NUFFIELD COUNCIL ON BIOETHICS

New approaches to biofuels

CONSULTATION PAPER

December 2009

How to respond

It would be most helpful if you could send your response to us electronically. Responses can be submitted online via our dedicated consultation website: https://consultation.nuffieldbioethics.org. Alternatively, you can email your response together with the respondent's form below (electronic document available at www.nuffieldbioethics.org) to: consultation@nuffieldbioethics.org.

If we receive your response electronically, there is no need for you also to send a paper copy. You will receive an acknowledgement of your response. If you would prefer to respond by post or by fax, you may send your completed response and respondent's form to:

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For information about obtaining a large print version of the consultation paper, please contact the Council using the above details.

Thank you.

Closing date for responses: 15 March 2010

Web references throughout the consultation were accessed December 2009.

Respondent's form

Please complete and return with your response by **15 March 2010**.

Your details

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Organisation (if applicable):

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Closing date for responses: 15 March 2010

Nuffield Council on Bioethics

Secretariat

The Terms of Reference of the Council

1 to identify and define ethical questions raised by recent advances in biological and medical research in order to respond to, and to anticipate, public concern;

2 to make arrangements for examining and reporting on such questions with a view to promoting public understanding and discussion; this may lead, where needed, to the formulation of new guidelines by the appropriate regulatory or other body;

3 in the light of the outcome of its work, to publish reports; and to make representations, as the Council may judge appropriate.

Working Party members

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The members of the Working Party were appointed for their personal knowledge and expertise, and will not necessarily be representing the views of their organisations.

Working Party Terms of Reference

1. To review:

   a) advances in the development of future generation biofuels, including the use of advanced plant breeding strategies, genetic modification and synthetic biology;

   b) the potential of these advances to address climate change mitigation and energy needs and to contribute to economic development.

2. To identify and consider both the advantages and benefits, as well as the ethical, social, legal and economic implications of the development of such future generation biofuels, including:

   a) issues of environmental sustainability and protection;

   b) impact on food security, particularly for the poor and vulnerable;

   c) implications for the rights of workers and farmers in developing countries, including labour and land rights, and health effects;

   d) issues surrounding land use for biofuel production;

   e) implications for future generations;

   f) implications in relation to intellectual property issues;

   g) issues surrounding public acceptance of biofuels;

   h) governance of future generation biofuels and related policy issues.

3. To consider the development and implementation of policies, legislation and governance that could promote the safe development and use of future generation biofuels.

4. To draft a report and make recommendations.

Contents

The Nuffield Council on Bioethics Working Party on new approaches to biofuels is publishing this consultation paper to invite views on the ethical implications of new developments in biofuel production.

The following pages set out some background information, together with the questions that we would like to ask. The Working Party places great value on having feedback from people and organisations in diverse locations with different interests and perspectives. We would like to hear from anyone with either a personal or professional interest in biofuels. This includes members of the public, farmers, scientists, members of advocacy groups and NGOs, policy makers, the biofuels industry, from both developing and developed countries. We are also interested to hear from anyone concerned with energy security, climate change and the environment, and agricultural and economic development. Due to the complexity of the issue, some questions in this consultation are more general in nature, whereas others are more specialised. Please feel free to answer whichever questions interest you.

In each section, some of the more specialist terms appear *in italics*. Additional information on these terms can be found in the Index at the end of the document.

Introduction and General Questions

The Nuffield Council on Bioethics examines ethical issues raised by new developments in biological and medical research. It is an independent body, funded jointly by the Nuffield Foundation, the Medical Research Council and the Wellcome Trust. It works by considering topics in depth, publishing reports on its findings and making recommendations to policy makers. The Council has established a Working Party to examine and write a report on New Approaches to Biofuels.

Biofuels are renewable liquid fuels derived from microorganisms, plant or animal material (biomass). They can be used, in their pure form or as part of blends, to fuel transport vehicles as well as to generate heat and power. With increasing concern about climate change, energy security, and agricultural and economic development, interest in biofuels has grown rapidly in recent years. The main types of biofuels currently in commercial use (often referred to as *first generation biofuels*) are bioethanol, biodiesel and biogas. Bioethanol is produced from sugar/starch from crops such as sugar cane, sugar beet, corn or wheat. Biodiesel is made from oils of plants, for example, soybean, oilseed rape, sunflower or palm. Biogas is a methane-rich gas that can be compressed to fuel vehicles, and it is generated by anaerobic digestion (digestion in the absence of oxygen) of biomass.

Although first generation biofuels were initially regarded as a renewable and sustainable energy source, they have been found in some circumstances to have made only small or even negative greenhouse gas emission (GHG) savings in their *lifecycle assessment* compared to fossil fuels. Additionally, some first generation biofuel production has also raised concerns about its effects on the environment; on land usage and *food security*; and on the human rights of workers and communities in developing countries where some biofuel crops are grown.

Future generation biofuels are being developed with the expectation that they will avoid such problems, involving new *feedstocks* and *biofuel processing* technologies. Such new fuels can, in principle, be made from almost every kind of biomass including, for example, the inedible, 'woody' parts of crops, trees and grasses (*lignocellulosic* biomass); from agricultural, horticultural, municipal and animal wastes; and from marine resources such as algae. A range of chemical and bio-technology is being employed to enhance the production of biofuels from these new sources, including *advanced plant breeding strategies*, *genetic modification*, and *synthetic biology*. The aim of the first two of these technological approaches is to improve the characteristics of the feedstocks (e.g. by introducing genes to enable higher yields), and to increase the efficiency

of processing them into biofuel (e.g. by utilising digestive enzymes to help break down the feedstock). Meanwhile, synthetic biology is being used to develop microorganisms such as bacteria, yeasts and algae which produce biofuels.

These recent advances in biofuel technology have given rise to the hope that future generation biofuels might mature into a useful component of an economically and environmentally sustainable route towards energy security, both for the UK and the rest of the world. Some of the new approaches show potential for significant GHG savings, and, carefully managed, it might be possible to circumvent some of the problems of first generation biofuels.

The Nuffield Council on Bioethics Working Party aims to identify and explore the potential benefits and disadvantages as well as the ethical, social, legal and economic issues raised by new approaches to biofuels and to develop policy recommendations where appropriate. It will seek to identify an ethical framework by which new approaches to biofuel production can be evaluated. An ethical framework is made up of important principles or values that can be used to give some guidance on how to make decisions in a particular area. In the process of writing its report, the Working Party wants to invite comments from as many interested parties as possible.

Question 1

What is your view on society moving towards greater use of biofuels?

Question 2

What are the most important ethical challenges raised by the prospect of future generation biofuels?

Question 3

Do you regard yourself as well informed about biofuels? Where do you get your information from?

Drivers, hopes and benefits

The development of future generation biofuels is mainly driven by three factors: the need to mitigate climate change and achieve lower greenhouse gas (GHG) emissions; worries about energy security; and an interest in agricultural and economic development, both in the developed world and developing countries. It is hoped that future generation biofuels will be successful in addressing these concerns. There might also be other benefits to future generation biofuels.

Question 4

Which factors are going to be the most important in driving the development of biofuels in the future? To what policy concerns should priority be given? What advantages not mentioned here could and should future biofuel production aim to deliver?

Climate change

If we continue to use fossil fuels at current and projected levels, the scientific consensus suggests that there will be a detrimental impact on the Earth's climate which may have global implications. To reduce the potentially destructive social, environmental and economic consequences of climate change, greenhouse gas emissions (GHG) need to be lowered.

Some *first generation biofuels* were shown to generate only small reductions in GHG emissions in their *lifecycle assessment*. New approaches could do better in this regard. For example, *lignocellulosic biofuels* produced from agriculture or forestry residues have been estimated to have GHG savings of 80 to 90 percent, when compared to petrol or diesel. This assumes no land-use change has occurred in supplying the biofuel *feedstock*.[1]

Question 5

Which of the new approaches to biofuels will be most successful in generating GHG emission savings? How should these be encouraged? Are there any reasons why these new approaches should NOT be encouraged?

[1] Renewable Fuels Agency (2008) *The Gallagher Review of the Indirect Effects of Biofuels Production*, available at: http://www.renewablefuelsagency.gov.uk/_db/_documents/Report_of_the_Gallagher_review.pdf, p24.

Energy security

Individual nations need a reliable supply of affordable energy – often referred to as energy security. Energy security can be increased by lowering energy consumption, using energy from a diverse mix of sources, and by producing energy domestically to reduce the need for imports.

Question 6

Which of the new approaches to biofuels will be most successful in improving energy security? How should these be encouraged? Are there any reasons why these new approaches should NOT be encouraged?

Economic development

New approaches to biofuel production could potentially create jobs and new sources of income both in the developed world and in developing countries – the so-called "Green Economy". This could in turn contribute towards improving infrastructure, and support overall economic and agricultural development.

Question 7

Which of the new approaches to biofuels will be most successful in supporting economic development? How should these be encouraged? Are there any reasons why these new approaches should NOT be encouraged?

Science, technology and research

Feedstock development and processing

In contrast to most *first generation biofuel* production, research is exploring the use of *lignocellulosic* biomass – the fibrous, inedible material from plants. Materials for lignocellulosic biofuels include non-food crops such as bushes/trees, and perennial grasses that can be grown specifically for biofuel production; as well as waste materials from agriculture, forestry and other urban sources. Another research area is the development of marine resources, such as algae, as biofuel *feedstock*.

In order to turn lignocellulosic feedstocks into biofuel end products, the feedstock first has to undergo *pre-treatment* to produce an intermediate form that is more amenable to *conversion* and reduces costs. Pre-treatment can also make the material denser so it is more efficient for being transported. For example, sugars can be recovered from lignocellulose using chemicals/enzymes to break the lignocellulose down (a process called *lignocellulosis*); carbon monoxide and hydrogen gases (a mixture known as synthetic gas or syngas) can be generated by *gasification*, and bio-oil can be produced by *pyrolysis*. Following pre-treatment of the material, conversion processes and refining technologies are applied – including blending – so that the biofuel can be used for transport.

Question 8

Of all the new approaches to biofuel feedstock development, pre-treatment and processing (including any additional to those mentioned here), which is looking most promising for eventual commercial and sustainable use? Over what timescales might such developments be commercialised? Are there any risks associated with these developments?

Advanced plant breeding strategies, genetic modification and synthetic biology

Some of the new approaches to biofuel production involve *advanced plant breeding strategies, genetic modification* and *synthetic biology*. For example, advanced plant breeding strategies can be combined with conventional breeding to help produce new varieties of plants that express desired traits. Genetic modification can be used to introduce genes to produce favourable traits for biofuel production, such as higher yields or the ability to grow on land which cannot be used for food crops. Genetic modification is also used to enhance the biofuel production process. For example, microbes have been genetically altered to secrete enzymes which help break up the *feedstock* to enable easier *biofuel processing* and energy extraction. The emerging field of synthetic biology is aiming to develop entirely new means of producing biofuels. This might involve, for example, the specific design and construction of microorganisms (such as bacteria, yeast and algae) as *biofactories* producing biofuel: e.g. microorganisms which secrete fuel using waste water, sunlight, oxygen etc.

Question 9

Is the use of the following technologies to develop new approaches to biofuel production appropriate? Why?

Advanced plant breeding strategies

Genetic engineering

Synthetic biology

Intellectual property issues

Successful future generation biofuel production "from lab to tank" requires knowledge of the technologies involved at different stages of the production pathway, such as plant selection and production, growth/production of the *feedstock*, *biofuel processing* of the material, extraction of the fuel, and finally refinement and blending. Researchers are working to improve each step of the process. For example, *advanced plant breeding strategies* and *genetic modification* of feedstocks can be used to enhance yields or to make crops more resistant to heat or drought. Microorganisms can be genetically altered so that they secrete 'digestive' enzymes that enable more efficient processing of the feedstock into fuels. Several such technological tools and processes in future generation biofuel production have been patented or will be patented in the near future. Thus, if researchers, producers or companies want to use these technologies, they will have to apply and pay for a licence.

In addition, the future development of plants with desired traits may require access to plant material which is only available from other countries. Many developing countries, the main source of novel plant material, are raising concerns about intellectual property and in particular the appropriation of traditional knowledge by companies in the developed world. In some cases countries have adopted intellectual property legislation based on issues of access and benefit sharing in keeping with the *Convention on Biological Diversity*. The full implications of such legislation are yet to be understood.

These intellectual property and patenting systems protect the commercial interest of the patent holder, ensuring they can make a return on their often substantial initial investment. On the other hand, patents can hinder further research and create barriers to using the technology particularly for poorer populations and countries.

Given the rapid technological advances in the field, it is likely that questions regarding intellectual property, knowledge transfer and sharing of expertise will play an important role in future biofuel production.

Question 10

What are the most important intellectual property and access issues raised in new approaches to biofuels? What is the best way of governing these?

Research and development (R&D)

Several elements of new approaches to biofuel production, including generation and *biofuel processing* of new *feedstocks*, are still being developed. A great deal of research is currently underway in the field.

Question 11

What are currently the main constraints to R&D in new approaches to biofuels?

Question 12

Where should R&D for new approaches to biofuel be targeted, and who should decide about future biofuel R&D strategies?

Land use, environmental and food security and human rights

Land use

The amount of land that is used for biofuel production has increased significantly in recent years, and is predicted to increase dramatically over the next 20 years. Such land use has raised various concerns over environmental and *food security*, as well as human rights and health. The expansion of biofuel production has in the past sometimes resulted in local populations losing control of their land, and even in their removal from the land. Biofuels might be grown at the expense of basic food commodities resulting in local, and even global, food shortages and price rises. Even if biofuels are grown on land that is marginal for food production, this may result in the loss of natural or semi-natural *biodiversity*-rich areas, and endanger national parks and other protected areas, which in turn may result in severe impacts on critical *ecosystem services* (the benefits people derive from their ecosystem). Discussions around new approaches to biofuels have highlighted an awareness of these land use issues, and a desire to avoid them.

In addition, questions surround whether *life cycle assessments* of biofuels should consider the greenhouse gas (GHG) emissions released through indirect land use change (iLUC). Indirect land use change occurs when farmers direct existing cropland or crops into biofuel production. It is hypothesised that in response, farmers elsewhere in the world convert more forest land into cropland (e.g. for food agriculture), thereby releasing more carbon.

Question 13

Are new approaches to biofuels likely to raise problems related to land use? If yes, how? If not, how do new approaches avoid these issues?

Question 14

What differences are there between the developed world and developing countries with regards to the potentially problematic effects of future generation biofuel production on land use?

Question 15

Should iLUC be considered when evaluating the GHG emissions savings of new approaches to biofuels, and if so, how?

Environmental security

Current approaches to biofuel production can themselves have some effect on the environment. There have been criticisms over air pollution through activities like deforestation and the drying and burning of peatland. Water pollution can also occur through the escape of sediment and chemicals used in agriculture into water sources. This way, water catchment areas may be reduced. In addition, the use of large amounts of water, the destruction of land of high conservation value such as peatlands and rainforests, and the reduction in *biodiversity* and *ecosystem services* have been attributed to biofuel production.

Some of the new approaches to biofuels have been specifically developed to address these concerns. For example, enhancing crop yields, using waste materials or developing crops which grow under hostile conditions might reduce the need for resources such as water and land. This could relieve pressure on drinking water reserves, help to protect land of high conservation value, as well as potentially alleviate competition with food agriculture. Additionally, new approaches might benefit the environment, for example, by creating new habitats. On the other hand, *lignocellulosic biofuel* crops could actually be planted in areas of high biodiversity precisely because these have hitherto been unsuitable for crops. Moreover, there is a danger that trees in natural environments will be harvested unsustainably since this approach may often be cheaper compared to the management of plantations.

Question 16

What advantages and disadvantages for environmental security could new approaches to biofuels have? How could harms for environmental security be dealt with?

Food security

There have been concerns regarding the effect of *first generation biofuel* production on *food security* – that is the availability, price and accessibility of food at local, national and global levels. For example, there has been a debate about whether current biofuel production diverts agricultural resources (such as land and water) away from food production, potentially limiting local food supply. The diversion of US corn to produce fuel rather than food has also raised grave concerns over food prices. In January 2007, the price of corn tortillas, a dietary staple in Mexico, rose by over 400 percent, prompting riots.[2] Mexico is a net importer of corn.

New approaches to biofuels aim to avoid problems associated with food security. For example, *feedstock*s such as algae and *lignocellulosic* feedstocks might not compete with food.

Question 17

Are new approaches to biofuels likely to raise problems related to food security? If yes, how? If not, how do new approaches avoid these issues?

Question 18

What differences are there between the developed world and developing countries with regards to the potentially problematic effects of future generation biofuel production on food security?

[2] Ziegler J (2007) *The right to food: Note by the Secretary-General*, available at: http://www.righttofood.org/new/PDF/A62289.pdf, p12.

Rights of farmers and workers

Discussions around new approaches to biofuels have highlighted an awareness of issues around the rights of farmers and workers both in the developed world as well as in developing countries. In first generation biofuel production, as with many other types of agriculture, there have been concerns that workers and farmers could experience inadequate working conditions and negative health effects, for example due to pesticide use. There have also been reports that workers have sometimes been provided with inadequate wages, particularly in developing countries. On the other hand, both small scale and large scale industrial biofuel production have given farmers and workers new possibilities of income and of developing their businesses.

Question 19

Are new approaches to biofuels likely to raise problems related to rights of farmers and workers? If yes, how? If not, how do new approaches avoid or benefit these issues?

Question 20

What differences are there between the developed world and developing countries with regard to the effects of the production of future generation biofuels on the rights of farmers and workers?

Investment, policy and governance

Globally, current biofuel production takes place within many different business models, ranging from small scale domestic production (such as of biogas) to large scale industrial production (for example of bioethanol) in both developing and developed countries. Through their investment strategies, industry can shape to some extent how biofuel production develops. For example, they may be more likely to invest in new biofuel production pathways that are considered to be economically viable for large scale production. Such investment decisions also have a lot of influence on the way research progresses.

Investment in biofuels takes place within a policy context, which is shaped by the desire to mitigate climate change, improve energy security, and support agricultural and economic development without endangering environmental or food security or the rights of farmers and workers. National and international policies issued by governments and international institutions have the ability to promote or inhibit biofuel use and affect financial investment in research and development (R&D) from industry and the public sector. Such policies include greenhouse gas (GHG) emissions and bioenergy targets, incentives, subsidies and regulatory policies, research funding, and trade agreements.

Policies that affect biofuel production currently take the form of guidelines, legislation and agreements specific to biofuels as well as those from areas relevant to biofuel production such as agricultural practice, environmental protection, and technological standards. They operate at both *domestic and regional* levels.

Some policies have been *revised*, following concerns that some *first generation biofuels* might be harmful, and/or that policies might conflict with other regulations. The changeable nature of biofuel governance has created a lack of investor confidence.

Question 21

Where do you think investment in new approaches to biofuels should be directed and where should it come from (public sector, private sector or public-private partnerships)?

Question 22

Which policy issues in relation to new approaches to biofuels would you like to bring to our attention?

Question 23

What would be the most effective policies a) to promote and incentivise; and b) to regulate the development of new approaches to biofuels?

Any other issues

Question 24

Are there any other issues not mentioned in this consultation that we should consider in the ethical evaluation of new approaches to biofuels? Please expand below.

Thank you. We appreciate your participation in this consultation.

Index

advanced plant breeding strategies
Advanced plant breeding strategies include marker assisted breeding in which a molecular marker linked to a trait of interest, such as stress resistance,[1] is used during conventional breeding programmes to select lines with that trait, obviating the need to grow to maturity and score large numbers of plants for the trait itself. With the advent of high throughput screening for molecular markers, many such markers can be used simultaneously to select for multiple or complex traits. [2]

biodiversity
Short hand for "Biological diversity" which is the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. [3]

biofactories
Biofactories are microorganisms (such as bacteria, yeast or algae) built using synthetic biology that produce fuels or chemicals. In this way, scientists have developed microbes that produce fuels with properties "indistinguishable" from petrol, diesel and jet fuel.[4]

biofuel processing
Processing involves two stages: pre-treatment and conversion. Pre-treatment produces an intermediate that is both denser than the raw material – and therefore easier to transport – and easier to process – thus reducing conversion costs.[5] Conversion involves processing these intermediates into biofuel end-products.

Biofuel pre-treatment
Feedstocks such as lignocellulosic crops or wastes need to be pre-treated and broken down into intermediates before they can be made into biofuels. Approaches to pre-treatment include lignocellulosis, pyrolysis and gasification.

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[1] Collard BCY and Mackill DJ (2008) Marker-assisted selection: an approach for precision plant breeding in the twenty-first century *Philosophical Transactions of the Royal Society B: Biological Sciences* **363**: 557–72.
[2] Varshney RK, Graner A and Sorrell ME (2005) Genomics-assisted breeding for crop improvement *Trends in Plant Science* **10**: 621–30.
[3] United Nations Treaty Series (1993) *Convention on Biological Diversity*, available at: http://www.cbd.int/doc/legal/cbd-un-en.pdf, article 2.
[4] LS9, Inc. (2007) *UltraClean™ Fuels*, available at: http://www.ls9.com/products/.
[5] The Royal Society (2008) *Sustainable Biofuels: Prospects and challenges*, available at: http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5501, p21.

Lignocellulosis is the breakdown of lignocellulose (the fibrous, inedible parts of plants making up the cell walls) to release sugars for ethanol production. Lignocellulosis can be achieved by using chemicals such as acid or alkali, enzymes,[6] and genetically engineered microorganisms that produce certain enzymes.[7]

Pyrolysis uses very high temperatures to break down biomass. Bio-oil is produced and this can be used as a fuel in existing industrial boilers.[8] Another product is syngas – a carbon monoxide and hydrogen-rich gas – that can be burned to generate heat and power.[9]

Gasification involves the partial combustion of biomass to produce syngas that can be eventually converted to petrol and diesel.[10]

Conversion technology
After feedstocks have undergone pre-treatment, the intermediates produced – such as syngas – are converted into liquid fuel. Conversion technologies include the Fischer-Tropsch process, and more recent methods such as methanol synthesis followed by the MTG or MOGD processes, and hydroprocessing.

The Fischer-Tropsch process converts syngas – a carbon monoxide and hydrogen-rich gas produced by pre-treatment methods – into petrol or diesel.[11]

Methanol synthesis from syngas followed by methanol to gasoline (MTG) or methanol to olefins, gasoline and diesel (MOGD) processes are an alternative to Fischer-Tropsch, and produce petrol or diesel.[12]

Hydroprocessing can convert plant oil or bio-oil – produced by pyrolysis – into an end-product which can be refined in a conventional refinery.[13]

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[6] The Royal Society (2008) *Sustainable Biofuels: Prospects and challenges*, available at: http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5501, p22.
[7] Lynd LR, van Zyl WH, McBride JE *et al*. (2005) Consolidated bioprocessing of cellulosic biomass: an update *Current Opinion in Biotechnology* **16**: 577–83.
[8] Laird DA, Brown RC, Amonette JE *et al*. (2009) Review of the pyrolysis platform for coproducing bio-oil and biochar *Biofuels, Bioproducts & Biorefining* **3**: 547–62.
[9] Laird DA, Brown RC, Amonette JE *et al*. (2009) Review of the pyrolysis platform for coproducing bio-oil and biochar *Biofuels, Bioproducts & Biorefining* **3**: 547–62.
[10] The Royal Society (2008) *Sustainable Biofuels: Prospects and challenges*, available at: http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5501, p26.
[11] The Royal Society (2008) *Sustainable Biofuels: Prospects and challenges*, available at: http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5501, p25.
[12] The Royal Society (2008) *Sustainable Biofuels: Prospects and challenges*, available at: http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5501, p25.
[13] The Royal Society (2008) *Sustainable Biofuels: Prospects and challenges*, available at: http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5501, p27.

Convention on Biological Diversity

The objectives of the Convention on Biological Diversity (CBD) are: to conserve biological diversity; to use biological diversity in a sustainable fashion; to share fairly and equitably the benefits arising from use of genetic resources, for example by enabling appropriate access to genetic resources, appropriate technology transfer and appropriate funding.[14]

domestic and regional policy

In the UK, 5 percent of automobile fuel must come from renewable resources by 2013.[15] In the US, biofuels must account for at least 36 billion gallons of US fuel supply by 2022, of which at least 21 billion gallons must be 'advanced' biofuels (i.e. non-corn ethanol).[16]

In the EU, renewable sources of energy must account for 10 percent of automobile fuel by 2020,[17] and follow criteria for sustainable production. For example, land should not be converted for biofuel production if the carbon dioxide emissions released in land conversion could not be compensated for by greenhouse gas (GHG) emission saving from the production of biofuels or bioliquids, within a reasonable period, taking into account the urgent need to tackle climate change.[18] Additionally, bioethanol can be incorporated at up to 10 percent and biodiesel at up to 7 percent (both by volume) in petrol and diesel respectively.[19]

ecosystem services

Ecosystem services are the benefits people obtain from an ecosystem (a system occurring in nature in which plant, animal, fungal and microorganism communities and their non-living environment interact). These include provisioning services such as of food and water; regulating

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[14] United Nations Treaty Series (1993) *Convention on Biological Diversity*, available at: http://www.cbd.int/doc/legal/cbd-un-en.pdf, article 1.

[15] Office of Public Sector Information (2009) *The Renewable Transport Fuel Obligations (Amendment) Order 2009*, available at: http://www.opsi.gov.uk/si/si2009/uksi_20090843_en_1, Amendment of article 4(vi).

[16] US Senate and House of Representatives, 110th Congress (2007) *Energy Independence and Security Act*, available at: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf, Sec 202(2).

[17] The European Parliament and the Council of the European Union (2009) Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC *Official Journal of the European Union* **140**: 16–62, Article 3(4).

[18] The European Parliament and the Council of the European Union (2009) Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC *Official Journal of the European Union* **140**: 16–62, paragraph 73.

[19] The European Parliament and the Council of the European Union (2009) Directive 2009/30/EC amending Directive 98/30/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC *Official Journal of the European Union* **140**: 88–113, Annexes I&II.

services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.[20]

feedstock

"Feedstock" refers to any material that can be converted to another form of fuel, chemical or energy product.[21]

first generation biofuels

"First generation" commonly refers to biofuels that are made from food crops, such as sugar cane, sugar beet, wheat, corn, soy been, oilseed rape, oil palm and sunflower. They include bioethanol (fermented from the sugars and broken-down starch) and biodiesel (derived from plant oils). Biogas (collected from landfill sites or produced in dedicated biogas plants that can be small or industrial-scale, and use animal and food wastes, and dedicated crops) is also a current biofuel source.

food security

The Rome Declaration on Food Security – agreed at the 1996 FAO World Food Summit in Rome – acknowledges the multifaceted nature of food security and refers to it as "physical and economic access by all, at all times, to sufficient, nutritionally adequate and safe food and its effective utilization".[22]

genetic modification

Genetic modification of a plant typically involves the transfer of genes from another organism, such as a plant, virus or bacterium, into its DNA. The aim is to accelerate breeding and to confer on the recipient plant desirable features or traits such as higher yields, better digestibility in processing, or resistance to insects. Genetic modification allows the combination of genetic material that would be very difficult or impossible to obtain by conventional breeding. However, it can also be used to combine genetic material in a way that would be possible through conventional approaches.

lifecycle assessment of biofuels

Lifecycle assessment of a biofuel most commonly includes estimating greenhouse gas (GHG) emissions from all the processes involved in development, distribution and end-use of the biofuel in order to calculate overall GHG emissions of a particular biofuel production pathway.

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[20] Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Synthesis*, available at: http://www.maweb.org/documents/document.356.aspx.pdf, pv.

[21] The Royal Society (2008) *Sustainable Biofuels: Prospects and challenges*, available at: http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5501, p76.

[22] World Food Summit (1996) *The Rome Declaration on World Food Security*, available at http://www.fao.org/docrep/003/w3613e/w3613e00.HTM.

Processes include: change in land use, soil cultivation, fertiliser production/use, irrigation, harvesting, processing, refinement and transportation of the biofuel. There is debate over whether current lifecycle assessments of biofuels, as required by legislation, should also include GHG emissions from indirect land use change (worldwide change in land-use to agriculture, prompted by existing cropland being used for fuel instead of food agriculture) given the state of the methodology for such calculations.[23] There is considerable uncertainty over how GHG emissions from indirect land use change should be measured and included in lifecycle assessments.[24] Some also argue that indirect GHG emissions should either be analysed for all fuels or for none.[25]

Multi-factorial life cycle assessment can alternatively analyse other outcome measures, such as energy used in production or resources used like water.

lignocellulosic biofuels

"Lignocellulosic" refers to the fibrous and inedible parts of a plant which make up the cell walls (lignocellulosic biomass) and the fuels derived from these. Lignocellulose is broken down using a process called lignocellulosis to release the sugars for fuel production. Consequently, lignocellulosic biofuels can utilise various non-food crops and wastes. Materials for lignocellulosic biofuels include non-food crops such as bushes/trees (e.g. spruce, pine, larch and fir plantations; short rotation coppices of willow, poplar, eucalyptus and red alder) and perennial grasses (e.g. miscanthus, switchgrass, reed canary grass and giant reed) that can be grown specifically for biofuel production; and waste materials from agriculture (e.g. cereal straws, corn stover, cane bagasse), forestry and other urban sources (e.g. packaging and food, human and cooking waste, fabric). Another area is the development of marine resources (e.g. macroalgae, seaweed and microalgae) as biofuel sources. Lignocellulosic biofuels are also known as "second generation" biofuels.

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[23] For example, see the discussion surrounding the ongoing amendment of the US Renewable Fuels Standard (RFS2): National Biodiesel Board (2009) *Comments of the National Biodiesel Board on Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program*, available at: http://www.biodiesel.org/news/RFS/rfs2docs/NBB%20RFS2%20Comments%2009%2025%2009.pdf, p51.

[24] Mathews JA and Tan H (2009) Biofuels and indirect land use change effects: the debate continues *Biofuels, Bioproducts & Biorefining* **3**: 305–17; Renewable Fuels Agency (2008) *The Gallagher Review of the Indirect Effects of Biofuels Production*, available at: http://www.renewablefuelsagency.gov.uk/_db/_documents/Report_of_the_Gallagher_review.pdf, p46.

[25] National Biodiesel Board (2009) *Comments of the National Biodiesel Board on Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program*, available at: http://www.biodiesel.org/news/RFS/rfs2docs/NBB%20RFS2%20Comments%2009%2025%2009.pdf, pii.

revision of biofuels-related policy

There have been cases of biofuels-related governance being revised because there has been conflict with other policy. For example, partly in response to the worry that *first generation* biofuels were produced in an unsustainable way, the UK Renewable Transport Fuel Obligation (RTFO) Order was amended so that that the target of 5 percent of automobile fuel from renewable sources by 2010 was revised to be reached by 2013 instead.

A 2003 European Directive set a biofuel reference target for all petrol and diesel[26] that was incompatible with the then European fuel specifications.[27] A 2009 European Directive later addressed this.[28]
In the US, the 2007 Renewable Fuel Standard program – which stated that biofuels must account for at least 36 billion gallons of US fuel supply by 2022 – is currently under revision following concerns over the sustainability of first generation biofuel production.

synthetic biology

Synthetic biology is an emerging field of science. It can be understood as the building of novel biological networks or organisms to perform certain functions. They can be made by either building from scratch or modifying existing organisms. 'Building blocks' of DNA with standardised functions are used.

[26] The European Parliament and the Council of the European Union (2003) Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport *Official Journal of the European Union* **123**: 42–6, Article 3, 1b(ii).

[27] The European Parliament and the Council of the European Union (1998) Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC *Official Journal of the European Union* **70**, Annexes III&IV.

[28] The European Parliament and the Council of the European Union (2009) Directive 2009/30/EC amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC *Official Journal of the European Union* **140**: 88–113, Annexes I&II.