Bioenergy for heat and electricity in the UK

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Abstract

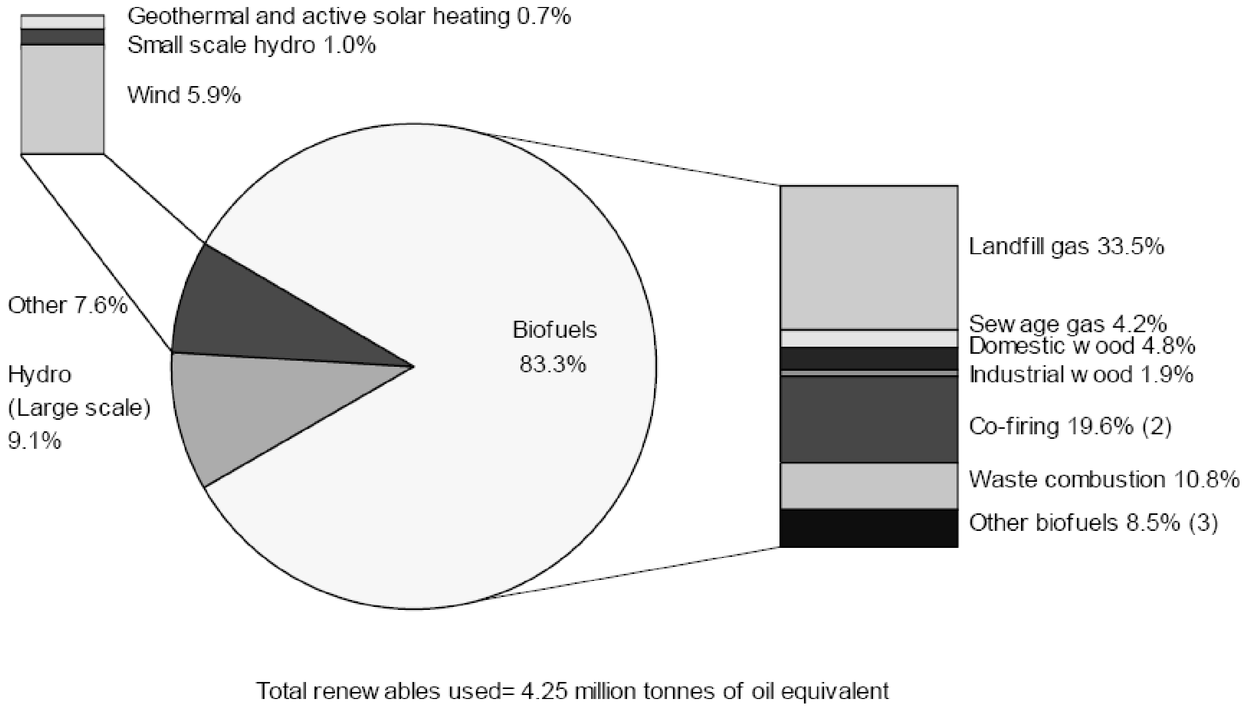
Bioenergy from biomass is the ultimate source of renewable energy and the UK has a considerable biomass resource, estimated at an annual 20 Million tonnes, although only a fraction of this resource is effectively captured for energy, contributing approximately 2. 5 % to heat and electricity supply in the UK. Much combustion technology may be considered as 'mature' although bottle necks in the quality and quantity of feedstock are apparent and further fundamental research is required to increase crop yield in a sustainable manner with low chemical in puts ensuring efficient energy balance. In the short term, it might be useful for the UK to focus on developing a limited number of bioenergy chains, linked to CHP-microgeneration and the use of bioenergy for community and public sector projects. This has to be linked to a joined-up policy and regulatory framework. A clear strategy for land management is also required. In the long-term future, considerable excitement exists on the possibility of new bioscience technologies harnessed to improve photosynthetic gains and plant systems biology for bioenergy. The designer energy plant is tractable, with energy streams in future linked to high quality chemical and liquid biofuels outputs as part of the biorefinery.

Background: contribution of biomass to UK energy mix

Bioenergy from biomass is the ultimate source of renewable energy. Biomass may be defined as any biological mass recently derived from plant or animal matter, including material from forests (round wood, cutting residues and other wood brashings), dedicated crop-derived biomass (woody short-rotation coppice energy crops – willow and poplar, grass crops – miscanthus, timber crops), dry agricultural residues (straw, poultry litter) and wet waste (slurry, silage), food wastes, industrial and municipal waste. Bioenergy derived from these biomass streams is, in general, a low-carbon technology relative to the use of fossil fuels and biomass to liquid conversions.

The UK has a considerable biomass resource, estimated at an annual 20 million tonnes, that may be utilised as a source of renewable energy, including for small-scale heat and power production using a variety of waste streams, dedicated energy crops and forest residues (Biomass Task Force 2005). The Energy White Paper (Department of Trade and Industry et al. 2003) suggested that bioenergy could make an important contribution to the Government's energy and environment objectives, including energy security and the reduction of greenhouse gas emissions, relative to current practices. It also highlighted the role of bioenergy in rural diversification and development. Despite this, attempts by the Government to stimulate the bioenergy sector in the UK have so far had limited success, although recently this market has seen increasing activity in micro combined heat and power (CHP) developments and the use of biomass to co-fire power stations such as Drax. The Royal Commission for Environmental Pollution (2004) report on bioenergy and the Biomass Task Force (2005) report attribute the general lack of progress to a focus on promoting specific technologies without full consideration of the wider market; the lack of integration of biomass supply with its utilisation; and issues of public perception and planning, i.e. a whole-systems approach requiring policy incentives and investment from several Government departments.

Bioenergy for heat and electricity is complicated since several feedstocks (sources of biomass), as identified, may contribute to this output for electricity generation, as depicted in Figure 1 (Department of Trade and Industry 2006). In addition to the type of feedstock, different conversion technologies, including combustion, thermal and biological routes, are all possible. For electricity, bioenergy contributes over 80% of the renewable input (Department of Trade and Industry 2006), although for both heat and electricity the total contribution to the UK supply is approximately 2.5%. Specialist biomass crops include fast-growing grasses such as miscanthus (called elephant grass) and coppiced trees – willow and poplar. These crops are perennial and may achieve phenomenal yields in ideal conditions producing in excess of 30 oven dried tonnes per hectare per year) – close to the theoretical optimum (Department of Energy 2006), although these are rarely observed in commercial-scale operations. Traditional food crops such as wheat and rape may also be used for bioenergy.



(1) *Excludes all passive use of solar energy and all non-biodegradable wastes.*
(2) *Biomass co-fired with fossil fuels in power stations.*
(3) *'Other biofuels' include farm waste, poultry litter, meat and bone, and short rotation coppice.*

Figure 1: The contribution of bioenergy to the generation of electricity from renewables in the UK in 2005. (Source: DTI *Digest of UK Energy Statistics*.) The contribution of bioenergy to the total UK electricity supply is approximately 1.5%.

It has been estimated that of the 17 million hectares (ha) of UK agricultural land, approximately 1 million ha could be available for bioenergy crops in the future and that this could provide 8 million tonnes of energy crop (Biomass Task Force 2005). Large-scale changes in the agricultural landscape in the UK may be envisaged if specialist bioenergy crops are widely planted. For dedicated bioenergy crops, all science outputs suggest that perennial crops are preferable to annual crops with a better energy ratio and more effective mitigation of greenhouse gases, and yet farming practice is such that this type of agronomy may be slow to develop. Alongside agricultural feedstocks, the recovery of energy from waste streams should also be considered further since changing legislation relating to landfill will reduce the amount of landfill gas, whilst co-firing of power stations such as Drax is a market for biomass use that has developed since 2002 and could in future utilise a large amount of dedicated biomass resource from crop supplies.

A further factor that is likely to increase the economic favourability of bioenergy is the decentralisation of power generation through microgeneration (small combined heat and power units serving individual homes, businesses or communities). This will help to alleviate the need to transport biomass from point of production to large regional power stations. Microgeneration is currently a small contributor to the UK energy economy but, with careful development, could become a very major one by 2030. No clear strategy currently exists in the UK to capture bioenergy from biomass 'waste' including municipal solid waste and agricultural waste, and this should be an important future priority (Department for Environment, Food and Rural Affairs 2004) and will now be addressed as part of the Government response to the UK Biomass Task Force (2005) report.

Current science in the UK

Annex 1 provides an overview of current funding and scientific expertise in the use of biomass for heat and electricity. This research atlas is being developed within the activity of the UK Energy Research Centre (UKERC) and will cover research, development and deployment to demonstration-scale (http://www.ukerc.ac.uk) and reveals a considerable increase in science activity in this area in recent years, partly because of the multiple benefits likely to arise from increased use of bioenergy, but also because of a small but strong and vocal research community. Figure 2 provides an overview of activity illustrating the fragmentation across government departments and limited co-ordination. Development of the research atlas and co-ordination events by the UKERC should help in future to overcome this fragmentation.

Summary of major findings from the research atlas

● The UK bioenergy community has, in the past, lacked coherence and co-ordination, with several UK funding agencies and research programmes now initiated in bioenergy research. These are complemented by significant current activity in the USA and EU, particularly in research roadmapping and the development of action plans for bioenergy.

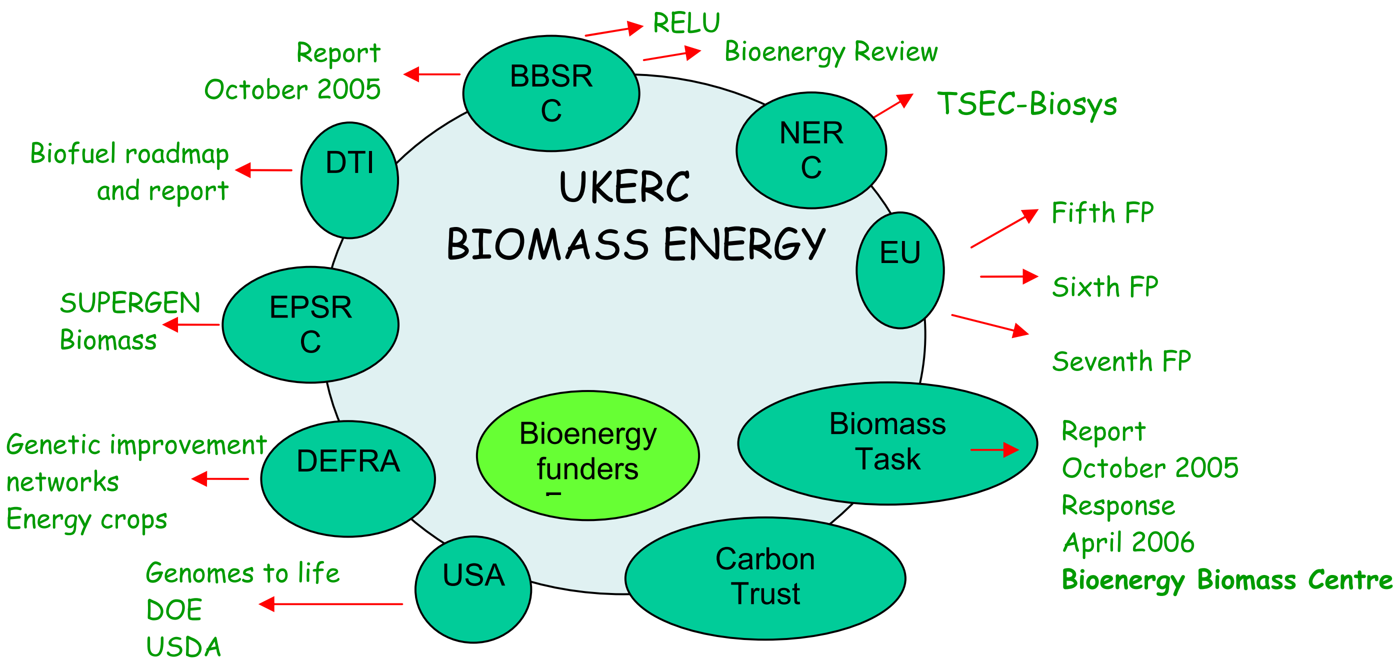


Figure 2: An overview of current activity in bioenergy science in the UK in 2005. The BBSRC (2006) review of bioenergy is in consultation (May 2006), the Rural Economy and Landuse Programme was initiated in 2006, as was TSEC–Biosys. The seventh European Framework Programme is currently being drafted. The Biomass Task Force reported and central government has responded to over 40 recommendations. The USA has finished a major roadmapping exercise in bioenergy with an emphasis on lignocellulosic biomass to bioethanol (Department of Energy 2006). DEFRA has developed two genetic improvement networks (http://www.biomass4energy.org/index.php), one for miscanthus and one for SRC. In 2005, the Carbon Trust completed an analysis of the bioenergy sector for the UK. The Engineering and Physical Sciences Research Council (EPSRC) is coming to the end of the first SUPERGEN Bioenergy project (http://www.supergen-bioenergy.net/) and the DTI has undertaken some roadmapping activities, particularly for biofuels. The Bioenergy Funders Forum first reviewed UK research in bioenergy in 2000 and is currently working on an updated document.

● The UK has strength in basic crop science, in particular for food crops. This includes breeding, improvement and agronomy as well as increased understanding of likely response to global change. However, this has not been applied widely to likely dedicated bioenergy cropping systems. Ongoing research within TSEC–Biosys and SUPERGEN–Biomass may address some of these gaps, but with limited long-term strategic vision.

● The land resource in the UK is finite. Predictions suggest that, by 2020, Europe may be food-limited once more because of the impacts of climate change. Much remains unknown on how the agricultural landscape will develop in Europe. Of the 17 million ha of current agricultural land, 1 million ha is being suggested as a reasonable target for biomass heat and electricity (supplying 8 million tonnes of biomass), representing the current amount of land 'set aside', but this and arable land may be required for food and for other bioenergy crops providing sugar and oil for liquid biofuels. Currently, this predicted land competition remains unresolved.

● The Biotechnology and Biological Sciences Research Council (BBSRC) review (2006) was undertaken with an expert group to consider the basic bioscience research that is required to enable the bioenergy sector to develop in the UK.

● Co-firing of power stations with biomass has, to date, largely relied on imports, but new regulations demand more dedicated energy crops and this may stimulate increased growth of crops within a 25-mile radius of major coal-burning power stations such as Drax (http://www.draxpower.com/environment.php?page=biomass).

● A complex regulatory framework is currently in place to support the development of new bioenergy projects. This includes the energy crop scheme, capital grants scheme and renewables obligation certificates. More than 17 different schemes were identified by the Biomass Task Force, and yet poor incentives for heat rather than power are apparent.

● The 'chicken and egg' concept is well recognised in the bioenergy sector, where feedstock or technology may be available but not integrated correctly, reflecting the complexity and number of potential bioenergy chains that rely on different feedstocks, and conversion technologies, which have spatio-temporal limitations. Each chain also has an environmental cost and these may differ considerably even when just comparing greenhouse gas emission, hydrology and biodiversity.

Future advances to 2050 and beyond

Combustion technologies for heat and electricity are largely 'mature' and so key challenges relate to the deployment and integration of these technologies for the future. In contrast, bioenergy crops and the supply of high-quantity and high-quality feedstocks from a limited landscape remain largely unknown. New crop varieties, the introduction of genetic modification technologies and the development of minimum-input agricultural systems remain key research challenges, as does ensuring landscape-level changes that are environmentally acceptable with respect to biodiversity, water resources and greenhouse gases balance. By 2020 and beyond, gasification and other technologies may be deployed, and advanced technologies for heat and power generation from green plants may be possible at commercial scale using biological rather than thermochemical conversion pathways. One advantage of such a change is that land requirements could be reduced, although no figures are available to confirm this.

1 Key challenges

a) Land resource in the UK

The limited land resource within the UK is a pressing issue in the development of dedicated bioenergy crops and also for the multipurpose use of traditional food crops. For example, in the future, will wheat straw be fermented for ethanol or combusted for heat and electricity? Limited land resource is also partnered with the behaviour of growers, which is driven by financial and regulatory incentives. Nevertheless, all indications are that bioenergy could *potentially* contribute up to 7% of the UK demand for heat and electricity, but land will become an issue if it is deployed for liquid biofuels, as this is in addition to this figure.

b) Identification of a restricted number of bioenergy chains

The complexity of a large number of potential bioenergy supply chains acts to prevent large-scale deployment of bioenergy for heat and power. A limited number of future bioenergy chains for 2010, 2020 and 2050 would enable clear planning and focus to be achieved.

c) Development of better efficiencies within each bioenergy chain

Although energy ratios for heat and electricity generation from biomass are much better than those for biomass to liquid fuels, there are still inefficiencies in the system, beginning with the capture of sunlight by the green plant and production of lignocelluloses from the process of photosynthesis. Further fundamental advances in plant biology are necessary in order for increases in efficiency to be achieved.

d) Integration of policy mechanisms and a regulatory framework linked to long-term delivery of emissions trading scheme
Several government departments and mechanisms exist to support this fragmented activity. Both a capital support programme and renewables obligation certificate for heat have been suggested as mechanisms that might provide a step-change incentive for development. Others will include more financial incentives for dedicated perennial bioenergy crops and the use of CHP in public buildings such as schools and hospitals. Central government and regional development agencies must act together to ensure that these mechanisms are put in place. In the long term, the European emissions trading scheme should help to give bioenergy a considerable boost but, until the cost of carbon is better understood, the future remains uncertain.

e) The uncertainty of climate change
The threat of a changing climate is ever present. This is an overarching future consideration, for example, in determining strategy in crop improvement (Will we be growing the right crops in future? What will their yield be? Will we have more pests and disease?). Also, in determining the balance between heat, electricity and liquid biofuels (Will the land resource be better used to grow wheat for ethanol or willow for heat?).

f) Biotechnology and the deployment of genetically modified bioenergy crops
Public perception, understanding and acceptance of biotechnological routes to crop improvement may be a key challenge for the deployment of future bioenergy crops. On the one hand, technological advances may provide the step-change necessary for improved yields while, on the other, this may not be acceptable to the public. Urgent engagement with the public is required to understand this complex area further.

2 Key scientific advances

a) Designer crops for bioenergy
Using the latest biotechnological tools that are not necessarily genetically modified, better crops for bioenergy should be developed. This requires a step-change in current thinking that is only considering marker-assisted selection of willow for pathogen resistance and improved yield. Systems biology now enables us to follow gene, metabolite and protein profiles simultaneously, and an array of genomic and post-genomic technologies linked to molecular genetic can be utilised to provide:

- high-yield crops that require inputs (optimised to maximised), thus improving efficiency further. A move to perennial (more efficient) and away from annual cropping systems. A 30% increase in yield will be necessary over the next 10 years for bioenergy crops and this should be tractable
- crops with different qualities – increased lignin for calorific combustion, or improved oils, starches and sugars for liquid biofuels
- crops with improved resistance to biotic and abiotic stresses that are likely to occur in future
- designer microbes and *in situ* degradation of the plant cell wall, for combustion or other conversions.

Model bioenergy crops include poplar (for which the DNA sequence and genomic resources are already available), maize and now brachypodium as a model grass which the US Department of Energy will sequence shortly. These are important resources for future advances. There are only limited germplasm collections for these crops and this should be addressed as a future priority.

Likely to occur Yes, in the next 5–10 years
Future capacity We have good core skills but these are not being currently applied to bioenergy.
Future applications Bioethanol, biodiesel, heat, power produced efficiently with better life cycle analysis.

b) New biological processes for bioenergy – microbial and *in planta*
Many new advances are possible, including hydrogen from green plants through dark processes, artificial photosynthesis and other processes that are very much contained at the research (laboratory scale) at present.

Likely to occur for robust commercialisation High risk, large reward.
Future capacity and applications UK capacity is limited in this area, with the exception of one or two very strong groups.

c) A land management framework linked to an ecological assessment tool
Identification of optimum land-use strategies for the UK biomass resource and likely future use of arable, 'set aside' and marginal land in a changing climate is required. We need to quantify the environmental consequences of bioenergy crops, developing tools for 'well to wheels' type analysis. Further research to capture the evidence base is required, including for bioenergy crops' response to future climates. Some greenhouse gases data are missing and there are limited 'tools' for end users. The Environment Agency has developed 'BEAT' to assess greenhouse gas emissions in planning new developments in bioenergy, but this area requires further input.

Likely to occur Yes.
Future capacity and applications? The UK has good expertise as yet not applied to bioenergy systems, but that may be changing.

d) Development of new gasification technologies and other advances linked to the biorefinery concept
New technologies for conversion are likely to develop to commercial scale by 2020. These will be essential again for improved efficiency but also because they offer the possibility of primary, secondary and tertiary uses of green plants as we move towards the bio-based economy.

Likely to occur? Yes.
Future capacity and applications? Wide-ranging potential to utilise low-input lignocellulosic crops for CHP and then link this to the extraction of other bioresources.

e) Identification of a limited number of bioenergy chains
It seems likely that focus on a limited number of bioenergy chains would be useful. Which should be chosen? US roadmapping suggests all future activity will focus on improving the quality and quantity of biomass in green plants and also improving all biochemical steps in the bioethanol synthesis pathway.

Likely to occur:? Yes, in both the USA and Europe – better co-ordination required.
Capacity Potentially good, but no strategic thinking in the UK.

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ANNEX 1 – Summary of basic, strategic and applied research funding in bioenergy in the UK – 2006

Table A1: Research funding: Basic and applied strategic research

Programme	Funding agency	Description	Committed funds	Period	Representative annual spend
NERC: Towards A Sustainable Energy Economy	NERC/EPSRC	A whole-systems approach to analysing bioenergy demand and supply, mobilising the long-term potential of bioenergy. A multidisciplinary consortium to address gaps in the whole system.	£2.2 million	2005–2009	£500,000
RELU: Rural Economy and Land Use, Research Councils UK	BBSRC/ESRC/NERC	Social, economic and environmental implications of increasing rural land use under energy crops This project integrates social, economic, hydrological and biodiversity studies in an interdisciplinary approach to develop a scientific framework for sustainability appraisal of the medium- and long-term conversion of land to energy crops. We will provide scientific tools for updating best practice guides and environmental impact assessments, strategic environmental assessments or sustainable appraisals involving projects, policies or programmes, where increased planting of energy crops is proposed or anticipated. The project profits from involvement of the Regional Development Agencies of the East Midlands and South-West regions used as study areas, industry representatives and DEFRA	£859,000	2006–2008	£285,000
SUPERGEN	EPSRC	The SUPERGEN Biomass, Biofuels and Energy Crops Consortium will carry out research into renewable energy generation from biomass – any plant material which can be used as a fuel, such as wood, agricultural waste and vegetable oils. Researchers will be studying the production of several types of biomass and investigating their behaviour in thermal conversion processes. The conversion processes will be studied for production of biofuels that can be used to generate	£2.9 million	2003–2007	£75,000

		renewable energy more efficiently. The results will be used to create computer models for designing and maximising the efficiency of the thermal processes, and to identify the ideal specifications of biomass fuels for different processes. System studies will evaluate the performance, cost, and socioeconomic benefits of the full range of bio-energy systems considered			
SUPERGEN	EPSRC	The UK Sustainable Hydrogen Energy Consortium (SHEC) was established on 1 April 2003 by the EPSRC (in collaboration with the BBSRC, ESRC and NERC) as part of the SUPERGEN Initiative. SHEC will target many of the forefront fundamental, multidisciplinary research challenges in the production, storage, distribution and utilisation of hydrogen. In addition, it will study the feasibility and acceptability of sustainable hydrogen as an energy carrier through a range of socioeconomic projects, ranging from the public awareness and acceptability of hydrogen, impact analyses and regulatory issues	£3.5 million	2003–2007	£900,000
Energy Crops – Genetic Improvement	DEFRA	Underpinning and strategic research to deliver improved grass and tree crops for bioenergy, with high yield and pest and disease resistance. Two networks have been initiated. The first, BEGIN, aims to produce improved willow genotypes with high yield and improved pest and disease resistance. The second is for the improvement of the grass, miscanthus	£3.5 million	2003–2008	£90,000
UKERC	EPSRC/NERC/ESRC	Networking and development of the research atlas and roadmap for UK Bioenergy Research. Contribution to TSEC.	£290,000	2005–2009	£50,000
Responsive Mode	BBSRC	The Plants and Microbial committee of BBSRC research topic, Fossil Carbon Substitution: Biomass to Biosynthesis	Limited to date	2005–	Limited to date
Responsive Mode	EPSRC		Variable	2002–current	Variable
Sustainable Urban Environment: Waste Consortium	EPSRC	Cluster on waste, water and land management			

Programme					
TOTAL					

Table A2: Research funding: Applied research (including RDA support)

Programme	Funding agency	Description	Committed funds	Period	Typical annual spend
New and Renewables Energy Programme	DTI	Past research on fuel supply systems for energy crops, and agricultural and forestry residues, including Target of doubling energy crop yields (based on short-rotation coppice willow) from current yields of 8 oven dried tonnes per hectare. Equipment development for reduced costs and increased efficiency Energy crop production work supported by DTI is coming to a conclusion. Future projects to be funded on a responsive basis through the Technology Programme, and taking account of the Innovations Review, but energy crops unlikely to be a priority The New and Renewable Energy Research and Development Programme is now being delivered through the Collaborative Research and Development Business Support Product. Open competitions for funding under this product happen twice a year			
Technology Programme	DTI	A new DTI Technology Innovation Programme was announced in April 2006. Technology priority areas include emerging energy technologies (low-carbon energy technologies, including development of the biorefinery concept); sustainable production and consumption (energy efficiency technologies); bioscience and healthcare (exploitation of plant and microbial bioscience for industry, safety biomarkers for pharmaceutical development); advanced materials (materials for extended first use and re-use); information and communication technology (data, scientific and	£80 million in total	2006–	£20 million?

		medical visualisation for innovative products and services)			
Applied Research Grants	The Carbon Trust	The Carbon Trust is an independent company funded by Government. Its role is to help the UK move towards a low-carbon economy by helping business and the public sector reduce carbon emissions now and capture the commercial opportunities of low-carbon technologies. It supports the development of low-carbon technologies through research and development grants, with several of these placed within the bioenergy sector in recent years. Other activities of the trust with specific relevance to bioenergy are given below	£672,000	2003–2007	
Carbon Vision	The Carbon Trust	The overall aim of this Carbon Trust project is to develop a pragmatic lifecycle methodology that will allow a systematic estimation of carbon inventories in different industrial sectors that supports the incorporation of the carbon intensity of the full supply chain. This will involve both environmental and economic aspects of carbon footprints and embodied carbon, enabling estimation of 'carbon added' and 'valued added' at each stage in the supply chain	£1.05 million	2005-2008	
Biomass Heat Accelerator	The Carbon Trust	The broad aim of the BHA programme is to help make the UK biomass heat market self-sustaining by reducing costs and addressing supply chain risks. The project aims to work with existing and new sites to develop benchmarks from robust case studies, identify and demonstrate cost reductions, and raise awareness among end users and other stakeholders	£5 million	2006–2011	
Tyndall Centre	NERC/EPSRC/ESRC	Transdisciplinary research related to climate change, with some limited desk studies on the low-carbon economy related to bioenergy	£200,000	2001–2006	
SEERAD	Scottish Executive	Currently reviewing priorities in the area, and reviewing ways forward for biofuel development in Scotland. SEERAD has indirect investments through 'GREEN grain', co-funded with Defra and the Home-Grown Cereals Authority (genetic reduction of nitrogen emissions and growing costs of wheat production while enhancing the value of wheat grain for the bioethanol industry,			

		among others)			
Environment Agency	Environment Agency	Funds small-scale hydroelectric and biomass energy. Developing BEAT: computer-based predictive tool for potential environmental impacts and mitigation responses to aid decision-making on biomass developments from an environmental perspective, especially for environmental impact assessment scoping			
Forest Research	Forestry Commission	Co-funding, with DTI/Defra/DARD, the Yield Models for Energy Coppice Poplar and Willow: Phase IV project. Other activity is highly applied, near market, e.g. extraction, drying and chipping of woodfuel from plantations – ash recycling – medium- to large-scale recovery, baling, handling of residue from logging	£2 million approx	1999–2006	
Biomass Energy Centre	DEFRA	Established in May 2006, the Biomass Energy Centre is an expert centre for advice to growers, technologists and developers in bioenergy	£20,000	2006	