific Committee on Greenhouse Gas Accounting

Eickhout B, van den Born GJ, Notenboom J, van Oorschot M, Ros JPM, van Vuuren DP & Westhoek HJ (2008). *Local and global consequences of the EU renewable directive for biofuels: testing the sustainability criteria*. Netherlands Environmental Protection Agency

Ellis E (2011). *Anthropogenic transformation of the terrestrial biosphere.* Philosophical Transactions of the Royal Society A **369**, 1010–1035

Eurostat (2008). *Europe in figures - Eurostat yearbook 2008*. European Communities

Haberl H, Sprinz D, Bonazountas M, et al. (2012). *Correcting a fundamental error in greenhouse gas accounting related to bioenergy.* Energy Policy **45**, 18–23

Hamelinck C, Koper M, Berndes G, et al. (2011). *Biofuels baseline 2008*. European Commission

Hitchcock G (2006). *Biogas as a road transport fuel*. National Society for Clean Air and Environmental Protection, UK

IPCC (2007). *IPCC Fourth assessment report: climate change 2007*

Johansson K & Liljequist K (2009). *Can agriculture provide us with both food and fuel? a survey of present agricultural production.* Uppsala University, Sweden http://www.tsl.uu.se/uhdsg/publications/agriculture.pdf.

Johansson K, Liljequist K, Ohlander L & Aleklett K (2010). *Agriculture as provider of both food and fuel*. Ambio **39**, 91–9.

Koh LP & Ghazoul J (2008). *Biofuels, biodiversity, and people: understanding the conflicts and finding opportunities.* Biological Conservation **141**, 2450–2460

Koh LP & Wilcove DS (2008). *Is oil palm agriculture really destroying tropical biodiversity?* Conservation Letters **1**, 60–64

Koh LP & Wilcove DS (2009) *Oil palm: disinformation enables deforestation*. Trends in Ecology & Evolution **24**, 67–68

Kretschmer B (2011). *The land-use implications of EU bioenergy policy: going beyond ILUC*. Institute for European Environmental Policy, London

Leopoldina (2012). *Bioenergy – Chances and Limits: A Statement.* Nationale Akademie der Wissenschaften Leopoldina, Halle, Germany.

Lisboa CC, Butterbach-Bahl K, Mauder M & Kiese R (2011). *Bioethanol production from sugarcane and emissions of greenhouse gases - known and unknowns*. Global Change Biology Bioenergy **3**, 277–277

Meehan TG, Hurlbert AH, & Gratton C (2010). *Bird communities in future bioenergy landscapes of the Upper Midwest.* Proceedings of the National Academy of Sciences of the USA **107**, 18533–10538

Morweiser M, Kruse O, Hankamer B & Posten C (2010). *Developments and perspectives of photobioreactors for biofuel production*. Applied Microbiology and Biotechnology **87**, 1291–1301

Murphy JD, Braun R, Weiland P & Wellinger A (2011). *Biogas from crop digestion*. http://www.iea-biogas.net/

Nemry F & Brons, M (2010). *Plug-in hybrid and battery electric vehicles: market penetration scenarios of electric drive vehicles*. Draft technical note JRC-IPTS, June 2010

Pimentel D (editor) (2008). *Biofuels, Solar and Wind as Renewable Energy Systems.* Springer Science + Business Media

Riffell S, Verschuyl JP, Miller D & Wigley TB (2011). *Biofuel harvests, coarse woody debris, and biodiversity—a meta-analysis*. Forest Ecology and Management **261**, 878–887

Rockström J, et al. (2009). *A safe operating space for humanity*. Nature **461**, 472–475

Royal Society (2008). Sustainable biofuels: prospects and challenges. http://royalsociety.org/policy/publications/2008/sustainable-biofuels/

Scarlat N & Dallemand JF (2011). *Recent developments of biofuels/bioenergy sustainability certification: A global overview*. Energy Policy **39**, 1630–1646

Schulze ED, Körner C, Law B, Haberl H & Luyssaert S (2012). *Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral*. GCB Bioenergy. doi: 10.1111/j.1757-1707.2012.01169.x

Sharman A & Holmes J (2010). *Evidence-based policy or policy-based evidence gathering? Biofuels, the EU and the 10% target*. Environmental Policy and Governance **20**, 309–321

Sheehan J, Dunahay T, Benemann J & Roessler P (1998). *A look back at the U.S. Department of Energy's aquatic species program—biodiesel from algae.* National Renewable Energy Laboratory, U.S. Department of Energy

Singh A, Smyth BM and Murphy JD (2010). *A biofuel strategy for Ireland with an emphasis on production of biomethane and minimisation of land take*. Renewable and Sustainable Energy Reviews **14**, 277–288

Slade R, Saunders R, Gross R & Bauen A (2011). *Energy from biomass: the size of the global resource.* Imperial College Centre for Energy Policy and Technology and UK Energy Research Centre, London

Smil V (2000). *Feeding the World: A Challenge for the Twenty-First Century*. MIT Press

Sparovek G, Berndes G, Egeskog A, Mazzaro de Freitas FL, Gustafsson S & Hansson J (2007). *Sugarcane ethanol production in Brazil: an expansion model sensitive to socioeconomic and environmental concerns.* Biofuel, Bioproducts & Biorefining **1**, 270–282

Stephenson, AL, Kazamia E, Dennis JS, Howe CJ, Scott SA & Smith AG (2010). *Life-cycle assessment of potential algal biodiesel production in the United Kingdom: a comparison of raceways and air-lift tubular bioreactors*. Energy Fuels **24**, 4062–4077

Stromberg PM, Gasparatos A, Lee JSH, Garcia-Ulloa J, Koh LP & Takeuchi K (2010). *Impacts of Liquid Biofuels on Ecosystem Services and Biodiversity*. UNU-IAS Policy Report

Subhadra BG & Edwards M (2011). *Coproduct market analysis and water footprint of simulated commercial algal biorefineries*. Applied Energy **88**, 3515–3523

Thamsiriroj T & Murphy JD (2009). *Is it better to import palm oil from Thailand to produce biodiesel than to produce biodiesel from indigenous Irish rape seed?* Applied Energy. **86**, 595–604

Union of Concerned Scientists (2012). *International scientists and economists statement on biofuels and land use*. http://www.ucsusa.org/assets/documents/global_warming/International-Scientists-and-Economists-Statement-on-Biofuels-and-Land-Use.pdf

US DOE (2009). *National Algal Biofuel Technology Roadmap*

van Dam J, Jungingera M, Faaija A, Jurgens I, Bestb G & Fritschec U (2008). *Overview of recent developments in sustainable biomass certification*. Biomass and Bioenergy **32**, 749–780

WBGU (2008) *Future bioenergy and sustainable land use*. German Advisory Council on Global Change

Wibe S (2012). *Carbon dioxide emissions from wood fuels in Sweden 1980-2100.* Journal of Forest Economics, **18**, 123–130

Wijffels RH & Barbosa MJ (2010). *An outlook on microalgal biofuels.* Science **329**, 796–799

Zamalloa C, De Vrieze J, Boon N & Verstraete W (2012). *Anaerobic digestibility of marine microalgae* Phaeodactylum tricornutum *in a lab-scale anaerobic membrane bioreactor.* Applied Microbiology and Biotechnology **93**, 859–869

Zhou D, Zhang L, Zhang S, Fu H & Chen J (2010). *Hydrothermal liquefaction of macroalgae* Enteromorpha prolifera *to bio-oil*. Energy Fuels **24**, 4054–4061

Annex 1 Definitions

The term *Bioenergy* comprises any kind of renewable energy generated from material derived from recently living organisms, which includes wood, any plants, animals and their by-products.

Biomass is defined according to the EU Renewable Energy Directive 2009 (EU-RED) as 'the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste'. It excludes fossil organic material and does not take into account solid biomass for combustion purposes (e.g. wood).

Biofuel means 'liquid or gaseous fuel for transport produced from biomass'.

Bioliquids are 'any liquid fuel derived from biomass used for energy purposes (electricity, heating and cooling) but not for transportation' (EU-RED).

Feedstock is the term used to refer to the source biological material used to create bioenergy (e.g. oil palm, soy, grain, grass, wood, etc). In the case of power generation (heat and electricity), wood and agricultural waste are the main sources.

Indirect land use change (ILUC) means the conversion of agricultural land to biofuel production, displacing the agricultural use, possibly to previously uncultivated land.

Roundwood means wood in its natural state as felled, with or without bark. It may be round, split, roughly squared or in other forms.

Annex 2 Certification systems for biomass/bioenergy

Certification systems

Bioenergy is assumed to provide sustainable alternatives to fossil fuels, additional incomes for rural communities and contribute to development under the right conditions. For this to be realised, however, bioenergy development must be very carefully planned, implemented and continuously monitored for its environmental and social sustainability. Depending on which crops are produced, where and how bioenergy developments can cause significant negative environmental and social impacts including deforestation, biodiversity loss, soil erosion, soil carbon loss, unsustainable water use, conflicts over land rights, food shortages and staple food-crop price spikes. It should be also acknowledged that inappropriately developed bioenergy production can lead to increased GHG emission and cause poverty and loss of traditional tenure rights.

To ensure sustainability of bioenergy sources, in particular of those imported from other countries, framework standards for environmental and social bioenergy criteria must be developed that are partly based on existing credible commodity roundtables and certification schemes. Precisely defined standards are needed in the context of ambitious bioenergy targets. Countries and producers of sustainable bioenergy (refiners, fuel retailers) have to fulfil a set of key performance indicators (based on international norms as set out below and agreed through stakeholder consultations) for the main environmental and social issues associated with bioenergy feedstock growing, processing/refining, transport and GHG balance:

1. *Strategic economic and environmental assessment and planning for bioenergy industry development with public participation, for example suitability mapping that includes the environmental and social availability of water as well as land.*

2. *Mapping of the raw material sources at a regional/landscape/catchment level including existing forest resources, short rotation woodland, peat land and other carbon-rich soils, dedicated agricultural crops, and residues from existing forest and agricultural operations.*

3. *Strengthening and improvement of mapping systems for high conservation value areas (HCVAs) and other ecologically sensitive and important areas such as habitats of priority species, corridors and buffer zones.*

4. *Definition of effective policy mechanisms to protect these high priority areas from bioenergy development, and deployment of adequate resources to ensure effective implementation and enforcement of those policies.*

6. *Enforcement of and zero burning and forest protection policy and other environmental legislation.*

7. *Absence of degradation of soil quality.*

8. *Absence of adverse impact on the quantity and quality of freshwater resources.*

9. *Absence of damaging releases of toxic compounds into the environment.*

10. *Full and effective participation of potentially affected communities including all aspects of possible conflicts between wildlife and people that may be exacerbated by bioenergy development.*

11. *Respect of traditional rights of land and resource use and access.*

12. *Guaranteeing social standards for workers (health, safety and labour rights).*

The following voluntary sustainability schemes for biofuels are recognised by the European Commission (this recognition applies directly in 27 EU Member States) (http://ec.europa.eu/energy/renewables/biofuels/sustainability_schemes_en.htm/). Only the first four schemes (in bold type) are principally supported by environmental non-governmental organisations such as the World Wide Fund for Nature.

ISCC (International Sustainability and Carbon Certification).

Bonsucro EU (Better Sugar Cane Initiative).

RTRS EU RED (Round Table on Responsible Soy EU RED).

RSB EU RED (Roundtable of Sustainable Biofuels EU RED).

2BSvs (Biomass Biofuels voluntary scheme).

RBSA (Abengoa RED Bioenergy Sustainability Assurance).

Greenergy (Greenergy Brazilian Bioethanol verification programme).

Further certification schemes have been implemented (with participation of environmental non-governmental organisations such as the World Wide Fund for Nature) for forest products and palm oil, both of which are relevant for the bioenergy sector:

FSC (Forest Stewardship Council), http://www.fsc.org/.

RSPO (Roundtable on Sustainable Palm Oil), http://www.rspo.org/.

Annex 3 Working Group Members

Professor Lars Tegnér, Chairman	The Royal Swedish Academy of Sciences
Dr András Báldi	Institute of Ecology and Botany, The Hungarian Academy of Sciences
Professor Venko Beschkov	Institute of Chemical Engineering, The Bulgarian Academy of Sciences
Professor Detlev Drenckhahn	Institute of Anatomy and Cell Biology, University of Würzburg, Germany
Dr Alenka Gaberšcik	Department of Biology, University of Ljubljana, Slovenia
Professor Gerhard Glatzel	Institute of Forest Ecology, University of Vienna, Austria
RNDr. Lubos Halada	Institute of Landscape Ecology, The Slovakian Academy of Sciences
Professor Valdis Kampars	Department of General Chemistry, Riga Technical University, Latvia
Professor Reinhold Leinfelder	Institute of Geological Sciences, Free University of Berlin, Germany
Professor Leo Michiels	The Royal Academies for Science and the Arts of Belgium
Professor Michele Morgante	Institute of Applied Genomics, Udine, Italy
Dr Ladislav Nedbal	Institute of Systems Biology & Ecology, The Academy of Sciences of the Czech Republic
Professor Remigijus Ozolincius	Lithuanian Forest Research Institute, The Lithuanian Academy of Sciences
Dr Algirdas Raila	Department of Heat and Biotechnological Engineering, Aleksandras Stulginskis University, Kauno rajonas, Lithuania
Professor Rolf Thauer	Max Planck Institute for Terrestrial Microbiology Marburg, Germany
Dr John Holmes	Energy Programme Secretary, EASAC
Professor John Murlis	Environment Programme Secretary, EASAC

Annex 4 EASAC Environment Programme Steering Panel Members

Professor Kevin Noone (Chairman)	The Royal Swedish Academy of Sciences, Sweden
Professor Michael Depledge	The Royal Society, United Kingdom
Professor Alenka Gaberščik	The Slovenian Academy of Arts and Science, Slovenia
Professor Atte Korhola	The Council of Finnish Academies, Finland
Professor Christian Körner	The Swiss Academies of Arts and Sciences, Switzerland
Professor Rajmund Michalski	The Polish Academy of Sciences, Poland
Professor Francisco Garcia Novo	The Spanish Royal Academy of Sciences, Spain
Professor Július Oszlányi	The Slovakian Academy of Sciences, Slovakia
Professor Andrea Rinaldo	The Accademia Nazionale dei Lincei, Italy
Professor Hans-Joachim Schellnhuber	The German National Academy of Sciences Leopoldina, Germany
Professor Tarmo Soomere	The Estonian Academy of Sciences, Estonia
Professor John Sweeney	The Royal Irish Academy, Ireland
Professor Christos Zerefos	The Academy of Athens, Greece
(Professor John Murlis	Environment Programme Secretary, EASAC)

Annex 5 EASAC Energy Programme Steering Panel Members

Professor Sven Kullander (Chairman)	The Royal Swedish Academy of Sciences, Sweden
Professor Marc Bettzüge	The German National Academy of Sciences Leopoldina, Germany
Professor Sébastien Candel	Académie des Sciences, France
Professor Petr Krenek	The Academy of Sciences of the Czech Republic, Czech Republic
Professor Peter Lund	The Council of Finnish Academies, Finland
Professor Enn Lust	The Estonian Academy of Sciences, Estonia
Professor Mark O'Malley	The Royal Irish Academy, Ireland
Dr Michael Ornetzeder	The Austrian Academy of Sciences, Austria
Professor Alojz Poredos	The Slovenian Academy of Sciences, Slovenia
Professor Ferdi Schüth	The German National Academy of Sciences Leopoldina, Germany
Professor Eugenijus Uspuras	The Lithuanian Academy of Sciences, Lithuania
Professor Jan Vaagen	The Norwegian Academy of Science and Letters, Norway
Professor Wim van Saarloos	Royal Netherlands Academy of Arts and Sciences (KNAW), The Netherlands
(Dr John Holmes	Energy Programme Secretary, EASAC)

EASAC, the European Academies Science Advisory Council, consists of representatives of the following European national academies and academic bodies:

Academia Europaea
All European Academies (ALLEA)
The Austrian Academy of Sciences
The Royal Academies for Science and the Arts of Belgium
The Bulgarian Academy of Sciences
The Academy of Sciences of the Czech Republic
The Royal Danish Academy of Sciences and Letters
The Estonian Academy of Sciences
The Council of Finnish Academies
The Académie des Sciences
The German Academy of Sciences Leopoldina
The Academy of Athens
The Hungarian Academy of Sciences
The Royal Irish Academy
The Accademia Nazionale dei Lincei
The Latvian Academy of Sciences
The Lithuanian Academy of Sciences
The Royal Netherlands Academy of Arts and Sciences
The Polish Academy of Sciences
The Academy of Sciences of Lisbon
The Romanian Academy
The Slovakian Academy of Sciences
The Slovenian Academy of Arts and Science
The Spanish Royal Academy of Sciences
The Royal Swedish Academy of Sciences
The Royal Society

The Norwegian Academy of Science and Letters
The Swiss Academies of Arts and Sciences

For further information:

EASAC Secretariat
Deutsche Akademie der Naturforscher Leopoldina
German National Academy of Sciences
Postfach 110543
06019 Halle (Saale)
Germany

tel +49 (0)345 4723 9831
fax +49 (0)345 4723 9839
email secretariat@easac.eu

EASAC Brussels Office
Royal Academies for Science and the
Arts of Belgium (RASAB)
Hertogsstraat 1 Rue Ducale
B 1000 - Brussels
Belgium

tel +32 (2) 550 23 32
fax +32 (2) 550 22 05
email brusselsoffice@easac.eu

Printed by DVZ-Daten-Service GmbH, Halle/Saale, Germany