Appendix 2

UK Capabilities in Advanced Biofuels

Claire Smith

1 EXECUTIVE SUMMARY

This assessment has been carried out to identify the strengths and weaknesses of the UK's biofuels R&D sector. The UK has a number of key strengths and capabilities upon which it can build an advanced biofuel industry. These include the quality of its R&D, a sophisticated and well developed petrochemical industry, a world leading financial sector and an emerging first generation biofuels industry.

The UK's academic capability within the advanced biofuels sector is broad. Areas of technological strength are pyrolysis and gasification research at, for example, Aston, Nottingham, Newcastle and Leeds Universities, the development of micro-organisms for lignocellulosic bioethanol production at the University of Nottingham and Imperial College London and algal technology research at SAMS and PML. There is also broad research capability into the development and use of plant biomass resources. Institutions such as the John Innes Centre, Rothamstead Research and National Institute of Agricultural Botany (NIAB) have expertise in the development of genomic tools underpinning crop improvement. University based establishments such as IBERS, Rothamstead Research and the University of Southampton carry out fundamental applied research into plant biomass productivity, particularly in poplars, willow and Miscanthus as part of the Biomass for Energy Crop Genetic Improvement Network (BEGIN) and the Miscanthus Genetic Improvement Network at IBERS. The Towards a Sustainable Energy Economy Programme (TSEC) and Rural Economy and Land Use (RELU) programmes investigated the social and economic impacts of increased biomass use within the UK.

As well as academic research, there are also several centres within the UK working on industrial R&D scale up. These centres have sponsors drawn from both the academic and industrial arenas, and thus provide an important link between academic research and the industrial application of science. These centres include:

- The Centre for Excellence in Biocatalysis, Biotransformations and Biocatalytic Manufacture (CoEBio3) based in Manchester. CoEBio3 is a national centre for commercialisation and scale up of biocatalysts. It works with a number of partners, including the Centre for Process Innovation (CPI), the Universities of York, Strathclyde and Heriot Watt.
- The Centre for Process Innovation, located on Teesside, contains the National Industrial Biotechnology Facility. It provides pilot scale fermentation, anaerobic digestion and gasification (to be built) facilities.
- The Questor Centre in Belfast is focussed towards the application of environmental technologies, especially wastes and covers bioenergy as part of its remit.

The UK also has a number of companies developing and supporting advanced biofuel technologies or looking to develop projects. These include:

- Ineos Bio, BA, Biossence and Airproducts who are developing projects to produce biofuels and/or bioenergy from syngas produced from high biomass waste;
- Graphite Resources and Sterecycle who manufacture high biomass flocc from wastes using autoclave technology;
- Johnson Matthey, BP and Oxford Catalysts who are developing syngas cleaning and upgrading processes to produce fuels;
- BiogenGreenfinch, Exergy, Entec and UTS Biogas who are establishing an increasing AD production base in the UK, albeit primarily for power, supported by companies such as Hardstaff Group, Tennans, Leeds City Council and Lincolnshire County Council in rolling out the use of biomethane fuelled vehicles;
- TMO Renewables, Biocaldol, Green Biologics and Butamax who are developing microbial routes for conversion of biomass to fuels; and
- North Energy Associates and LCAworks who specialise in life cycle analyses.

These developments are supported by the strong UK petrochemical industry, its emerging first generation biofuels industry and its strong financial sector centred on London which provides access to business networks, venture capitalists, banks, brokers, lawyers and accountants. The UK has the 4th largest refining capacity in Europe which produces about 90% of the UK's transport fuels from eight large crude oil refineries operating around the UK coast. There is an existing but struggling biodiesel manufacturing base and an emerging bioethanol production base with a number of bioethanol plants operating or in the planning and construction phases.

Contents

2 CAPABILITIES ANALYSIS

The UK has a number of strengths and capabilities, lying across all technology readiness levels (TRL's) from basic research through to industrial scale deployment[1], upon which it can build an advanced biofuels industry. These strengths include its international reputation for the quality of its R&D, its sophisticated and well developed petrochemical industry, its world leading financial services sector and its growing first generation biofuels industry.

In this section, UK strengths and capabilities are reviewed and compared with those in the rest of the world, thereby facilitating the identification of the UK's competitive position by pathway. These strengths and capabilities are tabulated[2] by the feedstock, intermediates and fuels categories shown in Figure 1 and cover the following:

- UK and rest of world academic (or basic) research capability
- UK and rest of world industrial capability
- Active and planned scale up/pilot facilities
- Active and planned demonstration facilities

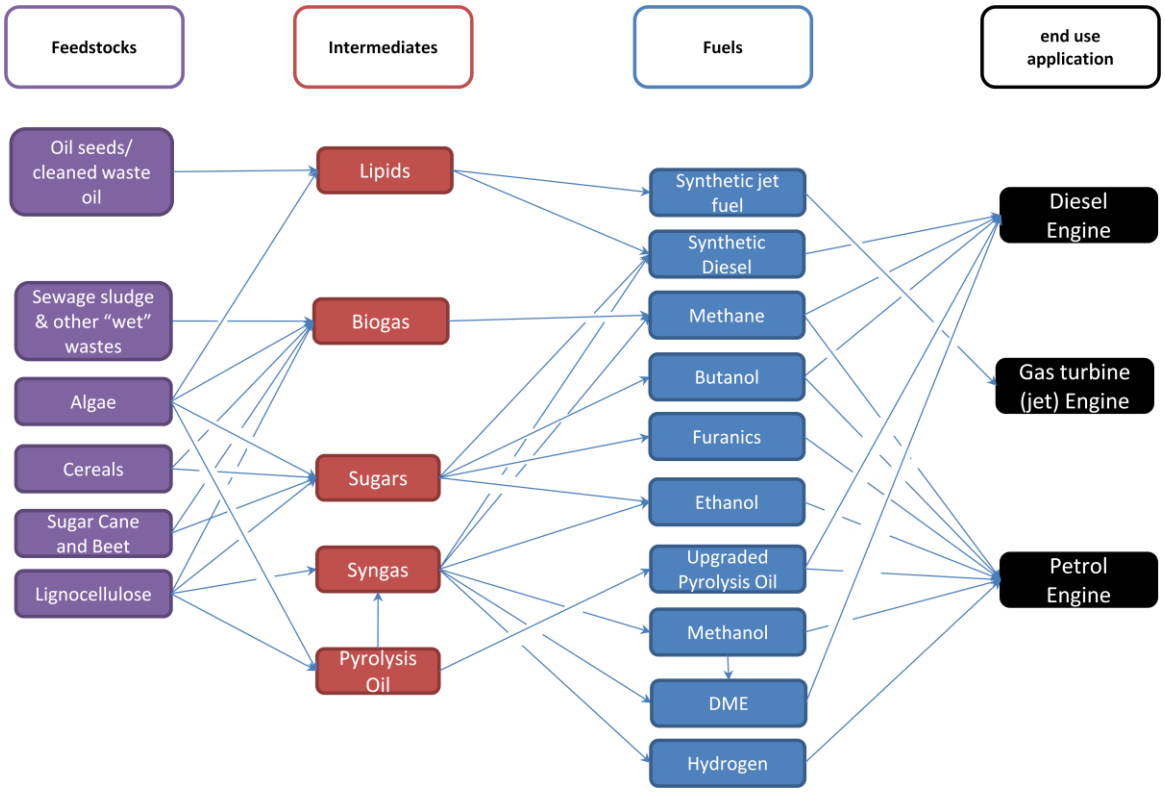


Figure 1 Biofuel Pathways Map

[1] See http://www.hq.nasa.gov/office/codeq/trl/trlchrt.pdf for more information about TRL's.
[2] Areas of identified strengths are highlighted by grey shading.

2.1 Feedstocks

2.1.1 Algae

2.1.1.1 Microalgae

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial
UK	Culture collections at SAMS[3] and Marine Biological Association. Excellent underpinning algae capability at CEFAS[4], SAMS, Plymouth Marine Labs, Swansea, Bangor and Stirling Universities. Other relevant expertise in algae fuels and products at Birmingham City University, University of West England, Cambridge, Queen's University Belfast, Newcastle, University College London and University of East Anglia. Research on growth systems at Plymouth Marine Labs, Heriot Watt, Sheffield, Loughborough, UCL[5] (photobioreactors) and Cranfield (sea growth) [6]	A number of small and medium enterprises (SME) are developing photobioreactor technology (Varicon Aqua, Scottish Bioenergy, photobioreactor.co.uk). A handful of companies are investigating bioremediation with algae culture (Scottish Bioenergy, ExAlga, photobioreactor.co.uk). Strong interest from major airlines, Airbus, BA, Finnair, IATA, etc on the production of microalgae at sea for biofuels production (1).	Boots and PML have developed a 32,000 l photobioreactor at Nottingham using CO_2 emissions from a combined cycle gas turbine power station (1). There are plans to develop an Algal Innovation Centre from 2014 near Cambridge which will showcase a variety of bioreactors, raceway ponds and fermentation systems (2).	Microalgae are produced for aquaculture at Seasalter Whitstable and a hatchery in Barrow, Cumbria. However, this scale is significantly smaller than what would be needed for fuels or energy.
ROW	Significant work in the USA, particularly at NREL, Texas A and M, Sustainable Algal Biofuels Consortium (Arizona State) and the Consortium for Algal Biofuels Commercialisation (University of California, San Diego). In Australia, University of Adelaide, and in Israel, Ben Guirion University are significant players. In Europe, CEVA (FR), Florence University (IT) and Wageningen (NL) have considerable research strength.	A large number of companies working on this, including Algenol, Solix, Sapphire, Solazyme, Seambiotic, Martek, Cellana, Petrosun, Origin Oil, Algae Tech, Aquaflow Bionic. Interest from Haldoe Topsoe, Monsanto, DARPA, Quantas, Exxon, BP, Shell, Toyota, Synthetic Genomics. Some players have invested then withdrawn from this area, for example Shell who partnered with Cellana (4).	Existing plants in USA include Algenol, Solix, Livefuels, Aurora (0.1 million US gallon) and Solazyme (0.3 million US gallon) (3). In Israel, Seambiotic have a 0.1 million US gallon facility. Planned plants include Bioprocess Algae in the USA, 0.01 million US gallon, from 2011. Kumho in Korea, 0.39 million US gallon from 2011, and MBD Energy, Australia 0.01 million US gallon (3).	There are no commercial scale microalgae facilities. The USA leads in demonstrating microalgae biofuels production. Greenstar products plan a 2 million US gallon facility from 2012, Sapphire have plans for a 1 million US gallon from 2015. In Australia, MBD Energy will scale up to 3 million US gallon from 2013 (3).
UK and International Networking	The NERC/Bioscience KTN Algal Bioenergy Special Interest Group is investigating the sustainability implications of micro (and macro) algae cultivation at scale (4). Algae Biotechnology Wales (5) , the Oasis project at Cranfield University (6) and Incrops (7) provide knowledge transfer services. The Cambridge Algal Bioenergy Consortium brings together Cambridge University, Exeter University, Imperial College, Rothamsted Research and UCL to investigate algae to fuel applications (8). SUPERGEN Biomass and Bioenergy II has a marine biomass strand looking at algae as a feedstock for fermentation and thermochemical routes (9).			
Examples of European projects	Energetic Algae and BioMara, both Interreg projects, are investigating the potential for using microalgae and macroalgae grown in the UK area to be used for biofuels and bioenergy (10) (11). The EU FP7 project Aquafuels, involves Imperial College London, and is investigating microalgae for fuels for deployment abroad (12). The EU FP7 project BioAlgaeSorb involves Swansea University, British Trout Association, Varicon Aqua and University of Durham to investigate algae for bioremediation (13). The UK is involved in EERA project on macro and microalgae, through SAMS, Newcastle, Cambridge, and University College London. Algae form part of the European Industrial Bioenergy Initiative.			

[3] Scottish Association for Marine Sciences
[4] Centre for Environment, Fisheries and Aquaculture Science
[5] University College London
[6] Grey shading indicates an area of highlighted UK strength

Assessment UK Competitive Position	The UK has a strong competitive position in basic and applied research in microalgae based technologies, and a strong capability investigating the use of microalgae for biofuels, on par with other leading countries. There is some industrial activity in this area in the UK, this is focussed on the production of microalgae for high value products and aquaculture feed and bioremediation of waste water and CO_2 rather than for large scale fuels applications, so the UK is weak compared to countries such as the USA. Given the UK climate it is unlikely that the UK will produce oil based fuels from algae at scale, so will be an IP developer rather than an implementer. However, after the removal of high value products, algal residues could be used in AD processes, to provide biomethane which could be used heat, electricity or biomethane fuels. The UK has the potential to lead in this area, but the Netherlands are also actively researching this area.

2.1.1.2 Macroalgae

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	Excellent, world-class research capability at Scottish Association for Marine Science. Expertise at Plymouth University, Newcastle University and Queens University Belfast on macroalgae growth. There is a germplasm collection at Culture Collection of Algae and Protozoa. Research into macroalgae conversion for thermochemical and biochemical processing at Leeds and IBERS as part of the SUPERGEN project. Research at Plymouth, Leeds and Aston Universities on thermochemical conversion processes. There has been research on macroalgae AD at Newcastle University and SAMS under the Scottish Enterprise Seaweed AD project.	There is limited activity in the UK from industrial companies although ostensibly the UK's fermentation and anaerobic digestion companies could contribute here.	SAMS have demonstrated the feasibility of farming brown seaweed, and Queens University Belfast has plans for a pilot scale macroalgae farm as part of the Energetic Algae project (12).	None for biofuels - although the UK does have a small industry based on the harvesting of wild macroalgae stocks for high value products and animal feed.
ROW	Significant expertise in macroalgae cultivation in Asia, Norway and Ireland. World class research into the use of macroalgae for biofuels and energy in Scandinavia especially at NTNU Norway, Risoe Denmark, ECN Netherlands and Japan.	Most activity is in developing macroalgae as a source of ethanol and butanol. DuPont/Bioarchitecture Lab (USA) are investigating seaweed for biobutanol. Bioarchitecture Lab is collaborating with Statoil in Norway, and Chilean Economic Development Organisation to investigate ethanol from macroalgae (14). The City of Venice is investigating macroalgae for electricity (14).	Commercial scale production of macroalgae for food uses in Asia, particularly China, Korea, Philippines and Thailand. Other commercial scale production in Chile. Several major pilot and demonstration projects announced predominantly looking at making ethanol from seaweed. South Korea's National Ministry aims to produce 400 million gallons of ethanol by 2020 (14). The Chilean Economic Development Organisation and Bioarchitecture Lab are aiming to produce 105 million litres of ethanol in a $7 million project (14). The Philippines National Government are planning a 250 acre macroalgae farm in a $5 million project (14). The Ocean Sunrise project in Japan has the ambitious aims to produce ethanol from *Sargassum horneri*, on 4.47 million km of unused sea around Japan (15).	
UK and International Networking	The Macro-algae Cultivation & Marine Biomass Forum is investigating issues and challenges, and the potential for a macroalgae farm in the UK (18). NERC/Bioscience KTN Algal Bioenergy Special Interest Group is investigating the sustainability implications of micro (and macro) algae cultivation at scale (4). SUPERGEN has a marine biomass strand which is investigating algae as a feedstock for fermentation and thermochemical routes (9). The European Algal Biomass Association has several members from the UK (16).			
Examples of international projects	Energetic Algae and BioMara, both Interreg projects, which are investigating the potential for using microalgae and macroalgae grown in the UK area to be used for biofuels and bioenergy (10) (11). UK involved in the EERA project on macro and microalgae, through SAMS, Newcastle, Cambridge, and University College London. The FP7 Project Biowalk4Biofuels is investigating the potential to use macroalgae in anaerobic digestion (17)			
Assessment of UK Competitive Position	Despite the UK's strength in basic macroalgae research, the UK is lagging in the deployment of macroalgae cultivation, especially compared to Asia and Chile. The UK is generally on par with the capabilities of leading countries within the EU for macroalgae farming at scale, although plans for macroalgae farms elsewhere appear further developed than elsewhere in the EU. The UK has a strong competitive position in the thermal conversion and anaerobic digestion of macroalgae to fuels and energy at the basic research level, and is leading in the utilisation of macroalgae within AD facilities. However, despite a strong academic and industrial capability in sugar conversion to ethanol and butanol, the UK is lagging other countries in the developing macroalgae as a source of ethanol and butanol.			

2.1.2 Arable Crops

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale Up Facilities	Demonstration and Commercial Scale
UK	World class research into plant science at Rothamsted Research, John Innes Centre, Sainsbury Laboratory, Oxford, Cambridge, IBERS[7] and NIAB[8]. Considerable expertise in photosynthesis with particular expertise at Cambridge University, Imperial College London, York. Expertise in plant manipulation and breeding at Rothamsted, John Innes Centre, IBERS, Warwick, CNAP[9], Southampton, Oxford Nottingham and Manchester amongst others.	ADAS have been involved in a number of projects investigating the breeding and agronomy of crops for biofuels uses including wheat and oilseed rape with several companies including Scotch Whisky Research Institute.	The cereals wheat, barley and oats and the oilseeds oilseed rape and linseed are commercially grown in the UK.	
ROW	In the USA the principal research establishments for arable crop research are Purdue, Michigan State University, University of Illinois at Urbana Champaign, University of Kansas and in Canada, University of Saskatchewan Saskatoon. In Europe the principal crop research agencies are INRA, Plant Research International at Wageningen University in the Netherlands, various Max Planck Institutes in Germany and Uppsala University in Sweden.	Several plant breeding companies involved in this area including Syngenta, Senova, KWS, NK, Elsoms Seeds. While all have bases in the UK, they are all foreign owned. Arable crops, regardless of whether they are for biofuels or not, are largely developed elsewhere and these varieties are then trialled in the UK.	The production of cereals and oilseeds is commercial around the world	
UK and international networking	WGIN (Wheat Genetic Improvement Network) and OREGIN (Oilseed Rape Genetic Improvement Network) are both Defra funded networks that pull together stakeholders interested in the improvement of oilseed rape and wheat in the UK (18) (19). Monogram is a cereals and small grasses improvement network (20), and Garnet is an Arabidopsis network funded by BBSRC (21).			
Examples of international projects	The NUE Crops FP7 project aims to improve nutrient efficiency in major European food, feed and biofuel crops to reduce the negative environmental impact of crop production. It is led by Newcastle University and includes SCRI[10] and KWS (22). FP7 project TriticeaeGenome involves John Innes Centre, SCRI, NIAB and aims to elucidate the genomics of triticeae species so that they can be improved (23). The FP6 project Tritimed involves Rothamstead Research and Bristol University and is investigating the adaptation of wheat genome for wheat growth in the Mediterranean (24) . FP7 Project AGFOODTRADE is investigating the effects that biofuels can have on agriculture and food crop trade (25). The BEE project investigated biomass availability including arable crops (26).			
Assessment of UK Competitive Position	The UK expertise in plant genetics is on par with that elsewhere in the world. The UK has particular strengths in photosynthesis, cereal and oilseed genetics and in high throughput screening technologies which can be used to identify novel, agronomically useful traits. However, the UK has a major gap in the development of new varieties and so fails to capitalise on its plant genetics strength. This is because all of the major plant breeders are located outside of the UK and the agrobiotechnology companies left the UK with the EU moratorium on GM crops in the 1990s. While the UK will inevitably need to import new varieties from abroad, the UK does have a good capability in trialling varieties. Therefore, while elements of arable crop development are strong, there are gaps.			

[7] Institute of Biological Environmental and Rural Sciences
[8] National Institute of Agricultural Botany
[9] Centre for Novel Agricultural Products (University of York)
[10] Scottish Crop Research Institute

2.1.3 Perennial Energy Crops

Location	University/Research Institutes Activity	Industrial Activity	Pilot and Scale Up Facilities	Commercial and Demonstration Scale
UK	There is world class expertise in Miscanthus at IBERS and world class expertise in Short Rotation Coppice at Rothamsted Research and at University of Southampton. IBERS have a collection of Miscanthus varieties, and Rothamsted Research has the National Willow Collection. These facilities not only allow the trialling of specific varieties to see how they apply to the UK, but also allow studies into the natural variation of these varieties which could infer novel traits for fuels and energy applications.	Several companies are active in this area. These are mainly companies which provide plant material and facilitate contracts with end users. There is little or no work carried out in the UK into the genetic improvement of perennial energy crops by large plant science corporations. ADAS, John Amos and Renewable Energy Crops all provide rhizomes and agronomic advice for Miscanthus production. Energy Crops Company, Coppice Resources Limited and Forest Research are developing SRC willow as a bioenergy feedstock, and both Energy Crops Company and Coppice Resources offer willow cuttings, agronomic advice and supply contracts for industrial users. ADAS have a collection of *Miscanthus*, giant reed and coppice but do not have an active research programme in this area.	Both Poplar and Miscanthus are grown commercially for bioenergy production in the UK	
ROW	The Universities of Illinois (USA), Antwerp (Belgium) and Umea (Sweden) are among the leading institutions in this area. Most of the willow, poplar and *Miscanthus* genotypes developed have been developed at University groups at University at Illinois, and University of Umea.	Most R&D done at universities. In USA, USDA providing support looking at cellulosic crops; Ceres looking at energy cane, miscanthus, sorghum, Switchgrass in USA. Swee sorghum research in India.	A variety of energy crops are grown commercially throughout the world including Miscanthus and coppice varieties	
UK and international networking	Research on perennial energy crops is funded as part of the BBSRC Sustainable Energy Centre (27). The SUPERGEN project has involved a large component of work related to assessing the use of energy crops in different conversion systems (28). The UK is part of IEA Task 43 on Biomass Feedstocks for Energy Markets and is represented by Forest Research (29). The UK has previously been involved in IEA project 30 'Short Rotation Crops for Bioenergy Systems' through TV Energy (30), and Task 31 'Biomass Production for Energy from Sustainable Forestry' through Forest Research (31).			
Examples of international projects	The UK is involved in the FP7 project Energy Poplar which aims to enhance poplar traits for bioenergy applications through Imperial College and University of Southampton (32) and, is involved in the Intelligent Energy Europe programme EuBionet through Imperial College (33). Significant initiatives in this area include the Intelligent Energy Europe programme EnCrop which aimed to promote the cultivation, and utilisation of energy crops in the EU (34) , and the IEE project Biomass Trade Centres, looking at development of trading of biomass (35).			
Assessment of UK Competitive Position	As for arable crops, the UK is extremely strong at plant genetics and high throughput screening technologies which could be used for variety development; however, this is not supported by an active energy crop breeding sector so varieties will be imported. The UK has world leading expertise in the agronomy and utilisation of perennial energy crops. However, this could be compromised by the removal of funding for maintenance of the national willow collection at Rothamsted and *Miscanthus* collection at IBERS by Defra from FY 2011/2012.			

2.1.4 Forestry

Location	University/Research Institutes Activity	Industrial Activity	Pilot and Scale Up Facilities	Demonstration and Commercial Scale
UK	Forestry Research is the premier institute for UK forestry research. There is basic research into forestry production at the following universities: Napier, Cranfield, Edinburgh, Imperial College, Oxford, Bangor, Aberdeen, Cumbria. A wide variety of colleges offer training in forestry skills including Harper Adams University College, Askham Bryan College, Plumpton College, Writtle College, Moulton College and Sparsholt College amongst others.	Forestry is a commercial activity in the UK. Around 60% of UK forested area is Forestry Commission/Forestry Services managed; the remainder is privately owned and often undermanaged. There is scope to increase this to yield additional tonnages of forestry products (1). Industrial activity for bioenergy is in the area of harvesting and chipping for woodfuels. ETI's bioenergy projects indicate strong potential for the UK to produce significant volumes of biomass by 2050 for bioenergy purposes. A set of four projects are underway including the Ecosystems land use modelling project which is looking at the actual impacts of land use change and the value chain modelling project which is looking at optimising the UK bioenergy system.	The harvesting of wood materials for sawmills and panel board industries has been commercially practiced in the UK for decades. There is an increasing infrastructure and capacity for harvesting of forestry materials for other uses, driven through the development of the wood fuel industry, including the deployment of wood chip blowers through regional wood fuel organisations such as Midland Wood Fuels, CO_2 Sense Yorkshire, Northwoods and Heartwoods.	
ROW	Particular expertise around Scandinavia though Uppsala University, Lund University, Copenhagen University, University of Oulu, Finland, Finnish Forestry Research Institute, Forest Research Institute Sweden, VTT Finland and Swedish University of Agricultural Sciences. Significant research strengths in Germany and Austria through Forest Research Institute of Baden Wurttemberg and University of Natural Resources and Applied Sciences, Vienna (BOKU). In addition, almost every country has their own forestry institutions, such as Scion, New Zealand, Canadian Institution of Forestry etc.		Utilisation of forestry for bioenergy is already at the commercial scale. Biofuels will use the same chipping infrastructure as for other bioenergy uses. Harvesting, treatment, transport and storage of wood for bioenergy is commercial around the world but is particularly well developed in Scandinavia and Austria.	
UK and international networking	There are a large number of groups and international initiatives in this area. Amongst the most prominent are: • The Confederation of Forest Industries (Confor) is a trade association for the forest industries, helping to promote the developments of markets for timber and timber products (37). • The Institute of Chartered Foresters provides information and guidance to the public and industry about the specific expertise offered by those in the profession; and training and educational advice to students and professionals looking to build upon their experience (38). • The Royal Forestry Society provides information and training on wood management and increasing awareness of forestry (39). • Forestry Contracting Association is a trade association for forestry contractors. The FCA contributes to industry initiatives and assists members with business development and training opportunities (40). • The European Forest Institute provides networking in the area of forestry, promoting knowledge exchange and promoting and organising new research (41). • The Commonwealth Forestry Association provides networking in forestry, promoting the development of people working in the forestry sector (42). • The International Forestry Group is an international forum for discussion of areas relevant to sustainable use of forests (43).			
Examples of international projects	The UK has a strong involvement in international projects, particularly in EU Framework projects. These include "Eforwood" was an FP6 project investigating the sustainability of the whole forestry wood chain (44). The FP7 project "Motive" is developing models for adaptive forestry management; "NovelTree", funded through FP7 is investigating novel tree breeding strategies (44). The FP6 project "Treebreedex" is developing models for tree improvement sustainability and multifunctional uses (44). There is also a considerable activity in other projects, including the COST actions, ECHO which is investigating the effects of climate change on EU silviculture, the Forsys action which is developing a decision support system for forestry management, and an action investigating phytophthora effects on forestry (45), Interreg projects including projects investigating sustainability tools, multifunctional use of forests, and investigation of the effects of climate change on forestry (46).			
Assessment of UK Competitive Position	Through Forest Research, the UK has one of the leading research institutes in the world investigating forestry systems. The UK forestry community is also well linked both within the UK and to other forest associations world-wide through involvement in networking activities and research projects. Given that the UK has one of the lowest coverage of forestry areas in the EU at 12%, it cannot compete in terms of production quantities with other countries, particularly Scandinavian countries. However, the work of Forestry Research and other UK research institutes can be combined with the UK's developing biomass transport infrastructure (e.g. ports) to develop the use of imported sustainable forestry products			

2.1.5 Wastes

Location	University/Research Institutes Activity	Industrial Activity	Pilot and Scale Up Facilities	Demonstration and Commercial Scale
UK	The Open University through their Household Waste Survey is one of the lead providers of information on the composition of MSW streams in the UK. The universities of Brighton, Northampton, Cranfield and Teesside have programmes on waste management and characterisation. The ETI have an energy from waste programme which has commissioned Cranfield University to evaluate the energy value of UK wastes and to test wastes in different types of gasifier / pyrolyser. As part of the same programme, CPI are using the Cranfield data along with earlier economic models to produce detailed optimised system models for waste to energy deployment in the UK.	Waste handling and treatment is a well established industry. New technologies such as MBT[11] and MHT[12] are being developed, particularly with respect to extracting recyclables and to producing a high biomass waste fraction suited potentially for biofuel/bioenergy production. The UK has a number of companies running and developing MBT/MHT processes including Graphite Resources, Orchid, Sterecycle, Premier Waste Management, Viridor and Global Renewables, Dornabon and Waste Recycling Group.	MBT technology, for the separation of wastes from mixed municipal waste streams is already commercial in the UK. MHT (autoclave) technology is commercial for treating hazardous wastes such as from hospitals and is emerging commercially for the treatment of non hazardous wastes.	A number of MBT and MHT facilities are operational or are in development in the UK. There are around 18 MBT plants in the UK, with 43 in construction or planned (47). These include: • Orchid Environmental who have an 80 Kt plant in Huyton, and a 160 kt plant in Flintshire (48). • Viridor Laing who have developed a 100 kt plant in Manchester and have plans for a further 3 plants in the Manchester area (48). • Graphite Resources who have a 320 kt plant on Tyneside and plans for a 500kt plant on Teesside from 2011 (49). • Sterecycle who have a 100 kt plant in Rotherham, are developing a 200 kt plant in Cardiff due to open in 2011 and have plans for a 240 kt plant in Essex (50).
ROW	There are numerous examples of waste research. For example, under Altener1, Belgium investigated a regional development plan for obtaining renewable energy from waste.		MBT/MHT treatment is a commercial technology in several areas of the world.	The uptake of MBT and MHT processes vary throughout Europe. Italy has the highest number of MBT plants in Europe with over 100 plants, treating over 25% of Italy's MSW (52). Germany, Spain, Portugal, France and the UK also have some MBT activity (52).
UK and international networking	There are a number of organisations in this area: • WRAP (Waste & Resources Action Programme) is a Defra funded body which works in England, Scotland, Wales and Northern Ireland to help businesses and individuals reduce waste, develop sustainable products and use resources in an efficient way (48). • WARMNET is a network for all universities involved in waste management education and research. • The Environmental Sustainability KTN provides a forum for organisations to interact and investigate better uses for materials. The End of Life Management subgroup provides networking related to waste management options (49). • The Chartered Institute of Wastes Management (CIWM) provides professional development and networking in the area of waste management with a number of specific subgroups (50). • The Recycling and Waste Research and Development Active Network are a North West based group investigating funding opportunities and research in waste (51).			
Examples of international projects	The EU project WasteKit will run until 2012 and will bring together four regions from throughout Europe (NL, BE, UK and BU) to investigate different waste use options in the region (52). Ineos Bio is building a $130 million waste to ethanol plant in Florida (53).			
Assessment of UK Competitive Position	The UK has a strong capability in waste collection and processing of wastes; wastes arise densely in large conurbations and are collected to key centralised points. The increasing pressure to divert waste from landfill has led to an increase in the deployment of MBT/MHT facilities in the UK over the last five years. However, the withdrawal of PFI funding may mean that many of the planned facilities in the UK will not now reach fruition. The UK has a good research capability in this area and there is a strong networking capability. The increased deployment of MBT/MHT facilities in the UK should help provide confidence in the deployment potential of this technology in the UK for biofuel plants. A potential derailer to accessing wastes for advanced biofuel projects will be limitations arising from the waste hierarchy and subsequent competition for available wastes, for example from heat and power applications.			

[11] Mechanical biological treatment
[12] Mechanical heat treatment (autoclave)

2.2 Intermediates

2.2.1 Lipids

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	There is little research on the extraction of oils from oilseeds in the UK. There is some expertise at Bangor University in CO_2 extraction, but this is unlikely to be used for bulk applications such as extraction of oil from oilseeds due to the price. Basic research into extracting oil from microalgae at Coventry University and University of Manchester, investigating acoustic cavitation and ultrasonic cavitation respectively. The University of Sheffield are investigating microbubble technology.	Ecosolids has a novel oil extraction process known as CELLRUPTOR which could be applied to wet oil feedstocks such as algae.	The extraction of oils from oilseeds is already commercial. There are no pilot or scale up facilities to our knowledge for algal oil extraction.	Commercial extraction of oils from oilseeds at three locations in the UK, namely Erith, Hull and Merseyside. There is interest in developing another oilseed crusher in the North East of England (62).
ROW	There is a world leading centre for the development of oil extraction for oilseeds at Creol, near Bordeaux in France. The centre investigates the whole crush process, from pre-processing and dehulling to crushing, extraction and refining of higher value co-products. Other facilities include Iowa State University and AMES lab in the USA.	Origin oil combines electromagnetic pulses and pH to rupture cells while Diversified Energy uses only electromagnetic pulses. Caitlin has a mesoporous particles technology for oil extraction from algae.	Creol, in France have a pilot facility for optimising the extraction of oils from a variety of oilcrops (59). A number of pilot facilities principally in the USA are testing technologies for algal oil extraction. Algenol, Solix, Livefuels, Aurora (0.1 million US gallon) and Solazyme (0.3 million US gallon) (3). Seambiotic in Israel have a 0.1 million US gallon facility (3). Plans include Bioprocess Algae in USA, 0.01 million US gallon, from 2011, Kumho, Korea, 0.39 million US gallon from 2011, MBD Energy, Australia 0.01 million US gallon (3).	The extraction of oils from oilseeds is commercial world-wide. .
UK and international networking	None			
Examples of international projects	The FP7 Sustoil project led by the University of York aimed to develop advanced biorefinery schemes to convert EU oil rich crops into energy, food and bioproducts. Workstreams included projects looking at farming, harvesting and primary processing. There are numbers of projects looking at, for example, establishing non food oils such as Jatropha (e.g. UK company D1 Oils) and Camelina. Work is also ongoing looking to establish sustainability standards for oil crops. E.g. Roundtable for Sustainable Palm Oil for palm; Roundtable on Responsible Soy for Soy.			
Assessment of UK Competitive Position	The UK currently has three oilseed crushers, with a combined capacity of around 2 million tonnes per annum. As a commercial technology, there is little research in this area either in the UK or elsewhere. The notable exception of the Creol facility in France which provides process optimisation facilities for different oilseeds. The UK does have some strengths in cavitation technologies which could be applied to the extraction of oils from algae, although this is likely to be deployed outside of the UK.			

2.2.2 Biogas

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	A number of high quality research groups generally focussed on the optimisation of the AD process, through reactor optimisation and identifying optimal feedstock composition and pre-treatments including Southampton, Glamorgan, Newcastle, Cranfield , IBERS (North Wyke) and Birmingham Universities.	The UK has a number of companies which are active in the development of Anaerobic Digestion technology including, Biogen Greenfinch, MT Energy, Marches, UTS biogas. Veolia, Shanks and Ecosolids International also have active research projects in this area	Pilot facilities are typically at universities, i.e., Southampton and Newcastle Universities. The Anaerobic Digestion Development Centre (ADDC), located at CPI, is an open access facility which aims to provide the expertise to help UK businesses compete in world markets and optimize their AD process (60).	Anaerobic Digestion is a rapidly growing, commercial technology in the UK with 54 active plants at the beginning of 2011, 31 on farm and 23 off farm (61). The majority of these plants use biogas for the production of heat and or electricity. Injection of the biomethane in to the national grid is being demonstrated at three sites in the UK, Adnams Brewery, Suffolk and Didcot Water Treatment Works, Oxon and United Utilities, Manchester.
ROW	Academic research strengths in Sweden, Germany and USA. Other key players include Wageningen University, Lund University, Ghent Universities.	Large number of technology developers, principally from Germany, Denmark and Austria, including Bekon (DE), Biogas Nord (DE), Farmatic (DE), Schmak Biogas (DE), Xergi (DA) Weltec (DA), Zorg (CH) and Entec (AU).		Anaerobic digestion is commercial in many countries of the world with 8.3 mtoe of biogas produced in the EU alone in 2009 (62). The leading country in the EU is Germany producing 3,561 mtoe biogas, followed by Austria producing 141 mtoe biogas and Netherlands producing 179 mtoe of biogas (62).
UK and international networking	The UK has a number of organisations promoting the development of this sector. • The AD Biogas Association and REA Biogas both cover the whole AD area (63) (64). • The UK is linked in with the International Energy Agency Task 37 on energy from biogas and landfill gas (64) • Defra are involved in the Methane to Markets Initiative and UK China Sustainable Agriculture Innovation Network. • NNFCC have an active stakeholder group in this area and are working with stakeholders to develop the AD sector.			
Examples of European projects	The FP7 project Valorgas, led by Southampton University, is investigating how the whole process of using food waste for anaerobic digestion could be optimised (66). The EU FP6 Agrobiogas project, involving IBERS, developed a European Biogas Initiative to improve the yield of agricultural biogas plants (67). Biogas Regions, involving Severn Wye Energy Agency aims to overcome barriers to AD in Europe (68). The Biores project, involving Islenet from the Outer Hebrides of Scotland, aimed to promote MSW AD deployment in rural areas (69). The Altner project, Geronimo II Biogas, aimed to provide information to allow farmers to produce biogas, and the Farmgas project aimed to show how biogas could be produced from agricultural waste in Europe (70). European Agricultural AD helpdesk is funded through the Agrobiogas initiative and provides free advice http://www.adhelpdesk.eu/website/index.htm (71)			
Assessment of UK Competitive Position	While the UK has historically lagged other leading countries such as Germany and Denmark in anaerobic digestion, it is developing both its applied research capabilities and infrastructure rapidly and thus could develop a late-mover advantage. The UK is, alongside Italy, leading the utilisation of food wastes for anaerobic digestion at larger scale. The UK has less capability, especially at the commercial level in the digestion of energy crops as say Germany or the USA. Deployment potential will however be constrained by the availability of land to utilise digestate.			

2.2.3 Sugars

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	Wide range of research capability producing sugars from lignocellulosic biomass. Research on ionic liquids at Imperial College, Queens University Belfast, and University of York, supercritical fluids research at University of Nottingham and Birmingham and steam explosion at Institute of Food Research and Bangor BC. Dilute acid research at Queens University Research on biological pre-treatments at University of York, Liverpool John Moores University and University of Dundee.	Limited. Mycologix, a spin out from Imperial College, are developing fungal methods for break-down of lignocellulosic biomass.	Pilot facilities for steam explosion are at Institute for Food Research and Bangor BC. York University are looking to build demonstration plant at FERA[13] to include pilot facilities for hydrolysis.	None for advanced processes. Production of sugars for bioethanol in 1st generation processes is commercial at British Sugar (55ktonnes/year) (from sugar beet) and Ensus (300ktonnes/year) (from wheat starch). Vivergo Hull about to start commissioning. Wider activity in industrial starch isolation at Roquette, Corby, and Cargill nr. Manchester. Kingston Research are about to start commissioning of their starch to biobutanol pilot plant at BP's Saltend factory in Hull.
ROW	Significant expertise in North America for biomass pretreatment technologies and expertise in Scandinavia for enzymatic breakdown techniques. Key institutions in North America include Michigan State University, University California Riverside, Auburn University, Purdue, Texas A and M, NREL and University of British Columbia.	Verenium, Genencor and Novozymes are the leaders in the development of enzyme technologies, with Iogen, Abengoa, Royal Nedalco and IFP also active.	Wide range of technologies and enzymes being piloted, especially in the USA by Verenium, Blue Fire, Iogen, Poet, Lignol, DuPont/Danisco. Abengoa in Spain.	Production of sugars and starch is a mature, commercial, industry world-wide.
UK and international networking	The £27 million BBSRC Sustainable Energy Centre is investigating lignocellulose breakdown as part of its programme (27). The British Bioalcohols Group aims to exploit agricultural residues as a source of sugars (72). The UK is involved in the IEA Task 39 on Commercialising 1st and 2nd Generation Biofuels (73) . The USA Consortium for Applied Fundamentals and Innovation Consortium are investigating the efficiency of different biomass pre-treatment technologies (74). The Energy Biosciences Institute in the USA is investigating processes for breakdown of lignocellulosic materials for biofuels production (79).			
Examples of European projects	Liverpool John Moores University, UK Health and Research Institute and Biofuels Wales are involved in an FP7 project entitled Micrograss which aims to use microwave pyrolysis to release sugars from lignocellulosic biomass (75). The BABETHANOL project is investigating the use of waste materials for ethanol production using combined extrusion saccharification process (76). FP7 project BioLyfe is investigating novel processes for hydrolysis and fermentation (77). HYPE is developing consolidated bio-processing technologies (78). The FP7 project NEMO is investigating novel enzymes for lignocellulose breakdown (79). FIBREETOH is investigating the breakdown of paper waste for ethanol (80).			
Assessment of UK Competitive Position	The UK has a significant strength in the production of cereal crops, particularly wheat and has developed a commercial industry for both extraction of starch and utilisation in bioethanol. This will facilitate the development of other starch based fuels such as biobutanol. The UK is on par with leading countries world-wide in the development of pre-treatment of lignocellulosic biomass to extract sugars at the academic level, but, with limited industrial activity, significantly lags the principal technology developers throughout the world. As such, the UK will likely need to import pre-treatment and hydrolysis technologies from elsewhere should it develop a lignocellulosic ethanol or butanol capability.			

[13] Food and Environment Research Agency

2.2.4 Syngas Production

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	The UK has expertise in a range of gasification technologies. Broad gasification expertise at Aston, Cranfield and Leeds Universities. Bath University, Queens University, Ulster and Newcastle University have expertise of downdraft gasification. Fluidised bed gasification expertise at UCL and University of Cambridge. Expertise into CFB gasification at Ulster and Nottingham. There is expertise in syngas cleaning at Nottingham, Newcastle and Sheffield Universities.	A number of project developers exist within this space, but largely at small scale, including Biomass CHP Ltd, Rural Generation, ITI Energy (downdraft gasifiers), Envirothermal (multidirectional fixed bed), and Wellman Process Engineering (MSW gasifiers) and Refgas.	CPI are building a gasification pilot plant at their Teesside facility. York University are planning to include a gasifier in their biorefinery demonstration centre planned to be built at FERA near York.	No existing plants but a number of planned projects. Ineos Bio are planning a 24 kt per annum hybrid gasifier/ethanol plant on Teesside from 2011 – they plan to scale this up to 150 ktonnes/year from 2015 (86). British Airways/Solena has plans for a 50 tonnes/year waste to jet fuel plant, possibly located in East London (81). Air Products have plans to develop a 49 MW waste to electricity plant from 2014 – this may be converted to produce hydrogen in the future (81). Biossence are developing gasification based waste to energy projects in the UK which could convert to biofuels production in the future (81).
ROW	Substantial work in Europe both into gasification and syngas clean up i.e., Netherlands (ECN, Delft, Twente), Germany (Freiburg, Munich and FZK), Finland (VTT) and Austria (Vienna University of Technology). Some work in the USA, for example at the Gas Technologies Institute.	Gasification technologies for producing syngas are generally international companies – a company building a BTL facility would consider gasifiers from across the world. Gasifiers, of varying configurations, are produced by GE Energy, Prenflow, Choren, Siemens/Future Energy, MPG, Shell and Conoco Phillips, Foster Wheeler, Metso (Repotec design), Udhe, Noell, Winkler. KRW, TPS, VTT amongst others. Gas clean up equipment supplied by Air Products, Johnson Matthey, Linde and Lurgi.	Large number of demonstration and commercial scale plants announced, principally in the EU and USA covering a range of feedstocks and end products. ROW projects are typically based around woody biomass feedstocks – UK projects are all based on waste biomass feedstocks.	Large number of demonstration and commercial scale plants announced, principally in the EU and USA covering a range of feedstocks, technologies and end products.
UK and international networking	The NNFCC Thermochemical and Lignocellulosic Biomass Group is a group of stakeholders wishing to promote the development of gasification and other technologies in the UK (81). Gasification is covered under the SUPERGEN Biomass and Bioenergy project but there is little work on gasification (28).			
Examples of international projects	Johnson Matthey and Porvair are involved in the FP7 project Greensyngas which aims to produce a clean syngas for subsequent conversion steps (82). The FP6 project Chrisgas aimed to develop methods for producing a hydrogen rich syngas at Vaxo gasifier (83). The FP7 project Unique aims to compact gasification by integrating gasification, hot gas cleaning and conditioning into one reactor vessel (84). The Gussing gasifier brings together expertise from around the world. Oxford Catalysts have an FT unit operational at Gussing which makes UK world leading in that respect (85).			
Assessment of UK Competitive Position	The UK is lagging on the gasification of biomass for biofuels at the research level, although there is some experience in applying gasification processes for energy. As a result the UK would have to buy in gasification technologies for the scales needed for biofuels production. Syngas clean up research and syngas upgrading is on par with the rest of the world. The UK is developing a leading position in the gasification of wastes to fuels through the INEOS Bio and BA/Solena projects, and while the Air Products and Biossence waste to energy facilities are focussing initially on energy, these could convert to fuels production at a later date. The implementation of these projects could provide an impetus for further research and development work in biomass gasification in the UK.			

2.2.5 Pyrolysis Oil Production

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	There are a handful of world class research groups in this area, including the Aston University, University of Leeds, Newcastle University, Southampton, Imperial College and Nottingham. University of York and University of Exeter are investigating microwave pyrolysis methods.	There are a small number of UK pyrolysis companies, largely focussed upon the heat and power market (e.g. CARE Ltd) and waste treatment (e.g. 2G Biopower and Hudol). Johnson Matthey and Catal International are developing catalysts for pyrolysis. Symphony Energy works on pyrolysis of waste.	Carbon Trust Pyrolysis Challenge aims to produce bio-oil at a pilot plant in 2014 using wood waste and MSW, possibly co-locating with landfill sites (89). Aston University have developed an intermediate pyrolysis plant using 15,000 tonnes/year dry biomass to produce vapours which are then gasified for heat, power and fuels production (96).	Two projects in development but both will produce power. 2G Biopower will use UOP technology to develop a power plant which could be retrospectively converted to fuels production. ROC Power is planning to use UOP technology to produce power.
ROW	Several active research groups in Canada, the US, Netherlands and Finland.	Main players are Biomass Technology Group, Dynamotive, FZK/Lurgi, Sustainable Power Corporation, TNO and Ensyn and UOP who are working together in a JV with Envergent technologies.	Hopewell UOP/Aquaflow bionomics 0.01 m gallon facility due to open in USA in 2011 (3). Ensyn have a number of pyrolysis units operational. UOP have plans for a pyrolysis plant in Hawaii which will produce upgraded pyrolysis oil. Karlsruhe Institute of Technology have developed a 608 t/a pilot facility due to open in 2011.	Ensyn are developing a 22.5 M gallon fast pyrolysis in Alberta, Canada. Commercial scale production of pyrolysis from biomass through the FP7 Empyro project (90). This will develop a 5t/hr unit in the Netherlands using clean and waste wood, initially for energy but with potential for production of biofuels later (90).
Uk and international networking	The Supergen Biomass and Bioenergy II project brought together key stakeholders in thermal processing of biomass including pyrolysis (9). The UK is linked in with the International Energy Agency Task 34 on Pyrolysis, which has developed out of the Pyrolysis Network of Excellence (PyNE) (91).			
Examples of international projects	Pyrolysis is part of an FP7 project entitled Dibanet which will produce bio-oil after acid treatment of lignocellulosic biomass for levulinic acid production (92). The FP7 project Empyro is developing a 5 t/hr commercial scale unit in the Netherlands, initially for energy (90).			
Assessment of UK Capability	The UK has a leading position in pyrolysis research but industrial activity is limited and may only in the near term develop for heat and power. As a result, the UK is likely to bring in technologies developed elsewhere as they develop. Wide scale pyrolysis won't develop until the upgrading technology (whether mild for power generation via engines or extensive for fuels production) is available.			

2.3 Conversion to End Fuels

2.3.1 Hydrogenated Vegetable Oil

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	None known.	None specifically on HVO for biofuels although UOP, one of the major international companies in this area, have a base in the UK. The UK has a well developed oil refinery capacity with the technology and expertise to exploit HVO. Strong catalysts expertise from Johnson Matthey, Oxford Catalysts and UOP.	None – but there has been some indications of interest from one or more UK oil refineries in this concept.	
ROW	Texas A and M University are conducting research into the pre-treatment of oils for HVO. The Romanian Petrochemical University have done some research into HVO.	Key players are UOP, Neste (Finland), Petrobras, Braskem, Dynamic Fuels, Sustainable Oils. Other players include IFP, BP in Australia and ConocoPhillips. Significant interest in the utilisation of HVO in aviation with a number of test flights completed world-wide.	UOP have a number of pilot facilities in the USA <37l/day (100).	Neste have commercial plants in Finland (2 x 170,000 t) and Singapore (800,000 t). A Neste facility at Rotterdam will open in 2011 with a capacity of 800,000 tonnes/year (100). Dynamic Fuels have a commercial plant in Louisiana, with a capacity of 220,000 tonnes/year (101). Conoco Philips had a HVO demonstration at the Whitegates refinery in Cork, Ireland but it is not clear whether it is still operational (103). UOP have had a demonstration facility in Texas since 2008 with a capacity of 200 bbl/day (100). UOP / Eni have plans for a 330,000 plant in Italy 2013 using their Ecofining process (100). Galp, Portugal has plans for a 330,000 plant in 2014 (100). Sustainable Oils and Altair plan to produce 100 million US gallon (330,000 tonnes/year) jet fuel and green diesel from 2012/13 in Washington (104). Diamond Green Diesel (a joint venture between Darling Energy and Valero) has plans for a 137 million US gallon (500,000 tonnes/year) HVO plant in Lousiana using tallow (105).
UK and international networking	International airlines and aircraft manufacturers are strongly raising the profile of this biofuel type, particularly via international biofuel conferences.			
Examples of international projects	Much interest from airlines around the world and US military. A number of test flights have been carried out including KLM and Lufthansa			
Assessment of UK Capability	The UK is weak compared to other countries world-wide in both HVO development and deployment. HVO technologies would therefore need to be imported from elsewhere. There may be some interest in using HVO processes in the UK but this is unclear at the moment. Although HVO is highly compatible with the UK fuel infrastructure, the potential uptake of this technology would be limited as a result of vegetable oil availability and due to potential issues surrounding the utilisation of the UK hydrocracking infrastructure.			

2.3.2 Syngas Upgrading to Production

2.3.2.1 Synthetic Diesel/Aviation Fuel (Fischer Tropsch)

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	Aston University, Manchester, Sheffield, Imperial, UCL, Newcastle all have capability in this area but few work directly on gasification to synthetic diesel production. Newcastle University are working on developing micro FT reactors. University of Sheffield are working on GTL aviation fuels.	Catalyst expertise at Johnson Matthey and Oxford Catalysts. Compact GTL are developing production of synthetic diesel from gas via steam methane reforming. Oxford Catalysts are developing microchannel FT processes for diesel production. BP has expertise on FT. Significant interest in FT fuels from the aviation industry BA, Airbus and Rolls Royce.	Test facilities/ongoing research at Compact GTL (North East), BP (Hull), Johnson Matthey and Oxford Catalysts	BA/Solena plant in East London will produce 50,000 tonnes of aviation kerosene from 2014/15 using wastes (81) .
ROW	Karlsruhe Institute of Technology are developing micro FT reactors. ECN in the Netherlands are investigating high efficiency FT production from biomass. Work at Technical University of Vienna and Paul Scherer Institute at the Gussing gasifier. The Department of Energy in the USA are also active in this area.	A large number of FT developers worldwide including BP, Conoco Phillips, Exxon, IFP/ENI, PDVSA/Intevep, PetroSA, Rentech, PetroSA, Sasol, Shell, Statoil and Syntroleum. These are being / will be demonstrated in the EU by Choren, NSE Biofuels and Xyngero and in the USA by Flambeau River, Rentech and Clearfuels. Growing interest world-wide in this concept for production of aviation fuels in particular. Qatar and Airbus are investigating the use of BTL to produce aviation fuel in the 'Qatar Advanced Biofuel Platform' (93) while the Solena Group (who are working with BA) have also been linked with Qantas, Easy Jet, Ryanair and Aer Lingus (93).	The Gussing BTL project is a research gasifier where a range of syngas upgrading processes can be investigated. Oxford Catalysts have demonstrated their microchannel FT process at this facility (88). CEA in France announced in 2009 plans for the development of a BTL plant in Bure Saudon, which will use forestry and agricultural residues to produce 23,000 t of liquid biofuels (diesel, naptha and kerosene) (93). The $155 million, BioTFuel project (France and Germany) will develop two pilot facilities in France to produce BTL diesel and kerosene (94).	Production of synthetic diesel is commercial for gas and coal feedstocks. The use of biomass feedstocks is not yet commercial. Choren have built a demonstrator in Germany and commissioning is ongoing. This plant has a capacity of 12,000 tonnes/year. The first scale up plant (Sigma plant) will have a scale of 200,000 tonnes/year, and is expected for 2014. This will be followed by subsequent roll out in Latvia, Canada, Chile and USA. There are several other planned commercial plants using biomass. These include Rentech, who are developing a 26,000 tonnes/year diesel plant in California due to open in 2012 and Flambeau River who are developing a 52,000 tonnes/year FT liquids plant in 2013 in the USA. Several EU plants are planned which will use biomass: Xynergo (Norway, 51,000 tonnes/year), and NSE Biofuels (105,000 tonnes/year) Finland (97).
UK and international networking	Thermalnet was a European network for combustion, pyrolysis and gasification (95). The Omega project, led by Manchester Metropolitan University (96) and the Sustainable Aviation Group covered aviation biofuels more generally (97). The Commercial Aviation Alternative Fuels Initiative (CAAFI) in the USA is an alliance of aviation stakeholders investigating alternative fuels for aviation (98)			

Examples of international projects	The UK is involved in the FP7 Alfa Bird project 'Alternative Fuels and Biofuels for Aircraft Development' is investigating alternative fuels for aviation (99). The EU project 'Sustainable Way for Alternative Fuels and Energy for Aviation' (SWAFEA) involves several UK players evaluated the potential and perspectives of new energy sources (100). The $155 million, BioTFuel project (France and Germany) is investigating will develop two pilot facilities in France to produce BTL diesel and kerosene (94).
Assessment of UK Capabilities	The UK has developed a leading position in syngas upgrading technologies. In particular, the UK has a leading position in the development of BTL fuels from waste materials (ref BA/Solena aviation fuel project and Ineos Bio waste to ethanol project). However, several other countries are interested in this and thus it is imperative that the momentum developed by this planned project is maintained or the UK may fall behind in this competitive area.

2.3.2.2 Hydrogen

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	Research capability on the production of biomass derived hydrogen at the Universities of Glamorgan, Leeds, Cambridge and Oxford. The University of Glasgow is investigating novel catalysts for the production of hydrogen from methane. Other research capability in this area is towards storage and hydrogen fuel cells with expertise at Birmingham, Coventry, Loughborough Universities and Imperial College.	Companies with an interest in hydrogen technologies in the UK including Cenex, H2gogo, Intelligent Energy, Johnson Matthey Catalysts, ITM Energy, Mast Carbon and Logan Energy.	There is a pilot plant at Leeds University producing hydrogen from glycerol. ITM are trialling biohydrogen vehicles at Stansted Airport (117).	Air Products, a French company, have plans to develop a 49 MW waste to power plant on Teesside (2014) (82). They may convert this to produce hydrogen after this (82).
ROW	A handful of groups are active in this area world-wide. Research in the USA at NREL, Iowa, Purdue, Penn State and Stanford. There are groups also in Denmark and China. The Netherlands biohydrogen network appears to be the leading activity in Europe bringing together 12 actors in this sector. There is also the Nordic BioH2 project.	A large number of interested parties including Air Products, BOC/Linde, Air Liquide, MTU and Hydrogenics.		Potential biohydrogen plant in Chile with links to Choren.
UK and international networking	A number of organisations including the Sustainable Hydrogen Energy Consortium, London Hydrogen Partnership, Hydrogen and Fuel Cells Association, H2 Net, H2 Wales. These are, however, not focussed on bio hydrogen production. Internationally well networked through industrial partnerships for a Hydrogen and Fuels Cells in the Economy. Fuel Cells and Hydrogen Joint Undertaking - a public private partnership supporting research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe			
Examples of international projects	The FP6 EU project Hyvolution investigated the potential for hydrogen production from forestry residues and involved several partners from the UK (104). The FP6 project Solar H investigated the potential to use algae and cyanobacteria as routes to hydrogen production via chemical engineering (105). Systems for Alternative Fuels: This JRC project supports the penetration of natural gas and hydrogen as alternative fuels in the energy sector, particularly in road transportation. Special attention is given to hydrogen as a long-term alternative fuel option in vehicles (powered either by fuel cells or modified internal combustion engines)			
Assessment of UK Capabilities	The UK has a strong international position on hydrogen research and development which is possibly on par with other countries. There are a number of universities investigating the production of hydrogen from biomass in the UK, and a wider, extensively networked community of academic and industrial players looking at the infrastructure and storage requirements needed for hydrogen utilisation. The UK is also well linked in with major international projects in this area. There is some interest in the deployment of hydrogen in the UK with advanced plans for the development of a waste to hydrogen plant in the UK from 2014. In the short term, infrastructure will limit the deployment of hydrogen for transport fuel, but it may be a longer term opportunity.			

2.3.2.3 Methanol and Derivative (dimethylether/DME)

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	The University of Lincoln is currently investigating DME production. Oxford University is investigating the conversion of carbon dioxide to methanol. There is some work at Brunel investigating methanol use in engines.	Delphi Diesel Systems are involved in a FP7 project in this area (106). BP has investigated the use of DME as a feedstock for acetic acid production. Lotus cars have developed a trifuel engine which can operate using a fuel containing up to 85% methanol (balance petrol) – M85.	None	None
ROW	Expertise in Scandinavia (Chalmers University, Royal Institute of Technology), Technical University of Denmark, and USA, (Penn State University and University of Utah, University of South California, NREL, ANL, PNNL).	Methanol and DME research is centred on Scandinavia, particularly Sweden with some activity in the USA. Key players in DME include Volvo, Haldoe Topsoe, Chemrec, Total and Preem Petroleum and Lurgi. Developers of biomethanol as a transport fuel include Sakab, Eon, PEAB, Structor. JTE Holdings Japan, UOP and Mobil have activities in DME or biomethanol.	Chemrec have a pilot plant for producing DME via black liquor gasification in Pitea, Sweden (107). LCE Bioenergy in USA planning were planning to develop a biomass to DME plant in USA (60tpd) using willow and wood waste in 2009, although no further information has been found (108).	BioMCN have a commercial facility in Groningen in the Netherlands which converts glycerine from biodiesel production to 200,000 t of methanol (118) and have plans for a second plant using residual wood (109). Varmlandsmethanol AB are planning to build a facility which will gasify forestry residues to produce 400,000 l/d fuel grade methanol and 15MW hot water which will begin production in 2014 (110) Chemrec are planning a demonstration scale facility in Ornskoldsvik, Sweden which will produce 140,000 t bio methanol or 100,000 t DME from black liquor gasification (111).
UK and international networking	International DME Association consists of 50 companies interested in DME use world-wide (106).			
Examples of international projects	FP7 Project BioDME: this aims to demonstrate BioDME production at the commercial scale in Sweden (107) – lead company is Chemrec who have built a DME production facility in Pitea, Sweden. Project partners include Volvo, Delphi diesel engines, Haldor Topsoe, Total and Preem. The FP7 project Supermethanol is investigating the reforming of glycerine in supercritical water to produce methanol although from the perspective of using this in biodiesel production (108).			
Assessment of UK Capabilities	The UK is lagging other countries, especially Scandinavia, in the development of methanol and DME based fuels. There is negligible academic activity into the production of either methanol DME in the UK and while the development of other BTL based processes could provide an impetus and the practical knowledge base to catalyse the development of methanol and DME production, it is likely that the UK will be a technology importer in this area. The development of UK projects in this area will be limited without the development of a specific infrastructure for utilisation of these fuels.			

2.3.2.4 Ethanol from Gasification (Catalysis and Fermentation)

Location	University/Research Institute Activity	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	There are no groups working specifically in this area but will draw upon expertise in *Clostridia* (see butanol) and catalysis (see synthetic diesel). Expertise in catalysts at several universities, and through Johnson Matthey, Oxford Catalysts and UOP.		INEOS Bio are planning to build a 25,000 tonnes/year waste to ethanol plant on Teesside from 2012 – the plant will convert wastes to syngas which will be fermented to produce ethanol (86)*.	INEOS Bio are planning to scale up their 2012 plant to 125,000 tonnes/year from 2014-2015 (86)*.
ROW	Research in the USA at Ames laboratory, Iowa State University, Louisiana State University. Expertise at Eindhoven University, Chinese Academy of Sciences and in Japan.	Companies working specifically on the conversion of syngas to ethanol include Plasma Biofuels, Celanese (albeit from coal), and Bioengineering Resources Ltd.	Activity is largely in based in North America. Coskata have had a 120 t/a plant using woodchips in Pennsylvania since 2009 (128) and have an operational pilot plant in Illinois (129)*. INEOS Bio are developing 25,000 tonnes/year waste to ethanol plant in Florida which will be operational from 2012-2013 (58)*.	Enerkem Westbury plant in Canada uses waste telegraph poles to produce 5 million litres of ethanol‡ (131). Enerkem's Edmonton plant will produce 36 million litres of ethanol and methanol from sorted MSW from end of 2011‡ (132). Their Mississippi plant will convert MSW to 36 million litres ethanol from 2013‡ (133). Fulcrum Bioenergy are constructing a MSW to ethanol plant in Nevada, opening in 2012 which will produce 10.5 million US gallon (~31,000 tonnes/year) of ethanol per year‡ (114). Coskata are planning a 55 M gallon ethanol plant in Alabama (130)*.
UK and International Networking	NNFCC Thermochemical and Lignocellulosic Biomass Group (84) and the REA Renewable Transport Fuels Group (114) provide networking in this area.			
Examples of International Projects	The FP7 project GAS2ALCO is investigating the development of novel catalysts for converting syngas to C2 and C4 alcohols (115).			
Assessment of UK Capabilities	The UK has little research activity in the production of ethanol from syngas. However, the UK does have significant strengths in both fermentation and catalysts which could be applied to the conversion of syngas to ethanol. Despite this lack of activity, there are plans to develop a pilot scale facility on Teesside from 2012 and for a commercial scale plant between 2014 –2015, both of which will use a fermentation process to convert syngas to ethanol. Although there are several other waste to ethanol plants planned globally, all except one will use a catalytic mechanism to convert the syngas to ethanol. The UK has the potential therefore to develop a leading position in the utilisation of syngas for ethanol via fermentation based processes.			

* Fermentation based processes

‡ Catalytic based processes

2.3.2.5 BioSNG from Gasification

Location	Basic Research	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	Some feasibility studies conducted by National Grid and by NNFCC.	No industrial research in this area. National Grid, Centrica and Progressive Energy have proposed a conceptual design for a demonstration project (117).	None	National Grid and Centrica believe the UK has potential for a BioSNG demonstration plant in the North East.
ROW	BioSNG research is concentrated in the Netherlands (ECN), Austria and Switzerland. Key players include Paul Scherer Institute.	Only two technology developers' world-wide, Reprotec-CTU (Austria and Switzerland) and ECN (Netherlands). Both are focused on woody biomass only.	Repotec CTU project has developed a 1 MW methanation pilot plant in Gussing, Austria, operational since 2008 (127).	Gazebois have plans for a 21.5 MW plant in Switzerland from 2012 (127). Plans for ECN to develop a 50 MW bioSNG plant by 2015 (118). The GoBiGas Project has plans for a 20MW plant in Gothenburg in 2012. Phase two will add an extra 80 MW capacity from 2015/16 (118).
UK and International Networking	None			
Examples of International Projects	The EU BioSNG project aims to demonstrate the production of SNG from solid biofuels at the Gussing plant (120). The use of gasification as a route to bioSNG production is one of 7 workstreams under the European Industrial Bioenergy Initiative.			
Assessment of UK Capabilities	The UK lags other countries, particularly Sweden, Netherlands and Switzerland in the development of BioSNG. To our knowledge, there is no academic or industrial research undertaken into BioSNG production in the UK, and as a result, any technology would need to be imported from abroad. There is some interest in BioSNG from UK stakeholders and the development of UK based gasification processes could provide expertise which could be leveraged for the development of BioSNG. The deployment potential of BioSNG for transport will, as for biomethane, be limited by the need to develop a fuelling and distribution infrastructure and any differential in incentive between the different end markets in which the SNG (or methane) could be used.			

2.3.3 Biomethane for Transport

Location	Basic Research	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	Cranfield University conducts research in the upgrading of biogas for grid injection and transport use.	CNG services and Chesterfield Biogas both have expertise in cleaning, storage and distribution of biomethane. Man Truck and Bus, and Hardstaff have developed technology for vehicle conversion.	HGV vehicle trials have been carried out by Coca-Cola, Sainsbury's, Tesco.com, Howard Tennans, local councils and refuse vehicles. Leeds City Council has installed refuelling facilities; Lincolnshire County Council is setting up a county wide biomethane vehicle infrastructure.	Not at commercial scale yet in the UK (for transport).
ROW	Significant research in Scandinavia in this area.	A number of biogas upgrading plant suppliers world-wide, including Acrona Systems, Air Liquide, Carbotech, Cirmac, Flotech, GtS, HAASE, Lackeby Water Group, Malmberg Water, MT Energie, Prometheus, Terracastus, Xebec (121).	Utilisation of biomethane for transport is already commercial in several countries.	The leading countries in the use of biogas for transport are Sweden and Switzerland. Sweden has a range of vehicle modes running on biogas including private cars, busses, HGV and a train. The use of natural gas as a transport fuel is commercial with over 5 million vehicles world-wide. Key countries here are Argentina and Brazil with over 1 million vehicles each, and in Europe, Italy with 380,000 vehicles.
UK and International Networking	The REA biogas group covers different fuel and energy uses for biogas and a subgroup investigates biomethane for transport (121). The Biomethane for Transport Forum covers the use of biomethane as a transport fuel (122).			
Examples of International Projects	UK has been involved in several EU projects in this area, aiming to stimulate the market for biomethane in transport. These include the MADEGASCAR project (124) and Biogasmax (125). Other international projects in this area involved focus directly developing biomethane markets in Central and Eastern Europe (Biogasin) (126) and projects looking to boost the input of biogas into the natural gas grid (GreenGasGrids) (126), and uptake of vehicles (Gashighway) (128) The IEE project Redubar (128) is investigating the non technical barriers surrounding injection of biomethane into the gas grid and will suggest appropriate regulatory measures needed to facilitate this.			
Assessment of UK Capabilities	The UK has a rapidly developing AD sector, but the UK lags other countries, especially Sweden and Switzerland, in both the development and deployment of biomethane for transport fuel use. Although there is an increasing interest in the use of biomethane for transport, and a number of trials completed, it is likely that technology for gas upgrading will be brought in from elsewhere. Commercial interest in biomethane for transport, as for BioSNG, is limited by the need to develop a fuelling and distribution infrastructure and any differential in incentive between the different end markets in which it could be used.			

2.3.4 Furanics/Novel Sugar Fuels

Location	Basic Research	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	Southampton University are reported to be working on the development of furanic based fuels. Birmingham University are researching the development of 2,5 Dimethylfuran as a biofuel. The CoEBio3 facility at Manchester could be leveraged to help develop novel catalysts for conversion of sugars to fuels.	Shell's Research Centre near Chester may be supporting Shell's work with Virent on the development of biofuels from sugars. The UK's catalyst companies, Johnson Matthey, Oxford catalysts and companies such as UOP which have catalyst manufacturing capabilities in the UK could provide expertise here.	None known in the area. Potential to use CPI facilities (Teesside) for scale up research.	None announced
ROW	There is research on furanics as a biofuel in the USA, at University of Wisconsin, Pacific Northwest National Laboratory and CNRS in Montpellier, France Isoprenoid research at Joint Bioenergy Institute in USA and Lawrence Berkeley National Laboratory, UC Berkley Isobutene research at Iowa State University. Levulinic Acid research at University of Limerick, Ireland.	A number of companies are active in this area, but most are investigating distinct technologies. Avantium in the Netherlands are developing HMF furanic biofuels. US company Amyris, one of the world's leading synthetic biology companies, are developing isoprenoids. LS9 also in the USA are using synthetic biology to produce hydrocarbon fuels. Virent are working with Shell to developing biogasoline. Global Bioenergies are investigating the production of isobutene from biomass.	Avantium have developed a 20-40 tonnes/year plant at Geleen to demonstrate the production of biofuels and biomaterials (130), (153) and have plans for a semi-commercial scale plant due on stream from 2013 which will have a capacity of 200-400 tonnes/year (153). Virent Energy Systems and Shell started operating their BioForming pilot plant in Wisconsin USA in March 2010 (28.5 tonnes/year scale) (131).	Avantium have plans to develop a commercial demonstration plant, with a capacity of 30-50 ktonnes/year in 2015 which will initially target higher value markets (153).
UK and International Networking	Shell, who are partnered with Virent Technologies, is a member of the Energy Technologies Institute (132). We are not aware of any specific networking in this area.			
Examples of International Projects	Research on sugar to hydrocarbons is one of the seven workstreams under the European Industrial Bioenergy Initiative.			
Assessment of UK Capabilities	The UK lags countries, particularly the Netherlands and USA, in the development of sugar-based hydrocarbon fuels. The UK would therefore likely to be an importer of these technologies rather than a developer.			

2.3.5 Ethanol (from Biochemical Processing)

Location	Basic Research	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	There is expertise in fermentation of C5 sugars at University of Ulster, Imperial College, Bath University and Nottingham University. Wider fermentation expertise at Heriot Watt International Centre for Brewing and Distilling and Scottish Whisky Research Institute.	The UK has a number of innovative companies in the UK all of which are based on the development of thermophillic bacteria to ferment C5 and C6 sugars from lignocellulosics. These are Agrol, Biocaldol and TMO. Hycagen in Cambridge may also have capabilities in this sector.	The National Industrial Biotechnology Facility has a range of open access facilities including fermenter capacity up to 10 tonnes (144).	TMO have a pilot/demonstration plant in Surrey (143). Scarab, a consortium of several UK and Finnish companies, intends to develop a number of modular industrial food waste to ethanol facilities in the UK using a biochemical Finnish technology (133). TMO's technology will be commercialised in the USA by Fibreright (145).
ROW	The world's leading researchers working on fermentation are located in Scandinavia, Germany and the USA.	Microbial strains for fermentation are typically developed by project developers, for example, Abengoa, BBI, Iogen, Poet, Fibreright, Sekab and Inbicon.	Strengths are concentrated around Scandinavia and North America.	Strengths are localised around Scandinavia and North America. Developers include Abengoa, BBI, Iogen, Poet and Fibreright (North America) and Sekab, in the EU. The FP7 project Kacelle is demonstrating the Inbicon technology from pre commercial to full commercial level (134) whilst the LED project will demonstrate Abengoa's technology in Spain (135).
UK and International Networking	The UK is involved in the EU SusChem network (134). The BBSRC Sustainable Bioenergy Centre (BSBEC) brings together several of the key researchers in this area (27). The UK is involved in the IEA Task 39, commercialising liquid fuels through British Sugar and DECC (97). The REA Renewable Transport Fuels Group provides networking in this area (115).			
Examples of International Projects	The FP6 project NILE involved Imperial College and aimed to overcome barriers to production of lignocellulosic ethanol by developing strains which overcame the barriers associated with fermentation of these sugars (135). The SUNLIBB project, led by York University with input from Sheffield and Cambridge Universities and Bioconversion Technologies are investigating feedstock and fermentation for bioethanol production (136). The FP7 project Kacelle is demonstrating the Inbicon technology from pre commercial to full commercial level (137) whilst the LED project will demonstrate Abengoa's technology in Spain (138).			
Assessment of UK Capabilities	The UK has significant strengths in fermentation of both C5 and C6 sugars and is on par with the leading countries world-wide both in terms of academic research and industrial research. While the UK has been developing facilities for the scale up of fermentation based technologies, it is likely that technology developers will commercialise their technology elsewhere before the UK due to the better support and incentives elsewhere, thus, at least initially, the UK is likely to be an IP exporter and buy in technologies developed and demonstrated elsewhere.			

2.3.6 Butanol

Location	Basic Research	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	Academic groups working in this area include Nottingham University who have expertise in *Clostridium difficile* and are part of the BBSRC Sustainable Bioenergy Centre, Napier University who are investigating both Clostridia and algae as butanol feedstocks, and IBERS who have done gene expression studies in Clostridia.	The UK has a number of innovative companies in this area. Green Biologics are working on manipulating the ABE process to enhance butanol yield. Solvert are also using the ABE process to produce butanol and other chemicals. Other research is through Kingston Research Limited who will provide a technology package to Butamax advanced fuels, another BP/ Dupont joint venture.	None known.	Nb Biobutanol production is commercial via the ABE process. Kingston Research Limited, a JV between BP and DuPont has built a biobutanol pilot plant at Hull (139). The technology developed at this plant will be used by Butamax, another BP/Dupont joint venture to convert existing starch bioethanol plants to biobutanol production. The first plants to be converted are expected to be in North and South America. There will be subsequent conversions in Europe, one of the first is likely to be Vivergo's Hull ethanol plant. Solvert are planning a wastes to butanol (plus other products) plant on Teesside and are looking for investors. They are looking at lignocellulosic production of butanol via the ABE process (139).
ROW	There are a limited number of research groups with strong expertise in fermentation to butanol world-wide. These include Ohio University, University of Illinois in USA, UCLA and UC Berkley, Frankfurt University, IFP and Wageningen University.	A number of companies are working on bio-butanol world-wide. Gevo and Tetravitae are focussing on the retrofitting of first generation ethanol plants. Dupont are interested in butanol from algae (141). Cobalt, Tetravitae, Butalco, Cathay Industrial Biotech, and Metabolic Explorer, Gevo are looking at strains which metabolise sugars from lignocellulosic feedstocks. Sunopta and Arbor fuels also involved.	Butalco have a pilot in Germany (5) Butylfuel have apparently piloted their process with support from the USA DoE (155). Cobalt have a 0.01 million US gallon pilot in the USA and have plans to open a 2 million US gallon (6 ktonnes/year) per year plant in 2011. They plan to increase production by a further 100 million US gallon per year in California (300 ktonnes/year) (5).	Gevo have plans for a 30-50 million US gallon per year (150 ktonnes/year) due online in 2011, and have plans for an additional two full scale plants in 2012 (5). Cathay Industrial Biotechnology reportedly has a 100,000 tonnes/year plant in China and plans for a 100,000 tonnes/year plant either in the USA or China (156).
UK and International Networking	Bio-butanol research is part of the BBSRC Sustainable Energy Centre (27).			
Examples of International Projects	The University of Nottingham are coordinators of the EU FP7 project Clostnet which aims to help increase knowledge about the basic biology of Clostridia for both overcoming diseases and for commercial exploitation in biofuels (140).			
Assessment of UK Capabilities	The UK activity in bio-butanol is on par with the leading activity elsewhere in the world, with a number of innovative companies in this area, especially in respect to R&D work on fermentation routes to biobutanol. However, while the UK has plans for the development of both pilot and commercial scale butanol production plants, biobutanol production has already been piloted in Germany and the USA, and will be commercialised in 2011, so the UK will be lagging the leading countries in this area.			

2.3.7 Upgraded Pyrolysis Oil

Location	Basic Research	Industrial Activity	Pilot and Scale-Up Facilities	Demonstration and Commercial Scale
UK	There are a handful of groups working on pyrolysis oil upgrading in the UK including the University of Nottingham, Aston University, Queens University Belfast and Cardiff University.	The Carbon Trust Pyrolysis Challenge project is looking at options to upgrade pyrolysis oil using refining techniques to produce transport fuels (89). Key players in this project include Axion Energy, CARE, Aquafuels Research and Catal International (89). There are some companies looking at tyre pyrolysis to produce transport fuels, carbon black and fuel gas (e.g. Pyreco).	Carbon Trust Pyrolysis Challenge aims to produce bio-oil at a pilot plant in 2014 using wood waste and MSW, possibly co-locating with landfill sites (89). 2gbiopower plan to build a pyrolysis to power plant using waste derived biomass with a view to developing in the future biofuels plants using pyrolysis. There are some university pilot plants (such as at Nottingham University).	None announced
ROW	Research is centred upon the USA, with key players Iowa State University, PNNL, Batelle and GTI.	There are a number of technology developers world-wide clustered around North America (Dynamotive, KiOr, UOP, Ensyn) and Europe (KIT, BFT, IFP, BTG Bioliquids) are upgrading pyrolysis oil for transport applications.	UOP have received funding from the US DOE to develop a pyrolysis plant in Hawaii which will produce 60,000 gallons (180 tonnes/year) of upgraded pyrolysis oil per year from 2014 from a range of lignocellulosic feedstocks (143).	Not at commercial scale yet but UOP are moving towards commercial production within the next 5 years.
UK and International Networking	The UK is part of the IEA Task 34 on Pyrolysis (91). Thermalnet – European network for pyrolysis, gasification and combustion (98).			
Examples of International Projects	BIOCOUP – aim is to develop a chain of process steps, which would allow biomass feedstock to be co-fed to a conventional oil refinery (143).			
Assessment of UK Capabilities	Although the UK has strengths in pyrolysis, activity in the upgrading of pyrolysis oil for transport fuel use has been less well developed. The Carbon Trust's Pyrolysis Challenge has provided some impetus in this area and there is evidence of some companies developing pyrolysis processes which could be used for transport fuel use. Thus, pyrolysis oil upgrading is a growing area of interest in the UK. However, elsewhere in the world, there are several developers investigating pyrolysis oil upgrading, and it is estimated that this could be commercial within the next 5 years. Thus, the UK is likely to import this technology.			

3 DISCUSSION

In this section, the UK's capability, from basic research through to industrial deployment, with respect to advanced biofuel pathways has been assessed to facilitate the identification of the most suitable pathways for UK deployment. The findings of this assessment are summarised qualitatively in Table 1.

Technology	Basic research	Industrial development / research activity	Pilot and scale up	Demo and commercial scale
Feedstocks				
Algae				
Microalgae				
Macroalgae				
Arable Crops				
Perennial Energy Crops				
Forestry				
Wastes				
Intermediates				
Lipid Production				
Biogas Production				
Sugar Production				
Syngas Production				
Pyrolysis Oil Production				
End Products				
HVO				
Syngas Upgrading to Products:				
Synthetic Diesel/Aviation Fuel				
Biohydrogen				
Methanol/DME				
Thermochemical Ethanol				
BioSNG				
Biomethane				
Furanics/Novel Sugar Fuels				
Biochemical Ethanol				
Butanol				
Upgraded Pyrolysis Oil				

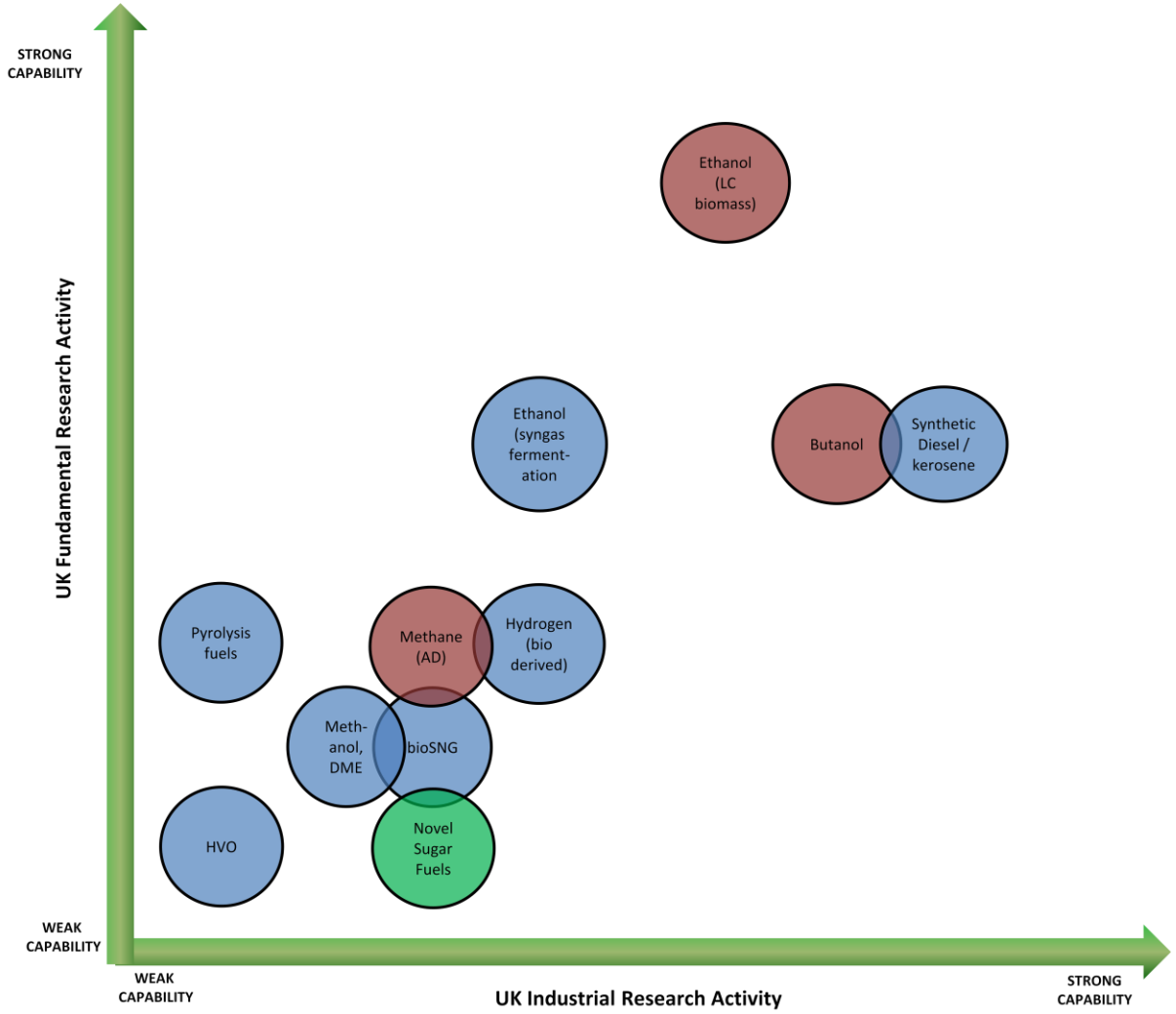
Key:

- Very Little or No Activity or Planned Activity
- Limited Activity or Planned Activity
- Good Activity or Planned Activity
- Substantial Activity or Planned Activity
- ? Unknown
- \- Not Relevant

Table 1 Summary of UK Capabilities

3.1 Pathway R&D Relative Strengths

Figure 2 provides an indication of the relative strengths of UK fundamental research and UK industrial research by biofuel pathway – a short summary of each pathway is provided below. High rankings indicate that there is a UK strength in UK R&D and UK experience aligned towards a pathway. Transferrable expertise from one pathway to another has also been considered.



Blue circles represent thermochemical conversion technologies; red circles represent fermentation based conversion technologies; green circles represent the novel fuels produced from sugars.

Figure 2 Relative Comparison of UK Fundamental and Industrial Research Activities.

1. **Synthetic diesel / aviation fuel via Fischer Tropsch processing of syngas (sometimes known as BTL[14]) and ethanol via syngas fermentation**

   Although BTL processes suppliers are typically large international companies, the UK does have a strong industrial R&D base in syngas upgrading technologies. This includes Fischer Tropsch development at BP Hull, Johnson Matthey and Oxford

[14] Biomass to Liquids

Catalysts and syngas cleaning development, also by Johnson Matthey. Academic research into syngas upgrading by chemical synthesis is perhaps weaker with work ongoing for example at Newcastle and Aston Universities. Despite these existing and potential strengths in syngas upgrading, UK gasification research is weaker, especially for the types of gasifier most relevant to fuels production such as the entrained flow gasifier.

Across the rest of the world, there is significant BTL R&D ongoing and numbers of projects are planned and being built. Notable projects are in development in Scandinavia, France, Germany and the USA; most are expected to use woody biomass. The UK is leading in the development of BTL projects which plan to use waste feedstocks although this lead may diminish once waste to biofuel BTL projects in the USA and Canada are built.

BTL projects are developing across the world with the first commercial scale flagship plants expected to be operational by the middle of this decade. One BTL plant is planned for the UK (BA/Solena, London) and is notable in its proposed use of waste feedstocks.

2. Butanol via fermentation.

UK biobutanol research capability both at the academic level and industrially, is acknowledged to be comparable to that elsewhere in the world. In the UK, there is academic research ongoing at the BBSRC Sustainable Bioenergy centre which is supporting a workstream on lignocellulosic biobutanol at Nottingham University. Industrially, Green Biologics and Solvert are developing the ABE process which, as well as butanol, also produces some acetone and ethanol while Butamax, a BP company, are about to start pilot operations at their BP Hull site. Green Biologics have demonstrated their process in China and are developing butanol production from lignocellulosic materials while Solvert plan to deploy their process, which will use wastes as the feedstock, on Teesside. Butamax expect to deloy their process by converting existing starch and sugar ethanol plants to biobutanol – they plan to deploy their third ethanol plant conversion in Europe, potentially in the UK.

Across the rest of the world, biobutanol production has been piloted in the USA and Germany by Cobalt, Butylfuel and Butalco. There are plans to develop commercial scale plants in the USA in the next few years by Butamax, Cobalt, Gevo and Cathay Industrial Biotechnology – these are mostly expected to be ethanol plant conversions.

3. Ethanol via lignocellulosic biomass fermentation

There are a large number of lignocellulosic ethanol demonstration and commercial scale plants developing, especially in the USA and Europe. However, despite TMO

Renewables having demonstrated the feasibility lignocellulosic ethanol production since 2007, no UK demonstration or commercial projects have yet materialised although there is interest, particularly in producing ethanol from sugars extracted from waste biomass. UK R&D expertise in this area is very strong and there are clear areas where the UK has a particular strength and is internationally competitive. These areas include biomass pre-treatment, fermentation, (especially using thermophillic microbes able to metabolise pentose sugars). UK expertise is less strong in the area of biomass hydrolysis. The UK also has significant strengths in technologies which could be used to develop a lignocellulosic ethanol industry, for example plant sciences, microbiology, molecular biology and engineering.

4. Ethanol production via syngas fermentation

There is increasing interest in the upgrading of syngas by fermentation to ethanol and other fuels in particular given its potential for low cost. A recent announcement from the USA indicated that one research group is looking at producing butanol in this way while in New Zealand, Lanzatech have a process designed to produce ethanol from steelworks offgas which contains carbon monoxide.

In the UK, there is strong research into industrial biotechnology which underpins this technology, for example the work by the BBSRC Sustainable Bioenergy Centre groups, CoEBio3 and the CPI on Teesside. In addition, to this capability, there are the plans by Ineos Bio to build a waste to bioethanol plant on Teesside. Ineos Bio was the first company to announce the building of a commercial waste to 2nd generation bioethanol plant which is expected to be operational towards the middle of the decade. The UK plant will likely be Ineos Bio's second operational plant; the first is under construction in Florida. There are no other known commercial projects of this type in the world.

5. Hydrogen produced from syngas

Plans for the production of hydrogen from waste biomass are fairly advanced: Air Products are planning to develop a 49 MWe waste to power via syngas project on Teesside, expected to be operational from 2014. This plant may be converted to produce hydrogen at a later date.

Although hydrogen is one of the more cost effective fuels to be produced from syngas, a key limitation is the availability of a refuelling infrastructure and the availability of hydrogen vehicles. A number of UK groups are researching the use of hydrogen including the University of Glamorgan, Coventry University and Birmingham University. Hydrogen use in transport is being trialled at Stansted Airport by ITM-Power, a company producing hydrogen via water electrolysis.

6. Biomethane via anaerobic digestion (AD)

The UK's R&D capability in anaerobic digestion is fairly weak. Whilst anaerobic digestion is an emerging commercial technology in the UK, deployment is largely focussed on heat and power and the capability in applying this fuel to transport is relatively weak. Whilst the use of biomethane for transport fuel is already a commercial technology, especially in Scandinavia, there are only a small number of pilot trials in the UK such as those by Lincolnshire County Council and Leeds City Council.

7. BioSNG produced from syngas

There is only limited UK R&D activity in the areas of bioSNG production from syngas. Lead development countries are Austria (Gussing), Sweden (Chalmers University) and the Netherlands (ECN). Demonstration projects are planned for Goteburg, Sweden (GoBiGas who are partnered with EOn) and France (Gaz de France). These projects are all based around the use of a specific design of gasifier which directly produces a large amount of methane in the syngas[15] (indirect gasifier) using woody biomass only; no research is known to be planned on using waste derived biomass. Despite this limitation, there is interest in the potential to develop a UK bioSNG project with at least one project in the scoping phase and with National Grid keen to support potential developers.

8. Novel sugar based fuels

There is only one research group at Southampton University researching these new and emerging pathways and no announced plans for any pilot, demonstration or commercial projects in the UK. However, these fuels are likely to be very compatible with the existing UK fuels infrastructure including diesel and hence it could be possible that such a technology could be brought in from abroad to take advantage of the UK's strength in wheat.

9. Methanol/DME[16] produced from syngas

Methanol is the simplest alcohol and, amongst other uses, is used to convert vegetable oils such as rape oil into biodiesel for example. As a fuel, biomethanol can either be used blended directly in petrol, converted into MTBE or used to produce fully renewable biodiesel. A market may exist from biodiesel manufacturers although expected changes to the RO with respect to power generation from

[15] Typically, gasifiers designed for producing a syngas for chemical synthesis are designed to minimise the amount of syngas methane as this is usually an undesirable component, indicating the presence of tars which foul up downstream equipment and catalysts.

[16] Dimethyl ether is a gas at room temperature in the same way as LPG and can be easily liquefied by compression. It can be used to fuel specially modified internal combustion engines.

biodiesel may limit this demand. Alternatively, methanol can be converted into DME for use in specially converted compression ignition engines. DME is a gas at room temperature in the same way as LPG and is easily liquefied by compression.

Although a new biomethanol plant could be built, there is no known UK interest. However, existing UK methanol plants could be converted to produce biomethanol as BioMCN have done in the Netherlands where glycerol from the biodiesel process is commercially converted into biomethanol.

There is little or no interest in DME production in the UK. Outside of the UK, there is one consortium led by Chemrec in Sweden developing DME as a truck fuel. The consortium have built a DME demonstration plant, have developed modified trucks (Volvo) and are setting up a European refuelling infrastructure to refuel heavy duty trucks only. This could be project the UK could key into.

10. Fuels derived from pyrolysis oil

Although the UK has a fairly strong pyrolysis R&D capability, there is weaker capability in developing processes to upgrade pyrolysis oils to fuels, the key technology limitation for this pathway. Whilst the Carbon Trust's Pyrolysis Challenge has provided a major stimulus to this area by developing a dedicated funding project integrating expertise from throughout the supply chain, a number of companies are working on the development of pyrolysis for biofuels, particularly UOP in the USA. Regardless of the R&D and commercial deployment status, non-technical issues such as fiscal incentives and reduced technology risk may determine that it is more attractive to utilise both biomethane and pyrolysis for energy than deploy for advanced biofuels technologies.

11. Hydrogenated Vegetable Oil (synthetic diesel/aviation fuel)

HVO is a high quality diesel/aviation fuel produced by hydrogenating vegetable oils such as palm oil. As such, the sustainability and limited resource issues surrounding biodiesel apply to this fuel also. HVO fuel is similar in quality to BTL fuels having high cetane and low sulphur – it has been widely tested recently by a number of aircraft operators who are detecting no significant operational issues and is in commercial use by Lufthansa on an internal German route.

The technology to produce HVO is commercial – the key technology developers / suppliers are UOP (USA) and Neste Oil (Finland). In the UK, this technology could be developed on the back of existing or planned infrastructure. The UK has a well established oil refinery infrastructure, where hydrogenation (albeit for fossil feedstocks) is a well understood and practiced procedure, and an excellent capability in catalyst development. There have been suggestions that at least one refinery in the UK could be considering developing a HVO capability.

4 CONCLUSIONS

The UK has an international reputation for the quality of its R&D, both in universities and in industry. The research base within advanced renewable transport biofuels is broad and across the whole supply chain. Areas of UK R&D strength identified in this assessment are:

- Fundamental R&D capability in the development and use of plant biomass resources. A number of institutions have expertise in the development of genomic tools underpinning crop improvement while university based establishments carry out fundamental applied research into plant biomass productivity, particularly in poplars, willow and Miscanthus.
- Algal technology fundamental research
- The development (fundamental research) of micro-organisms for lignocellulosic bioethanol, in particular in the areas of biomass pre-treatment and fermentation (especially using themophillic microbes to metabolise pentose sugars) – UK expertises is less strong in the area of biomass hydrolysis.
- Biobutanol fundamental and industrial research
- Syngas upgrading industrial research – there are a variety of UK based companies developing syngas upgrading technologies and a number of UK projects which will use a syngas intermediate derived from wastes. UK research in syngas production (i.e. via gasification) is not a strength.

There are also several centres within the UK working on industrial R&D scale up. These centres have sponsors drawn from both the academic and industrial arenas, and thus provide an important link between academic research and the industrial application of science.

However, it should be noted that although developing a research base is desirable and can provide advantages, it is not essential with respect to pathway deployment in the UK as evidenced by the cases of Ineos Bio whose technology was wholly developed in the USA and British Airways whose proposed plant will use US gasification and Fischer-Tropsch technologies.

5 WORKS CITED

1. **Cranfield University.** Airbus and British Airways join forces with Cranfield University to accelerate availability of algae for aviation fuel . *Cranfield University.* [Online] 16 September 2010. [Cited: 4 May 2011.] http://www.cranfield.ac.uk/news/pressreleases/2010/page50413.html.

2. **BBSRC.** Towards the quintessential green technology. *BBSRC.* [Online] 13 October 2010. [Cited: 4 May 2011.] http://www.bbsrc.ac.uk/news/industrial-biotechnology/2010/101013-f-towards-quintessential-green-technology.aspx.

3. **Schlarb Ridley, B.** 4 May 2011.

4. **Cellana.** HR BioPetroleum To Acquire Shell's Shareholding In Cellana Algae Joint Venture. *Cellana.* [Online] 27 January 2011. [Cited: 4 May 2011.] http://cellana.com/news.

5. **Biofuels Digest.** Advanced Biofuels Tracking Database v. 1.7. *Biofuels Digest.* [Online] 14 January 2011. [Cited: 4 May 2011.] http://biofuelsdigest.com/bdigest/2011/01/14/10-advanced-biofuelsprojects-now-planned-in-advanced-biofuels/.

6. **NERC.** Algal Bioenergy Special Interest Group. *NERC.* [Online] 10 November 2010. [Cited: 4 May 2011.] http://www.nerc.ac.uk/research/programmes/algal/.

7. Algal Biotechnology for Wales - Knowledge Transfer Centre. *Algae KTC.* [Online] n.d. [Cited: 4 May 2011.] http://www.algaektc.com/.

8. Oasis Network New Opportunities for Suppliers in the East of England. *Oasis Network.* [Online] n.d. [Cited: 4 May 2011.] http://www.oasisnetwork.co.uk/index.php.

9. Welcome to the Incrops Project. *Incrops.* [Online] n.d. [Cited: 4 May 2011.] http://www.incropsproject.co.uk/.

10. **University of Cambridge.** The Algal Bioenergy Consortium - The ABC of bioenergy. *University of Cambridge.* [Online] 2010. [Cited: 4 May 2011.] http://www.bioenergy.cam.ac.uk/abc.html.

11. **Supergen.** Supergen Biomass and Bioenergy . *Supergen.* [Online] June 2009. [Cited: 4 May 2011.] http://www.supergen-bioenergy.net/?_id=442.

12. 215G EnAlgae Energetic Algae. *Interreg IVB NWE.* [Online] n.d. [Cited: 4 May 2011.] http://www.nweurope.eu/index.php?act=project_detail&id=4124.

13. Welcome to the BioMara project . *BioMara.* [Online] n.d. [Cited: 4 May 2011.] http://www.biomara.org/.

14. **AquaFuels.** AquaFuels - Algae and aquatic biomass for a sustainable production of 2nd generation biofuels. *AquaFuels.* [Online] 2010. [Cited: 4 May 2011.] http://www.aquafuels.eu/.

15. **BioAlgaeSorb.** BioAlgaeSorb. [Online] n.d. [Cited: 4 May 2011.] http://www.bioalgaesorb.com/.

16. **Biofuels Digest.** Seaweed: A New Wave of Investment in Macro-Algae. *Biofuels Digest.* [Online] 4 October 2010. [Cited: 4 May 2011.] http://biofuelsdigest.com/bdigest/2010/10/04/seaweed-a-new-wave-of-investment-in-macro-algae/.

17. **Anon.** Seaweed Bioethanol Production in Japan - The Ocean Sunrise Project . *IEEE Explore Digital Library.* [Online] n.d. [Cited: 4 May 2011.] http://ieeexplore.ieee.org/Xplore/login.jsp?url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F4446228%2F4449115%2F04449162.pdf%3Farnumber%3D4449162&authDecision=-203.

18. **Crown Estate.** Commercial scale trials to test green harvest from the sea. *Crown Estate Winter Spring Bulletin.* [Online] 2011. [Cited: 4 May 2011.] http://www.thecrownestate.co.uk/scotland_bulletin_winter_spring_2011.pdf.

19. **EABA.** Welcome to the EABA website. *European Algal Biomass Association.* [Online] n.d. [Cited: 4 May 2011.] http://www.eaba-association.eu/.

20. **Biowalk4Biofuels.** BioWALK4Biofuels: Project financed by the European Commission to produce biofuel from algae cultivation. *Biowalk4 Biofuels.* [Online] n.d. [Cited: 4 May 2011.] http://www.biowalk4biofuels.eu/.

21. **WGIN.** Welcome to WGIN 2nd Phase (2009-2013). *WGIN.* [Online] November 2009. [Cited: 4 May 2011.] http://www.wgin.org.uk/.

22. Defra Oilseed Rape Genetic Improvement Network. *OREGIN.* [Online] n.d. [Cited: 4 May 2011.] http://www.oregin.info/.

23. **Monogram.** MONOGRAM UK focus on grain and grass research. *monogram.* [Online] n.d. [Cited: 4 May 2011.] http://www.monogram.ac.uk/.

24. **GARNet.** Welcome to GARNet. *Garnet community.* [Online] n.d. [Cited: 4 May 2011.] http://www.garnetcommunity.org.uk/.

25. **Anon.** Improving Nitrogen Use Efficiency in Major European food, feed and biofuel crops to reduce the negative environmental impact of crop production (Project NUE Crops). *European Commission.* [Online] n.d. [Cited: 4 May 2011.] http://ec.europa.eu/research/fp7/pdf/19072010/nue_crops_-_kbbe.pdf.

26. **Triticeae Genome.** Triticeae Genome. *Triticeae Genome.* [Online] n.d. [Cited: 4 May 2011.] http://www.triticeaegenome.eu/.

27. **Rothamsted Research.** TRITIMED Exploiting the wheat genome to optimize water use in Mediterranean Ecosystems. *Rothamsted Research.* [Online] [Cited: 4 May 2011.] http://www.rothamsted.bbsrc.ac.uk/cpi/tritimed/indexcontent1.html.

28. **AgFoodTRAde.** NEW ISSUES IN AGRICULTURAL, FOOD AND BIOENERGY TRADE. [Online] n.d. [Cited: 4 May 2011.] http://www.agfoodtrade.eu/.

29. **BEE.** Biomass Energy Europe – BEE. [Online] 9 February 2011. [Cited: 4 May 2011.] http://www.eu-bee.com/.

30. **BBSRC.** BBSRC Sustainable Bioenergy Centre. [Online] [Cited: 4 May 2011.] http://www.bsbec.bbsrc.ac.uk/.

31. **Supergen.** The home of UK bioenergy research. *Supergen Biomass and Bioenergy.* [Online] [Cited: 4 May 2011.] http://www.supergen-bioenergy.net/.

32. **IEA Bioenergy Task 43.** Biomass Feedstocks for Energy Markets. *IEA.* [Online] n.d. [Cited: 4 May 2011.] http://www.ieabioenergy.com/Task.aspx?id=43.

33. **IEA Task 30.** Welcome... to the IEA Bioenergy Short Rotation Crops for Bioenergy Systems, Task 30 website. *Short Rotation Crops.* [Online] n.d. [Cited: 4 May 2011.] http://www.shortrotationcrops.org/.

34. Biomass Production for Energy from Sustainable Forestry. *IEA Bioenergy Task 31.* [Online] n.d. [Cited: 4 May 2011.] http://www.ieabioenergytask31.org/.

35. **EnergyPoplar.** EnergyPoplar. *EnergyPoplar.* [Online] n.d. [Cited: 4 May 2011.] http://www.energypoplar.eu/.

36. **Eubionet.** Eubionet - Solutions for biomass fuel market barriers and raw material availability. *Eubionet.* [Online] n.d. [Cited: 4 May 2011.] http://www.eubionet.net/.

37. **ENCROP.** Welcome to ENCROP website! *ENCROP.* [Online] n.d. [Cited: 4 May 2011.] http://www.encrop.net/.

38. **Biomass Trade Centres.** Biomass Trade Centres. *Biomass Trade Centres.* [Online] 2 Feb 2011. [Cited: 4 May 2011.] http://nuke.biomasstradecentres.eu/.

39. **Forestry Commission.** *Forestry Facts and Figures.* 2010. available from: http://www.forestry.gov.uk/pdf/fcfs210.pdf/$file/fcfs210.pdf.

40. **Confor.** Confor. *Confor.* [Online] n.d. [Cited: 4 May 2011.] http://www.confor.org.uk/Default.aspx?pid=1.

41. **Institute of Chartered Foresters.** Institute of Chartered Foresters. *Institute of Chartered Foresters.* [Online] n.d. [Cited: 5 May 2011.] http://www.charteredforesters.org/.

42. **Royal Forestry Society.** Royal Forestry Society. *Royal Forestry Society.* [Online] 2011. [Cited: 4 May 2011.] http://www.rfs.org.uk/.

43. **Forestry Contracting Association.** Forestry Contracting Association. *Forestry Contracting Association.* [Online] n.d. [Cited: 4 May 2011.] http://www.fcauk.com/.

44. **European Forestry Institute.** European Forestry Institute. *European Forestry Institute.* [Online] n.d. [Cited: 4 May 2011.] http://www.efi.int/portal/.

45. **Commonwealth Forestry Association.** Commonwealth Forestry Association. *Commonwealth Forestry Association.* [Online] n.d. [Cited: 5 May 2011.] http://www.cfa-international.org/.

46. **International Forestry Group.** International Forestry Group. *International Forestry Group.* [Online] n.d. [Cited: 5 May 2011.] http://www.forestry.gov.uk/forestry/INFD-6TYBHV.

47. **Forest Research.** EU Framework projects in which Forest Research is involved. *Forest Research.* [Online] n.d. [Cited: 4 May 2011.] http://www.forestresearch.gov.uk/fr/infd-63jghm.

48. —. COST Actions in which Forest Research is involved. *Forest Research.* [Online] n.d. [Cited: 4 May 2011.] http://www.forestresearch.gov.uk/website/forestresearch.nsf/ByUnique/INFD-63JGYC.

49. —. Interreg projects in which Forest Research is involved. *Forest Research.* [Online] n/d/. [Cited: 4 May 2011.] http://www.forestresearch.gov.uk/website/forestresearch.nsf/ByUnique/INFD-7PSCQL.

50. **Read, A and Godley, A.** How Green in Mechanical Biological Treatment? . *Waste Management World.* 2011, March-April.

51. **Lets Recycle.com.** Green light for £20m Flintshire MHT plant . *Lets Recycle.com.* [Online] 15 December 2008. [Cited: 4 May 2011.] http://www.letsrecycle.com/news/latest-news/waste-management/green-light-for-ps20m-flintshire-mht-plant.

52. **Let's Recycle.** First Greater Manchester waste deal MBT plant opens . *Lets Recycle.com.* [Online] 11 April 2011. [Cited: 4 May 2011.] http://www.letsrecycle.com/news/latest-news/councils/first-greater-manchester-waste-deal-mbt-plant-opens.

53. **Graphite Resources.** Locations and Sites. *Graphite Resources.* [Online] n.d. [Cited: 4 May 2011.] http://www.graphiteresources.com/locations.aspx.

54. **Sterecycle.** Sterecycle secures planning permission for third site. *Sterecycle.* [Online] 26 October 2010. [Cited: 4 May 2011.] http://www.sterecycle.com/downloads/Sterecycle%20Harlow%20announced%2026%20October%202010%20Final%20version.pdf.

55. **Waste Management World.** MBT in Europe. *Waste Management World.* [Online] n.d. [Cited: 4 May 2011.] http://www.waste-management-world.com/index/display/article-display/304397/articles/waste-management-world/volume-8/issue-4/features/mbt-in-europe.html.

56. **Wrap.** Wrap material change for a better environment. *Wrap.* [Online] 2011. [Cited: 4 May 2011.] http://www.wrap.org.uk/.

57. **Environmental Sustainability KTN.** End of Life Material Management . *Environmental Sustainability KTN.* [Online] n.d. [Cited: 4 May 2011.] https://ktn.innovateuk.org/web/integrated-product-policy.

58. **CIWM.** Chartered Institution of Wastes Management. *CIWM.* [Online] 2011. [Cited: 4 May 2011.] http://www.ciwm.co.uk/CIWM/CIWMHome.aspx.

59. **Envirolink North West.** Recycling and Waste Research and Development Active Network . *Envirolink North West.* [Online] 2011. [Cited: 4 May 2011.] http://www.envirolinknorthwest.co.uk/Envirolink/library0.nsf/039e7b59c07eb15c80256d4f0042987f/ca094bb9426d78d48025759a00364bb4?OpenDocument.

60. **WasteKIT.** WasteKIT. *WasteKIT.* [Online] 2011. [Cited: 4 May 2011.] http://www.wastekit.eu/.

61. **INEOS Bio.** Indian River BioEnergy Center. *INEOS Bio.* [Online] n.d. [Cited: 4 May 2011.] http://www.ineosbio.com/94-Indian_River_BioEnergy_Center.htm.

62. **Axion Consulting Ltd.** *Business plan for a regional oilseed rape crushing operation in North East England.* s.l. : North East Biofuels, 2010. http://www.nepic.co.uk/WebformFolder/NEPICOSRCrusherBusinessPlanFinalMar2010.pdf.

63. **CREOL.** le pilote d'huilerie le plus complet d'Europe. *CREOL.* [Online] n.d. [Cited: 4 May 2011.] http://www.creol.fr/CTMSite/creol/index.html.

64. **CPI.** February 2011: Launch of CPI's cutting edge Anaerobic Digestion Development Centre drives advancement of bio-energy technologies . *CPI .* [Online] 2011. [Cited: 4 May 2011.] http://www.uk-cpi.com/3_pages/media-centre/news/2011/addc-launch.html.

65. **NNFCC.** Biogas Plant Map. *Biogas Info.* [Online] [Cited: 4 May 2011.] http://www.biogas-info.co.uk/.

66. **EurObserv-er.** Biogas Barometer. *EurObserv-er.* [Online] November 2010. [Cited: 4 May 2011.] http://www.eurobserv-er.org/pdf/baro200b.pdf.

67. **AD Biogas Association.** Welcome to the AD and Biogas Association! *AD Biogas Association.* [Online] 4 May 2011. [Cited: 4 May 2011.] http://www.adbiogas.co.uk/.

68. Biogas. *Renewable Energy Association.* [Online] 2011. [Cited: 4 May 2011.] http://www.biogas.org.uk/.

69. **IEA Task 37.** Task 37: Energy from Biogas and Landfill Gas . *IEA Biogas.* [Online] n.d. [Cited: 4 May 2011.] http://www.iea-biogas.net/.

70. Valorisation of Food Waste to Biogas. *University of Southampton.* [Online] 29 March 2010. [Cited: 4 May 2011.] http://www.valorgas.soton.ac.uk/.

71. **Agrobiogas.** Agrobiogas. *Agrobiogas.* [Online] n.d. [Cited: 4 May 2011.] http://www.agrobiogas.eu/.

72. **Biogas Regions.** Biogas Regions. *Biogas Regions.* [Online] n.d. [Cited: 4 May 2011.] http://www.biogasregions.org/.

73. **Biores.** Biores. *Biores.* [Online] [Cited: 4 May 2011.] http://www.biores.eu/?secid=1.

74. **Geronimo II Biogas.** Turning waste into profit: GERONIMO II-BIOGAS . *Geronimo II Biogas.* [Online] n.d. [Cited: 4 May 2011.] http://www.dairyenergy.eu/index.php?option=com_content&task=view&id=904&Itemid=192.

75. European Agricultural AD Helpdesk. *AD Helpdesk.* [Online] n.d. [Cited: 4 May 2011.] http://www.adhelpdesk.eu/website/index.htm.

76. **British Bioalcohols Group.** British Bioalcohols Group. *British Bioalcohols Group.* [Online] 2007. [Cited: 4 May 2011.] http://www.britishbioalcoholsgroup.nrp.org.uk/.

77. IEA Bioenergy Task 39 - Commercializing Liquid Biofuels . *IEA Task 39.* [Online] n.d. [Cited: 4 May 2011.] http://www.task39.org/.

78. Biomass Refining Consortium for Applied Fundamentals and Innovation (CAFI). [Online] n.d. [Cited: 4 May 2011.] http://www.eng.auburn.edu/cafi/.

79. **Energy Biosciences Institute.** Energy Bioscience Seeking a New World of Renewable Energy. *Energy Biosciences Institute.* [Online] 2010. [Cited: 4 May 2011.] http://www.energybiosciencesinstitute.org/.

80. **Liverpool John Moores University.** Micrograss project. *Liverpool John Moores University.* [Online] 5 June 2009. [Cited: 4 May 2011.] http://www.ljmu.ac.uk/NewsUpdate/index_99484.htm.

81. BABETHANOL New feedstock and innovative transformation process for a more sustainable development and production of lignocellulosic ethanol. *BABETHANOL.* [Online] n.d. [Cited: 4 May 2011.] http://babethanol.com/.

82. **BIOLYFE.** BIOLYFE Demonstrating large-scale bioethanol production from lignocellulosic feedstocks. *BIOLYFE.* [Online] n.d. [Cited: 4 May 2011.] http://www.biolyfe.eu/.

83. **HYPE.** HYPE. *Inbicon.* [Online] n.d. [Cited: 4 May 2011.] http://www.inbicon.com/Projects/HYPE/Pages/HYPE.aspx.

84. **NEMO.** NEMO - NOVEL HIGH PERFORMANCE ENZYMES AND MICRO-ORGANISMS FOR CONVERSION OF LIGNOCELLULOSIC BIOMASS TO BIOETHANOL . *VTT.* [Online] n.d. [Cited: 4 May 2011.] http://nemo.vtt.fi/.

85. **European Commission.** Bioethanol from paper fibres separated from solid waste, MSW (FIBREETOH) . *CORDIS.* [Online] 21 December 2010. [Cited: 4 May 2011.] http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=1&CAT=PROJ&QUERY=012a41ce380a:99ac:6fa38ec3&RCN=94485.

86. **IEA Task 42.** Database. *IEA Bioenergy Task 42 Biorefineries .* [Online] 2010. [Cited: 4 May 2011.] http://www.iea-bioenergy.task42-biorefineries.com/nc/biorefinery-database/pf-single-view/?tx_powermailfrontend_pi1%5Bshow%5D=32&cHash=e1575fc2ce0017f5bc43441811791843.

87. Solena Group's British Airways Jet BioFuel Facility. *Invest Thames Gateway.* [Online] 27 October 2010. [Cited: 4 May 2011.] http://www.investthamesgateway.com/thames-gateway-news/news_details.php?id=127.

88. **One North East.** Air Products announces plans for renewable energy plant in the Tees Valley . *One North East.* [Online] 20 July 2010. [Cited: 4 May 2011.] http://www.onenortheast.co.uk/page/news/article.cfm?articleId=4602.

89. About Us. *Biossence Renewable Energy.* [Online] 2011. [Cited: 4 May 2011.] http://www.biossence.com/.

90. **NNFCC.** Thermochemical LC Biomass TWG. *NNFCC.* [Online] 2011. [Cited: 4 May 2011.] http://www.nnfcc.co.uk/energy-fuels/working-groups/thermochemical-lc-biomass-thematic-working-group.

91. **GreenSyngas.** GreenSyngas. *Lund University.* [Online] 3 April 2011. [Cited: 4 May 2011.] http://www.eat.lth.se/greensyngas/.

92. **Linneaus University.** CHRISGAS - Fuels from Biomass. *Linneaus University.* [Online] 24 November 2010. [Cited: 4 May 2011.] http://lnu.se/research-groups/chrisgas?l=en.

93. Unique. *Unique.* [Online] n.d. [Cited: 4 May 2011.] http://www.uniqueproject.eu/theme.asp.

94. FT Demonstration Start-up Underway in Güssing. *Oxford Catalysts.* [Online] 27 May 2010. [Cited: 4 May 2011.] http://www.oxfordcatalysts.com/press/news-archive/pr20100527.php.

95. **Carbon Trust.** Pyrolysis Challenge. *Carbon Trust.* [Online] 2011. [Cited: 4 May 2011.] http://www.carbontrust.co.uk/emerging-technologies/current-focus-areas/pages/pyrolysis-challenge.aspx.

96. **Sagi, S.** *Intermediate Pyrolysis: A Sustainable Biomass-to-Energy Concept.* Birmingham : s.n., 2010. http://www.google.co.uk/url?sa=t&source=web&cd=1&ved=0CB8QFjAA&url=http%3A%2F%2Fwww1.aston.ac.uk%2FEasySiteWeb%2FGatewayLink.aspx%3FalId%3D84914&rct=j&q=aston%20university%20intermediate%20pyrolysis&ei=or3BTYSDCsTX8gOTp-jBBQ&usg=AFQjCNEY8lx4HixqrF96X7AcFq.

97. **EMPYRO.** EMPYRO Energy and Materials from Biomass. *EMPYRO.* [Online] n.d. [Cited: 4 May 2011.] http://www.empyroproject.eu/.

98. IEA Bioenergy Task 34 Pyrolysis. *Pyne.* [Online] n.d. [Cited: 4 May 2011.] http://www.pyne.co.uk/.

99. **Dibanet.** Dibanet. *Dibanet.* [Online] n.d. [Cited: 4 May 2011.] http://www.dibanet.org/.

100. **Woodger, J. UOP.** personal communication. 2011.

101. *HIGH QUALITY TRANSPORTATION FUELS FROM RENEWABLE FEEDSTOCK.* **Lindfors, P.** Montreal : XXI World Energy Congress, 2010. http://www.worldenergy.org/documents/congresspapers/178.pdf.

102. **Dynamic Fuels.** About . *Dynamic Fuels.* [Online] n.d. [Cited: 4 May 2011.] http://65.60.63.147/.

103. **Evans, G.** *International Biofuels Strategy Report.* York : NNFCC, 2008. http://www.nnfcc.co.uk/tools/international-biofuels-strategy-project-liquid-transport-biofuels-technology-status-report-nnfcc-08-017/at_download/file.

104. Airlines sign deal for camelina-based renewable jet fuel. *Energy Efficiency News.* [Online] 17 December 2009. [Cited: 5 May 2011.] http://www.energyefficiencynews.com/air/i/2667/.

105. Algae Holds Promise as Renewable Fuel — Just Not Yet. *CNBC.* [Online] 15 April 2011. [Cited: 5 May 2011.] http://classic.cnbc.com/id/42194565.

106. **Greenaironline.com.** Qatar Airways-led consortium plans development of economically viable sustainable jet biofuel production. *Greenaironline.com.* [Online] 13 January 2011. [Cited: 4 May 2011.] http://www.greenaironline.com/news.php?viewStory=714.

107. **Guardian.** Qantas on brink of £200m biojet fuel joint venture. *Guardian .* [Online] 2 Jan 2011. [Cited: 4 May 2011.] http://www.guardian.co.uk/business/2011/jan/02/qantas-biojet-fuel-joint-venture.

108. **TheGreenCarWebsite.co.uk.** France Launches Biomass to Liquids Project. *TheGreenCarWebsite.co.uk.* [Online] 26 December 2009. [Cited: 4 May 2011.] http://www.thegreencarwebsite.co.uk/blog/index.php/2009/12/26/france-launches-biomass-to-liquids-project/.

109. **Biofuels Digest.** $155.1 million BioTFuel project launches in France: investigating low-cost F-T biofuels. *Biofuels Digest.* [Online] 14 March 2010. [Cited: 4 May 2011.] http://biofuelsdigest.com/bdigest/2010/03/14/155-1-million-biotfuel-project-launches-in-france-investigating-low-cost-f-t-biofuels/.

110. **IEA Task 39.** IEA Task 39 Commercialising 1st and 2nd generation liquid biofuels from biomass. *IEA Task 39.* [Online] n.d. [Cited: 2011 May 2011.] http://biofuels.abc-energy.at/demoplants/projects/mapindex.

111. **ThermalNet.** ThermalNet - the European Network for biomass pyrolysis, gasification and combustion. *ThermalNet.* [Online] n.d. [Cited: 4 May 2011.] http://www.thermalnet.co.uk/.

112. **Omega.** Omega Aviation in a sustainable world. *Omega.* [Online] n.d. [Cited: 4 May 2011.] http://www.omega.mmu.ac.uk/.

113. **Sustainable Aviation .** Sustainable Aviation . *Sustainable Aviation .* [Online] n.d. [Cited: 4 May 2011.] http://www.sustainableaviation.co.uk/.

114. **Caffi.** Commercial Aviation Alternative Fuels Initiative. *Caafi.* [Online] 2011. [Cited: 4 May 2011.] http://www.caafi.org/.

115. **ALFABIRD.** ALFABIRD Alternative Fuels and Biofuels for Aircraft Development. *ALFABIRD.* [Online] n.d. [Cited: 4 May 2011.] http://www.alfa-bird.eu-vri.eu/.

116. **European Commission.** SWAFEA – Sustainable Way for Alternative Fuels and Energy for Aviation. *SWAFEA.* [Online] n.d. [Cited: 4 May 2011.] http://www.swafea.eu/.

117. **Fuel Cell Today.** ITM Power's HOST Programme Successfully Launched at Stansted. *Fuel Cell Today.* [Online] 8 March 2011. [Cited: 5 May 2011.] http://www.fuelcelltoday.com/online/news/articles/2011-03/ITM-HOST-Launch.

118. **Hyvolution.** Hyvolution. *Hyvolution.* [Online] n.d. [Cited: 4 May 2011.] http://www.biohydrogen.nl/hyvolution.

119. **Solar H.** SOLAR-H, overview. *Uppsala Universitet.* [Online] 6 November 2005. [Cited: 4 May 2011.] http://www.fotomol.uu.se/Forskning/Biomimetics/solarh/overview.shtm.

120. **BioDME.** BioDME . *BioDME.* [Online] n.d. [Cited: 4 May 2011.] http://www.biodme.eu/.

121. **Chemrec.** BioDME inauguration Sept 9, 2010. *Chemrec.* [Online] n.d. [Cited: 4 May 2011.] http://www.chemrec.se/biodme_project_inauguration.aspx.

122. **AltFuelTechnology.** LCE Bioenergy LLC Project Summary. *AltFuelTechnology.* [Online] n.d. [Cited: 4 May 2011.] http://www.altfueltechnology.com/files/LCE_BioEnergy_Summary_2_.pdf.

123. **bioMCN.** World's largest 2nd generation biofuel up and running. *bioMCN.* [Online] 14 July 2009. [Cited: 5 May 2011.] http://www.biomcn.eu/news/news/97-successful-start-up-new-plant.html.

124. **BioMCN.** Dutch consortium takes initiative to build the world's largest biomass refinery in Delfzijl. *BioMCN.* [Online] 11 February 2011. [Cited: 4 May 2011.] http://www.biomcn.eu/news/news/128-dutch-consortium-takes-initiative-to-build-the-worlds-largest-biomass-refinery-in-delfzijl.html.

125. **varmlandsmetanol.** varmlandsmetanol. *varmlandsmetanol.* [Online] 15 March 2011. [Cited: 4 May 2011.] http://www.varmlandsmetanol.se/index.htm.

126. European Commission Approves $75 Million Swedish Energy Agency Grant for Chemrec BioDME Plant in Ornskoldsvik. *Biofuels Journal.* [Online] 27 January 2011. [Cited: 4 May 2011.] http://www.biofuelsjournal.com/articles/European_Commission_Approves__75_Million_Swedish_Energy_Agency_Grant_for_Chemrec_BioDME_Plant_in_Ornskoldsvik-104268.html.

127. **International DME Association.** DME: Multi-Use, Multi-Source Low Carbon Fuel. *International DME Association.* [Online] 2011. [Cited: 4 May 2011.] http://www.aboutdme.org/.

128. **Supermethanol.** Supermethanol The GtM Concept. *Supermethanol.* [Online] n.d. [Cited: 4 May 2011.] http://www.supermethanol.eu/.

129. **Coskata.** Semi-Commercial Facility . *Coskata.* [Online] n.d. [Cited: 5 May 2011.] http://www.coskata.com/facilities/index.asp?source=568A3D3C-AACF-4D95-B297-7264DD2C17B5.

130. —. Pilot Facility. *Coskata.* [Online] n.d. [Cited: 5 May 2011.] http://www.coskata.com/facilities/index.asp?source=C3C8A85B-7736-4D64-87F8-9E4FBD45D1B0.

131. **Enerkem.** Westbury, Quebec (Canada). *Enerkem.* [Online] 2010. [Cited: 5 May 2011.] http://www.enerkem.com/en/our-locations/plants/westbury-quebec-canada.html.

132. —. Edmonton, Alberta (Canada). *Enerkem.* [Online] 2010. [Cited: 5 May 2011.] http://www.enerkem.com/en/our-locations/plants/edmonton-alberta.html.

133. —. Pontotoc, Mississippi (United States) . *Enerkem.* [Online] 2010. [Cited: 4 May 2011.] http://www.enerkem.com/en/our-locations/plants/pontotoc-mississippi.html.

134. Sierra Biofuels . *Fulcrum Bioenergy.* [Online] 2011. [Cited: 4 May 2011.] http://www.fulcrum-bioenergy.com/biofuel-plants.html.

135. **Coskata.** Commercial Facility. *Coskata.* [Online] n.d. [Cited: 5 May 2011.] http://www.coskata.com/facilities/index.asp?source=9982EDF1-D98F-4662-9217-5B889ADB9157.

136. **REA.** Sector Groups - Renewable Transport Fuels Group. *REA.* [Online] n.d. [Cited: 4 May 2011.] http://www.r-e-a.net/REA/sector-groups/transport-fuels-group.

137. **European Commission.** Novel efficient catalysts for bio-syngas conversion to C2-C4 alcohols . *Cordis.* [Online] n.d. [Cited: 4 May 2011.] http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RCN=10553455.

138. **Energy, Progressive.** *Feasibility Study and Establishment of the Regional BioSNG Project.* Teesside, UK : North East Biofuels, 2010. http://www.northeastbiofuels.com/_assets/file/bio-sng_report.pdf.

139. **E4Tech.** *The potential for bioSNG production in the UK.* York : NNFCC, 2010. http://www.google.co.uk/url?sa=t&source=web&cd=6&ved=0CEEQFjAF&url=http%3A%2F%2Fwww.nnfcc.co.uk%2Ftools%2Fpotential-for-biosng-production-in-the-uk-nnfcc-10-008%2Fat_download%2Ffile&rct=j&q=repotec%20austria&ei=JcXBTbDIEZOt8QO_hOXLBQ&usg=AFQjCNEpIwrKj1sPC.

140. **ECN.** The ECN/HVC project for BioSNG. *BiofuelsTP.* [Online] n.d. [Cited: 4 May 2011.] http://www.biofuelstp.eu/spm2/pdfs/Poster_ECN.pdf.

141. Gothenburg Biomass Gasification Project, GoBiGas. *Goteburg Energi.* [Online] n.d. [Cited: 4 May 2011.] http://www.goteborgenergi.se/English/Projects/GoBiGas__Gothenburg_Biomass_Gasification_Project.

142. **European Biofuels Technology Platform.** Bio-SNG (Synthetic Natural Gas). *European Biofuels Technology Platform.* [Online] 22 December 2010. [Cited: 4 May 2011.] http://www.biofuelstp.eu/bio-sng.html.

143. **IEA Task 37.** *Biogas upgrading technologies – developments and innovations.* s.l. : IEA Task 37, 2010. http://www.iea-biogas.net/_download/publi-task37/upgrading_rz_low_final.pdf.

144. **Renewable Energy Association.** Sector Groups Biogas Group. *Renewable Energy Association.* [Online] n.d. [Cited: 4 May 2011.] http://www.r-e-a.net/REA/sector-groups/biogas-group.

145. Biomethane Transport Forum. *Environmental Protection UK.* [Online] 2011. [Cited: 4 May 2011.] http://www.environmental-protection.org.uk/transport/biomethane-transport-forum/.

146. **MADEGASCAR.** Madegascar - Market development for gas driven cars. *MADEGASCAR.* [Online] n.d. [Cited: 4 May 2011.] http://www.madegascar.eu/.

147. **Biogasmax.** Biogasmax. *Biogasmax.* [Online] n.d. [Cited: 4 May 2011.] http://www.biogasmax.eu/.

148. **Intelligent Energy Europe.** Sustainable biogas market development in Central and Eastern Europe (BIOGASIN). *Intelligent Energy Europe.* [Online] n.d. [Cited: 4 May 2011.] http://ieea.erba.hu/ieea/page/Page.jsp?op=project_detail&prid=2393.

149. Boosting the European Market for Biogas Production, Upgrade and Feed-In into the Natural Gas Grid (GREENGASGRIDS). *Intelligent Energy Europe.* [Online] n.d. [Cited: 4 May 2011.] http://ieea.erba.hu/ieea/page/Page.jsp?op=project_detail&prid=2457.

150. **GasHighWay.** GasHighWay. *GasHighWay.* [Online] 29 March 2011. [Cited: 4 May 2011.] http://www.gashighway.net/.

151. **Redubar.** REDUBAR the project. *Redubar.* [Online] 2007. [Cited: 4 May 2011.] http://redubar.eu/the_project.

152. **ICIS .** Avantium starts bio-polyester pilot plant. *ICIS Green Chemicals.* [Online] 3 May 2011. [Cited: 4 May 2011.] http://www.icis.com/blogs/green-chemicals/2011/05/avantium-starts-bio-polyester.html.

153. *A family of bio-based materials and fuels.* **den Ouden, D.** York : NNFCC, 2010. http://www.nnfcc.co.uk/events/green-supply-chain-2010/docs/waking-up-a-sleeping-giant-furanic-building-blocks-for-materials-and-fuels-dirk-den-ouden-avatium.

154. **Virent and Shell.** Virent and Shell start the world's first biogasoline production plant. *Virent.* [Online] 23 March 2010. [Cited: 4 May 2011.]

http://www.virent.com/News/press/03-23-10_Virent_and_Shell_Start_Worlds_First_Biogasoline_Demonstration_Plant.pdf.

155. Current Members. *Energy Technologies Institute.* [Online] n.d. [Cited: 4 May 2011.] http://www.energytechnologies.co.uk/Home/Aboutus/Current-Members.aspx.

156. **CPI.** NIBF Demonstrator Facility. *CPI.* [Online] 2011. [Cited: 4 May 2011.] http://www.uk-cpi.com/3_pages/focus/susproc/services/national-industrial-biotechnology-facility/NIBF-Demonstrator-Facility.htm.

157. **TMO Renewables.** The Technology. The Demonstration Unit. *TMO Renewables.* [Online] n.d. [Cited: 4 May 2011.] http://www.tmo-group.com/technology/demonstration_unit.aspx.

158. **Scarab.** Scarab . *Scarab.* [Online] 2010. [Cited: 4 May 2011.] http://www.scarab-energy.com/.

159. **TMO Renewables.** TMO signs 20 year, multi-site bio-ethanol contract with Fiberight . *TMO Renewables.* [Online] 20 September 2010. [Cited: 4 May 2011.] http://www.tmo-group.com/news/news-20-09-10.aspx.

160. **KACELLE .** KACELLE . *KACELLE .* [Online] n.d. [Cited: 4 May 2011.] http://www.inbicon.com/Projects/KACELLE/Pages/KACELLE_Project.aspx.

161. **Led.** Led lignocellulosic ethanol demonstration. *Led.* [Online] 2010. [Cited: 4 May 2011.] http://www.ledproject.eu/en/home.

162. **Suschem.** Suschem. *Suschem.* [Online] 2010. [Cited: 4 May 2011.] http://www.suschem.org/.

163. **NILE.** NILE New Improvements for Lignocellulosic Ethanol. *NILE.* [Online] 8 July 2009. [Cited: 4 May 2011.] http://www.nile-bioethanol.org/.

164. **Sunlibb.** Sunlibb Sustainable Liquid Biofuels from Biomass Biorefining. *University of York.* [Online] n.d. [Cited: 4 May 2011.] http://www.york.ac.uk/org/cnap/SUNLIBB/index.html.

165. **Biofuels East.** New advanced biofuels research centre for Hull. *Biofuels East.* [Online] n.d. [Cited: 4 May 2011.] http://www.biofuelseast.org.uk/News/NewsArticleContainer/New-advanced-biofuels-research-centre-for-Hull.aspx.

166. **Solvert.** Welcome to Solvert Ltd. *Solvert.* [Online] 2011. [Cited: 4 May 2011.] http://www.solvertltd.co.uk/.

167. **ARPA-E.** E.I. du Pont de Nemours and Company: MacroAlgae Butanol . *ARPA-E.* [Online] n.d. [Cited: 4 May 2011.] http://arpa-e.energy.gov/ProgramsProjects/OtherProjects/BiomassEnergy/MacroAlgaeButanol.aspx.

168. **Butylfuel.** Butylfuel Biotechology. *Butylfuel.* [Online] n.d. [Cited: 4 May 2011.] http://www.butanol.com/biotechnology.html.

169. Biobutanol Progress. *ICIS Green Chemicals.* [Online] 12 November 2010. [Cited: 4 May 2011.] http://www.icis.com/blogs/green-chemicals/2010/11/biobutanol-progress.html.

170. **Clostnet.** Clostridia.net. *Clostnet.* [Online] n.d. [Cited: 4 May 2011.] http://www.clostridia.net/index.html.

171. Honeywell's UOP Awarded DOE Grant for Hawaii Biomass Project. *Sustainable Business.* [Online] 1 December 2010. [Cited: 4 May 2011.] http://www.sustainablebusiness.com/index.cfm/go/news.display/id/19537.

172. **Biocoup.** Biocoup. *Biocoup.* [Online] n.d. [Cited: 4 May 2011.] http://www.biocoup.com/.

173. Times Higher Education. *World University Rankings 2010/11.* [Online] 2010. [Cited: 4 April 2011.] http://www.timeshighereducation.co.uk/world-university-rankings/.

174. **Cushman and Wakefield.** *European Cities Monitor2010.* 2010. http://www.europeancitiesmonitor.eu/wp-content/uploads/2010/10/ECM-2010-Full-Version.pdf.

175. **Eforwood.** Eforwood Sustainability Assessment for the forestry-wood chain. *Eforwood.* [Online] n.d. [Cited: 4 May 2011.] http://87.192.2.62/eforwood/default.aspx.