Working Paper: Plant Genomics and the Bioeconomy (March 2007)

CASE STUDY ON BIOENERGY

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I. Workshop rationale and aims: the need for a holistic approach to bioenergy

This workshop will (1) discuss the socioeconomic, scientific and policy context in which bioenergy development is taking place, and (2) map out different stakeholder perspectives and activities in light of this context, with the aim of capturing the dynamics of bioenergy development in the UK and identifying possible opportunities, synergies, conflicts and pressing needs. This exercise should provide a valuable opportunity for networking and discussion among a group of diverse stakeholders in the bioenergy debate. In light of the workshop deliberations, we will aim to produce a series of 2-page briefs or perspectives that capture the trajectory of bioenergy development in the UK, highlighting trends, emerging opportunities and issues requiring attention.

Context

Biomass is receiving renewed attention in several arenas as a source of 'carbon-neutral' renewable energy. The development of a bioenergy industry is often cited as making a positive contribution to the policy goals of combating climate change (by cutting greenhouse gas emissions), securing energy supply (by reducing dependence on foreign oil reserves), and stimulating the rural economy (by providing new markets and employment opportunities for the rural sector), as well as to the broader goal of sustainable development and well-being.

However, the landscape for bioenergy R&D is complicated and finely balanced, being distributed among many stakeholders and set against a backdrop of existing regulatory frameworks and policy targets for climate change, environmental protection, land use and Common Agricultural Policy reform, transport, trade, and energy supply. Furthermore, and despite strong political goodwill towards bioenergy development, a robust economic case for bioenergy has not been systematically made, and it is increasingly apparent that there are a number of complicated social and environmental implications to consider.

This being said, there is a great deal of activity and increasing public attention is being focused on bioenergy development and implementation. Whether this activity is appropriately coordinated is another matter — the policy frameworks and targets guiding bioenergy development in the UK are often cited as fragmented in approach, with several different agendas resulting in inconsistent support mechanisms and incentives to foster a fledgling bioenergy industry.

There are several reviews and activities currently underway to try and increase the coordination of bioenergy research, development and implementation, within (and among) academic, industrial, public sector and policy circles. Even so, most of the studies and reports published in recent years approach the question of bioenergy development from a fairly specific perspective (for example, biofuels for transport). This seems like an opportune time to start integrating some these different perspectives, and to push the discussion forward with a more holistic or 'systems' approach to bioenergy development in mind.

The challenge for this workshop is to try and capture the current dynamics of the bioenergy sector in a holistic manner, taking an almost 'structural' approach to assessing the trajectory of bioenergy development in the UK. This will involve mapping out bioenergy issues from a number of perspectives, identifying possible tensions, synergies and opportunities, and considering how governance frameworks, policy targets, financial incentives, stakeholder relationships and developments in science and technology are influencing bioenergy development. To do this effectively, we hope to assemble a small but highly interdisciplinary group of experts from across the spectrum of stakeholders involved in the bioenergy debate.

The notes that follow are intended to stimulate thinking and discussion on the topic of bioenergy, rather than provide a comprehensive overview. A brief outline of different policy areas, research questions and socioeconomic issues implicated in bioenergy development is presented, to begin setting the context or backdrop against which bioenergy development is taking place.

Bioenergy and the Bioeconomy

A parallel aim of this workshop is to start framing the issue of bioenergy as part of the emerging concept of the **bioeconomy**[1]. This notion of a bio-based economy links the goals of economic prosperity and growth with the sustainable development agenda.

Bioenergy is just one potential commodity in the emerging bioeconomy: improvements in our ability to harness biological processes for practical applications will almost certainly affect sectors as diverse as health, industry, environment, agriculture, energy and security. Rather than assuming traditional divisions between these sectors, the OECD has identified a need to consider the convergence and integration of "research domains, technologies, economic infrastructures, and government practices", and is currently working on a long-term roadmap for policy formulation relating to the bioeconomy[2]. Furthermore, the policy and regulatory frameworks currently governing activities related to bio-science are identified as "often unsuited to the economic, social, and ethical issues now emerging".

Considering bioenergy as an example or case-study within the bioeconomy, it seems clear that academic research disciplines are converging, as are traditionally distinct economic and industrial sectors and policy areas. How can consistent but flexible governance frameworks be developed to promote and appropriately regulate the development not just of a bioenergy industry, but of a bio-based economy more generally?

> *"Civilization's ability to meet this immense challenge clearly depends on our strengths in natural science and engineering. But it also depends on our strengths in the social sciences and in 'social technology' in the form of business, government, and law, as well as on the societal wit and will to integrate all of these elements in pursuit of the sustainable-well-being goal."*
> — Holdren, J.P. *Science* **315,** 737 (2007).

The Genomics Policy and Research Forum exists to foster discussion and debate among natural scientists, social scientists, policymakers, business leaders and civil society on matters relating to the development of new life science technologies. The bioeconomy will no doubt become an increasingly prominent issue in academic, industrial, policy and public arenas, and it seems worthwhile to start engaging with the possible implications of such a transition now.

Can the dynamics within the bioenergy sector be viewed as an indication of what might occur in other emerging sectors of the bioeconomy?

[1] A working paper on plant genomics and bioeconomy is available to download from the Genomics Forum website.
[2] OECD 2006 Scoping Document *The Bioeconomy to 2030* (p.5).

II. Context and policy landscape for bioenergy development

> "…researchers and policymakers see a perfect storm of political attention, rising oil prices, fear of environmental impacts from fossil fuels, and new genomics tools that can modify plants and microbes." — *Nature* **444,** 648–640 (2006).

A successful bioenergy industry in the UK should contribute to multiple policy arenas, including energy, environment, agriculture, trade, transport, and sustainable development. This being said, most published reports and public debates relating to bioenergy seem to approach the issue from a single, reasonably specific policy perspective (see section VIII). Furthermore, many bioenergy-related discussions are specific to one of the following variables:

- **Geographical scale.** Issues relating to bioenergy can be considered at many different scales — which is most appropriate for the given question? Local (decentralization/microgeneration), national (UK), regional (EU), international (global trade).

- **Biomass source.** Over 100 types of biological waste can be used as bioenergy feedstock (for example, dedicated energy crops, forest material, municipal waste, algae, etc), and many possible supply chains for bioenergy production are possible.

- **Application for bioenergy.** Principal applications for bioenergy include biofuels for transport, biomass for electricity generation (including through co-firing in coal plants), and biomass for combined heat and electricity.

Although such levels of specificity are clearly important for the development of individual bioenergy supply chains (see section VI), how can these variables be accounted for when it comes to integration and policy formulation at a more holistic or systems level?

In addition to these variables, a number of different policy areas and socioeconomic issues are implicated in bioenergy development (see Figure 1).

In this complicated landscape, what are some of the main drivers, tensions and trade-offs with regards to bioenergy development? How might we begin to integrate different agendas and perspectives to develop a consistent approach to bioenergy?

This section will (1) very briefly summarize some of the main socioeconomic and policy issues associated with bioenergy development, (2) identify growing debates taking place with regards to bioenergy, and (3) highlight some of the key drivers and policy interventions that stand to shape the development of a bioenergy industry in the UK.

Climate Change

Although it might seem more appropriate to begin any discussion of bioenergy with reference to the wider energy context, the UK government has identified climate change and the need to reduce carbon dioxide emissions as the principal driver for bioenergy development (e.g. Defra's 2005 *Biomass Task Force Report*). This is in contrast to other EU member countries developing bioenergy industries, where energy security is seen as the primary driver (2006 House of Lords report). This being said, climate change issues are closely linked to energy concerns (for example, the 2003 *Energy White Paper* made recommendations for carbon dioxide emission targets).

The UK has a Kyoto Protocol commitment to reduce greenhouse gas emissions by 12.5% below 1990 levels by 2008–2012, and there is a national goal for a 20% reduction in carbon dioxide by 2010. On a longer timescale, the UK government is working towards a 60% reduction in carbon dioxide emissions by 2050.

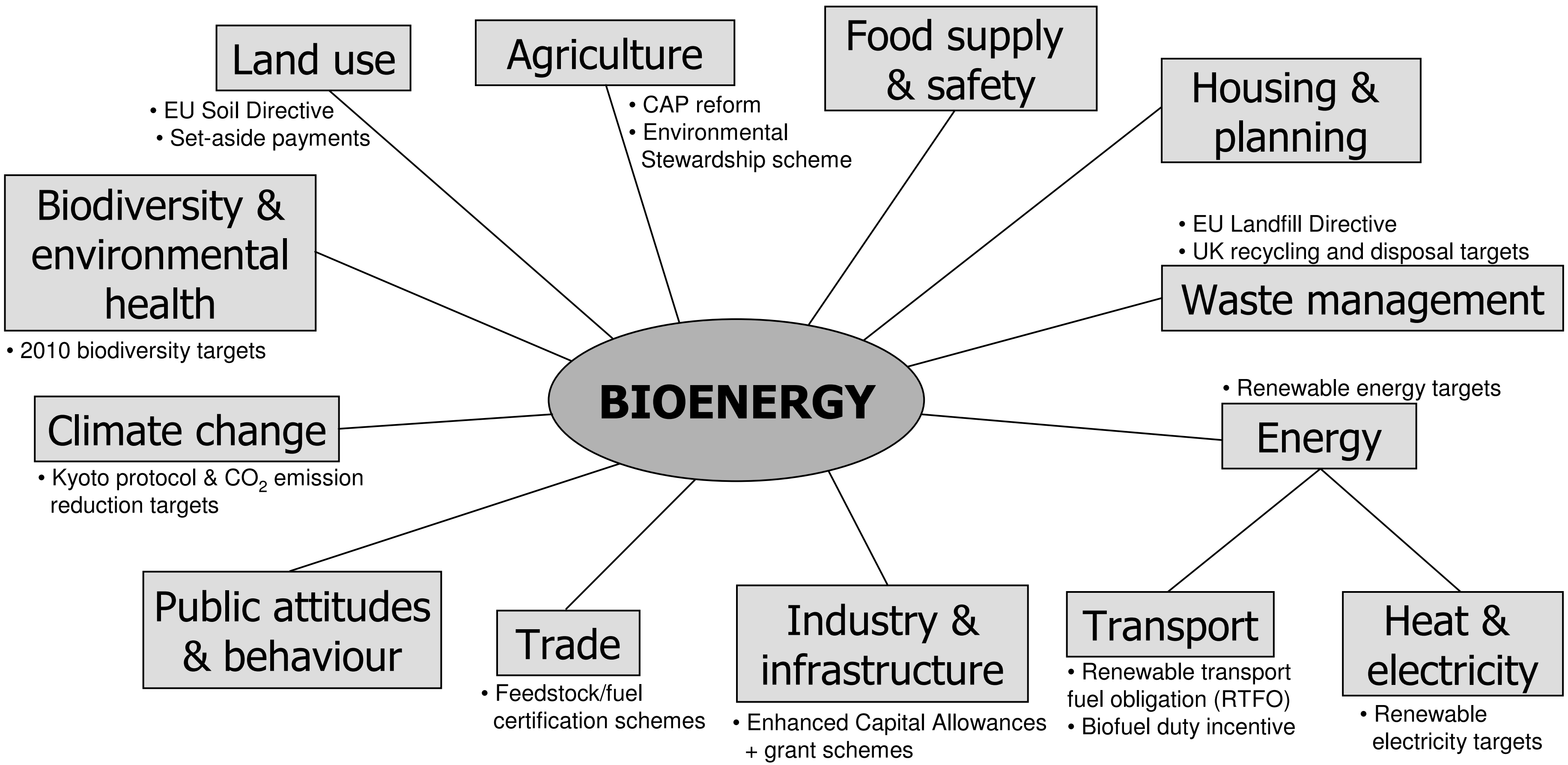

Figure 1. Socioeconomic issues and policy areas implicated in the development of a national bioenergy industry. Included are some examples of policy targets and incentives that may influence the trajectory of bioenergy development. Where do some of the main tensions and trade-offs lie in this picture? How are the relationships between different areas and stakeholders changing through bioenergy development and the emergence of a bio-based economy? How can a consistent approach to bioenergy development be fostered in light of this complexity?

The possible contribution of biomass to reducing CO_2 emissions is not entirely clear-cut. Net emission levels must be determined on the basis of the entire bioenergy production life cycle, taking account of the crop variety, farming methods (e.g. pesticide/fertilizer use), harvesting, collection and transport of plant material, biomass processing, by-product purification, waste treatment, and bioenergy storage and distribution.

How does bioenergy compare to other low-carbon technologies when it comes to reducing CO_2 emissions?

Are existing governance frameworks and research strategies regarding bioenergy (and other energy sources) in the UK consistent with a primary goal of reducing carbon dioxide emissions?

Energy Supply and Security

Global context

Energy is a global issue. Currently, 80% of the world's primary energy comes from oil, coal and natural gas. Global energy needs are likely to grow steadily for at least the next 25 years, with an average annual growth rate of 1.2–1.6% (Birol, 2005). A number of economic, geopolitical and environmental factors (including high oil prices, supply instability, and climate change concerns) are contributing to the revived interest in renewable resources. With oil prices likely to remain high in the foreseeable future, concerted investment in the development of alternative energy sources is increasingly seen as a sound strategy.

National context

A recent enquiry by the Royal Society of Edinburgh (RSE) into energy issues for Scotland (June 2006) identified as its core aim the achievement of a "secure, competitive, socially equitable and low carbon emissions supply of energy" (p.3), based on the use of a mixture of energy sources and technologies. Arguably, the UK will require a 'step-change' in its energy system, involving both energy production and consumption patterns (Ekins, 2003) — energy efficiency should be central to any such strategy.

The UK government has set a target of 10% of electricity supply from renewable energy sources by 2010.[3] Some EU countries have thriving renewables sectors: for example, Austria produces 70% of its electricity from renewable sources, and Sweden aims to stop using oil for energy purposes by 2020 (John, 2006). Recent reports suggest that success in these and other EU member states is owed to a consistent but flexible set of market support measures and financial incentives (2006 House of Lords report). At present, the UK government is not seen to have a coherent and integrated energy strategy (RSE enquiry, 2006).

Renewable sources of energy include onshore and offshore wind, geothermal, tidal, hydroelectric, photovoltaic, landfill 'biogas', and biomass. Biomass is in theory a carbon-neutral source of renewable energy (although estimates vary), and has the advantage that it can be stored and supplied on demand. It is a potential source of both heat and electricity, and is suitable for use on small and large scales, in both rural and urban environments, and for domestic, commercial and industrial applications. However, it is ultimately a limited resource owing to the land required for biomass production. Transportation and storage of biomass can be prohibitively expensive, and the capital costs involved in building biomass processing plants are high compared with fossil fuel processing. At present, wind power seems to be the only economically viable and scaleable renewable energy technology in the UK (Renewables Innovation Review, 2004).

What is the role for bioenergy among other energy options in the UK? What role can it be expected to play in the short-, medium- and long-term?

[3] In 2005, about 4% of the UK's electricity supply came from renewable energy sources (see http://www.dti.gov.uk/energy/sources/renewables/index.html).

Biofuels for transport

The road transport sector accounts for 30% of total energy consumption in the EU, and is based almost exclusively on the use of petroleum products, most of which are imported (House of Lords report, 2006). Substitution of fossil fuels with biofuels would reduce necessary oil imports, and biofuels are the most easily deployed existing technology for reducing carbon dioxide emissions by the transport sector[4]. Brazil started developing a bioethanol industry in the 1970s (using sugarcane), and bioethanol now forms 40% of its automotive transport fuel (Marris, 2006). Currently, biodiesel produced in some European states is just about economically competitive without subsidies, but bioethanol is not[5].

European targets for biofuel use in transport have been set in Directive 2003/30/EC: a minimum of 5.75% biofuel as a proportion of total transport fuel sales is required by 2010. In terms of its investment in biofuels, the UK lags behind much of the EU. However, government measures have recently been introduced, including a 20p/litre duty incentive on biodiesel and bioethanol, and capital grants to help build biofuel production facilities. A renewable transport fuel obligation (RTFO) will be introduced from 2008, which requires transport fuel suppliers to have a minimum proportion of their overall fuel sales from renewable energy sources (2.5% in 2008–9, rising to 5% by 2010–11) (UK Department for Transport, 2006). It is unlikely that these targets will be met without importing biofuels.

Biomass for heat and electricity

Over one-third of the primary energy used in the UK is for heat. Combustion of biomass for heating has been identified as the most cost-effective use of biomass in terms of carbon emission savings (Carbon Trust 2005 report). Furthermore, studies also suggest that non-fuel applications of biomass are ecologically more efficient than the use of biomass as fuel for transport (Slingerland & van Geuns, 2005). Consistent with these findings, the European Environment Agency recently released a report advocating the burning of energy crops for power, instead of conversion to biofuels for transport[6]. Despite this recognized potential, when the Royal Commission on Environmental Pollution (RCEP) published its 2004 report *Biomass as a Renewable Energy Source*, it noted that there was no financial support from government for heat or combined heat and power (CHP) from biomass.

This is starting to change, for example with the recent launch of Defra's Biomass Capital Grant Scheme to fund the installation of biomass heating and CHP projects at industrial, commercial and community levels. Market barriers to the use of biomass for heat and electricity include the capital costs for CHP plants (3–6 times more expensive than for fossil-fuel alternatives), and the high cost of transporting wood (AES/Defra conference report, 2007). Co-firing of biomass in coal plants (which can burn up to 20% biomass) has been identified as a useful way of getting the sector off the ground, by helping to establish supply chains and making a contribution to CO_2 emission reduction (2004 RCEP report, p.42).

Local, small-scale production or 'microgeneration' of heat and electricity by individual homes or small communities is increasingly being acknowledged as a practical and economically attractive use for biomass. This type of distributed generation is also seen to offer opportunities to engage local communities to develop a sense of ownership and responsibility for energy production and consumption (see below).

> Which of the emerging bioenergy sectors and supply chains have dominated the development of the field? How would you position the emerging sectors in terms of relative potential?

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[4] Existing vehicles can burn pure biodiesel or mixtures of up to 10% bioethanol with no modifications to their engines or changes to petrol station infrastructure. 'Flex-fuel' cars can use higher ethanol concentrations, and adjust their workings on the basis of different petrol–ethanol mixtures (Marris, 2006). Alternative fuels such as bio-derived hydrogen and methane still pose practical and technological challenges (Herrera, 2006).

[5] Based on crude oil prices of about $76 per barrel (NFU report, 2006). Biodiesel breaks even at oil prices of about $76 per barrel, but bioethanol becomes competitive only at prices of $133 per barrel.

[6] *Transport and Environment: On the Way to a New Common Transport Policy.* EEA Report 1/2007, Feb 2007 (p.25).

Agriculture and Land Use

The UK has about 18.5 million hectares of land at its disposal, facing competing demands for food production, energy production, and environmental and recreational use. In 2004, less than 0.01% of the total arable land in the UK was dedicated to energy crops (RCEP report, p.19). Common Agricultural Policy reform will undoubtedly affect the agricultural landscape in the UK. Quite how land-use patterns will change is unclear, but the uncoupling of subsidies from production volume is predicted to encourage farmers to manage their land in the most cost-effective manner. Farmers are currently allowed to grow energy crops on set-aside land, and a grant of €45 per hectare is available for energy crops grown on non-set-aside land (RCEP report, p.73).

A number of delicate questions arise when considering the possible effect of bioenergy development on land use and the agricultural landscape, including:

- *The amount of agricultural land required to grow energy crops*. Can the UK produce enough biomass to meet existing targets for renewable energy and transport biofuel? This is not a straightforward question to address, as the amount of land required will vary in relation to factors including biomass demand, energy crop species/cultivar, climate and soil fertility[7]. Under current conditions, achieving 10% biofuel as a proportion of total EU fuel consumption is estimated to require an area equivalent to 50% of the total arable land area (AES/Defra conference report, 2007).

- *Competition between food and fuel production*. There will almost certainly be a tighter balance between supply and demand for grains and oilseeds, especially if the same crops and land are used for food and fuel production[8]. Food security has been highlighted as an issue of particular concern to developing countries, but it is unclear whether food/fuel competition will increase hunger and poverty, or actually work to reduce poverty in developing countries (IIED Briefing, 2007; von Braun & Pachauri, 2006) — further research into the social, economic and environmental consequences of this competition under different policy and trade regimes is required.

- *Competition for water resources*. This issue may gain increased visibility, as water becomes an increasingly valuable commodity worldwide.

- *Landscape character, biodiversity and social acceptability.* Approximately 70% of the land in the UK is farmed, and in fact, the British countryside has been modified for so long that farmland is generally considered ‘natural’ landscape. The visual appearance and character of the landscape will almost certainly change if large areas of land are turned over to energy crop production[9]. It will be important to gauge public opinion on the acceptability of such changes, and to carefully monitor the effects of any changes on biodiversity and environmental health.

There are clearly many trade-offs and issues relating to land use that require careful attention in the context of bioenergy — how should these tensions be negotiated?

The harnessing of science and technology to develop dual- or multi-use crops, as well as crops that require fewer inputs (water, fertilizer, etc), may in the long run help to alleviate some of the current land-use concerns (see section III).

[7] Land-use issues are separate from but should be considered alongside the potential for CO_2 emission reduction through energy crops, which is also dependent on a number of factors (see above).
[8] For example, the FAO noted that conversion of corn to bioethanol resulted in a sharp decline in world grain stocks and a rise in grain prices in the first half of 2006.
[9] These need not be in the form of monocultures. In fact, a recent paper by Tilman *et al* (2006) suggests that low-input, high-diversity grassland perennials can have higher biomass yields than monocultures.

Trade

A global trade market in bioenergy (mostly transport biofuels) is emerging, owing largely to geographical and economic discrepancies in supply and demand: many countries with set targets for biofuel consumption do not currently produce enough feedstock to meet these targets[10]. Currently, the most economically competitive producers of biofuels are mostly developing countries, and several regions are rapidly building biofuel export markets, including southeast Asia (especially Indonesia and Malaysia, also Thailand and the Philippines), South America[11], sub-Saharan Africa and India.

However, differences in import taxes and agricultural and energy trade regimes, together with the lack of clear biofuel classification schemes[12] and common standards are cited as possible impediments to the development of an equitable and socially and environmentally sustainable global trade in bioenergy feedstocks (IIED Briefing, 2007). Systems should be developed to maximize the positive contributions of biomass to sustainable development, while minimizing the negative effects and ensuring a consistent product quality. Environmental and social certification/accreditation schemes will almost certainly have a role to play in promoting sustainable trade in bioenergy, and a number of EU member states (including the UK) are currently starting to investigate different options for such schemes (EEA Report, 2007).

Wider environmental issues

Demand for bioenergy feedstocks can put pressure on farmland, forests, and soil and water resources. Although it is widely acknowledged that biomass development should not happen at the expense of environmental health, this issue seems to have been largely overlooked in the bioenergy debate until recently. However, a number of countries and stakeholders are now expressing concerns about the possible negative environmental effects of energy crops, particularly in the context of the emerging international trade market for biofuels (see above). For example, despite being widely held up as a model for bioethanol development, the Brazilian bioethanol industry is facing increasing concerns about the environmental effects of its large-scale sugarcane plantations (e.g. Howden, 2007). Even more worryingly, the clearing and draining of Indonesian peatlands to make way for oil-palm plantations has recently been found to result in 33 tonnes of CO_2 emissions for each tonne of palm oil produced[13].

In the UK, there are strong sociocultural links between agriculture and environment, and there is increasing emphasis to manage farmland as part of wider agro-ecosystems[14]. Over time, there has been a shift away from breeding/farming for high yields, and the adoption of less intensive, wildlife-friendly farming techniques has been supported by government measures including the Environmental Stewardship scheme, launched in 2005 (POSTnote, 2005).

Any changes in land-use patterns as a result of biomass cultivation should be sensitive to existing frameworks for land management and conservation. Further research is needed into the possible effects (positive or negative) of bioenergy crops on biodiversity, ecosystem health and ecological stability. The potential invasiveness of energy crops optimized for efficient growth (whether through traditional GM or other methods) is also an issue worthy of investigation (and possibly regulation?).

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[10] Arguably though, only domestic feedstock production will satisfy the aim of increasing the security of energy supply.
[11] Brazil is already a leading exporter in bioethanol, but several other South American countries are also looking to develop export industries.
[12] For example, there is no clear agreement at the moment on whether biofuels are 'industrial' or 'agricultural' goods, which are subject to different trade rules (IIED Briefing, 2007).
[13] *The Economist*. Burned by the sun, 24 February 2007, p.42.
[14] The Genomics Forum working paper on 'Genomics for Biodiversity, Conservation and Land Use' contains a more detailed discussion of the links between farming and the environment in the UK (http://www.genomicsforum.ac.uk/documents/pdf/Genomics_for_biodiversity.pdf).

Waste Management

The production of bioenergy from waste materials is receiving increased attention of late. Waste management is a pressing issue in the UK, with available UK landfill sites predicted to be full in six years' time (Webb, 2007). The 1999 EU Landfill Directive and recent UK targets for reducing the amount of waste sent to landfill sites mean that local councils are starting to look seriously for alternative disposal routes for biodegradable waste, and that waste management is becoming an increasingly profitable business. An estimated 200 new plants for treating, separating and recycling waste will be required over the next decade to meet targets[15].

The waste industry currently generates just under one-third of all the renewable electricity in the UK[16]. In 2005, 2.5 million tonnes of municipal solid waste were used for energy generation, although in principle there is much more waste material that could be used (Defra 2005 *Biomass Task Force Report*). Recent reports highlight the need to see energy recovery from waste as an element of the broader waste management strategy[17]. More than 100 types of biological waste can be used as feedstock for bioenergy production, including the biodegradable fraction of municipal solid waste, clean waste wood, agricultural residues, and sewage (Adam, 2006). Some changes to the current classification schemes for 'waste' materials will be required in order to maximize the potential of waste materials for bioenergy production (Defra 2005 *Biomass Task Force Report*). The process of obtaining planning permission to build bioenergy processing plants can also be cumbersome and is proving an obstacle to the development of this sector.

Public attitudes and behaviour

A sustainable energy policy should start with promoting energy efficiency and reduction in energy use, which is closely linked to behaviour and consumption patterns at the individual and community levels. Social scientists are developing an increasingly sophisticated understanding of how public attitudes and behaviours are shaped and constrained by physical, social, cultural and institutional contexts (Owens & Driffill, 2006).

A recent meta-analysis of over 30 polling studies investigating public understanding and opinion of energy and energy technologies suggests "insufficient levels of basic knowledge to ensure an informed opinion" (McGowan & Sauter, 2005; p.29). Although a clear majority of the public is in favour of renewable energy sources in general, knowledge about specific renewable technologies was found to vary considerably, with biomass showing the lowest rate of awareness in public opinion (p.15).

Uptake of technologies such as microgeneration will rely not only on public awareness and acceptance, but active support and commitment to installing new facilities at a local/domestic level. Furthermore, the traditional role of the individual as 'energy consumer' is likely to change in response to microgeneration technologies, with individuals instead assuming the role of 'energy citizens' or 'energy co-providers' (Owens & Driffill, 2006; see also section VI).

Traditional energy policy has relied — unsuccessfully, on the whole—on two main types of instrument to influence consumer behaviour in pursuit of environmental goals: information provision (through labelling and awareness campaigns), and financial incentives/disincentives. Achieving target CO_2 emission and renewable energy levels is predicted to require additional strategies, and a more robust understanding of the complex factors shaping individual and societal behaviours and practice with regards to energy[18].

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[15] At the moment, planning issues are slowing development of the sector.
[16] This is more than the electricity generated through than wind power or hydroelectricity.
[17] But waste management strategies should prioritise waste reduction, re-use and recycling before energy recovery.
[18] The RESOLVE project (ESRC Research Group on Lifestyles, Values and Environment) recently initiated at the University of Surrey is an interdisciplinary collaboration looking to explore links between lifestyle, societal values and environment; see http://www.surrey.ac.uk/resolve/.

Summary

The wider socioeconomic and policy context against which bioenergy development is taking place is clearly a complicated one, involving, among other factors:

- many stakeholders, involved in all aspects of bioenergy development, processing and consumption
- different geographical levels (local, national and international)
- different policy and regulatory frameworks (grounded in sectors such as transport, energy, environment, etc.)

What are some of the main drivers, tensions and trade-offs with regards to bioenergy development? How can we begin to assess these tensions, and integrate different agendas to develop a consistent approach to bioenergy development?

With this context in mind, the subsequent sections of this paper focus on some of the practical and more ‘structural’ ways in which bioenergy development is progressing in the UK — introducing some key research questions and initiatives, funding mechanisms, new collaborative and networking strategies, the development of new value chains, and wider governance issues. These sections are necessarily superficial and limited in scope, and it is hoped that participants at the workshop will share their experiences and perspectives to develop and elaborate these issues.

III. Science and technology for bioenergy development

Bioenergy is not a new commodity, and there is much existing technology for converting biomass into energy. In terms of establishing a bioenergy industry using existing technologies, the main obstacles seem to relate not to science and technology, but rather to economic constraints and the setting up of secure and reliable production chains to link feedstocks with markets (see section VI).

Is the development of a bioenergy industry dependent on scientific advances and new technologies?

There is undoubtedly a role for science and technology in increasing the sustainability and efficiency — and thereby the economic viability — of bioenergy production. Efficiency gains stand to be made in several areas. From a farming perspective, the aim is to produce energy crops in a cost-effective manner that minimizes soil erosion, water input, environmental damage, labour cost and competition with land being used for food/feed production. Bearing in mind that common domesticated crops have not been selected for efficient carbon capture, a number of plant traits might be targeted for increased biomass production. These include photosynthesis efficiency, nitrogen metabolism efficiency, biomass composition, abiotic stress tolerance and pest/disease resistance (Ragauskas *et al*, 2006).

Lignocellulose, the main component of plant cell walls, is receiving great interest as a bioenergy feedstock (Schubert, 2006). Efficient conversion of lignocellulose into bioenergy currently faces a number of technical hurdles, but is widely acknowledged as the future of bioenergy production if it can be successfully developed at a commercial scale. Plant breeding and genomics are being harnessed to develop so-called 'second-generation' bioenergy crops that can be more easily broken down into fuels (e.g. with lower lignin content).

Genomics will almost certainly be useful for selecting and optimizing plant biomass yield[19]. Economic analyses based on current yields suggest that energy crop production in the UK is only viable using set-aside land, but that with a 30% increase in yield, energy crops would become an economically attractive alternative to barley cultivation (LEK Consulting, 2004; RCEP 2004 report *Biomass as a Renewable Energy Source*, p.48). Achieving a 30% increase in energy crop yield over the next ten years is thought to be realistic — in fact, the BBSRC suggests that scientific research "can reasonably expect to double the plant biomass yield"[20]. Indeed, there are already reports of improved biomass crops (e.g. Semeniuk, 2007). This being said, reliably translating basic plant science research into improved crops may prove challenging in practice.

The UK has a small but strong research base in plant and microbial sciences, with particular strength in food crop research. The formation of strategic partnerships with countries and centres that have genomic resources for dedicated biomass crops (e.g. the US Department of Energy Centres, Genome Canada) has been identified as a possible means of complementing existing research expertise in the UK (BBSRC, 2006).

As well as improving plant feedstock material, biotechnology can be used to engineer microorganisms and enzymes for processing this feedstock. Better catalysts (biological and chemical) are being developed, as are processing technologies for biofuel conversion reactions. Engineers are also being called upon to help design efficient and cost-effective 'biorefineries' that produce bioenergy as well as byproducts for use by other industries[21]. The development of dual- or multi-use crops is a potentially valuable resource, not just for bioenergy production but for the wider bio-based economy. Support for biorefinery development can be found in several themes of the EU FP7 funding programme.

How might potential developments in science and technology affect the balance among possible bioenergy production chains? Should this be accounted for in policy incentives for bioenergy development?

[19] The potential role for traditional genetic modification in developing new energy crops is less clear, owing both to the complex traits that might be targeted and social acceptability issues surrounding GM.
[20] BBSRC 2006 *Review of Bioenergy Research*, p.4.
[21] These might include materials for plastics and lubricants, as well as fragrances, flavouring agents and high-value 'nutraceuticals' (Ragauskas *et al*, 2006; Russo, 2006; Cho, 2007).

IV. The UK bioenergy research agenda

Funding for bioenergy development can come from public or private sources, and be directed towards basic research, applied research, infrastructure development, technology deployment, and education and public engagement activities. Jamasb *et al* (2006) have recently called for a rebalancing of policy instruments away from technology deployment and in favour of R&D, arguing that levels of spending on renewable energy R&D in the UK is an order of magnitude lower than the funding given to promotion of existing renewable technologies.

> "The quantity of research in bioenergy is very low relative to the scale of policy interests and review activities." — BBSRC 2006 *Review of Bioenergy Research* (p.21)

Should the emphasis with regards to funding for bioenergy be on research and development, or deployment of existing technologies?

Public spending on energy research as a whole in the UK has declined sharply over the past 20 years, and is currently at about 20% of peak spending in the 1980s (less than £200 million per annum, compared with over £1200 million per annum in the mid-1980s)[22].

Despite the strong political momentum behind bioenergy, there is reasonably limited bioenergy research activity in the UK compared to the US and other EU member states. Bioenergy research has also suffered from a fragmented approach in terms of funding and priority-setting. At the national level, the UK Research Councils and government departments (principally the DTI and Defra) are the main public funders of bioenergy R&D. The Carbon Trust, an independent government-funded company, also funds a number of bioenergy-related projects under its remit of promoting the transition to a low-carbon economy. The EU will promote bioenergy research in its FP7 funding programme, and a number of European networks relevant to bioenergy are also being established (e.g. through the ERA-NET scheme).

Currently, approximately £2.5–3 million per annum is spent on basic and applied bioenergy research in the UK — comprehensive summaries are provided in the UKERC Energy Research Atlas[23] and the BBSRC's 2006 *Review of Bioenergy Research*. Notably, a number of large-scale bioenergy projects (including TSEC-BIOSYS, RELU-Biomass and the SUPERGEN Consortium on Biomass, Biofuels and Energy Crops)[24] are centred on collaborations between natural scientists, social scientists and engineers. Ties with industry are also being developed through these networks. Are these collaborations proving productive and successful? Are other stakeholders (NGOs, farmers, civil society) also being incorporated into these networks?

Commercial interests in bioenergy research are on the increase, and virtually every major energy, chemical, transport and oil company in the world is currently supporting research activities in bioenergy — be they biomass production, processing technologies and/or development of end-products that use bioenergy (Herrera, 2006). A number of SMEs are also being established to fill identified niches or gaps in existing bioenergy supply chains. The Renewable Energy Association (the UK's largest trade association for renewable energy) currently lists over 400 members, ranging in size from multinational corporations to individuals involved in growing, sourcing, generating, trading, and providing equipment and services for the renewable energy sector (not limited to bioenergy).

What is the balance among basic/applied research, public/private research, and infrastructure development for bioenergy? Is this balance consistent with short- and long-term bioenergy policy targets?

[22] See http://ukerc.rl.ac.uk/ERA002.html.
[23] See http://ukerc.rl.ac.uk/Landscapes/Bioenergy_Section3.pdf.
[24] TSEC-BIOSYS: Towards a Sustainable Energy Economy – A whole-systems approach to bioenergy demand and supply in the UK (http://www.tsec-biosys.ac.uk/); RELU-Biomass: Rural Economy and Land Use project on social, economic and environmental implications of increasing rural land use under energy crops (http://www.relu-biomass.org.uk/); SUPERGEN consortium (http://www.supergen-bioenergy.net/?_id=1).

V. Collaborative mechanisms and partnerships

What kinds of new partnerships and research strategies are being developed in relation to bioenergy? Are they proving successful at stimulating the development of a viable bioenergy sector?

Within the academic community, a number of large-scale coordination and networking activities have been initiated in the past 2–3 years, to promote a more holistic approach to energy and bioenergy research in the UK (consistent with the wider social, economic and policy objectives for energy supply). Prominent among these, the UK Energy Research Centre was established in 2004 as a consortium of eight academic institutions, with the aim of coordinating a National Energy Research Network (NERN). Increasing emphasis is also being placed on networking and partnerships between government departments, academic researchers and industrial organizations.

Ambitious plans for new public–private energy research collaborations are also underway. The UK Energy Technology Institute[25] currently being developed is seen by government as the most important development in UK energy research and innovation for decades. This institute will support energy research that falls in the gap between longer-term research funded by the Research Councils and the deployment of proven technologies. Funding is intended to provide £1 billion over 10 years, and will be on a 50:50 public:private basis. Seven major companies (BP, Caterpillar, EDF Energy, EON.UK, Rolls Royce, Scottish and Southern Energy, and Shell) have so far pledged a total of £32.5 million per annum to support the institute.

Other recent and noteworthy examples of collaborations involving different actors in the bioenergy sector include:

- **Industrial collaborations**. In June 2006, British Sugar, BP and DuPont (representing the sugar, energy and chemical industries, respectively) announced the joint construction of a biobutanol plant in Norfolk, using locally grown sugar beet as the feedstock.

- **Public–private collaborations**. On 1 February 2007, BP awarded $500 million over ten years to UC Berkeley, to set up an Energy Biosciences Institute. This institute will host both industrial and academic scientists under the same roof, and will focus on the use of biotechnology to develop new bioenergy sources[26].

- **Government–industry collaborations**. The Defra Renewable Materials LINK Programme[27] was launched in November 2005 as part of the wider LINK scheme, which seeks to promote exploitation of public research innovation for the benefit of industry (and wider government/societal goals) by providing research grants to public–private partnerships. A requirement for support is that government funds are matched by equivalent contributions from industrial partners. The Renewables Programme aims to develop non-food uses of renewable materials to support sustainable development.

- **Regional cross-sectoral collaborations**. Examples include North East Biofuels[28], a cluster of industrial and public sector bodies working together to establish a biofuels industry in the northeast of England. North East Biofuels describes itself as a 'vertical' cluster, with members representing different parts of the supply chain necessary to foster a successful biofuels industry.

What other collaborative mechanisms are evolving with regards to bioenergy development? Are all stakeholders in the bioenergy debate being represented in these various partnerships and strategies?

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[25] See http://www.dti.gov.uk/science/science-funding/eti/index.html.
[26] Some unease has been voiced by the academic community about the propriety of such a relationship between academia and industry (Dalton, 2007).
[27] See http://defrafarmingandfoodscience.csl.gov.uk/linkprogrammeoverview.cfm for details.
[28] See http://www.northeastbiofuels.com/ for details.

VI. New stakeholders and supply chains for bioenergy

A number of stakeholders not traditionally associated with the energy sector are becoming increasingly important players with regards to bioenergy development. On the supply side, **countries** that have not traditionally featured in the global energy market are developing thriving export markets (see section II). At the national level, UK farming and agriculture is also seen to have an important and long-term role in producing bioenergy feedstocks, and **farmers** are being drawn into energy crop production. Integration of the farming and energy sectors will undoubtedly take time. **Non-governmental organizations** such as the NFU will have an important role in negotiating with other stakeholders, and educating and raising awareness among farmers about possible options. A number of **rural consultancies** have also been set up in recent years, to advise farmers on bioenergy production and to help link them up with appropriate partners and supply chains. **SMEs** focused on specific bioenergy supply chains are also becoming established players.

Although the energy sector has always relied on consumers as end-users, the role of the general public as **energy consumers** is beginning to change as a result of increased investment in small-scale renewable technologies. For example, according to the Energy Saving Trust, microgeneration could supply up 40% of UK electricity by 2050. This would fundamentally change traditional supply–demand dynamics in the UK energy system, as many consumers would thus become energy producers. The possible effects of such a decentralized energy infrastructure on other stakeholders and governance mechanisms for bioenergy development are significant and worthy of further research.

New value chains

The production of bioenergy represents a process operating at the intersection of multiple sectors, including the energy, agriculture, biotech, chemical, and forest and land management sectors. Arguably, major infrastructure changes will be required and new partnerships and production chains will be created in order to satisfy policy targets for bioenergy production. Furthermore, given the number of potential biomass sources, processing/conversion technologies and possible end-uses of bioenergy supplies, a large array of different supply chains can be pursued[29]. There have been recent calls to prioritize among possible supply chains, with suggestions that the large number of potential chains is preventing concerted action for large-scale bioenergy development and deployment (Taylor, 2006).

The setting up of bioenergy supply chains is sometimes likened to a 'chicken-and-egg' problem, in that the supply sector cannot be established before there is a demand for its products, but the demand cannot be established before the supply infrastructure is in place. Because different actors/sectors are typically responsible for different steps within this chain, achieving the necessary coordination and security to invest in any single step can prove problematic[30].

Further research into the relative timescales, costs and risks associated with various steps in the supply chain might suggest useful strategies to promote their development. For example, as well as the high start-up costs associated with biomass processing facilities, the ongoing investment (cost and labour) associated with producing bioenergy feedstocks is a factor that should be taken into account when considering possible incentives and funding strategies. The distribution of costs and benefits along the value chain is also an issue that should be addressed.

One way of circumventing these problems is for a single agent to set up a series of partnerships with the aim of developing an entire, closed-loop value chain that encompasses biomass growth/collection, processing, conversion and distribution. For example, the UK-based biodiesel company D1 Oils Plc has an "earth-to-engines" approach that takes account of the entire supply chain. Is industry the main initiator of specific closed-loop supply chains? How might the dynamics of the bioenergy sector be affected by such a strategy?

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[29] See p.56 of the BBSRC 2006 report for a visual overview of possible bioenergy production chains.
[30] One clear example of the relative timescales of various elements in the bioenergy supply chain is presented in the 2004 RCEP report *Biomass as a Renewable Energy Resource* (p. 63–64).

VII. The economics and governance of (bio)energy

At the end of the day, economic considerations will have a key role in determining the fate of bioenergy. If a single driver had to be identified to account for the increased commitment to developing renewable energies in recent years, it would almost certainly be high oil prices — and the prediction that these prices are likely to remain high for the foreseeable future. This being said, science and technology stand to contribute to the economic viability of bioenergy in at least three ways: (1) improving the efficiency of carbon capture into an amenable storage form by plants, (2) improving the efficiency of the bioenergy conversion process (which at the moment is often energy-intensive), and (3) developing dual- or multi-use plants that yield valuable by-products as well as bioenergy (Bevan & Franssen, 2006).

A great challenge rests in identifying "how to manage the tensions between policy and regulation such that consumers/citizens gain the benefits of competitive markets, affordable energy services and environmental security, while energy businesses remain financially viable and investors are prepared to take on the policy, regulatory and market risks to ensure reliability of supply" (Ekins, 2003; p.3).

Owing to the number of stakeholders involved and the complicated value chains associated with bioenergy, government incentives and targets should be carefully balanced to successfully promote bioenergy development. Vertès *et al* (2006) suggest that resistance to change from traditional energy sources to renewable energy sources stems from several areas, including the wider geopolitical situation, cultural considerations, technological innovation challenges, retrofitting/infrastructure issues, and market barriers[31]. How can government incentives, regulation and policy work in concert to ease these tensions and foster a supportive environment for development of bioenergy and other renewable energies?

Governance frameworks

Increasingly, governments are highlighting the need for 'joined-up' thinking, policy and practice to manage some of the complex issues facing society. With regards to bioenergy, Defra acknowledges that "successful policies depend on a comprehensive and consistent approach over the medium-term (six to seven years)" (Biomass Task Force Report, p.19). The notion of 'governance' reflects a general shift in policymaking away from 'government' (a top-down, process-based legislative approach) towards a more distributed, outcome-oriented approach. Governance strategies focus on "the coordination of multiple actors and institutions to debate, define and achieve policy goals in complex political arenas" (Lyall & Tait, 2005; p.4).

With regards to bioenergy development, a number of governance processes have emerged in the UK in recent years. In addition to top-down initiatives and central government policies to encourage renewable energy development, renewable energy governance mechanisms and targets have also emerged at the regional level, based on particular regional contexts (Smith, 2006). Local and regional public–private partnerships, supply chains, and support mechanisms involving many small-scale actors are thus emerging in the context of bioenergy. In addition to the tensions and trade-offs noted among different sectors implicated in bioenergy development (see section II), multi-level governance can also result in tensions "between hierarchy and autonomy, co-ordination and fragmentation, and accountability and legitimacy" among different levels (Smith, 2006; p.2). How might these tensions be negotiated to support the development of a successful bioenergy industry in the UK?

How might governance frameworks best promote the development of a bioenergy industry, and an environmentally sustainable bio-based economy more generally?

[31] "At the heart of the matter is the interaction between markets, behaviour and technology" (Ekins, 2003; p.3).

VIII. References

JOURNAL ARTICLES AND BOOK CHAPTERS

Bevan, M.W. & Franssen, M.C.R. (2006) Investing in green and white biotech. *Nature Biotechnology* **24,** 765–767.
Herrera, S. (2006) Bonkers about biofuels. *Nature Biotechnology* **24,** 755–760.
Holdren, J.P. (2007) Energy and sustainability. *Science* **315,** 737.
Lyall, C. & Tait, J. (2005) in *New Modes of Governance: Developing an Integrated Policy Approach to Science, Technology, Risk and the Environment.* Ashgate, pp 3–17.
McLaren, J.S.(2005) Crop biotechnology provides an opportunity to develop a sustainable future. *Trends in Biotechnology* **23,** 339–342.
Ragauskas, A. J. *et al* (2006) The path forward for biofuels and biomaterials. *Science* **311,** 484–489.
Rayner, S. (2006) What drives environmental policy? *Global Environmental Change* **16,** 4–6.
Sarewitz, D. & Pielke, R.A. Jr (2007) The neglected heart of science policy: reconciling supply of and demand for science. *Environmental Science & Policy* **10,** 5–16.
Schubert, C. (2006) Can biofuels finally take centre stage? *Nature Biotechnology* **24,** 777–784.
Tilman, D., Reich, P.B. & Knops, J.M.H. (2006) Biodiversity and ecosystem stability in a decade-long grassland experiment. *Nature* **441,** 629–632.
Vertès, A.A., Inui, M. & Yukawa, H. (2006) Implementing biofuels on a global scale. *Nature Biotechnology* **24,** 761–764.

NEWS STORIES

Anon. Fuels rush in. *The Economist*, 26 August 2006 (p.50).
Anon. Burned by the sun. *The Economist*, 24 February 2007 (p.42).
Adam, D. Human waste used to create green fuel. *The Guardian*, 29 November 2006.
Cho, A. Catalyzing the emergence of a practical biorefinery. *Science* **315,** 795 (2007).
Dalton, R. Berkeley's energy deal with BP sparks unease. *Nature* **445,** 688–689 (2007).
Howden, D. The big green fuel lie. *The Independent*, 6 March 2007.
Marris, E. Drink the best and drive the rest. *Nature* **444,** 670–672 (2006).
McNeely, J.A. Biofuels: Green energy or grim reaper? *BBC Online News*, 22 September 2006; http://news.bbc.co.uk/1/hi/sci/tech/5369284.stm.
National Farmers' Union. Biofuel crops pose no threat to UK food production, 14 August 2006; http://www.stackyard.com/news/2006/08/arable/06_nfu_biofuel_crops.html.
Russo, G. Bio bonanza. *Nature* **444,** 648–649 (2006).
Semeniuk, I. US mobilises for a biofuelled future. *New Scientist* **2592,** 12; 24 February 2007.
Webb. T. Oh what a lovely tip. *The Independent*, 21 January 2007 (Business section, p.7).

ISSUE BRIEFINGS and DISCUSSION PAPERS

AES/Defra conference report (2007). *One-day conference: Bioenergy — Green gold?* 31 January 2007; http://statistics.defra.gov.uk/esg/conference/aes2007/default.asp (accessed February 2007).

Birol, F. (2005) *World energy prospects and challenges.* IEA, 2005; http://www.iea.org/textbase/papers/2006/birol.pdf.

DTI and The Carbon Trust (2004). *Conclusions of the Renewables Innovation Review*. Website: http://www.dti.gov.uk/energy/sources/renewables/policy/government-renewable-energy-policy/renewables-innovation-review/page15308.html (accessed February 2007).

Dufey, A. (2007) *International Trade in Biofuels: Good for Development? And Good for Environment?* Environment for the MDGS brief, International Institute for Environment and Development; http://www.iied.org/pubs/pdf/full/11068IIED.pdf.

Energy Saving Trust. *Potential for Microgeneration: Study and Analysis*, November 2005; http://www.est.org.uk/uploads/documents/aboutest/microgen%20exec%20summary.pdf.

International Food Policy Research Institute (2006). *Bioenergy and Agriculture: Promises and Challenges*. 2020 Vision for Food, Agriculture, and the Environment: Focus 14, December 2006; http://www.ifpri.org/2020/focus/focus14/focus14.pdf.

Jamasb, T., Nuttall, W. & Pollitt, M. (2006) *The Case for a New Energy Research, Development and Promotion Policy for the UK*. Foresight review; http://www.foresight.gov.uk/HORIZON_SCANNING_CENTRE/Energy/PDF/The_case_for_a_new_energy_research_development_and_promotion_policy_in_the_UK.pdf

John, L. (2006) *The RELU Debates 2006? Energy crops running out of steam?* http://www.relu.ac.uk/events/SciWeek2006/DebateReport130306Energycrops.pdf

LEK Consulting LLP (2004). *Review of the Economic Case for Energy Crops in the UK*. Report for the DTI, 29 January 2004; http://www.dti.gov.uk/files/file22075.pdf.

Monaghan, A. & Steward, F. (2006) *Catalysing Innovation for Sustainability. Research Insights from the Economic and Social Research Council Sustainable Technologies Programme.* December 2006; http://www.sustainabletechnologies.ac.uk/PDF/online%20version.pdf.

National Farmers' Union. *Information & Analysis: Economics of Biofuels* Brief, 10 August 2006; http://www.nfuonline.com/documents/Bioenergy/Economics%20of%20Biofuels%20Brief%20200706%20final%20version.pdf (accessed March 2007).

Owens, S. & Driffill, L. (2006) *How to Change Attitudes and Behaviours in the Context of Energy*. Foresight review; http://www.foresight.gov.uk/HORIZON_SCANNING_CENTRE/Energy/PDF/How_to_change_attitudes_and_behaviours.pdf

Parliamentary Office of Science and Technology (2005) POSTnote Number 254, *Farmland Wildlife*; http://www.parliament.uk/documents/upload/postpn254.pdf.

Slingerland, S. & van Geuns, L. (2005) Drivers for an international biofuels market. Discussion Paper, *CIEP Future Fuel Seminar,* Clingendael Institute, Netherlands; http://www.clingendael.nl/publications/2005/20051209_ciep_misc_biofuelsmarket.pdf

Smith, A. (2006) *Multi-level governance: towards an analysis of renewable energy governance in the English regions*. SPRU Electronic Working Paper Series, Paper No. 153, December 2006; http://www.sussex.ac.uk/spru/documents/sewp156.pdf.

Taylor, G. (2006) *Bioenergy for Heat and Electricity in the UK*. Foresight review; http://www.foresight.gov.uk/HORIZON_SCANNING_CENTRE/Energy/PDF/Bioenergy_for_heat_and_electricity_in_the_UK.pdf.

UKERC Energy Research Atlas: Bioenergy, http://ukerc.rl.ac.uk/Landscapes/Bioenergy_Section3.pdf.

von Braun, J. & Pachauri, R.K. (2006) *The Promises and Challenges of Biofuels for the Poor in Developing Countries*. International Food Policy Research Institute Essay, 2006; http://www.ifpri.org/pubs/books/ar2005/ar05e.pdf.

POLICY DOCUMENTS and REPORTS

BBSRC. *Review of Bioenergy Research: A Report for the BBSRC Strategy Board.* March 2006; http://www.bbsrc.ac.uk/about/pub/reports/bioenergy_review.pdf.

Carbon Trust. *Biomass Sector Review for the Carbon Trust.* 26 October 2005; see http://www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=CTC512.

Commission of the European Communities. *An EU Strategy for Biofuels*. February 2006; http://ec.europa.eu/agriculture/biomass/biofuel/com2006_34_en.pdf.

Defra Biomass Task Force. *Biomass Task Force Report*. October 2005, http://www.defra.gov.uk/farm/crops/industrial/energy/biomass-taskforce/pdf/btf-finalreport.pdf (accessed February 2007).

Directive 1999/31/EC of the Council of the European Union *on the landfill of waste*, 26 April 1999; http://europa.eu.int/eur-lex/pri/en/oj/dat/1999/l_182/l_18219990716en00010019.pdf.

Directive 2003/30/EC of the European Parliament and of the Council *on the promotion of the use of biofuels or other renewable fuels for transport*, 8 May 2003; http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_123/l_12320030517en00420046.pdf.

Ekins, P. *Prospects and Policies for Step Changes in the Energy System: Developing an Agenda for Social Science Research.* Final report to the ESRC, June 2003; http://www.psi.org.uk/docs/2003/research/env-prospects-policies-step-changes-energy-system.pdf.

European Environment Agency. *Transport and Environment: On the Way to a New Common Transport Policy*. EEA Report 1/2007, February 2007; http://reports.eea.europa.eu/eea_report_2007_1/en/eea_report_1_2007.pdf.

House of Lords European Union Committee. *The EU Strategy on Biofuels: from Field to Fuel*. 47th Report of Session 2005–06, published 20 November 2006; http://www.publications.parliament.uk/pa/ld200506/ldselect/ldeucom/267/26702.htm.

International Energy Agency. *Biofuels for Transport: An International Perspective*, 2004; http://www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf.

ITI Life Sciences. *Market Foresighting: Liquid Biofuels*. February 2006.

McGowan, F. & Sauter, R. *Public Opinion on Energy Research: A Desk Study for the Research Councils.* September 2005; http://www.epsrc.ac.uk/CMSWeb/Downloads/Other/EnergyAttitudesDeskStudySussex.pdf.

OECD. *The Bioeconomy to 2030: Designing a Policy Agenda*. OECD International Futures Programme Scoping Document, Paris, 21 June 2006; http://www.oecd.org/dataoecd/48/1/36887128.pdf.

Royal Commission on Environmental Pollution. *Biomass as a Renewable Energy Source*. Special Report, 11 May 2004, http://www.rcep.org.uk/biomass/Biomass%20Report.pdf.

Royal Society of Edinburgh. *Inquiry into Energy Issues for Scotland — Summary Report.* June 2006; http://www.royalsoced.org.uk/enquiries/energy/summary_report.pdf.

UK Department for Transport (2006) *Promotion and Use of Biofuels in the United Kingdom. UK Report to European Commission under Article 4 of the Biofuels Directive (2003/30/EC)*; http://www.dft.gov.uk/stellent/groups/dft_roads/documents/pdf/dft_roads_pdf_611908.pdf