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Royal Society call for evidence
Developments for Biofuels

Memorandum by the Royal Society of Chemistry

The Royal Society of Chemistry (RSC) welcomes the opportunity to comment on the Royal Society call for evidence on developments for biofuels.

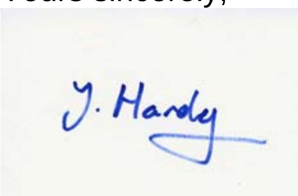
The RSC is the largest organisation in Europe for advancing the chemical sciences. Supported by a network of 43,000 members worldwide and an internationally acclaimed publishing business, our activities span education and training, conferences and science policy, and the promotion of the chemical sciences to the public.

This document represents the views of the RSC. The RSC's Royal Charter obliges it to serve the public interest by acting in an independent advisory capacity, and the RSC is happy for this submission to be put into the public domain.

The evidence submitted was for the most part published in an RSC report entitled "Chemical Science Priorities for Sustainable Energy Solutions" and the RSC responses to the DTI energy review, the EAC inquiry into Reducing Carbon Emissions from Transport and the joint RSC and Bioscience Federation response to the EFRA inquiry into Climate change: the role of bioenergy[1].

If you would like further information or need anything in this document clarified, please do not hesitate to contact me.

Yours sincerely,



Dr Jeff Hardy
Environment, Sustainability and Energy Manager
Tel: 020 7440 3395
Email: hardyj@rsc.org

[1] All of these documents are available at http://www.rsc.org/policy

Introduction

The RSC and Biosciences Federation jointly responded to the EFRA committee inquiry into biofuels in 2006. A copy of this report is appended for the interest of the working group. First generation biofuels, that is those derived from starch or sugar crops (bioethanol) or those derived from vegetable or animal oils (biodiesel) are already a mature technology. There are certain technological advances (for example pervaporation membranes for bioethanol purification and high throughput continuous reactors for biodiesel production) that could improve the efficiency of their production. In this submission the RSC concentrates on second generation biofuels (e.g. bioethanol, biobutanol and fuels produced from synthesis gas such as gasoline and diesel) that are derived from lignocellulosic biomass (such as cereal straw, trees, waste paper, etc.). It is the belief of the RSC that second generation biofuels offer far greater potential for reducing cost and environmental impact compared to first generation biofuels. Furthermore, second generation biofuels do not necessarily compete with food production unlike first generation biofuels. There are a number of key technological barriers that must be overcome before second generation biofuels are realised and these are addressed in our response. With significant effort second generation biofuels will have substantial market impact by 2015[2]. It is important to accept that biofuels alone cannot mitigate the environmental impact of transportation, but that second generation biofuels can play a significant role alongside other measures.

[2] From presentation of Trevor Robinson at the NNFCC Green Supply Chain conference 2006, University of York

1. What scientific developments could contribute to greater and more efficient production of biofuels for the transport sector?

(i) What are the potential developments in the conversion processes (such as biological, chemical and thermochemical)?

The major challenge is for cost and energy efficient biofuel production from lignocellulosic biomass. Broadly speaking there are two mechanisms of converting lignocellulosic biomass into biofuels, by **fermentation** or by **thermochemical treatment**.

In the **fermentation** route the polysaccharides in lignocellulose are depolymerised to produce simple sugars, which are converted into alcohols, such as ethanol or butanol, by fermentation. There are a number of technical challenges to overcome before the process will be cost competitive with conventional fuels. Lignocellulose is an insoluble complex of polysaccharides and lignin and requires pre-treatment in order to open up its structure and expose the polysaccharides for enzymatic hydrolysis. This pre-treatment currently involves steam explosion, or partial acid hydrolysis and adds greatly to the overall costs. The first challenge is therefore to identify more cost-effective approaches to pre-treatment. The second challenge is to improve the efficiency of the enzymatic hydrolysis of cellulose and hemicellulose, through the use of enzyme engineering or novel enzyme discovery. Thirdly, there is a need to discover/engineer microorganisms that can efficiently convert a mixture of C5 and C6 sugars (for example glucose and xylose) into the desired product (for example bioethanol or biobutanol). Finally, as fermentation leaves a dilute solution of product in water, there is a need for a cost and energy efficient system to concentrate the product into the desired form. For example there is significant research being carried out into pervaporation membranes. Additionally, it is critical that by-products (for example lignin) are utilised – this could be achieved by converting these by-products to chemicals or by burning them to recover energy or through a combination of both these methods.

Thermochemical treatment avoids the need to separate the lignocellulosic feedstock into its component parts as the whole biomass resource is used. Thermochemical methods can be used to maximise a yield of gas (for example synthesis gas, a mixture of hydrogen and carbon monoxide), liquid (for example bio-crude or bio-oil) or solid (for example charcoal). Two methods show promise for transforming biomass into biofuels cost effectively, **gasification** and **pyrolysis**.[3]

During **gasification** synthesis gas is produced from biomass. The hydrogen produced from the gasification of biomass can be burned to produce power in engines and turbines; this technology is fairly well developed with several demonstration plants in Europe. Alternatively, the synthesis gas (syngas) can

[3] It is important to mention that biomass combustion (either as sole fuel or co-fired with fossil fuels) can be used to produce heat and power but that this will not be considered in this submission as here the focus is on transport fuels.

be used to produce hydrocarbon fuels or chemicals via Fischer-Tropsch synthesis. Syngas may also be used to produce methanol which can be converted at high efficiency into gasoline and diesel for transport via Methanol to Gasoline (MTG) or Mobil Olefin to Gasoline Distillate (MOGD) processes. Gasification plants can be built with flexibility and therefore produce different products (e.g. power, fuels or chemicals) dependent on market drivers.

Fast pyrolysis of biomass directly gives a liquid at up to 75 weight% yield which can be used in engines and turbines for power production. The formation of a pyrolysis liquid is a mechanism for concentrating biomass into a form that can be readily and economically stored or transported. This makes it feasible to transport pyrolysis liquids to a large processing plant where it can be converted (chemically, biochemically or thermochemically) into liquid transport fuels at a scale much greater than achievable with straight gasification of biomass process.

There are examples of demonstration biomass gasification and pyrolysis plants operating at around the 15 kilo tonne scale today.[4] There is an opportunity to develop catalysts for both the gasification and pyrolysis process that maximise selectivity towards the desired products.

The RSC would also like to comment on the production of **biogas** (methane gas produced by anaerobic fermentation of biomass). In our response to the EFRA bioenergy inquiry we drew attention to the untapped UK potential for biogas production from marine biomass. Macroalgae (such as seaweed) can be grown at prolific rates (increasing biomass weight by up to 10% per day) and has been shown to yield methane via anaerobic fermentation at a greater rate than any other source of biomass. Research funding is required to marry well-developed marine culture skills with the latest developments in anaerobic digestion to test UK seaweed species for suitability in methane production. It is unclear as to whether research has been carried out for the production of biofuels from marine biomass via a fermentation process or via a thermochemical process (both described above).

(ii) What is the potential for biorefineries, particularly in the UK?

The UK renewable transport fuel obligation (RTFO) is currently set at 5% by 2010 and could rise as high as 10% by 2015. In order to meet this obligation without principle reliance on imported biofuels and to avoid, where possible, competition with food production, lignocellulosic biomass resources will be required for biofuel production.

The UK has a significant annual lignocellulosic biomass resource, including 20 million tonnes of cereal straw[5], >1 million tonnes forestry waste (such as branches and foliage), 4.7 million tonnes waste paper[6], etc. It has been

[4] From presentation of JP Lange at the 2nd Renewable Resources and Biorefineries conference, University of York, 2006 (http://www.rrbconference.net)
[5] From presentation of Charles Jackson at the NNFCC Green Supply Chain conference, University of York, 2006
[6] http://www.wrap.org.uk/downloads/Information_Sheet_8.e5381614.pdf

estimated that 1 tonne of timber could yield up to 0.2 tonnes of diesel via thermochemical transformation.[7]

The optimal scale of a biorefinery has been estimated to be around 100 times smaller than that of a petrochemical refinery.[8] As well as the cost of the feedstock, the economics are driven by the density (e.g. with unchopped wheat straw you mostly transport air) and form (e.g. wet biomass means transporting a large volume of water) of the biomass source; transporting virgin biomass large distances adds to both the cost and to the carbon emissions of the process overall[9]. As mentioned previously, local pre-treatment of biomass (such as drying, chopping, pelletising or converting to a pyrolysis liquid) can improve the economics of transportation. In a demonstration green biorefinery in Brandenburg, Germany (25,000 tonnes biomass (mainly grass) per year) it was found that biomass travelling more than 30km was uneconomic.[10] This model seems to favour production of biofuels (and other products) in close proximity to where the feedstock is grown.

(iii) What feedstocks can be used and how can they be adapted to optimise the conversion processes?

In theory any lignocellulosic feedstock could be used for both fermentation and thermochemical processes. However, because different biomass sources have different compositions of cellulose, hemicellulose and lignin (as well as other components) then certain sources may be more or less suitable for any given process.

Maximising the yield of usable biomass per hectare is an important goal. To date, much of the research in crop breeding has been aimed at maximising the yield of the desired produce (for example grain) and minimising the yield of the remainder of the plant (i.e. the stem). In the second generation biorefinery model it is possible to envisage a research programme that aims to maximise the yield of biomass as well as the desired product. Crop breeding, mutagenesis and genetic modification are tools that could be employed to achieve this.

Lignocellulose fermentability is a trait that has not previously been a target of crop breeding and therefore represents an area of great untapped potential that can be accessed without resort to genetic modification. By identifying key genetic loci controlling this trait, using a combination of genomics and high-throughput screening, improved raw materials can be produced using conventional crop breeding methods[11].

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[7] Information from Prof. Hütterman, University of Göttingen, Germany
[8] From presentation of JP Lange at the 2nd Renewable Resources and Biorefineries conference, University of York, 2006 (http://www.rrbconference.net)
[9] Information from Dr Fabien Deswarte, Green Chemistry Centre of Excellence, University of York
[10] Information from Prof. Birgit Kamm, University of Potsdam, Germany
[11] Information provided by Professor Simon McQueen-Mason, CNAP, University of York

Mutagenesis leads to changes in to the genetic material (either DNA or RNA) and occurs naturally or can be provoked by applying stress to plants in the form of exposure to radiation, chemicals (mutagens), viruses, or during processes such as meiosis or hypermutation. Plant mutants arising from the process can be screened and strains displaying favourable characteristics (for example increased biomass production) can be selected. Both crop breeding and mutagenesis are approved procedures under EU law.

Genetic modification (GM) of lignocellulosic biomass potentially offers a route maximising the yield of the desired component (e.g. cellulose) or altering the structure so that processing is made easier (e.g. less intensive conditions required to produce a fermentable solution). This improvement should not be at the expense of other desired attributes of the crop. GM is of course a highly controversial subject in the EU.

As mentioned previously, the potential of marine biomass is largely untapped in the UK.

(iv) What role do by-products (including polygeneration) have?

By-products of biofuels production are likely to play a crucial role in optimising the economics of renewable transport fuels systems. Value can be added to the agricultural production of energy crops by co-production of heat, electricity and chemical intermediates.

Ensuring that biofuels can compete alongside fossil fuels in terms of price will be a condition of their success. The economics of energy crops demand that an integrated systems approach is adopted that generates value from all processes and products. Flexible polygeneration of a variety of products could, moreover, allow producers to engage in the dynamics of the market for hydrocarbon and energy products, thus securing a more competitive position in the traditional market for petroleum products[12].

Second generation biorefinery concepts embrace the concept of polygeneration. It is considered that co-production of speciality chemicals could dramatically improve the economics of biorefineries by occupying profitable market niches. Innovative ideas for utilisation of the whole biomass source, including combustion of by-products for heat and power, should be supported in principle alongside attempts to maximise biofuels yields for subsidised fuel products.

Much can be done to make more efficient use of by-products of agriculture, forestry and municipal waste. A few examples are cited below:

- Burning of residues in dedicated biomass combined heat and power (CHP) plants for both electricity and heat generation (either for industrial or housing projects).
- Co-firing of residues in coal fired power stations.

[12] Information provided by Simon Bennett, Centre for Energy Policy and Technology, Imperial College London

- Gasification of residues (such as lignin) to make synthesis gas for either power production or to make fuels and chemicals or a combination of both.
- Pyrolysis of residues to make either bio-crude, charcoal or syngas.
- Extraction of valuable metabolites such as waxes, anti-oxidants and plant sterols prior to lignocellulosic processing.
- Flexible co-production of bulk[13] (for example succinic acid or glycerol) and speciality chemicals (for example pharmaceutical building blocks) and polymers (for example polylactic acid[14]) via chemical and/or biochemical processes.

[13] T. Werpy and G. Petersen, Top Value Added Chemicals from Biomass Volume I - Results of Screening for Potential Candidates from Sugars and Synthesis Gas, US DoE, 2004
[14] http://www.natureworksllc.com/

2. What international examples are relevant for biofuel research and development in the UK?

It is interesting to compare the situation in UK with that of other countries where biofuels have made a significant market impact. In the UK there is a £0.20 per litre subsidy on biofuels and a commitment under the RTFO of 5% by 2010. In Germany and Austria biofuels are tax exempt which has stimulated significant volumes of biofuel production, particularly biodiesel. In the USA corn growers are encouraged to build bioethanol plants and can get substantial state and national capital grants to assist. There is also a national tax credit on biofuels. In Brazil all gasoline must contain at least 26% bioethanol by law and the country has decades of experience in bioethanol production from sugarcane. There have been incentives for bioethanol producers in the past.

There are also warnings of the impact of using food crops for biofuel production, particularly in Brazil and the USA. In Brazil, significant areas of the rainforest have been cut down to provide land to grow biofuel cops upon – this impacts on the ability of the rain forest to act as a carbon sink and also upon biodiversity. In the USA a massive increase in bioethanol production in states such as Iowa has resulted in an increase in the price of corn and a forecasted shortage of corn for animal feed. The availability of water for crop irrigation is also a crucial issue and one that will be accentuated in certain areas by climate change.

The UK must be an active partner in national, European and international technology platforms, knowledge transfer networks and collaborative research projects to ensure involvement in key developments in biofuel technologies and energy policy.

The RSC plays a leading role in both the Chemical Innovation Knowledge Transfer Network[15] (where the RSC is the holding company) and the European Technology Platform (ETP) for Sustainable Chemistry[16] (SusChem). The RSC has noted with interest the formation of an ETP for biofuels and recommends that the Royal Society contact this platform[17].

A number of international second generation biorefinery demonstration projects already exist. There are pilot plant biorefineries in Sweden (based on wood pulping and includes bioethanol research)[18], Iceland (a 20,000 tonnes per year lignocellulosic biorefinery that produces 7 million litres ethanol per year as well as co-products)[19], Germany (a 25,000 tonnes per year green biorefinery that produces bioethanol and a range of co-products)[20] and in Canada (where the Iogen Corporation runs the world's largest demonstration

[15] http://ktn.globalwatchonline.com
[16] http://www.suschem.org
[17] http://www.biofuelstp.eu/
[18] http://www.processum.se
[19] http://www.biorefineryworkshop.com/presentations/Kamm.pdf
[20] http://www.biorefinery.de

plant for cellulose derived ethanol)[21]. Such demonstration projects are essential to gain knowledge in operating and optimising biorefineries.

Recent announcements from large companies indicate that there is a serious commercial interest in second generation biorefineries. BP and DuPont have teamed up in order to develop a process to make biobutanol from lignocellulosic biomass[22] and Shell has recently announced a partnership with CHOREN Industries who have developed a biomass gasification process[23].

[21] http://www.iogen.ca
[22] From presentations of J Pierce (DuPont) and J Adams (BP) at the 2nd Renewable Resources and Biorefineries conference, University of York, 2006 (http://www.rrbconference.net)
[23] http://www.shell.com

3. What are the relative priorities for research and development and how could they be incentivised?

Key research priorities are as follows (this is not in order of importance):

- Development of local pre-treatment processes to reduce cost and environmental impact of transport from field to refinery
- Cost-effective mechanism for converting lignocellulosic biomass into fermentable solution
- Development of microorganism/enzyme systems capable of converting a mixture of C6 and C5 sugars into desired products
- Improving lignocellulosic raw materials through the application of genomics, molecular breeding, and genetic modification
- A process to convert lignin into desirable chemicals at a competitive cost and relevant scale
- Energy efficient and economic processes to isolate and concentrate alcohol from an aqueous solution.
- Catalysts that improve selectivity of gasification and pyrolysis processes towards desired products
- Research, development and demonstration funding for biogas production from marine biomass
- Large-scale demonstration of second generation biorefinery in UK.
- Issues regarding long-term storage (security stocks) of biofuels need to be addressed, both at a political and technological level.

Several mechanisms will need to be in place in order to bring second generation biofuels through to commercial operations in the UK. In the immediate future, research and development funding should be made available so that key process barriers can be overcome (as described above). It is important that any funding here should facilitate international cooperation, as this will avoid duplication of effort. The supply chain for a second generation biorefinery requires a funding mechanism that allows a diverse range of key partners to work together – this may cut across the scope of several research councils. The DTI technology programme is one such mechanism and the RSC recommends that a strand of this programme be dedicated to second generation biofineries. Finally, it is vital that demonstration second generation biorefineries are built in the UK in order to prove the technology and gain valuable knowledge of the operation of the facility. Here it is critical that public money is used to share the risk with industry.

Second generation biorefineries will eventually be able to compete with, if not become a cheaper option than fossil fuels. However, in the early development phase it is vital that Government has in place mechanisms over an appropriate period (perhaps to 2015) that incentivise biofuels over fossil fuels. Significant cost reduction will arise through operational knowledge leading to biorefinery optimisation and through economy of scale; this process will occur much faster if there is an incentive for companies to invest in the technology.

4. What can these developments in the science and engineering deliver in terms of improvements in cost, yield and environmental performance (particularly greenhouse gas emissions savings) and what are the potential environmental and socio-economic impacts?

(i) How do these compare with other abatement technologies?

The RSC, in its response to the DTI energy review stressed that “Technology will not provide a short-term solution to meet Government carbon emission reduction targets; reducing energy demand is the only way to achieve these targets”.

The RSC believes that there is no technological silver bullet, but that a range of technology options will be required in order to provide the UK with clean, secure and affordable energy in the medium- and long-term (these technologies are outlined in the RSC report “chemical science priorities for sustainable energy solutions”). These technologies will cut across numerous sectors including power generation, domestic living, industry and transportation. Biomass can contribute to all these sectors, but in this submission the RSC focuses on transportation.

It is important to stress that in transportation the role of biofuels alongside other abatement technologies and measures will lead to reduced energy consumption and reduced carbon emissions. These include lighter materials of vehicle construction, improvements in engine performance, advanced fuel additives, hybrid and electric vehicles, hydrogen fuelled vehicles (assuming that the hydrogen production does not lead to significant carbon emissions) and measures to reduce vehicle use all have important roles to play in transportation.

Focusing on biofuels, it has been previously stated in this submission that second generation biofuels have a greater potential for carbon emissions reduction when compared to first generation biofuels. This has been the focus numerous life cycle analysis (LCA) studies. In an excellent review by Larson, he concludes that “Grain-based biofuels offer less greenhouse gas (GHG) mitigation than lignocellulosic-based fuels due primarily to lower effective yields” and also that “In longer term, land use efficiency for GHG mitigation is likely to be highest for lignocellulosic plantation biomass”.[24]

There is further scope for reducing carbon emissions throughout the supply chain of second generation biorefineries, many of which have been discussed in this submission. These include crop breeding, sustainable agriculture best practice, biomass pre-treatment, local production, co-generation, technology developments and minimising fuel miles.

[24] E. D. Larson, Lifecycle Analyses of GHG Impacts of Biofuels for Transport, presentation at Energy Week, The World Bank, Washington, DC, 7th March 2006

(ii) What are the socio-economic and environmental implications of biofuel development, for example for global sustainability, development?

There are other organisations that are better placed to comment on this than the RSC, however, several relevant points are made below.

Biofuels offer the only near-term response to the need for energy dense low-carbon transport fuels. As such, their development in a sustainable manner offers significant opportunities for global sustainability. In addition, the advantages of applying UK technology in regions that have limited access to fossil fuel resources can be realised in many less developed nations.

Sustainable biofuel use will be dictated by local constraints such as proximity to biomass resource and the nature of the resource itself, which necessarily varies between regions. This means that biofuel production is subject to different economies of scale compared to the existing energy infrastructure. This offers social and economic benefits at a local level.

Second generation biorefineries in the UK will lead to direct and indirect job creation. In a study in Iowa, USA, it was found that a first generation corn based bioethanol biorefinery (size) created 80 jobs directly and over 100 jobs indirectly[25]. In the UK, farmers incomes have been at a low point in recent history and the emergence of second generation biofuels represents an opportunity for an additional income stream from agricultural co-products.

The local production of biofuels derived from UK sourced biomass will reduce UK reliance upon imported crude oil. It is probable that the UK will import quantities of biofuels or the raw materials to make biofuels (such as vegetable oils and pyrolysis liquids). This situation needs to be carefully managed from an energy security perspective, as factors such as market forces and variable yields because of annual climatic conditions (which will be accentuated by climate change) will change biofuel availability and cost on an annual basis. The cost, in terms of carbon emissions due to fuel miles, should also be acknowledged for biofuel imports.

Second generation biofuels do not have to compete with food production as they can by produced from agricultural, forestry and municipal waste co-products. This is particularly important when the implications of increasing population and the effects of climate change are considered for food production globally. In order to boost national biofuel production arable land may be switched from food production to grow energy crops. In this scenario it is important that the implications for food production, for biodiversity and from the environmental impact of agrochemical usage are considered.

[25] From presentation of Jill Euken at the NNFCC Green Supply Chain conference, University of York, 2006