June 2011 Energy Research Partnership Technology Report

Bio-energy Technologies Review
Executive Summary and Recommendations

Energy Research Partnership

The Energy Research Partnership

The Energy Research Partnership is a high-level forum bringing together key stakeholders and funders of energy research, development, demonstration and deployment in Government, industry and academia, plus other interested bodies, to identify and work together towards shared goals.

The Partnership has been designed to give strategic direction to UK energy innovation, seeking to influence the development of new technologies and enabling timely, focussed investments to be made. It does this by (i) influencing members in their respective individual roles and capacities and (ii) communicating views more widely to other stakeholders and decision makers as appropriate. ERP's remit covers the whole energy system, including supply (nuclear, fossil fuels, renewables), infrastructure, and the demand side (built environment, energy efficiency, transport).

ERP is co-chaired by Professor David Mackay, Chief Scientific Advisor at the Department of Energy and Climate Change and Nick Winser, Executive Director at National Grid. A small in-house team provides independent and rigorous analysis to underpin ERP's work.

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Cover Images:* L** *- Farm vehicles harvesting a crop of young trees at a biomass demonstration project in Bruges, Belgium;* ***M *- View over a biofuel and sugar cane factor, in Sao Paulo, Brazil; and* ***R*** *- Pelletised wood used for heating stoves and boilers.*

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The Energy Research Partnership Technology Reports

The ERP Technology Reports provide an overarching insight into the Research, Development and Demonstration (R,D&D) challenges for key low-carbon technologies. Using the expertise of the ERP membership and wider stakeholder engagement, each report identifies the innovation challenges that face a particular technology, the state-of-the-art in addressing these challenges and the organisational landscape (both funding and R,D&D) active in the area. The work identifies critical gaps in innovation activities that will prevent key low-carbon technologies from reaching their full potential and makes recommendations for investors and Government to address these gaps.

The following have been involved in the ERP Bio-energy Technologies Review:

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Steering Group:

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Thanks also for the contributions of Professor Robert Lee (Shell Global Solutions) and Steven Vallender (National Grid).

This report provides a summary of high level findings from the review. The main report is available at **www.energyresearchpartnership.org.uk**

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Key Messages

There is substantial potential for the UK to develop a reliable, sustainable and economic supply of biomass and to encourage a multiplicity of uses for bio-energy. The potential importance of the role of bio-energy in the UK 2050 energy system and its significant contribution to attaining the 2050 goal of 80% reduction in greenhouse gas emissions, cost effectively, has only recently been fully realised. The extent of bio-energy's role would be increased by improvements in end-use technologies and in methods of supplying biomass, by taking advantage of good new ideas and, especially, by the support given to the deployment of bio-energy through development of the bio-energy supply chain. In addition, the sustainability of the wider economy may be enhanced by developing better understanding of the options for optimising land use. All of these issues are considered in this Review, which has been undertaken by the ERP in order to identify the opportunities and address the challenges to further development of bio-energy technologies by 2050. The Review, undertaken between May 2010 and January 2011, has involved structured interviews with 70 key people involved in bio-energy, both in the UK and internationally, and makes recommendations about UK bio-energy in 3 areas:

1. UK support for bio-energy

Substantial benefits would flow from a co-ordinated bio-energy strategy involving all relevant government departments and executive agencies. This should be facilitated by the Department of Energy and Climate Change which should be recognised as the Department responsible for leading the development and implementation of the strategy. The strategy should set long-term targets, make explicit the roles of domestic and imported supplies of bio-energy, and develop plans for utilisation of resources both within and outside government, including winning support from all relevant stakeholders. This review has also found that the government departments responsible for bio-energy policy would benefit from having deeper understanding of the specifics of bio-energy technologies. It is proposed that government should improve its capability in and access to expertise in bio-energy in order to develop more robust plans for the long-term[1].

2. UK research on bio-energy technologies

A number of existing areas of scientific research will underpin the successful development and deployment of bio-energy technologies, especially plant science, applied agronomy and conversion technologies. Continued support for research in a number of such areas is recommended as well as exploration of the potential in several prospective new ones which could become important by 2050, including:

- Growth of algae for energy as part of a broader study of these plants
- Bio-energy with CO_2 capture and storage
- "Drop-in" bio-fuels that could be substituted for conventional liquid fuels
- Development of large scale bio-refineries.

Each of these should be subject to preliminary assessment to confirm they have the potential for large-scale application with substantial reduction in specific greenhouse gas emissions at competitive cost.

3. Deployment of bio-energy

There is need for better information on land use, and improved understanding of how to optimise the use of available land to produce food, fibre and energy in a sustainable and cost-effective manner. It is also recommended that more work should be done with other countries through collaborative research programmes, which would allow the UK to benefit from advances elsewhere. The UK should also use its scientific and technical knowledge to assist other countries, including helping them understand their potential to supply part of the UK's bio-energy needs, including detailed assessment of the likely costs and sustainability. This would also assist bio-energy development globally. Development of improved methods of harvesting and transport suitable for use on marginal land, and of programmes of education for farmers about sustainable practices are also necessary. The EU's policy on genetically modified organisms should be reconsidered as many plant scientists believe this is inhibiting work in areas of great opportunity. It is essential that UK policy addresses concerns about financial risk along the whole bio-energy chain; without this there may not be sufficient incentive for farmers to dedicate land for biomass supply, or for users to deploy innovations in bio-energy, or to implement more sustainable practices.

The initial findings of the Review have been fed into Government since October 2010 and therefore some of the recommendations are in hand.

[1] The ERP is aware that an initiative has recently been started by the relevant Government departments to address this as a part of the DECC led cross-departmental Bio-energy Strategy refresh.

Summary

Introduction

Bio-energy is the production of energy from recently living biological materials (which are referred to as biomass). Use of bio-energy can provide benefits in terms of reduction in greenhouse gas emissions and as a means of lessening society's dependence on fossil fuels.

Biomass for energy can be used to provide heat, power and fuel for transport. There are many types of biomass (including purpose-grown crops, plant residues and waste materials, see Table S1) and many types of process that could be used to produce fuel from biomass (see Table S2). Growing biomass for energy can be an attractive crop for farmers but, in some cases, this would use land that might otherwise be used to grow food for humans or animals. Biomass may be used to generate bio-energy either in the form that it is harvested (such as by combustion in a boiler) or after conversion into bio-fuels designed for particular applications, such as liquid fuels for cars or aeroplanes. These and other issues, explored below, make consideration of the supply and use of bio-energy much more complicated than is the case for conventional fuels - especially where the sustainable biomass resource is limited. As a result it is difficult to gain a clear picture of the best options for future development of bio-energy. However, in view of the important benefits that widespread use of bio-energy could deliver, it is important to consider whether the understanding, planning and development of bio-energy in the UK could be improved.

In recognition of this, the ERP has undertaken a review of bio-energy technologies, in order to describe the opportunities and identify the challenges to further development of bio-energy technologies by 2050. This review provides the basis for understanding the role that research and development could play in addressing the opportunities and overcoming the challenges. Successful development of bio-energy technologies would need to be followed by UK-focussed demonstration as a key step before full-scale deployment could be expected.

A broad range of disciplines is involved in bio-energy; the supply chains are complex; many different players are already involved in researching and developing bio-energy applications. For these reasons, a global assessment of the state of development of the technology has been undertaken across all stages of the supply chain. This review has looked for key gaps in the UK capacity for bio-energy research, development and demonstration (R,D&D) as well as in deployment of bio-energy. It has also sought out the structural barriers that may reduce the effectiveness of UK policy in this area.

How has this review been undertaken?

This review has involved structured interviews with 70 key individuals concerned with the development and deployment of bio-energy, both in the UK and internationally. In addition, an international survey of bio-energy work has been carried out, as well as an assessment of UK capacity for bio-energy research and development. The project has been conducted by the ERP Analysis Team with input from ERP's Bio-energy Technologies Steering Group. Additional input was also sought from a number of outside organisations. The main report is available at www.energyresearchpartnership.org.uk

Introduction to bio-energy

Use of bio-energy reduces greenhouse gas emissions by utilising biomass to displace fossil fuels used in heating, power generation or transport. Because the growth of plants draws down carbon from the atmosphere, the eventual combustion of the biomass to produce energy releases more or less the same amount of carbon, making the process theoretically neutral in its effect on the concentration of carbon in the atmosphere. The production of biomass - planting, harvesting and conversion or the utilisation of waste - does have a carbon penalty, which for bio-energy to be beneficial, should be smaller than the fuel that it is substituting.

By using plants as feedstock to produce fuel, the UK would gain an alternative supply of energy that could reduce dependence on fossil fuels, much of which is and in the future will increasingly be imported. This is particularly important for sectors where there are few alternatives, such as road transport and, especially, aircraft. At the same time, growth of edible plants for fuel could divert them from food supply, something which is thought to have contributed to recent spikes in the prices of agricultural commodities. There are also concerns about the impact of widespread growth of single crops on biodiversity and also about the effects of intensified agriculture on water supplies. Coupled with these factors, there is also uncertainty about bio-energy's precise contribution to tackling climate change (not all forms of bio-energy are as beneficial as the best ones) and about the sustainability of some bio-energy approaches. These problems and uncertainties have, to some extent, inhibited the deployment of bio-energy.

What has been learnt about the potential for wider use of bio-energy in the UK?

It is confirmed by this review that bio-energy could make a significant contribution to the UK's 2050 energy system[2] in a cost effective manner[3]. It would also make an integral contribution to the goal of 80% reduction in greenhouse gas emissions by 2050 but the extent and focus of the contribution is subject to considerable uncertainty due to the range of options and the inherent competition for biomass supplies with other uses, the complexity of some bio-energy supply chains, and the very fragmented nature of innovation in bio-energy technologies. Development of a bio-energy supply chain would enable the UK to meet some of the country's anticipated demand for biomass from domestic sources; the rest would have to come from imported supplies. This underlines the importance of developing our own expertise and engagement and cooperation with other countries in order to ensure that supplies will be available in the future that meet the UK's needs.

In order that UK users have confidence in the reliability of supplies of biomass and bio-fuels, it is essential that an efficient domestic system is developed for production of these fuels, at a scale substantially greater than has so far happened. In order to improve the competitiveness of bio-energy in the UK, new science and technology can be brought to bear, as this has potential for increasing the supply and reducing the cost of bio-energy; UK has leading expertise in several important aspects of this science and technology. For example, amongst others, in the areas of fundamental plant science, micro and macro-algae, fermentation, pyrolysis, we also have industrial capacity for some thermo-chemical routes and bio-chemical routes.

Table S1: Some types of plants used to produce biomass for energy
Sugar cane
Sugar beet
Maize
Rape
Sunflower
Willow
Miscanthus
Poplar

Table S2: Some methods of processing biomass to bio-fuels	
Biomass may be processed in a number of ways to produce intermediate products (that require further treatment), or final fuels, or both. These processes include:	
Drying	Anaerobic digestion
Dedicated combustion	Fermentation
Co-firing	Hydrolysis
Gasification	Methanation
Pyrolysis	Esterification

Opportunities for improving the supply chain

At the start of the chain of supply and use, more systematic procedures are needed for optimising land use between the production of food, of materials and of bio-energy. In this way the expansion of UK capability for bio-energy can take place without risk of serious impact on the national food supply. Bio-energy also provides a route to make productive use of waste materials from various sources, including municipal solid waste.

The type of plants and biomass to be grown will be influenced by the end-use of the bio-energy (e.g. whether in heating, power generation, or transport) which determines the degree of processing needed (examples are given in Table S2). Power generation can use biomass straight from the field with relatively little treatment; based on present technologies the most attractive approach is co-firing with fossil fuels although power plants fuelled purely with biomass are also being developed. The use of biomass in heating, such as for domestic use, is likely to be best used in large installations due to the requirements for handling and storage of the fuel. However this means that the application will be constrained by the acceptability of local district heating schemes, which are not widely used in the UK, or in local combined heat and power systems (CHP) that may need more highly processed bio-fuels. The type of bio-fuel which has probably received the most publicity is that used in transport; for this purpose a liquid fuel is likely to be required, especially one that could be "dropped-in", i.e. without needing modifications to the vehicle (some options are shown in Table S3). One country, Brazil, has made major changes in its vehicle fuelling system by nationwide supply of ethanol derived from sugarcane. The UK has a different climate and does not have the same availability of land so alternative approaches are being developed although the potential may be more limited than in Brazil. At the same time, several competing methods of fuelling vehicles are also being developed (e.g. electric, compressed natural gas, hydrogen

[2] Recent modelling undertaken by the UK Energy Research Centre MARKAL, the Energy Technologies Institute Energy System Model Environment (ESME) and the DECC 2050 Pathways Calculator suggest a contribution of over 10%.
[3] The ETI ESME suggests that the non-deployment of bio-energy technologies has an opportunity cost of the order of £10's of billions.

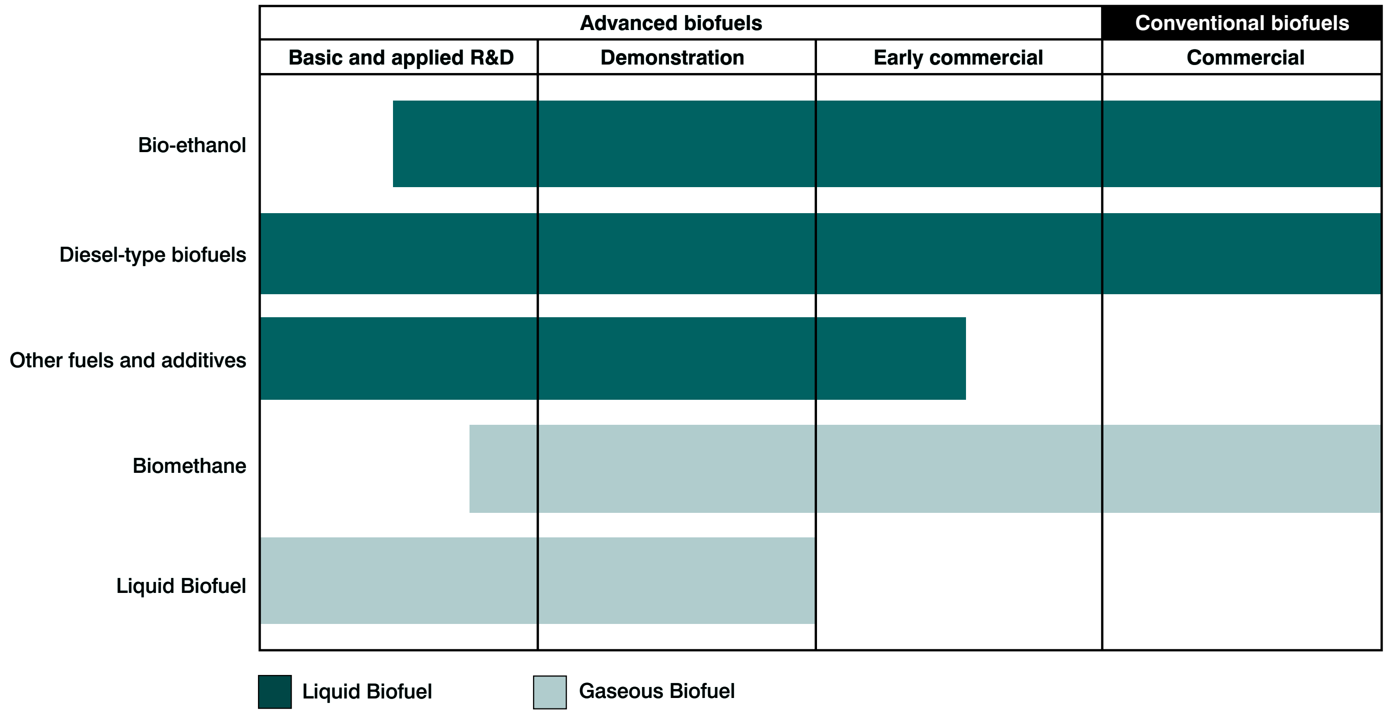
Table S3: Examples of the range of bio-fuels considered for transport uses	
Blended with conventional fuels and/or requiring vehicle modification	**Substituted for existing fuels without vehicle modification**
Ethanol (to legislated percentages)	**Syndiesel**
Bio-diesel (to legislated percentages)	**Upgraded pyrolysis oil**
DiMethylEther	**Synthetic petrol**
Butanol	
Methanol	
Bio-methane	
Hydrogen	

vehicles, etc.), some of which could also achieve the goal of reducing greenhouse gas emissions, so the future demand for bio-fuels is the subject of much debate. In contrast for aircraft and long haul road freight, which also use a substantial amount of hydrocarbon fuels worldwide, there are no alternatives currently in prospect for major reduction in greenhouse gas emissions which suggests the use of bio-fuels in aviation and road freight may take priority over light duty road transport. Relatively little consideration has been given to marine uses of bio-fuel, which also warrant attention. A means of prioritising the use of bio-fuel is needed, as is development of a consensus on how the results should be implemented.

A number of obstacles to the wider use of bio-energy in the UK have been identified through this work including the following:

- In relation to production of biomass, there may be competition for use of land between production of food, fibre and biomass for energy - particularly for presently utilised biomass though less so for future dedicated bio-energy biomass which can be grown on non-arable land. Also, the optimum forms of biomass that should be grown in any particular location are not yet clear.
- As regards transport of biomass, the sheer volume of matter to be moved raises issues about which systems would be acceptable for large-scale transport; the advantages of the pre-treatment of the biomass to reduce bulk are not clear.
- International trading of bio-fuels is inhibited by lack of agreed standards.
- The economics of the stationary production of heat and power. In the case of the utilisation of biomass for stationary production of heat and / or power, some options are already relatively well developed so this technology could be deployed on a wider scale once the economics justify investment in production and use of the fuel, and a reliable supply is available to the end-user.
- The conversion of biomass into transport bio-fuels is the subject of significant debate. Issues include identifying and agreeing on which are the most important sectors to address, understanding the infrastructure requirements and whether the optimal fuel would be one that is blended into conventional fuels or whether it would be one that has to be handled and used separately from existing fuels. In addition there may be a need for vehicle makers to develop and deploy vehicle power-trains adapted for bio-fuels. There is also a lack of appreciation of the role of bio-fuels for marine uses. The state of development of the various transport bio-fuels varies considerably, as shown in the figure below.

In view of the great potential benefits of bio-energy, the range of challenges to deployment must be addressed. This can best be done by a clear and focussed national strategy, that has broad stakeholder support.



The state of development of technologies for producing transport bio-fuels (adapted from Bauen et al[4])

Commerical biofuels include: bio-ethanol which is produced from sugar and starch crops; bio-diesel which is produced by the transesterfication of oily crops; and biomethane production from biogas generated by anaerobic digestion. It is noteworthy that these biofuels are only commercially viable due to regulation and policies.

Those technologies that are at the basic and applied R&D to early commercial are termed advanced bio-fuels.

What needs to be done?

There are key areas which would benefit from global R,D&D. These include aspects of the production, supply, conversion and use of bio-energy:

- Improved understanding of the factors which will influence demand for bio-energy; this would highlight the areas of greatest uncertainty so that account could be taken of them in scenario planning; this would also help to identify the least-cost actions that could have greatest effect in stimulating the use of bio-energy.
- Improve the understanding of how the production and costs of biomass development varies with location and conditions, so as to optimise the planning of supply. This needs to be done on relatively large-scale (>1ha) plots to generate representative data. Plant science should be deployed to enhance the production of current and dedicated energy crops and improve the economics and sustainability of this part of the process. In this vein, the EU's policy on genetically modified organisms should be reconsidered as many plant scientists believe this is inhibiting work in areas of great opportunity.
- Related to the above, the sensitivity of the economic viability of bio-energy to transport costs makes the need for assessment of spatial issues, logistics and value chain impact vital to the optimising of the use of bio-energy in the energy system.
- A range of feedstocks should be examined for biomass production in the UK and worldwide; this should prioritise the optimisation and the development of new applications for conventional crops as well as investigation of the value of unconventional biomass such as from algae, and development of better ways of using waste streams, especially cellulosic residues.
- Current technology is being used to produce heat and power from biomass at present. Further improvements in this technology will be possible but the rate at which the end-user makes these changes is likely to be determined by the economics of the process and the reliability of biomass supply. Specific action on these aspects of the supply is needed to encourage the wider deployment of bio-energy. In addition there are various novel approaches which would benefit from further development

[4] Bauen, A., Berndes, G., Junginger, M., Londo, M., and Vuille, F. **2009**, Bio-energy - a sustainable and reliable energy source. A review of status and prospects., IEA Bioenergy: ExCo: 2009:06.

in order to demonstrate their commercial potential (such as biomass combined heat and power systems, and novel power generation technologies such as large-scale gasification).

- The many options for advanced transport bio-fuels each have their own advantages and disadvantages which suggests that the range of possibilities will only be reduced once these products are closer to the market. A better understanding of how the fuels will integrate into the fuel supply system should help to distinguish the features of each bio-fuel option in terms of blending with conventional fuels, handling, distribution and end-use, especially the compatibility with the existing and future vehicle fleet. "Drop-in" fuels may be developed as substitutes for existing fuels but there is a need for a suitable policy and accounting framework that recognises these types of fuels. There are many options for conversion of biomass into bio-fuels and many of the processes are proprietary which suggests that work is required by a cross-industry body to illuminate society's understanding of the relative merits of the various options. Transport fuel is an internationally traded commodity so the UK should engage in international forums to ensure future fuel developments conform to international market needs and so that international transport fuel specifications reflect the opportunities for bio-fuels.
- Bio-energy supply systems are inherently more complex than the systems for supply and use of conventional fuels. Understanding the options is important but this must be done on the basis of the whole system; such analysis must take account of changes in land use consequent upon rising demand for biofuels, including the competition with growth of crops for food and other uses; the analysis must also take account of the balance of greenhouse gas emissions since the more processing that takes place, the smaller may be the reduction in CO_2 emissions; in addition it is very important to consider the sustainability of each bio-energy option and to be able to demonstrate that the claimed benefits can be achieved. One means of presenting such information is through the use of Life-Cycle Analysis (LCA); this needs to be done in a transparent, standardised and unbiased manner if the results are to be accepted by society at large; international cooperation on development of LCAs for bio-energy is essential.
- Several new opportunities have been identified in recent years which could have long-term potential for improving the prospects for bio-energy; because of their novelty they are mostly too risky for private sector activity, except perhaps as a watching brief. These opportunities include:
  - Large-scale bio-refineries, which would make a variety of energy and non-energy products from the biomass[5]
  - Bio-energy production with CO_2 capture and storage (BECCS) which offers the possibility of increasing the draw-down of carbon from the atmosphere (i.e. "negative emissions")
  - Engineering of the waste from production of biomass as "biochar", something which could be used to sequester carbon in the soil rather than releasing it to the atmosphere.

Recognising that the several technologies being addressed are at different stages of development there is a need for a flexible process for ongoing understanding and evaluation of options, in order that the best uses of biomass can be identified on a sound and rational basis.

Improvements in UK policy and plans for bio-energy

Although there is growing consensus about the important contribution that bio-energy could make towards achieving the UK's renewable energy targets, the development of policy and planning for bio-energy is hindered by the complexity of the issues. Unlike conventional fuels, there are many potential sources of biomass, each with their own costs, logistics and regional features, which means that national planning cannot easily develop a detailed picture of the future supply of biomass; this problem is exacerbated by the many options available for processing and distribution of bio-fuels, especially in transport applications, so that decisions about the future of bio-energy in some sectors will have to be taken in circumstances of considerable uncertainty.

These problems are reflected in the difficulty that potential users have in deciding on future use of bio-energy since the availability of supplies and the cost of them will be very much subject to government policy. With such uncertainty, identifying and selecting the most appropriate targets for R,D&D is especially difficult, not least because of the number of bodies in government and in executive agencies with responsibility for some aspect of bio-energy policy or implementation (for example, see Table S4).

[5] The ERP is aware that, as a part of the European Industrial Bio-energy initiative, the Centre for Process Innovation and the National Non Food Crop Centre is seeking to submit a proposal to develop a pilot large scale biorefinery in the UK.

Table S4: Some of the UK public and public/private bodies involved with bio-energy	
Government Departments	**Executive Agencies and others**
Department of Energy and Climate Change	5 Research Councils
Department for Transport	Technology Strategy Board
Department for Environment, Food and Rural Affairs	Carbon Trust
Department for Business Innovation and Skills	Energy Technologies Institute
Department for International Development	Forestry Commission
Foreign and Commonwealth Office	UK Energy Research Centre
HM Treasury	Environment Agency
	Devolved Administrations
	Regional Environment Agencies

It is recommended that the following would be appropriate actions for the UK Government to improve the capacity and reliability of bio-energy supply chains and end-uses in the UK:

- Provide a clear vision of the role that bio-energy is expected to play in the UK.
- Implement this vision by developing an up-to-date national policy and strategy for bio-energy.
- In recognition of the many government departments and executive agencies involved in bio-energy, identify and/or clarify the roles and responsibilities of those implementing each aspect of bio-energy policy.
- Gain industrial and institutional support for such a policy, which would be greatly aided if a framework could be developed that enhanced financial security along the supply chain.
- All of these steps are contingent upon government having sufficient understanding of the interaction and trade-offs between the different aspects of bio-energy. Developing such understanding would be facilitated by access to suitable expertise in all aspects; this could be achieved by increasing the level of specialist knowledge available to the appropriate government departments[6].
- Because of the complexity of the issues and the multiplicity of players in bio-energy, it is more than usually important that there is clear leadership of policy development and implementation of bio-energy policy. It is suggested that this can be best achieved by giving one Department the leadership in bio-energy with commitment from related departments to implement the policies in their areas of accountability.

A number of areas of bio-energy technology have been identified that are prospective and which could become important by 2050; taking account of UK areas of expertise, these would be suitable for long-term, directed research funding:

- Improvement of bio-energy crops, through use of fundamental plant science and applied agronomy.
- Development of liquid fuels that could be used as direct substitutes for conventional fuels (“drop-in” fuels).
- Exploration of the potential of algae as a competitive source of bio-fuels, including a consideration as to whether other applications of algae could help establish algae production in the early stages.
- Examination of the potential for Bio-energy with CO_2 Capture and Storage as a “negative emissions” technology.
- Identification of key gaps that could be overcome in order to strengthen the bio-refinery concept.

In these and other respects, there is need for co-ordination of research planning in government departments, in the Research Councils and with the private sector, so that key aspects are not missed and to avoid unnecessary duplication. The development of a unified, open source database of UK bio-energy capacity and of bio-energy projects would very much help this coordination. The Research Councils should be encouraged to build on the work of BBSRC Sustainable Bio-energy Centre (BSBEC) and SUPERGEN Bio-energy I and II and the emphasis given to the application and market-related aspects of proposals for directed-funding research. It is also suggested that the Research Councils should consider further encouragement for multi-disciplinary research in bio-energy, and that key elements of bio-energy research should be concentrated at particular establishments with significant funding for an extended period, such as 5 years (with strategic review half way through). If the UK were to collaborate with international leaders in bio-energy, such as Brazil, USA and certain European Countries - subject to the appropriate `fit’ - this would allow all parties to make best use of existing resources. If the UK expects to import a significant fraction of its bio-energy needs, collaboration with potential supply countries should also be encouraged to enhance the development of sustainable exports suited to UK needs.

[6] The ERP is aware that an initiative has recently been started by the relevant Government departments to address this as a part of the DECC led cross-departmental Bio-energy Strategy refresh.

Recommendations

This review makes recommendations about UK bio-energy in 3 areas:

- Management of the UK support for bio-energy
- Focus of UK research on bio-energy technologies
- Support for development and deployment of bio-energy

Management of the UK support for bio-energy.
This review has identified that substantial benefits would flow from a co-ordinated bio-energy strategy involving all government departments and executive agencies concerned with the subject. This should be facilitated by the Department of Energy and Climate Change which should be recognised as the department responsible for leading the development and implementation of the strategy. There is insufficient information available to develop a comprehensive 2050 strategy based on what we know now. For example, there is a need to better understand the impact of soil organic carbon and value chain issues to avoid locking bio-energy into parts of the energy system which may not be economic or sustainable in the long term. However, there is sufficient information to develop an informed strategy that can be improved with time. The strategy should set long-term targets, make explicit the roles of domestic and imported supplies of bio-energy, and develop plans for utilisation of resources both within and outside government including winning support from the relevant stakeholders. This review has found that there is a significant gap in the government departments responsible for bio-energy policy in that they are insufficiently staffed with people having the necessary understanding of the specifics of bio-energy technologies. This is all the more salient when consideration is made of the potential substantial contribution that bio-energy can make to the UK 2050 energy system and the economic benefits of doing so. It is proposed that government should improve its capability in and access to expertise in bio-energy in order to develop more robust plans for the long-term[7].

Focus of UK research on bio-energy technologies.
It is strongly recommended that there should be continued support for research in a number of existing areas that will underpin the successful development and deployment of bio-energy, such as plant science, applied agronomy and conversion technologies, with exploratory work in a number of new areas including use of algae for energy, bio-energy with CO_2 capture and storage, investigation of the potential for liquid "drop-in" bio-fuels that could be substituted for conventional fuels, and investigation of the opportunities for development of large scale bio-refineries. Each of these should be subject to preliminary assessment to confirm they have the potential for large-scale application and substantial reduction in specific greenhouse gas emissions at competitive cost.

Support for development and deployment of bio-energy.
This review has identified the need for better global information on land use, and understanding of how to optimise the use of available land to produce food, fibre and energy in a sustainable and cost-effective manner. It is also recommended that more work should be done with other countries through collaborative research programmes, which would allow the UK to benefit from advances elsewhere. The UK should also use its scientific and technical knowledge to assist other countries, including helping them understand their potential to supply part of the UK's bio-energy needs, and detailed assessment of the likely costs and sustainability. Development of improved methods of harvesting and transport suitable for use on marginal land, and of programmes of education for farmers about sustainable practices are also necessary. It is essential that UK policy addresses concerns about financial risk along the whole bio-energy chain; without this there may not be sufficient incentive for producers to dedicate land for biomass supply, or to make use of innovations in bio-energy, or to implement more sustainable practices.

[7] The ERP is aware that an initiative has recently been started by the relevant Government departments to address this as a part of the DECC led cross-departmental Bio-energy Strategy refresh.

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