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GLOBAL WATCH MISSION REPORT

Second generation transport biofuels – a mission to the Netherlands, Germany and Finland

MARCH 2006

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Second generation transport biofuels:

– a mission to the Netherlands, Germany and Finland

REPORT OF A DTI GLOBAL WATCH MISSION

MARCH 2006

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EXECUTIVE SUMMARY

Second generation transport biofuels offer a number of key benefits over both conventional fossil transport fuels and the current generation of biofuels. These benefits include the ability to achieve significant 'well-to-wheel' reductions in greenhouse gas (GHG) emissions, combined with dramatically reduced land requirements compared with first generation biofuels since most biomass, including many organic wastes, can be used as feedstock. Additionally, second generation biofuels are better internal combustion (IC) engine fuels than first generation fuels since they shouldn't present any of the technical problems of degradation and material incompatibility associated with first generation biofuels. A number of European countries are pioneering the development of next generation biofuels, and the first demonstration plants are now beginning to appear.

A DTI Global Watch Mission to Finland, the Netherlands and Germany in March 2006 evaluated the status of research and development (R&D) and likely time scales to commercialisation of next generation technologies, specifically thermal and related catalytic technologies, and identified some of the main barriers to exploitation and how they might be addressed.

Many of the underpinning technologies were seen to be well understood, although in adjacent applications, and much R&D work is now being undertaken to address their use for the efficient production of biofuels. A history of gasification of lignite in the former German Democratic Republic (GDR) for the production of coal gas has left a valuable legacy of expertise in this area. This know-how is now being developed for the gasification of biomass and also several classes of organic and municipal waste in several institutes and companies. While much of the basic technology is similar, and many technological barriers have been successfully overcome, some issues such as adequate gas clean up to remove the greater level of tar from the biomass derived syngas still remain to be proved. One of the key technologies, Fischer-Tropsch (FT) synthesis, is well established in gas to liquid (GTL) and coal to liquid (CTL) applications for the production of liquid fuels, but with few commercial plants. Following cleanup there are negligible differences between syngas from different feedstocks.

The first steps towards commercial use of these technologies with biomass feedstock are now being taken, with Choren Industries' construction of its 13,000 tonnes per year (t/y) SunDiesel beta plant, and plans for 200,000 t/y gamma plants. Even these, however, are still relatively small scale in the context of transport fuel requirements, and scaling to commercial sized plants remains to be demonstrated.

Many of the technologies have been demonstrated individually and the most significant issues to be addressed appear to be non-technical. Adequate, consistent, efficient feedstock supply for commercial scale plants will be a serious issue, and a number of organisations are modelling the biomass supply chain to optimise financial, carbon and energy costs. For countries with relatively low levels of forestation, like the UK (and the Netherlands), the necessity of efficient transportation of biomass, potentially from overseas, is prompting research into processes for the densification of biomass.

Torrefaction and flash pyrolysis are both being developed for this purpose, and their efficiency modelled. Torrefaction yields a solid product, more readily ground than raw biomass and then easily incorporated into existing coal handling systems, while flash pyrolysis yields a more energy dense bio-oil that requires specialised handling and gasification.

For UK grown feedstock, for which harvesting, handling and transport costs form the major cost component, feedstock costs are expected to account for a significant proportion of the final costs of second generation biofuels. The other major component, however, is the capital cost of the gasification and FT plant. Powerful economies of scale for the technologies, together with the requirement for large volume processing if biofuels are to form a significant proportion of the road transport fuel supply, demand that plant be as large as possible, with feedstock supply and logistics likely to form the limiting constraints. Capital investment of the scale of €2-3 billion (~£1.4-2.1 billion) will be required, not only contributing heavily to the product costs, but also presenting a major investment risk. This is a significant barrier to exploitation of these technologies, and until incentive mechanisms are in place that recognise the differential GHG benefits over first generation biofuels, there is no incentive to commit to such a major investment when smaller scale first generation plant can be built for a fraction of the capital outlay.

One approach to the relatively high cost of biomass feedstock is to make use of feedstock that carries a negative market cost, for which there is the requirement for disposal, such as organic waste and sewage sludge. Many of these have a high water content, making them unsuitable for gasification without (financially and energetically) costly drying. To make use of these feedstocks, hydrothermal upgrading (HTU) and supercritical gasification are in the early stages of development and require the feedstock in a pumpable, aqueous slurry. Other approaches to reduce cost include adopting simplified refinery type processes (such as hydroprocessing/hydrocracking) of biomass derived liquids together with catalyst development. The adoption of the biorefinery concept, with co-production of high value chemicals, might be another route to improved financial viability.

The level of activity in the three countries visited was impressive, on a range of scales from small and medium sized enterprises (SMEs) to large national research institutes and major multinationals. This was felt to be in sharp contrast to the situation in the UK. The UK is felt to be in the lead, though, in research into dedicated, high yield energy crops, a topic that appears to have attracted little interest elsewhere, especially in Finland and Germany. As these countries have large forestry resources this is not surprising.

In the Netherlands there has been research on microalgae and seaweeds as potential, extremely high output biomass feedstock with minimal land and fresh water demand; however, predicted costs are currently high. A significant difficulty with microalgae and seaweeds is the high water content. This causes difficulties both for handling and transport efficiency, and for conventional gasification, which requires low moisture content. HTU or supercritical gasification may again be suitable processing technologies for these materials.

The two key issues to be addressed if widespread second generation biofuel production is to be achieved in the UK are finance and feedstock. With the present mechanisms of both the Renewable Transport Fuels Obligation (RTFO) and the EU Biofuels Directive, which are based on a volume or energy basis respectively, there is no incentive for the massive investment required for second generation technologies over first generation ones, despite the significantly superior GHG (and other) benefits of the former, and the feedstock limitations of the latter. A mechanism that recognised the differential GHG benefits over first generation biofuels could, however, potentially provide the necessary incentive for investment in second generation technologies.

The development of an integrated biomass supply chain in the UK is critical for both this, and other biomass applications. The first round of the Bio-energy Infrastructure Scheme is acknowledged and was welcome; however, the available funding (£3.5 million) was very limited, and the application window restrictive. It is hoped that the proposed second round can be more generous on both counts. Government support for biofuels should be considered alongside that for other biomass heat and power initiatives, and the optimum use made of available biomass resources and infrastructure. However, the feedstock requirements for significant biofuels penetration into the transport fuels market are considerable and, with the scale of plant required for economic operation, bring unique issues. It must be acknowledged that international trade in biomass for energy applications is already a reality and must not be encumbered; importation of pretreated biomass could provide a way forward for the UK.

Three potential scenarios for UK implementation of second generation biofuels technologies arise:

- It would be possible to build a UK industry based on second generation biofuels produced in the UK from UK biomass feedstocks. However, the scale of production necessary both for significant biofuel penetration into the transport fuel market and for the economies of scale necessary for economic production, mean that the feedstock demand for a single plant would be likely to be of the order of 1-5 million t/y. This would represent a significant proportion of the total available UK biomass resource[1], and to attempt to gather all this to a single site would entail a massive logistical undertaking, and significant pressure on the transport infrastructure. However, significant acreages of high yield energy crops might make this more feasible.

- A second scenario would see large scale second generation biofuel production plant, located on a sea port, and using imported biomass feedstock. It is likely that a significant proportion of this feedstock would consist of low cost residue or waste material, and in order to improve both financial and energetic economics, various densification strategies such as torrefaction or flash pyrolysis might be employed.

- The third strategy is the ultimate extension of the second in that the biomass is imported in the most energy dense form possible, namely as the finished biofuel, with large scale production plant constructed in close proximity to regions of high feedstock availability.

Second generation biofuels present significant potential carbon reduction and socio-economic benefits, and no insuperable technical hurdles. The scale of plant required for economic operation, however, brings certain practical issues if the potential is to become a reality in the UK. Overall, the focus in the UK should be on accelerating the implementation of commercial, second generation biofuels.

1 *Woodfuel Resource in Britain* report, December 2003, The Forestry Commission

RECOMMENDATIONS

General

The nature of an integrated bioenergy chain for production of renewable transport fuels requires close integration of biomass production, biomass conversion and fuel synthesis. The relevant government departments, namely the Department for Environment, Food and Rural Affairs (Defra), DTI and the Department for Transport (DfT), should place a high priority on establishing an effective cross-department task force to oversee this development and hence ensure that the UK meets its aspirations for climate change mitigation measures as well as capturing wealth creation opportunities.

Feedstock

Biomass producers need to develop feedstock supply chains and optimise biomass production to deliver maximum GHG benefits. Coordination by government and linking with the process technology and engine developers will be required.

International trade in biofuels and feedstocks is likely to be of great importance and should continue unhindered. Sustainability and environmental impact issues must be covered in accreditation criteria.

Process technologies

The UK should take a lead on implementing second generation technologies that offer high GHG reduction potential. One way to achieve this would be to establish a consortium involving industry, biomass producers and governments. The biorefinery model is one in which there remains the potential for the UK to establish an international lead with appropriate funding and prioritisation.

A comparative analysis of the alternative processing routes would help identify the most promising technologies for transport fuels. The UK needs to build some capacity in understanding the science and technology (S&T) of transport fuel production from biomass.

R&D into technologies for economically viable transport fuel production at smaller scales to better match biomass resource availabilities in the UK should be funded.

Economics

The very high capital expenditure required for biomass to liquid (BTL) plant presents major financial risk, making such major investments unlikely in the short to medium term without significant incentives. Government policies to mitigate such large investment risks should be investigated. Mechanisms such as grants or loans, with repayment schedules linked to success, to assist in the development of such technologies on a commercial scale, or enhanced capital allowances (ECAs), might be considered.

Policy

The UK has limited land resources that need to be optimised for food, materials and energy production. All decision making should be undertaken with consideration that available limited land resources need to be used as effectively as possible.

Government policy for encouraging biofuels needs to change from a volume/energy basis to a GHG reduction basis. In this way, optimum choices of feedstock and technologies will be preferred by the market. The UK should attempt to use its influence in the EU to ensure policy mechanisms focus on GHG reduction.

Policies to encourage the increased use of biofuels should be linked to environmental sustainability standards.

Government support for second generation biofuels should be considered in conjunction with other UK biomass heat and power initiatives to ensure optimum integration of infrastructure, including the feedstock supply chain. Consideration of alternative uses for the available biomass resource should always be included in any decision making process, and there should be meaningful discussion between UK government and industry on the role of second generation biofuels in the UK energy mix.

Exhibit S.1 *Mission team outside the new Choren Beta plant (L-R): Tony Bridgwater, Geoff Hogan, Bob Saunders, David Bown, Anton Zimmermann, Warren Smith, Craig Jamieson, Nicola Yates, Nicki Smoker, Ian Barton*

1 INTRODUCTION

1.1 Background

Road transport represents 22% of UK carbon dioxide (CO_2) emissions[2] and is the one source that has been consistently rising since 1990, despite significant efficiency improvements by vehicle and engine manufacturers. In an interview with Reuters in May 2006, Richard Kinley, Officer-in-Charge of the UNFCCC (UN Framework Convention on Climate Change) said:

'Transport is the worst offender for releasing greenhouse gases into the atmosphere and governments must do more to cut emissions from cars and trucks.'

However, personal transport is a politically highly charged issue in the UK, as was seen by the September 2000 fuel protests, and a high energy density, portable power source with low carbon emissions represents a vital goal, both for the UK and globally, if GHG emissions are to be constrained without major restrictions on personal mobility. Fuel cells and the hydrogen economy represent one potential solution; however, they remain stubbornly the long term option and interim solutions are required to reduce GHG emissions from road transport long before the fuel cell solution will be available.

A future shift to a hydrogen/fuel cell economy will require a concurrent replacement of both vehicles and fuel supply infrastructure once all relevant technologies are sufficiently mature. Such simultaneous introduction of both technology and enabling fuel supply infrastructure is difficult to manage smoothly, typically leading to a transitional 'chicken and egg' situation with investment in each attempting to wait for significant rollout in the other. This can significantly delay uptake of a technology after it is technically ready for adoption. Interim solutions that do not require extensive simultaneous upgrading of infrastructure are therefore vital, and this strongly suggests that the short to medium term focus should rest on conventional hydrocarbon fuels such as diesel and gasoline.

For maximum ease of introduction, and minimal engine and infrastructure adaptation, therefore, low carbon liquid fuel, ie fuel that offers significantly reduced life cycle GHG emissions, that can be used by existing IC engines with the minimum of modification, and that can be readily handled and distributed by the current transport fuel distribution infrastructure, is the preferable option. In addition, such fuels should be obtainable on a renewable basis.

Renewable, liquid transport fuels that offer carbon reduction benefits in comparison with fossil fuels do already exist, in the forms of bioethanol (and derivatives, such as ETBE – ethyl tertiary butyl ether) for gasoline engines, produced via fermentation of sugar or starch, and biodiesel for diesel engines produced by transesterification of vegetable oils or animal fats. These are often referred to as first generation biofuels.

1.2 Limitations of first generation biofuels

First generation biofuels are derived from renewable, plant based feedstock and

2 Defra, 2004

typically represent lower carbon fuels than their fossil equivalents, owing to the CO_2 uptake of the growing plants. However, the benefits they offer are limited. As both conventional bioethanol and biodiesel are produced from high level outputs of plants – sugar from beet or cane, starch from cereals, or vegetable oils – fuel output per hectare (ha) of land is relatively low. With total UK road transport consuming 37.8 million tonnes (t) of petroleum products per year[3], 12.3 million ha of land would be required for rape cultivation, plus 7.8 million ha of sugar beet production to meet current usage levels. Since the *total* area of arable land in the UK is 6.5 million ha, first generation biofuels produced from UK grown feedstock can do little more than scratch the surface of UK road transport fuel requirements, purely on the basis of land availability. GHG emission reductions from first generation biofuels are also variable and in many cases modest due to the impacts of fertilisers, harvesting, transporting and processing large quantities of plant material to obtain relatively small amounts of biofuel.

Sugar cane and oil palm can produce significantly greater outputs per hectare, so international trade in feedstock and/or manufactured biofuels might help to address this land availability issue to a small extent; however, the environmental impacts of sufficiently widespread planting of dedicated fuel feedstock crops globally, together with the socio-economic impacts of turning over vast tracts of arable land from food production to fuel production, would be questionable on a number of counts.

Although used vegetable oil (UVO) can be used as a feedstock for the production of biodiesel there is a limited total volume potential (a maximum of around 100,000 tonnes per year (t/y) of diesel in the UK[4]), and variability of this feedstock makes it more difficult to ensure that the product meets appropriate standards (EN14214 in the EU) than when using virgin vegetable oil. It is vital that public confidence in biofuels is not damaged by a small proportion of poor quality product; the impact of a small number of negative experiences will have disproportionately greater impact than a far larger number of good experiences.

First generation biofuels therefore cannot offer a long term solution to growing GHG emissions from transport. However, both ethanol and FAME (fatty acid methyl ester) biodiesel processing technology is well established and relatively simple. First generation biofuels can be seen as representing a valuable first step in raising public and industry awareness and exploring the regulatory, fiscal, handling, blending and distribution issues associated with the introduction and promotion of a proportion of biofuels into the current distribution infrastructure, while achieving valuable reductions in GHG emissions. Many first generation biofuels also offer significant ancillary benefits including no sulphur content, improved lubricity over ultra low sulphur diesels, and significantly reduced particulate, nitrogen oxide (NO_x) and carbon monoxide (CO) emissions.

The characteristics of, and issues associated with, first generation biofuels are discussed in greater detail in Chapter 2.

1.3 Second generation biofuels

The promise of second generation biofuels is to offer a transport fuel with lower land use implications and improved GHG reduction performance, preferably at lower cost.

The principal difference between second generation biofuels and first generation biofuels is the ability to make use of a wide

3 DfT, 2004

4 British Association for Bio Fuels and Oils (BABFO)

range of biomass rather than just the oils, sugars and starch components. These sources include non-food biomass, dedicated energy crops, and biomass resources currently viewed as residue such as straw and forestry thinnings. Second generation biofuels may also be chemically different from their first generation alternatives, offering performance or emissions benefits, or they may be the same. Synthetic diesel can be both superior to (eg cetane number, heating value, stability, sulphur content etc) and, critically, a more consistent product than first generation biodiesel or the products obtainable from petrochemical refining; however, second generation (lignocellulosic) bioethanol is chemically identical to that currently available. Environmentally, however, the principal differences between first and second generation biofuels are in the feedstock, and consequently land use implications, well-to-wheel GHG emissions and in the required conversion processes.

Development of technologies for the production of second generation fuels is already well advanced in some areas, though at an earlier stage in others, and significant advances on first generation fuels in the important areas are potentially realisable.

Studies such as that performed by Woods and Bauen[5] at Imperial College, London, as part of the DTI New and Renewable Energy Programme, review the technology status of a range of renewable transport fuels and compare the likely costs and GHG emission reductions of each technology. The benefits of second generation technologies may be clearly seen.

Technologies for the production of second generation biofuels can broadly be divided into:

- Those employing biological and enzymatic processes, predominantly yielding bioethanol from cellulosic feedstock, eg using enzyme or acid hydrolysis (not considered in this mission)

- Those making use of thermal and associated catalytic technologies for a range of biofuels, including synthetic diesel and gasoline (the focus of this mission)

Thermal technologies have the advantage of allowing the production of hydrocarbons that are completely compatible with conventional fuels for reasons of infrastructure and fuel mixing. In addition, thermal processes can be used to produce both diesel and gasoline substitutes.

Thermal technologies for the production of second generation biofuels include:

- Gasification of biomass for the generation of synthesis gas

- Pyrolysis, particularly flash pyrolysis, for the production of pyrolysis oils or pyrolysis oil/char slurries as energy carriers

- Hydrothermal upgrading (HTU) of wet biomass

- Fischer-Tropsch (FT) synthesis of hydrocarbons from synthesis gas with associated upgrading and refining processes

- Synthesis of methanol followed by gasoline and/or diesel synthesis by MOGD (methanol to olefins, gasoline and diesel) or MTG (methanol to gasoline)

Ancillary topics such as choice of feedstock, novel feedstocks and supply chain issues, the biorefinery concept, and work on analysis of

5 Woods and Bauen, 2003; URN 03/982

environmental and financial impacts, and their optimisation, are all considered.

The term biomass to liquid (BTL) when used in this report will specifically refer to the gasification of biomass followed by FT synthesis of liquid biofuels.

In addition, the hydrogenation of vegetable oils may be considered as having some of the characteristics of these second generation processes in that it produces a product with superior properties to conventional biodiesel and some environmental benefits (in reduced net carbon and other emissions) compared with transesterification. The product is also totally compatible with conventional diesel in all proportions. However, as it uses vegetable oil feedstock, albeit potentially a wider range than is suitable for biodiesel, rather than more general biomass, it cannot be regarded as a genuine second generation process by the criteria employed here, but it may nevertheless have a useful role to play.

The thermal technologies for the production of second generation biofuels of interest to this mission are described in greater detail in Chapter 3.

1.4 Biofuels in context

The primary purpose for introducing biofuels is to reduce net global GHG emissions, not just to reduce CO_2 emissions from road transport, or even just to reduce UK carbon emissions. Technologies that may work in one country, therefore, may not be relevant to the UK if the net effect is an increase in GHG emissions (potentially elsewhere) because of the energetic inputs required for transport, processing or fertiliser requirements. It may also be appropriate to include consideration of other significant benefits of biofuels, such as domestic energy security, local (especially urban) air quality, rural regeneration and diversification, biodiversity, production of by-products, public education and motivation, or as an intermediate step to develop infrastructure, methodology, expertise, fiscal or regulatory mechanisms. However, it is important to maintain a clear understanding of the motivations and ensure that the optimum route is being chosen to achieve the intended goals. In particular it is vital to consider whether technologies or strategies chosen represent the optimum use of the resources that will be required, whether financial, land use, available biomass, research resources, social capital or manpower and either nationally or globally.

In order to achieve this broad perspective on the technologies the mission was to address, it was necessary to recruit a team with a wide range of backgrounds and expertise. As well as the S&T of the processes, the engineering and catalysis aspects, feedstock and its supply chain and environmental considerations, and the implications for engine development would all need to be addressed. A team with the expertise to consider all these aspects was therefore selected, and the names of the team members and the organisations represented are listed in Appendix B.

2 CURRENT STATUS OF UK BIOFUELS

The UK Government has decided to put the UK on a path to reduce UK emissions of CO_2 in 2050 to around 60% of the 1990 level. Road transport will have to contribute towards meeting this target. Government expects to achieve this by a combination of improved vehicle efficiency and biofuels, as a blend in petrol and diesel, and possibly other renewable fuels.

2.1 Legislation and government policy

The EU Biofuels Directive 2003/30/EC set indicative goals for the adoption of biofuels as:

- 2% of road fuel energy content by the end of 2005
- 5.75% by the end of 2010

A wide range of gaseous and liquid road fuels derived from biomass can be used to meet the indicative goals. Each member state has to set its own targets within this framework. For 2005 the UK set a target of 0.3% (by energy) of fuel sales, well below the indicative figure in the Biofuels Directive. The UK has set a 5% by volume (3.8% by energy content) target for 2010 as well as setting interim targets for 2008 and 2009. Exhibit 2.1 indicates the biofuel requirement to meet the Biofuels Directive indicative target.

The Government is taking concrete measures to encourage the use of biofuels for road transport. Budget 2006 confirmed that the 20 pence per litre (p/l) duty incentive in favour of biodiesel and bioethanol has been guaranteed until at least 2008. The Government will implement the application of enhanced capital allowances (ECAs) to support investment in the most environmentally beneficial biofuel processing plants. Further work on the details of an ECA scheme was announced in Budget 2006. In addition, the 2004 Energy Act contains enabling legislation for the introduction of a Renewable Transport Fuels Obligation (RTFO) which will require companies to provide biofuels as a given percentage of their total sales, or pay the buyout price. The basis and

Fuel	Sales (Nov 03-Oct 04) (Mt/y)	Energy content (GJ/t)	Energy (PJ/y)	5.75% of energy (PJ/y)	Biofuels required (Mt/y)
Petrol	19.165	43.99	843	48.5	
Diesel	18.570	42.82	795	45.7	
Total				**94.2**	
Bioethanol		26.8	48.5		1.81
Biodiesel		36.8	45.7		1.24
Total			**94.2**		**3.05**

Exhibit 2.1 *Biofuels required in the UK to meet the 2010 indicative value of 5.75% by energy content of EU Biofuels Directive 2003/30/EC*

feasibility of a RTFO has been examined by a Government interdepartmental committee; draft legislation is being developed with the aim of being in place from 2008.

The carbon saving and cost varies significantly between the various biofuel options. The net GHG emissions will vary with the crop or waste chosen as the feedstock, the agricultural system used to grow it, conversion technology used to process it and how efficiently the biofuel is used. While the RTFO is a valuable tool, both it and the EU Biofuels Directive are non-specific about the biofuels to be substituted and there is currently no incentive to achieve the greater GHG savings associated with second generation biofuels in the face of the massive capital investment required.

2.2 Biofuels

Biofuels produced in the UK and across the EU are currently manufactured from traditional food crops, although their use in the UK at present is limited. Their current use is more widespread in a number of other countries, so experience to guide their successful introduction in the UK is available.

Conventional biodiesel (FAME) is relatively easy to incorporate into diesel blends. Ethanol requires special handling and distribution due to its high blending vapour pressure and affinity for water. ETBE, which is made from bioethanol, eliminates these problems but raises concern over water contamination, similar to that experienced with MTBE (methyl tertiary butyl ether) in the USA. However, ETBE is safely used in many countries, including France, and is likely to be used to replace current MTBE production.

Biofuel	Crop/feedstock	Production process
Ethanol	Sugar beet, sugar cane, wheat, maize etc	Fermentation
ETBE	Made from bioethanol	Reaction with isobutene
FAME (biodiesel)	Rape, soya, palm, used cooking oil etc	Transesterification with methanol
Diesel	Rape, soya, palm etc	Refinery hydrotreater

Exhibit 2.2 *Examples of current biofuels and their production processes*

Year	Petrol	Diesel	Biofuels
2001-2	28,229	19,110	0
2002-3	27,837	20,102	5
2003-4	27,407	21,230	22
2004-5	26,540	22,395	35

Exhibit 2.3 *Total sales (millions of litres) of petrol, diesel and biofuels in the UK*

2.3 UK production facilities

Current UK biofuels production is in a fledgling status with two large scale biodiesel plants in operation, plus a number of small demonstration projects. However, there are approaching 300 micro scale producers and blenders. These are all biodiesel, largely processing used cooking oil and blending small volumes to supply a local market.

There have been a number of announcements to build conventional biofuel plants in the coming years and these are listed in Exhibit 2.5.

2.4 Biofuel production

In the short to medium term, conventional biofuels (bioethanol and FAME) are likely to form the bulk of biofuels used in road transport. They will either be produced in the UK from conventional crops (grains, sugar beet, oilseeds) and perhaps straw, or imported. Replacing 5.75% of the energy content of current UK petrol and diesel sales with bioethanol and FAME from conventional crops would require around 1.3 million ha of land.[6]

6 See Exhibit 2.6. (1) This corresponds to an average biofuel yield of around 1.75 t/ha which is the middle of the 1.5 to 2.0 t/ha range quoted by BABFO; (2) The data used are from well-to-wheel studies published by Sheffield Hallam and Imperial College Centre for Energy Policy and Technology (ICCEPT) and DTI's estimate of fuel sales; (3) This area could be reduced by utilising currently exported wheat and sugar for biofuels production; for example, the UK usually exports around 3 million t/y of wheat which could be used to produce about 1 million t of bioethanol

Company	Location	Capacity	Product	Feedstocks
Argent	Motherwell	45 kt	Biodiesel	Tallow and UVO
Biofuels Corp	Teesside	250 kt	Biodiesel	Rape, soya and palm
D1 Oils	Preston	7.7 kt	Biodiesel	UVO, rape
Ebony Solutions	Northwich	2.5 kt	Biodiesel	UVO
Global Commodities	Norfolk, Hull	300 kt	Biodiesel	Rape
Greenergy	Oldbury	12 kt	Biodiesel	Rape
Rix	Hull	50 kt	Biodiesel	Rape
Various	Widespread about UK	Small scale (eg 1 t/mo)	Biodiesel	UVO

Exhibit 2.4 *Current biofuel plants in the UK*

Company	Location	Capacity	Product	Feedstocks
British Sugar	Wissington	55 kt	Ethanol	Sugar beet
Greenergy	Immingham	100 kt	Biodiesel	Rape, used cooking oil
Green Spirit	Somerset	100 kt	Ethanol	Wheat
Rix	Hull	50 kt	Biodiesel	Rape
Roquette	Corby	100 kt	Ethanol	Wheat

Exhibit 2.5 *Proposed biofuel plants in the UK*

Fuel	Crop	Biofuels required (Mt/y)	Biofuels yield (t/ha)	Land required (million ha)
Bioethanol	50% from wheat	0.91	2.5	0.36
Bioethanol	50% from sugar beet	0.90	4	0.23
FAME	Rapeseed	1.24	1.75	0.71
Total		**3.05**		**1.3**

Exhibit 2.6 *UK land area to produce the 5.75% by energy content of biofuels required to meet the 2010 indicative value in EU Directive 2003/30/EC*

2.5 Limitations

2.5.1 Fuel standards

Conventional biofuel blending components are not ideal fuel molecules, and in Europe only a maximum of 5% ethanol by volume or 15% of ETBE (made from ethanol) may be blended into conventional petrol, or 5% of FAME into diesel. Using fuels with higher levels potentially invalidates vehicle warranties. The limits for ethanol and ETBE are also in the EU Fuels Directive 2003/17/EC. The limits are based on a variety of factors including compatibility of materials, effect of trace by-products from biofuel manufacture, and deposit formation. Other countries operate with higher blends, however, and the USA utilises a 10% blend of ethanol whilst 85% ethanol fuel vehicles are commonplace in Brazil and Sweden. Over time the limits may be changed by CEN (Comité Européen de Normalisation – European Committee for Standardization).

The use of flexible fuel vehicles (FFVs), which are specially designed to utilise a range of biofuel concentrations in either petrol or diesel, provide an alternative approach. Ford sells an ethanol FFV Focus in Sweden. Saab has launched an ethanol FFV in the UK, and Volvo has plans to introduce one into the UK market.

2.5.2 Available land

The UK can only devote a limited area of land to the cultivation of crops for biofuels. The total land area of the UK is around 24 million ha. In 2002 Defra estimated that about 6.5 million ha was arable land made up of around:

- 4.5 million ha under arable cultivation
- 0.7 million ha 'set-aside' (reduced in subsequent years)
- 1.2 million ha under grass less than five years old so could theoretically be brought back into use for growing crops, although there may be major cultural and environmental constraints including a significant reduction in animal husbandry

A further 11 million ha is specified to be grazing land for livestock including rough grazing. Around half of this is improved grazing which is intensively managed and low in biodiversity. This is theoretically suitable for arable or perennial energy crops, but in practice it is very unlikely that farmers would plough up grassland to plant an arable crop as this would be a reversal of current trends of agricultural specialisation.

Forest or woodlands cover 2.8 million ha. The remainder of the UK's land area is taken up by towns, roads, recreation and semi-natural environments, eg sand dunes, grouse moors and non-agricultural grasslands and inland waters.

Hence there are about 2 million ha of arable land available in the UK to grow biofuels, without affecting current food production. In practice, environmental constraints will reduce the area available to 1-2 million ha, limiting the amount of conventional biofuels that can be produced from UK grown biomass to around 5-10% of the UK's road fuel use. This would enable the maximum currently permitted by UK and European fuels standards, 5% by volume of bioethanol and FAME, to be added to petrol and diesel respectively. This would require 0.9 million ha of arable farmland. Meeting the Biofuels Directive indicative target for 2010 is also within reach for UK production of bioethanol and FAME. This would require around 1.3 million ha of arable farmland.

As UK FAME production requires more land than bioethanol production, the area required for biofuel production will increase if the demand for diesel continues to rise and the demand for petrol continues to fall. The area required for the UK production of bioethanol and FAME could be reduced by using the wheat and sugar currently exported for the production of bioethanol and, in the future, the conversion of straw to bioethanol.

Furthermore, energy crops for electricity generation will compete with land for fuel crops. It may be possible to alleviate this to some extent by developing 'biorefineries' to extract a range of products, including transport fuels, from the woody plant material with the residue being burnt for heat and/or power. Further work is required to explore this possibility.

In its study for DfT (*Liquid biofuels and hydrogen from renewable resources in the UK to 2050: a technical analysis,* December 2003), E4Tech estimated that around a third of UK road fuels could be replaced by biofuels provided these were from second generation production processes which give a higher yield of road fuels per ha, more land (4 million ha) allocated and waste streams converted. Imported biofuels would therefore be needed if the UK wanted to move to very high usage of biofuels.

2.5.3 Cost

In general, the cost of most domestic and overseas produced biofuels is around twice that of conventional road fuels, though Brazilian bioethanol is now very close, so some intervention in the market is required to stimulate the widespread introduction of biofuels in the competitive UK road fuels market. This could be a duty differential, the current policy, and/or a Renewable Transport Fuels Obligation (RTFO) under the 2004 Energy Act. Both these options have advantages and disadvantages.

Like many other ways of reducing CO_2 emissions from road transport, the cost per tonne of carbon saved with biofuels is high. No precise figures are available but published studies give a range of costs. For example, Sheffield Hallam's January 2003 study for Defra quotes £600-1200/tC for FAME from oilseed rape, British Sugar (private communication) estimate £450-500/tC and the December 2003 JRC/Concawe/Eucar well-to-wheel study quotes £570-900/tC for FAME and £660-1,500/tC for bioethanol. These figures are much higher than options in other sectors including the EU Emissions Trading Scheme where the current price of carbon is around £20/tC and the UK Treasury's illustrative cost of saving carbon of £70/tC in 2000 rising to £100/tC in 2030.

2.5.4 Environmental impact

The Low Carbon Vehicle Partnership (LCVP) is developing a biofuels accreditation scheme to ensure that biofuels are produced in a sustainable way and that the GHG savings from the various options are identified. The scheme will be non-bureaucratic and internationally accepted so that imported and domestically produced biofuels are covered. The objective is the global reduction of GHG emissions so it is important that biofuel 'farm to tank' emissions are fully established and options assessed on a global basis.

2.5.5 Availability of technology

The technology for producing biofuels from biomass could become available in the following timeframe. The timeframe could be altered by government support for development of the new processes or by advancement in the technology of conventional biofuel production:

2000-2010: Conventional biofuels, biogas, FAME from vegetable oil and bioethanol from wheat, sugar beet etc are available now. Other processes are at the demonstration or pilot plant phase. The first commercial plant converting straw to bioethanol will be commissioned towards the end of this period. Refinery conversion of vegetable oil to diesel will be proven. Combining liquid biofuel and electricity production will be used to improve the carbon efficiency of utilising biomass.

2010-2025: Fuels, electricity and chemicals are available from a range of energy crops, waste and biomass. Processes to convert lignocellulose to bioethanol are available, initially with straw as the feedstock. BTL (FT diesel) technology should also become available post 2015, along with improved power generation from gasification of biomass. The biofuel content of petrol and diesel may be increased from the current 5% by volume.

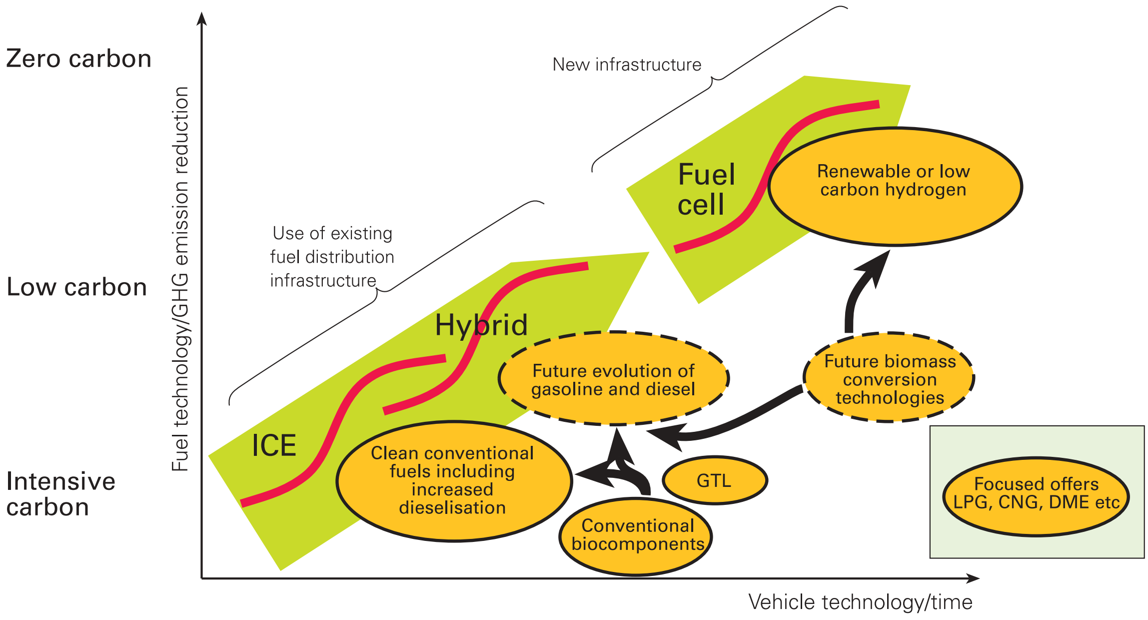

Exhibit 2.7 Future fuels pathway

3 THERMAL BIOMASS CONVERSION TECHNOLOGIES FOR TRANSPORT FUELS

There are three main thermal processes available for converting biomass to conventional hydrocarbon transport fuels: pyrolysis, pressure liquefaction and gasification. Exhibit 3.1 summarises the primary processes, primary products, secondary and refining processes and market applications.

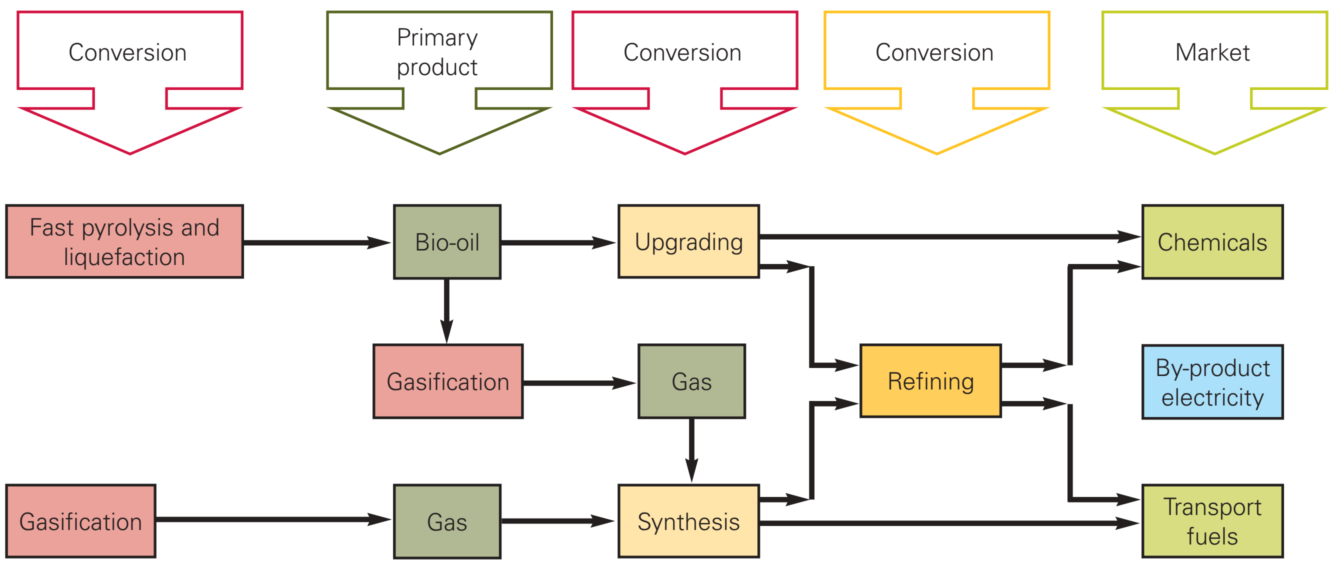

Exhibit 3.1 *Thermal biomass conversion processes for transport fuels and chemicals*

Fast pyrolysis and liquefaction are still at a relatively early stage of development but offer the benefits of producing a liquid fuel with concomitant advantages of easy storage and transport. Gasification utilising coal and oil feedstocks has been practised for many years, with the notable current example of Sasol in South Africa (Shell also has a small FT plant in Bintulu, Malaysia), and in the biomass area gasification has benefited from more R&D, with the result that there are more demonstration and commercial activities than for pyrolysis and liquefaction.

3.1 Pyrolysis

Pyrolysis is thermal decomposition occurring in the absence of oxygen. It is always also the first step in combustion and gasification, but in these processes it is followed by total or partial oxidation of the primary products. Lower process temperatures and longer vapour residence times favour the production of charcoal. High temperatures and longer residence times increase biomass conversion to gas, and moderate temperatures and short vapour residence times are optimum for producing liquids. Exhibit 3.2 indicates the product distribution obtained from different modes of pyrolysis.

Fast pyrolysis for liquids production is currently of particular interest as high yields of liquids are produced that are easy to store and transport from decentralised plants to a large central processing facility that offers economies of scale in conversion to marketable products.

3.1.1 Fast pyrolysis

Fast pyrolysis occurs in a time of a few seconds or less. Therefore heat and mass transfer processes and phase transition phenomena, as well as chemical reaction kinetics, play important roles. The critical issue is to bring the reacting biomass particles to the optimum process temperature as quickly as possible to release the volatile vapours, then cool these vapours as quickly as possible to minimise secondary reactions. The usual way of achieving the high heating rates necessary is by using small particles, for example in the fluidised bed processes that are described later. The alternative is to transfer heat very quickly only to the particle surface that contacts the heat source, as applied in ablative pyrolysis. A critical technical challenge is heat transfer to the reactor in commercial systems.

3.1.1.1 Principles

In fast pyrolysis, biomass decomposes to generate mostly vapours and aerosols and some charcoal. After cooling and condensation, a dark brown mobile liquid is formed which has a heating value about half that of conventional fuel oil. While it is related to the traditional pyrolysis processes for

Mode	Conditions	Liquid	Char	Gas	Examples visited
Fast	Moderate temperature, around 500ºC, short hot vapour residence time ~1 s	75%	12%	13%	BTG, TNO, VTT
Intermediate	Moderate temperature, around 500ºC, moderate hot vapour residence time ~10-20 s	50%	20%	30%	FZK
Slow (carbonisation)	Low temperature, around 400ºC, very long residence time	30%	35%	35%	
Gasification	High temperature, around 800ºC, long residence time	5%	10%	85%	FZK, Future Energy, SVZ

Exhibit 3.2 *Typical product yields (dry wood basis) obtained by different modes of pyrolysis of wood*

making charcoal, fast pyrolysis is an advanced process, with carefully controlled parameters to give high yields of liquid. The essential features of a fast pyrolysis process for producing liquids are:

- Very high heating and heat transfer rates at the reaction interface, which usually requires a finely ground biomass feed
- Carefully controlled pyrolysis reaction temperature of around 500ºC and vapour phase temperature of 400-450ºC
- Short hot vapour residence times of typically less than 2 s
- Minimum exposure to char and alkali metals as these are effective cracking catalysts
- Rapid cooling of the pyrolysis vapours to give the bio-oil product

The main product, bio-oil, is obtained in yields of up to 75% wt on a dry-feed basis, together with by-product char and gas, which can be used within the process to provide the process heat requirements so there are no waste streams other than flue gas and ash. The char can be sold as a valuable by-product if there is a market.

A complete fast pyrolysis process includes drying the feed to typically less than 10% water in order to minimise the water in the product liquid oil, grinding the feed to around 2 mm particle size in the case of fluidised bed (FB) reactors to give sufficiently small particles to ensure rapid reaction, pyrolysis reaction, separation of solids (char), and quenching and collection of the liquid product (bio-oil).

Virtually any form of biomass can be considered for fast pyrolysis. While most work has been carried out on wood because of its consistency and comparability between tests, nearly 100 different biomass types have been tested by many laboratories, ranging from agricultural wastes such as straw, olive pits and nut shells to energy crops such as miscanthus and sorghum, forestry wastes such as bark, and solid wastes such as sewage sludge and leather wastes. High ash content feedstocks of above around 3% can give a phase separated product from the catalytic effect of the alkali metals, particularly potassium.

In its 20 kg/h circulating FB pilot plant, VTT has focused on forest residues owing to the large resource available in Finland. BTG in the Netherlands has focused on woody biomass and energy crops, but it processes oil palm wastes as empty fruit bunches in its most recent 50 t/d demonstration or prototype commercial plant in Malaysia based on its rotating cone technology.

3.1.1.2 Reactors

At the heart of a fast pyrolysis process is the reactor. Although it probably represents at most only about 10-15% of the total capital cost of an integrated system, most R&D has focused on the reactor, although increasing attention is now being paid to control and improvement of liquid quality and improvement of collection systems. The rest of the pyrolysis process system consists of biomass reception, storage and handling, biomass drying and grinding, product collection, storage and, when relevant, upgrading. The key aspects of these peripheral steps are described later.

A key technical barrier is heat transfer to the reactor, as pyrolysis is an endothermic process. This is addressed in various ways in different reaction systems including recycling of hot sand from a separate char combustor as in the BTG prototype commercial plant, the VTT pilot plant and the FZK screw reactor; and indirect heat transfer as in the TNO and FZK rotary kiln system. In all cases there are unresolved concerns about scale-up to the large scale plants needed to maximise economies of scale.

Bubbling fluidised beds

Bubbling fluidised beds (usually referred to as just fluidised beds – FBs – as opposed to circulating fluidised beds – CFBs) have the advantages of a well understood technology that is simple in construction and operation, good temperature control and very efficient heat transfer to biomass particles arising from the high solids density. FB pyrolysers give good and consistent performance with high liquid yields of typically 70-75% wt from wood on a dry-feed basis. Small biomass particle sizes of less than 2-3 mm are needed to achieve high biomass heating rates and the rate of particle heating is usually the rate-limiting step.

Residence time of solids and vapours is controlled by the fluidising gas flow rate and is higher for char than for vapours. As char acts as an effective vapour cracking catalyst at fast pyrolysis reaction temperatures, rapid and effective char separation/elutriation is important. This is usually achieved by ejection and entrainment followed by separation in one or more cyclones so careful design of sand and biomass/char hydrodynamics is important. There is some experience of hot vapour filters for reducing solids.

Circulating fluidised beds and transported bed

Circulating fluidised beds (CFBs) have many of the features of bubbling beds described above, except that the residence time of the char is almost the same as for vapours and gas and there is greater attrition of the char owing to the higher gas velocities, which can lead to higher char contents in the collected bio-oil. An added advantage is that CFBs are suitable for very large throughputs even though the hydrodynamics are more complex. This technology is widely used at very high throughputs in the petroleum and petrochemical industry. Heat supply is usually from recirculation of heated sand from a secondary char combustor, which can be either a bubbling or circulating fluidised bed. In this respect the process is similar to a twin FB gasifier except that the reactor (pyrolyser) temperature is much lower and the closely integrated char combustion in a second reactor requires careful control to ensure that the temperature and heat flux match the process and feed requirements. A variation on the transported bed is the rotating cone reactor.

The BTG rotating cone concept is effectively a transported bed process. Sand is heated by combustion of by-product char and fed to the pyrolyser where it is mixed with biomass. The char and sand are recirculated to an FB combustor to reheat the sand. This is currently operating successfully in Malaysia on a prototype commercial plant of 50 t/d dry oil palm waste. The VTT process employs a CFB or transported bed for pyrolysis with a close coupled char combustor to reheat the sand which is then recirculated to the pyrolyser.

Ablative pyrolysis

Ablative pyrolysis is substantially different in concept from other methods of fast pyrolysis. In all the other methods the rate of reaction is limited by the rate of heat transfer through the biomass particles, which is why small particles are required. The mode of reaction in ablative pyrolysis is like melting butter in a frying pan – the rate of melting can be significantly enhanced by pressing the butter down and moving it over the heated pan surface. In ablative pyrolysis, heat is transferred from the hot reactor wall to 'melt' wood that is in contact with it under pressure. The pyrolysis front thus moves unidirectionally through the biomass particle. As the wood is mechanically moved away, the residual oil film both provides lubrication for successive biomass particles and also rapidly evaporates to give pyrolysis vapours for collection in the same way as other processes. The rate of reaction is strongly influenced by pressure, the relative velocity of the wood and the heat exchange surface and the reactor surface temperature. The key features of ablative pyrolysis are therefore as follows:

- High pressure of particle on hot reactor wall, achieved due to centrifugal force
- High relative motion between particle and reactor wall
- Reactor wall temperature <600°C

As reaction rates are not limited by heat transfer through the biomass particles, large particles can be used and in principle there is no upper limit to the size that can be processed. The process in fact is limited by the rate of heat supply to the reactor rather than the rate of heat absorption by the pyrolysing biomass as in other reactors. There is no requirement for inert gas, so the processing equipment is smaller and the reaction system is thus more intensive. However, the process is surface area controlled so scaling is more costly and the reactor is mechanically driven, and is thus more complex.

Cyclone and other reactors

A wide range of other reactor configurations have been developed such as the cyclone reactor of TNO. This also uses sand as a heat carrier but relies on the centrifugal motion of biomass and hot sand processing for good mixing and heat transfer. In all other respects the pyrolysis system behaves and performs like other fast pyrolysis systems. A rotary particle separator is also available to improve char separation. The work at TNO is supported by a novel cyclonic TGA (thermogravimetric analyser).

3.1.1.3 Pyrolysis liquid – bio-oil

Fast pyrolysis liquid typically is a dark brown, free-flowing liquid and approximates to biomass in elemental composition. It is composed of a very complex mixture of oxygenated hydrocarbons with an appreciable proportion of water from both the original moisture and reaction product. Solid char may also be present. It has a higher heating value of about 16-17 MJ/kg as produced with about 25% wt water that cannot readily be separated. The complex mixture of oxygenated compounds provides both the potential and challenge for utilisation. Pyrolysis liquid will not mix with any conventional hydrocarbon based fuels. It cannot be completely vaporised once it has been recovered from the vapour phase. If the liquid is heated to 100°C or more to try to remove water or distil off lighter fractions, it rapidly reacts and eventually produces a solid residue of around 50% wt of the original liquid and some distillate containing volatile organic compounds (VOCs) and water, much of which results from cracking of the liquid rather than evaporation. The important characteristics of the liquid are summarised in Exhibit 3.3. Different feedstocks, different feed characteristics and different reactor configurations will affect the characteristics of the bio-oil, but there are no clear relationships.

Bio-oil contains about 70% of the energy content of the initial biomass, while the char contains about 25% and the gas about 5%. A slurry of the bio-oil and char will contain nearly 90% of the energy content of the biomass, as long as additional energy is input to the process to provide the process heat, the requirement for which is about 15% of the energy content of the biomass.

3.1.1.4 By-products

Charcoal and gas are by-products, typically containing about 25% and 5% of the energy in

Physical property		Typical value
Moisture content		25%
pH		2.5
Specific gravity		1.20
Elemental analysis:	C	55–58%
	H	5.5–7.0%
	O	35–40%
	N	0–0.2%
	Ash	0–0.2%
HHV as produced		17 MJ/kg
Viscosity (40°C and 25% water)		40–100 cP
Solids (char)		0.2%
Vacuum distillation residue		up to 50%

Characteristics

- Liquid fuel
- Ready substitution for conventional fuels in many stationary applications such as boilers, engines, turbines
- Heating value of 17 MJ/kg at 25% wt water is about 40% that of fuel oil/diesel
- Does not mix with hydrocarbon fuels
- Not as stable as fossil fuels
- Quality needs definition for each application

Exhibit 3.3 *Typical properties of wood-derived crude bio-oil*

Exhibit 3.4 *Fast pyrolysis bio-oil*

the feed material respectively. The pyrolysis process itself requires about 15% of the energy in the feed, and of the by-products, only the char has sufficient energy to provide this heat. The heat can be derived by burning the gas and/or the charcoal by-product. The only waste arising from the process is the ash from char combustion if this is used in-process.

Char separation is a critical step in the process as char is both catalytically active and also causes a physical handling problem in utilisation. TNO has developed a rotary particle separator to enhance char separation. BTG recycles all the char and sand for combustion to reheat the sand which is used as the heat transfer medium. VTT also burns the char in a separate FB combustor for reheating the sand which is recirculated, and has also tested a hot vapour filter to minimise the char content of the product bio-oil. The higher turbulence of CFBs can lead to greater char attrition, leading to problems in char separation.

The combination of bio-oil and char into a pumpable slurry has been tested to maximise its energy content by FZK. This acts as an energy carrier to transport as much of the energy in the biomass as possible in a liquid form to optimise handling, storage and transport.

3.1.2 Bio-oil upgrading

The main concerns in utilisation of bio-oil relate to phase separation, ageing (a tendency for viscosity to increase over time), and solids content, mostly char. Phase separation is a result of high water content of the feed material and/or secondary cracking reactions from high ash, high char and/or long hot vapour residence time. A well designed and operated fast system operating on a low ash feed will consistently deliver a homogeneous, single phase bio-oil. Char separation remains a challenge and several devices have been tested such as hot vapour filtration at VTT and the rotary particle separator at TNO.

3.1.3 Intermediate and slow pyrolysis

If the residence time in fast pyrolysis extends to more than around 10 s, secondary reactions become more important and result in an increased effect of cracking reactions that reduce the liquid organic yield, increase the water yield and increase the char yield as shown in Exhibit 3.2 earlier. This invariably results in a phase separated liquid with a watery aqueous phase and a high viscosity liquid phase that is more tar-like than fast pyrolysis liquid.

Production of a bio-oil/char slurry will contain about 80-90% of the initial energy content of the biomass depending on the extent of secondary cracking reactions. It is not clear whether a phase separated liquid will produce a slurry with char that remains phase separated, or whether two slurries will be produced from each of the aqueous phase and the organic phase.

3.1.3.1 Screw pyrolysis

Screw pyrolysis is what is referred to as intermediate pyrolysis in Exhibit 3.2. It is not as fast as fast pyrolysis due to the mechanical nature of the system which intimately contacts biomass with a moving bed of sand. The hot vapour residence time is around 10 s rather than 1 or 2 s in the systems described above, and secondary cracking thus reduces the liquid yield to around 50% and the liquid is phase separated. The pilot plant at FZK has a capacity of around 20 kg/h and plans are in hand to install a 0.5 t/h demonstration plant utilising a displaced Lurgi LR test reactor. This is a part of a €22 million (~£15 million) bioenergy test centre under construction at FZK. The sand is heated with by-product gas, supplemented when necessary.

The two phase liquid is mixed with the char by-product to form a slurry that contains up to 90% of the energy in the biomass. Two slurries can be produced based on the aqueous phase and on the separated organic phase. This would complicate the handling of slurry.

Future Energy has carried out tests on pressure oxygen gasification of the slurry in its pilot plant in Freiberg.

3.1.4 Torrefaction

Torrefaction can be considered as a pre-pyrolysis process for substantially changing many of the characteristics of biomass that make it relatively difficult to handle, transport and prepare for thermal conversion. Torrefied biomass can be processed much like coal and thus existing coal gasification processes can be readily adapted to biomass feeding.

Torrefaction, as developed by ECN, is a low temperature pyrolysis process that is typically carried out at 200-250ºC before there is appreciable decomposition of cellulose and lignin, thus retaining a large proportion of the energy content of the original biomass. Torrefied biomass can be transported and processed more efficiently than raw biomass, particularly in size reduction for feeding to an entrained flow gasifier. However there is a significant energy and capital cost in the torrefaction process, and a waste water disposal problem, none of which are known to have been thoroughly explored.

Exhibit 3.5 *Torrefied pellets at ECN*

3.1.5 Transport fuels from bio-oil by upgrading

Bio-oil from fast pyrolysis or liquefaction processes can be catalytically upgraded to produce hydrocarbon fuels that can be conventionally processed for example in refineries. Full deoxygenation to high-grade products such as transportation fuels can be accomplished by two main routes: hydrotreating and catalytic vapour cracking over zeolites. The range of options is shown in Exhibit 3.6. VTT is planning to develop an integrated approach to upgrading and refining for transport fuels and chemicals, but no details are yet available.

There is considerable interest in the concept of decentralised fast pyrolysis and transport of bio-oil or bio-oil/char slurry to a central processing plant for upgrading. The bio-oil or slurry collected from several or many smaller plants can then be more economically and efficiently processed in much larger plants, for example for large scale gasification for synthesis of FT diesel or methanol. This is proposed by FZK and Future Energy for FT, and by Technische Universität Bergakademie Freiberg (TUB-F) for methanol.

3.1.5.1 Hydrotreating using traditional hydro-desulphurisation catalysts

Hydrotreating gives a naphtha-like product that requires orthodox refining to derive conventional transport fuels. The process is separate from fast pyrolysis and processes a liquid feed in a high pressure two stage process over conventional hydro-desulphurisation catalysts in the presence of hydrogen. The catalyst supports have been found to be unstable in the high water content environment of bio-oil and some progress has been made on the use of carbon catalyst supports. There is a substantial hydrogen requirement to both hydrogenate the organic constituents of bio-oil and remove the oxygen content as water. The hydrogen requirement can be represented by a requirement to process an additional amount of biomass equal to about 80% of that required to produce the bio-oil. The process is thus very inefficient and also very high cost from the high-pressure requirements and cost of hydrogen.

This technology can be applied to liquefaction products (see Section 3.2) and to vegetable oils, both of which have much lower oxygen contents than bio-oil and thus have a much lower hydrogen requirement. Neste is building a 170,000 t/y plant for hydrotreating vegetable oils in Finland and has recently

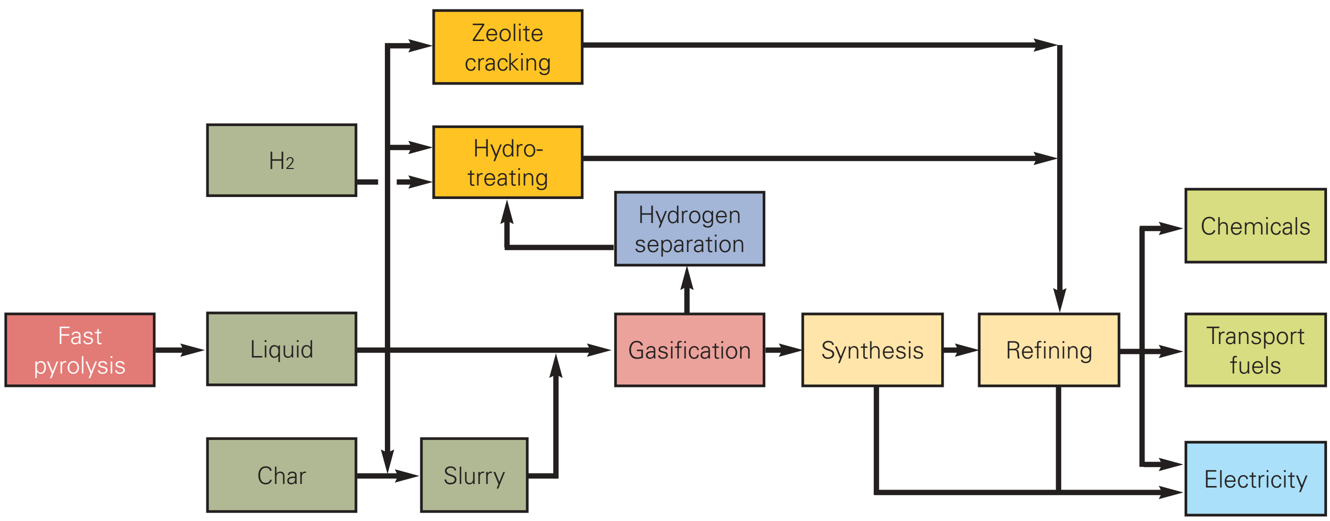

***Exhibit 3.6** Transport fuels and chemicals from fast pyrolysis*

announced plans for a similar plant in Austria. The advantage is that a synthetic diesel is produced that is completely compatible with existing diesel in all proportions.

3.1.5.2 Hydrotreating of separated product

A more recent development is to separate the bio-oil into organic and aqueous fractions. The aqueous fraction is steam reformed to hydrogen which is used to hydro-process the organic fraction. A crude product is obtained for refining in a conventional oil refinery. No details are available but it is claimed to be more promising economically and technically than the traditional approach discussed above.

3.1.5.3 Zeolite cracking

Zeolite cracking can be carried out on the primary vapours from fast pyrolysis and can thus be integrated into the fast pyrolysis process, thereby obviating the need for a separate upgrading process and need for high pressure. Close-coupled operation in a separate reactor is preferred to give better process control and more effective contact with the catalyst. In this process the oxygen is rejected as CO_2 rather than water, thus reducing carbon efficiency but avoiding the need for hydrogen. A further complication of zeolite cracking catalysts is the propensity for rapid coking, and thus a more complex rapid catalyst regeneration system is required. Hydrocarbon products from this process have a high octane number but have been found to contain high levels of aromatic hydrocarbons which are undesirable. Catalyst and process development may reduce this problem.

3.1.5.4 Gasification of bio-oil and synthesis of transport fuels

Pressurised oxygen gasification of bio-oil has only recently been tested to a limited extent. A variety of proprietary pressurised oxygen blown gasifiers are available from applications in coal and heavy oils. Substantial scales of operation are necessary to justify the expense of an oxygen plant and high pressure operation. This militates against small scale biomass gasification, hence the increasing interest in using bio-oil and bio-oil/char slurries as energy carriers to feed a state-of-the-art gasification and liquid fuel synthesis plant. Typical commercial size is likely to be between 15,000 and 20,000 barrels per day (bbl/d) fuel product. This equates to between 10,000 and 15,000 t/d biomass or between 3 and 4 million t/y biomass. Section 3.4 describes the options for synthesis of transport fuels.

Future Energy is engaged in a test programme for pressurised oxygen gasification of bio-oil/char slurry. It has concerns over the variability of feed quality that might result from a phase separated product. The aqueous fraction has a much lower heating value than the organic fraction and a sudden change in feed to the gasifier could result in oxygen overload in the gasifier with potentially serious consequences.

TUB-F is also developing a partial oxidation process for bio-oil prior to synthesis of methanol for conversion to gasoline.

The relative merits of the different process routes have not recently been evaluated and it would be valuable to establish the relative performance of the processes in terms of technology, economics and environment, including consideration of the refining needed to produce a transport fuel product that is totally compatible with current fossil fuel derived products.

3.2 Liquefaction

Pressure liquefaction is analogous to pyrolysis in that there is no oxidation of the reacting biomass. Biomass is fed to a pressurised system at up to 200 bar and is heated to around 300-400°C in a liquid environment. The biomass decomposes and reacts to give a product with a much lower oxygen content than bio-oil (10-15% wt compared to 35-40% wt), that is more stable than bio-oil, but which has much higher viscosity, often requiring temperatures above 60-80ºC to give a pumpable liquid. The earliest significant work in the USA around 1980 developed two processes, one based on recycled product liquid from which the light ends had been removed and the other based on a water or aqueous medium. This later approach is currently being researched in Europe. A water based system enables wet biomass to be processed without drying.

The 100 kg/h hydrothermal upgrading (HTU) pilot plant located at TNO operates at 330ºC and 175 bar with an aqueous feed. The liquid product is separated and the water fraction is recycled. A continuous run of 500 h has been successfully achieved. The liquid yield is around 40% wt with an oxygen content of around 15% which is substantially lower than bio-oil. There are plans for demonstration at 25,000 t/y.

3.3 Gasification

Fuel gas and syngas can be produced from biomass either by partial oxidation to give a mixture of CO, CO_2, hydrogen and methane with nitrogen if air is used as the oxidant, or by steam or pyrolytic gasification. Exhibit 3.7 summarises the main products in each case. The term syngas is often used in the context of a nitrogen free gas with high concentration of CO and hydrogen in proportions that are suitable for synthesis of hydrocarbons, alcohols and ethers etc.

The process of gasification is a sequence of interconnected reactions: the first step, drying, is a relatively fast process. The second step, pyrolysis, is also relatively fast but it is a complex process that gives rise to the tars that cause so many problems in gasification processes. Pyrolysis occurs when a solid fuel is heated to 300-600ºC in the absence of an oxidising agent, giving a solid char, condensable hydrocarbons or tar and gases. The relative yields of char, liquid and gas mainly depend on the rate of heating and the final temperature and this has been discussed in Section 3.1.1. In gasification by partial oxidation the gas, liquid and solid products of pyrolysis then react with the oxidising agent (air, oxygen or steam) to give the permanent gases CO, CO_2, H_2 and lesser quantities of hydrocarbon gases. In steam or pyrolytic gasification, the by-product char is burned in a secondary reactor to reheat the hot sand which is recycled to the gasification reactor to provide the heat for gasification.

3.3.1 Status of biomass gasification technology

Biomass gasifiers for production of transport fuels need to be very large by current biomass gasification standards, which limits technologies to CFBs and entrained flow systems. Similarly, oxygen blown pressurised systems are probably essential. There is limited experience of oxygen blown or pressurised biomass gasification in Europe generally, although VTT has considerable experience with pilot plant design and operation of both oxygen and pressurised systems.

However, extrapolation of experiences with coal and other materials is not unreasonable. There are significant differences that mostly relate to the high level of volatiles in biomass compared to coal (70-75% vs 20-25%) and the physical and structural characteristics of biomass vs coal, in that biomass is much more difficult to grind and much more resistant to compressive forces. Entrained flow biomass gasifiers will thus have a higher feed preparation requirement. Cold gas efficiencies of up to 75-80% are potentially achievable in a well integrated plant.

Gasification mode	Details	Examples seen on visits
Partial oxidation with air	The main products are CO, CO_2, H_2, CH_4, N_2 and tar, giving a low heating value gas of ~5 MJ/m^3. The high nitrogen content is a major diluent. Fixed beds, FBs, CFBs and entrained flow reactors are used.	ECN, TUB-F, VTT
Partial oxidation with oxygen	The main products are CO, CO_2, H_2, CH_4 and tar (no N_2), giving a medium heating value gas of ~10-12 MJ/m^3. There is a significant economic and energetic cost of using oxygen, but the product gas is essentially nitrogen free. While fixed beds have been used, CFBs and entrained flow reactors are more widely promoted.	Choren, Future Energy, TUB-F, VTT
Steam (pyrolytic) gasification	The main products are CO, CO_2, H_2, CH_4 and tar giving a medium heating value gas of ~15-20 MJ/m^3. The process has two stages: the primary reactor produces gas and char, and the fluidising sand and char is passed to a second reactor where the char is burned with air to reheat the sand, which is then recirculated to the first reactor to provide the heat for reaction. The gas heating value is maximised due to a higher methane and higher hydrocarbon gas content, but at the expense of lower overall efficiency due to loss of carbon in the second oxidising reactor. FBs, CFBs and entrained flow reactors are used and promoted.	FZK
Pressure operation	Pressurised gasifiers operate under pressures of typically 15-50 bar, with the hot gas being cooled to around 500°C to aid precipitation of alkali metals on the particulates prior to hot gas filtration to remove the particulates. As a tar free gas is needed for liquid fuel synthesis, an effective tar cracking and/or removal system is essential. Pressurised feeders need significant quantities of inert gas for flushing the lock hoppers during the feeding cycle, unless alternatives are used such as plug feeders. Both capital and operating costs are significantly higher for pressurised operation, although these are to some extent balanced by savings from reduced vessel and piping sizes, the avoidance of a gas compressor for the gas turbine and higher efficiencies. Examples include the CFB demonstration plant at Värnamo and Carbona. There is a trade-off between the high cost of a pressurised feeding system and compression of a product gas from an atmospheric gasifier. Currently, a pressurised gasifier is believed to have economic advantages. Liquid feeding as bio-oil or slurry has significant operational and economic advantages over solid biomass feeding.	Choren, Future Energy, SVZ, TUB-F, VTT
Oxygen gasification	The advantages of using oxygen include: • Higher reaction temperatures, which can lead to lower tar levels and smaller gasifiers • Lower gas volumes from the reduction or absence of nitrogen, leading to smaller vessel and piping sizes and hence lower costs • The absence of nitrogen leads to more efficient use of gas for synthesis of liquid fuels There is, however, a significant energy and financial cost associated with the use and supply of oxygen, from both its procurement and the additional measures needed to mitigate hazards in handling and use.	Choren, Future Energy, SVZ, TUB-F, VTT
Supercritical	High pressure and high temperature gasification in supercritical water.	ECN, FZK

Exhibit 3.7 *Modes of thermal biomass gasification*

Gasifier type	Examples visited
FB and CFB – air	VTT, ECN
FB and CFB – oxygen, pressure	VTT
CFB – air	VTT, ECN
CFB – oxygen, pressure	VTT
Updraft – air	VTT
Updraft – oxygen, pressure	SVZ
Entrained flow – air	
Entrained flow – oxygen, pressure	ECN, Future Energy, FZK, SVZ
Downdraft air	ECN
Downdraft oxygen	
Indirect, pyrolytic or steam gasification; typically in a twin FB	ECN
Bio-oil gasification	BTG, Future Energy, FZK, TUB-F

Exhibit 3.8 *Gasifers and examples visited during mission*

3.3.2 Synthesis gas quality

The synthesis gas (syngas) quality requirement for liquid fuel production is very high. Tar is a particular problem in biomass derived gas and probably remains the most significant technical barrier. Exhibit 3.9 gives typical product gas compositions for the more common gasifiers.

Exhibit 3.10 lists the more significant contaminants. The level of contamination will vary depending on the gasification process and the feedstock. Extensive gas cleaning is needed to deliver a sufficiently clean gas to the synthesis train. Trace contaminants containing sulphur (eg H_2S), chlorine (eg HCl, COCl) and nitrogen (eg ammonia) in a range of compounds will usually require reduction to a few parts per million (ppm) for most catalyst systems used in synthesising alcohols and hydrocarbons, and each catalyst has its own limitations and tolerances. All the technology is available for gas purification, but optimisation is necessary to maximise performance and minimise cost. Other components include CO_2, methane, higher hydrocarbons such as ethylene and ethane, propane and propylene, and nitrogen. Generally these act as diluents, but different generic and specific processes have different levels of tolerance for each component. ECN, FZK and VTT are carrying out extensive research on all aspects of contaminant control and management.

3.4 Synthesis of transport fuels

Fischer-Tropsch (FT) is a process for converting a mixture of carbon monoxide (CO) and hydrogen (H_2), known as synthesis gas or syngas, into hydrocarbon liquids. Hydrocarbon product distribution is defined by a single parameter, the alpha number, which is dependent upon the ratio of CO to H_2, the catalyst, and the reaction temperature and pressure employed. The process is best known for its application by Sasol in South Africa where coal is gasified in fixed bed gasifiers and the resultant, cleaned syngas is converted over an iron based catalyst to a range of transport fuels and chemicals.

	Gas composition, dry, vol%					HHV	Gas quality	
	H_2	CO	CO_2	CH_4	N_2	MJ/Nm^3	Tars	Dust
FB air-blown	9	14	20	7	50	5.4	Fair	Poor
Updraft air-blown	11	24	9	3	53	5.5	Poor	Good
Downdraft air-blown	17	21	13	1	48	5.7	Good	Fair
Downdraft oxygen	32	48	15	2	3	10.4	Good	Good
Twin FB	31	48	0	21	0	17.4	Fair	Poor
Pyrolysis (for comparison)	40	20	18	21	1	13.3	Poor	Good

Exhibit 3.9 *Typical product gas characteristics from different gasifiers*

Contaminant	Examples	Problems	Solution
Tars	Refractive aromatics	Clogs filters, difficult to burn, deposits internally	Tar cracking thermally or catalytically, or tar removal by scrubbing
Particulates	Ash, char, FB material	Erosion	Filtration, scrubbing
Alkali metals	Sodium, potassium compounds	Hot corrosion	Cooling, condensation, filtration, adsorption
Fuel-bound nitrogen	Mainly NH_3 and HCN	NO_x formation	Scrubbing, SCR (selective catalytic reduction)
Sulphur	H_2S	Catalyst poison, corrosion, emissions	Lime or dolomite scrubbing, absorption
Chlorine	HCl, COCl	Catalyst poison, corrosion, emissions	Lime or dolomite scrubbing, absorption
Carbon dioxide		Diluent	Scrubbing – many proprietary processes are available
Methane and higher hydrocarbons	CH_4, C_2H_6, C_3H_8 etc	Diluent and loss of energy if not processed	Reforming

Exhibit 3.10 *Synthesis gas contaminants and their problems*

Modern FT, based on high performance cobalt catalysts, has achieved further prominence in recent years as it is the core technology for converting natural gas into transport fuels both in Asia and more recently in the Middle East.

The basic process is reaction of CO and H_2 in the following conceptual process:

$$(2n+1)H_2 + nCO \longrightarrow C_nH_{2n+2} + nH_2O$$

The hydrocarbons produced range from methane to very heavy hydrocarbons, such as waxes that are solid at room temperature, depending upon the alpha value. An FT process therefore usually includes upgrading of the waxy liquids (such as by hydrotreating or hydrocracking), refining (such as distillation) and recycling of unwanted products to increase desired product yields. Very large plants are necessary to give acceptable economies of scale. The minimum size currently considered economically viable from natural gas is around 25,000-34,000 bbl/d or about 1.0-1.3 million t/y.

This process has been commercially operated by Sasol in South Africa since around 1955, where over 1 million t/y of coal are processed into a full range of marketable hydrocarbon fuels and chemicals, and is referred to as coal to liquid (CTL) technology. Since the oil shocks of the 1970s and 1980s all of the oil majors have have been active in developing gas to liquid (GTL) processes to convert natural gas and natural gas liquids to transport fuels. Although Shell has been operating a relatively small GTL plant in Malaysia for some years, it is only now that substantial GTL plants are being constructed in the Middle East and Asia. There are therefore a number of potentially suitable technologies for synthesis of transport fuels from syngas derived from biomass. Biomass to liquid (BTL) is currently attracting considerable interest in Europe for both environmental and security of supply reasons, but there is little activity in the UK. The biggest barrier is the limited availability of biomass at any one location that makes the economies of scale necessary for commercially viable FT difficult to achieve. There is potential for catalyst and process development to allow downscaling to address this barrier.

Both Choren and Future Energy are working in this area, Choren via biomass gasification followed by SMDS (Shell Middle Distillate Synthesis) and Future Energy via bio-oil (from fast pyrolysis such as by BTG or intermediate pyrolysis such as by FZK) gasification in an entrained flow gasifier. Liquid feeding to a pressurised gasifier is easier than with solid biomass. In particular it is lower cost as a liquid or slurry can be fed under pressure with simpler and lower cost equipment than solid biomass with lock hoppers or screw feeders. The product gas is also likely to be cleaner with lower tar content. A potential problem with liquid or slurry feeds is phase separation since a lower heating value/higher water content feed will require less oxygen and, if suitable controls are not in place, can lead to oxygen overload in the reactor with potentially serious consequences.

Methanol production from synthesis gas is well established, and this chemical can be converted to gasoline at high efficiency by the Mobil MTG (methanol to gasoline) process using zeolite ZSM–5 catalyst (see Exhibit 3.11). This process has been technically proven at full scale in New Zealand, where natural gas is converted to methanol and then to gasoline, although the plant no longer operates as the process is not commercially viable. The gasoline product is too aromatic but the potential exists for process development. An analogous process known as MOGD (methanol to olefins, gasoline and diesel) has been developed for diesel fuel.

There are similar concerns over economies of scale as for FT technology. TUB-F is focusing on this route to gasoline via methanol through system studies initially, although a gasification system is under development. It is also working on bio-oil gasification in a system that seems likely to be comparable to that of Future Energy.

Once-through systems have been proposed (see Exhibit 3.11) in which the syngas is not recycled, but passes to an integrated gasification combined cycle (IGCC) gas turbine after a single pass through the synthesis reactor. This reduces the complexity and hence cost of the synthesis processes and is claimed to offer the advantages of higher efficiency, lower cost and increased flexibility.

Methane or synthetic natural gas (SNG) is another fuel of interest because it can readily be distributed via gas grids in most European countries. ECN has a particular interest in this product.

A detailed, comparative analysis of the technologies for producing alternative transport fuels is not known to have been completed recently and this would help identify the most promising technologies and transport fuel synthesis routes.

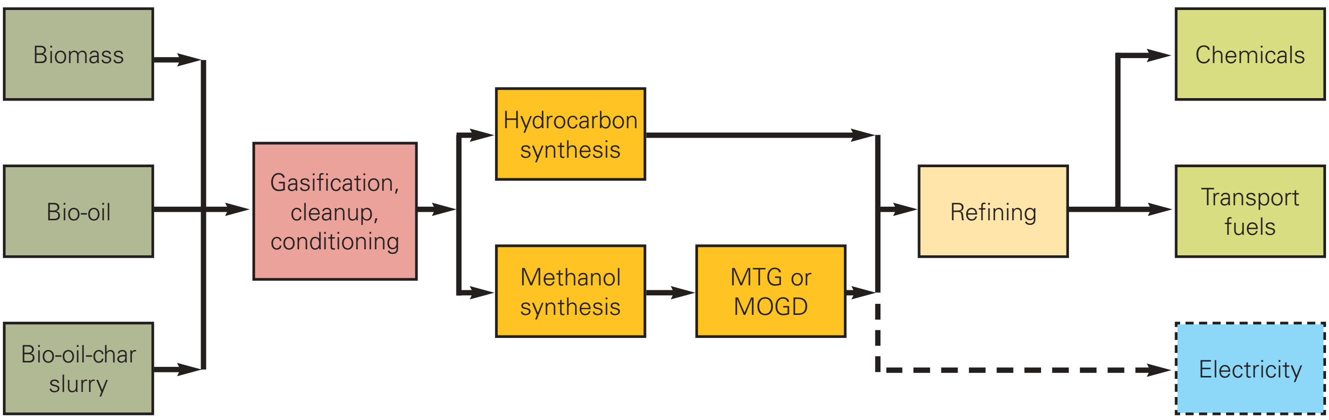

Exhibit 3.11 *Biomass or bio-oil to transport fuels*

Liquid fuel	Studies	Experimentation
Methanol	ECN, SVZ, TUB-F, VTT	FZK (planned), SVZ
FT diesel	Choren, ECN, Future Energy, VTT	Choren, ECN
Vegetable oil diesel	Neste	Neste
Gasoline via MTG	TUB-F	
Fuel alcohol		
SNG or methane	ECN, VTT	ECN
DME (dimethyl ether)	VTT	
Hydrogen	ECN, VTT	

Exhibit 3.12 Activities on synthetic transport fuels at organisations visited

3.5 Bioenergy system

A more global perspective of the opportunities for meeting the transport fuel requirements in the UK is shown in Exhibit 3.13. This includes the potential for production of:

- Biomass in the UK and/or overseas
- An intermediate such as bio-oil in the UK or overseas
- A finished transport fuel product in the UK and/or overseas

Included is consideration of integrated production of both transport fuels and chemicals to optimise energetically, economically and technically the use of biomass; this is commonly referred to as a biorefinery.

System analyses have been carried out by most of the organisations visited. The Öko-Institut in particular has carried out extensive and thorough analyses of a wide range of systems under different scenarios. VTT has explored the potential of integrating transport fuels production into pulp and paper mills by optimising the use of its existing resources with additional imports of supplementary biomass. This results in much higher overall energy efficiencies to transport fuels. ECN

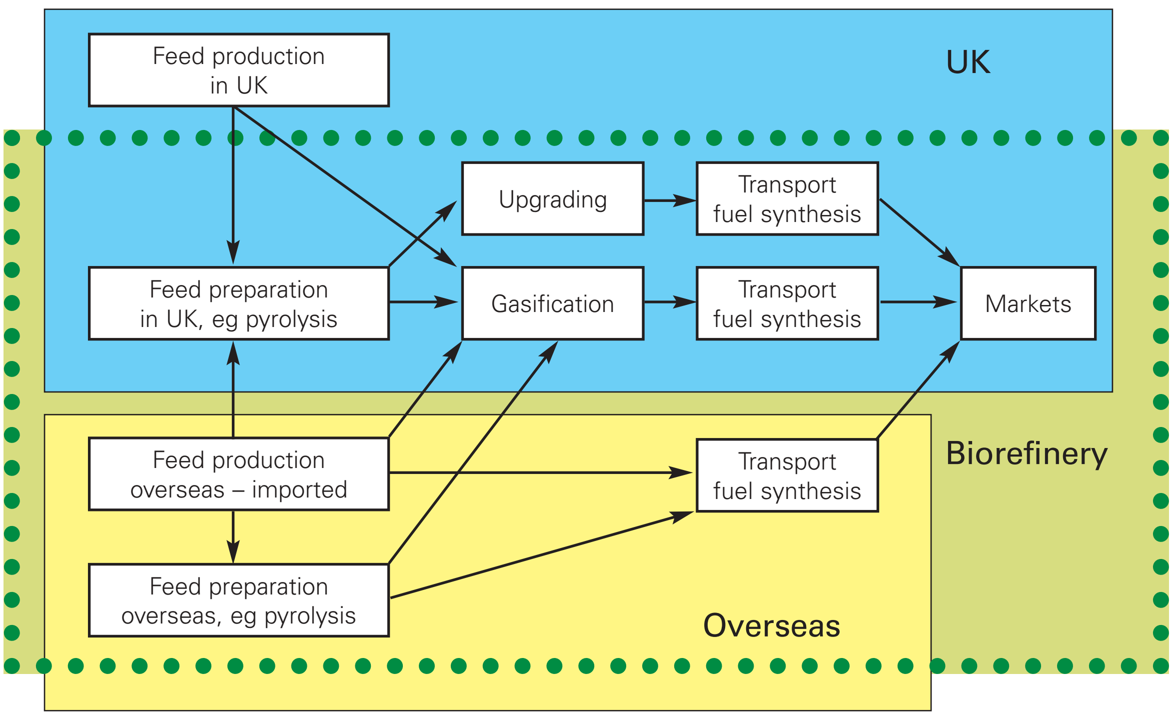

Exhibit 3.13 Opportunities for meeting the UK renewable transport fuel demand

has also carried out extensive studies on different bioenergy chain configurations for transport fuels.

3.6 Bibliography of further reading

Recent journals and articles

Bridgwater AV, *The production of biofuels and renewable chemicals by fast pyrolysis of biomass,* International Journal of Global Energy Issues (2006 in print)

Brammer JG, Lauer M and Bridgwater AV, *Opportunities for biomass-derived 'bio-oil' in European heat and power markets,* Energy Policy (2005)

Czernik S and Bridgwater AV, *Applications of biomass fast pyrolysis oil,* Energy and Fuel 18:590-598 (2004)

Bridgwater AV and Maniatis K, *The production of biofuels by the thermochemical processing of biomass,* pp 521-612 in *Molecular to global photosynthesis,* Ed Archer MD and Barber J (IC Press, 2004)

Bridgwater AV, *Biomass fast pyrolysis,* Thermal Science 8(2):17-45 (2004)

Recent books

Bridgwater AV and Boocock DGB (Eds), *Science in thermal and chemical biomass conversion,* 1946 pp (CPL Scientific Press, 2006)

Bridgwater AV (Ed), *Pyrolysis handbook, volume 3* (CPL Press 2005)

Bridgwater AV (Ed), *Pyrolysis and gasification of biomass and waste, Strasbourg,* September 2002 (CPL Scientific Press, 2003)

Bridgwater AV (Ed), *Fast pyrolysis of biomass – a handbook, volume 2,* ISBN 1-872691-47-1 (CPL Press, 2002)

Bridgwater AV (Ed), *Progress in thermochemical biomass conversion,* ISBN 0-632-055533-2, 1759 pp (Blackwell, Oxford, UK, 2001)

Recent reports

Bioenergy – a scoping mission to the USA and Canada, February/October 2005, DTI Global Watch Mission Report, URN 06/829, 56 pp, published February 2006: www.globalwatchservice.com/missions

4 ENGINEERING, PLANT DESIGN AND TECHNICAL ISSUES

This chapter deals with issues relating to the implementation of the second generation technologies outlined in Chapter 3.

4.1 Towards commercial scale biofuel plants

What will commercial scale biomass to liquid (BTL) plants look like? For thermal biomass conversion routes based on gasification and synthesis, the basic steps are similar to emerging coal to liquid (CTL) conversion processes, as described in Chapter 3. A big advantage for BTL is that it makes use of the same intermediate (syngas), and produces the same product (synthetic diesel) from FT synthesis. Also, solids handling systems are likely to be similar for solid biomass feed to the gasifier. With high oil prices and security of supply as key drivers, there is considerable activity today in demonstration plants and developing commercial scale CTL plants. Hence such developments should make modern gasification and synthesis plant designs proven and commercially available for any future BTL plant. In addition, gasification is relatively feedstock insensitive and so the same process and engineering designs should be capable of converting a wide diversity of biomass. Various concepts for commercial BTL plant presented to the mission team are discussed in Chapter 8.

4.2 BTL plant design

Basic routes for thermal biomass conversion to liquid fuels are covered in Chapter 3 and summarised in Exhibit 4.1. Engineering and design for thermal conversion routes to synthetic diesel will need to consider the following aspects:

4.2.1 Biomass feedstocks

Potential biomass sources are from forestry and agriculture. Such sources range from wood (residues and energy crops), grasses (eg miscanthus), and various agro-residues, such as straw, rice husks, sugar cane residues (bagasse) and palm oil residues. Industrial waste (MSW) can also be considered a potential biomass source. Feedstock considerations are discussed in Chapter 6.

4.2.2 Biomass pretreatment

Biomass has a very different nature from conventional fossil fuel feedstocks. Such sources represent a very wide range of potential feed type and characteristics to the conversion plant and a significant engineering challenge in preparing biomass for processing, compared to fossil fuels. Pretreatment is essential to allow stable feeding and operation into conversion units and to reduce transportation costs. A number of different steps under development were presented to the mission team, as follows:

- **Size reduction and drying** of very diverse material. High water content (can be up to 65% wt) and a fibrous nature are significant issues; the water content needs to be reduced to below 15% wt for efficient transportation and/or as gasifier feed. BTG discussed recent pretreatment difficulties in their demonstration plant, due to the fibrous nature of palm oil residues (empty fruit bunches)

- **Pelletisation** of the dried solids, in particular for long distance transportation

- **Torrefaction** (roasting), which upgrades biomass to dry coal powder properties, as presented by ECN (see Section 3.1.4)

- **Pyrolysis** to bio-oil. Several companies presented current designs, as outlined in Chapter 3. This technology is mostly developmental with a number of new reactor designs being developed and requiring scale-up

Very little large scale demonstration, scale-up or process integration has been done to date. Improved pretreatment is one of the targets for future demonstration plants being progressed by organisations such as Choren Industries and FZK.

Transportation of biomass, in particular over long distances, is an important consideration in pretreatment from both a cost perspective and energy use, ie well-to-wheel CO_2 emissions. Potential benefits from feedstock densification, such as using bio-oil as an energy carrier, need to be explored. Choren prefers not to use bio-oil as an energy carrier on efficiency reduction grounds and because of handling and stability concerns, whilst Future Energy is focusing on this route due to the attractions of large scale fuel synthesis and the ease of feeding liquids into a pressurised gasifier.

4.2.3 Conversion

There are three main considerations in the conversion section:

- **Gasification to syngas.** Biomass gasification technology is covered in Section 3.3. Biomass applications are similar to coal conversion to syngas, such as CTL processes, and the significant improvements in modern commercial scale gasifier designs can be applied to BTL

- **Syngas quality** issues are outlined in Section 3.3. Overall, with the exception of tar removal, clean-up requirements are similar to a raw syngas derived from coal, where the syngas is to be used for conversion to liquids. Contaminant removal, CO to H_2 ratio and pressure adjustment are needed. Hence process and plant design considerations are similar to those required for CTL processes. For MSW processing, however, syngas clean-up to remove contaminants may well require special consideration

- **FT synthesis and product upgrading** of the FT waxy liquids to diesel. As described in Section 3.4, there is growing interest in natural gas and coal based processes combined with FT synthesis technology. Process and plant designs for conversion of syngas from oxygen-blown gasification processes are being established by recent world-scale GTL project developments. Designs for modern commercial scale CTL plants, based on modern gasification technology and modern FT synthesis catalysts, are under development. A number of world-scale CTL projects should be under way within the next few years, making gasification and synthesis designs proven and commercially available for future large scale BTL plants

As described in Chapter 3, and shown in Exhibit 4.1, there are also non-syngas routes

<table>
<tr><th>Biomass feedstock supply</th><th colspan="2">Biomass pre-treatment</th><th colspan="2">Conversion</th><th>Product</th></tr>
<tr><td rowspan="5">Wood (residues and energy crops)

Grasses (eg miscanthus)

Agro-residues
• Straw
• Rice husks
• Bagasse (sugar cane)
• Palm oil residues</td><td rowspan="5">Size reduction

Drying</td><td rowspan="5">Pelletisation

Torrefaction (roasting)

Pyrolysis to bio-oil</td><td rowspan="3">Gasification (of pellets or bio-oil) and syngas treatment</td><td>FT synthesis and product upgrading</td><td>Synthetic diesel</td></tr>
<tr><td>Methanol synthesis (also DME production)</td><td>Methanol/(DME)</td></tr>
<tr><td>(Shift reaction and methanation)</td><td>(Hydrogen)</td></tr>
<tr><td colspan="2">Bio-oil hydroprocessing and deep refining</td><td>‘Second generation biodiesel’</td></tr>
<tr><td colspan="2">Zeolite cracking</td><td>Gasoline blendstock</td></tr>
</table>

Exhibit 4.1 *Process options in second generation biofuels*

to transport fuels under consideration, such as hydroprocessing. These technologies use more conventional refining and petrochemical engineering and plant design than the gasification route but require significant catalyst development. If successful, such schemes may offer lower capital cost and higher overall efficiency compared to syngas-based routes.

4.3 BTL development considerations

How commercially ready are the thermal biomass conversion routes? Overall the technologies in question are not mature; there is no commercial BTL (gasification and synthesis) biomass plant in operation. However, a number are in demonstration phase that will allow scale-up to commercial plant, as presented to the mission team. For example, Choren plans to link all of the BTL process steps together in a continuous plant. In addition, the syngas conditioning step is likely to benefit from future developments in coal conversion, which also produces a dirty raw syngas that needs significant clean-up before synthesis, in particular if a cobalt catalyst is used for the FT synthesis.

Access to FT technology may be an issue. Already Choren is linked with Shell, within its strategy of providing a whole technology package rather than individual technology blocks. Others may well follow a similar route.

Demonstration

Germany, in particular, has an impressive amount of demonstration work in progress, mainly based on modernising old German coal gasification technology and know-how. A summary of technologies at the demonstration stage presented to the mission team is shown in Exhibit 4.2.

Developmental

Other processes reviewed during the mission are at an earlier stage of commercialisation and have to be considered developmental. These have been tested on small scale units, sometimes in batch operation, but need proving on larger scale equipment in order to move towards commercialisation, in particular where novel reactor designs are involved. Developmental technologies presented to the mission team are summarised in Exhibit 4.3.

Technology	Company	Application	Comment
GSP entrained flow gasifier (Future Energy) (Note: GSP technology now owned by Siemens)	Sustec	Coal, wastes and biomass feed to syngas	Coal and biomass operation at Schwarze-Pumpe
Fast pyrolysis (rotating cone reactor)	BTG	Bio-oil production	2 t/h demonstration plant in Malaysia on palm oil residues; target market is power production due to low quality bio-oil; multiple small units planned
BTL (Carbo-V® gasification and Shell FT synthesis)	Choren	BTL process demonstration	Beta demonstration plant 13,000 t/y (~350 bbl/d) due to start 2007
Gasification and methanol synthesis (Lurgi fast pyrolysis/GSP gasification/Lurgi methanol)	FZK	Full chain testing, including bio-oil slurry feed to gasifier, and methanol production	2 MW demonstration plant (~4,000 t/y capacity) under construction; slurry feed to gasifier
NExBTL	Neste	Vegetable oil hydrogenation	Development unit under construction at Porvoo refinery; joint venture with Total in planning

Exhibit 4.2 *Process demonstration plants*

Technology	Company	Application	Comment
HTU and HDO (on biocrude from HTU)	TNO	Wet biomass (typical feed 25% wt biomass in water)	Pilot plant testing; potentially cheaper and more efficient than FT; based on old Shell technology
PyRos fast pyrolysis (cyclonic reactor	TNO	Bio-oil from biomass or wastes	Looking at FCC system for larger scale and adding zeolite to sand to help deoxygenation
Fast pyrolysis	VTT	Bio-oil production for power generation and refinery upgrading	20 kg/h pilot unit for biomass testing
Pressurised FB gasification (biosyngas)	VTT	Fuel flexible gasifier for biosyngas production	Pilot unit operated up to 20 bar pressure
VERENA (gasification of wet biomass)	FZK	Focus on lignocellulose (wood and grasses)	Pilot plant using supercritical water at very high pressure; high cost materials of construction
Methanol to gasoline (HTW gasifier + Lurgi MtSynfuel)	TUB-F	Biomass to gasoline	Looking to pilot at Total Leuna refinery

Exhibit 4.3 *Process plants under development*

More novel technology such as hydrothermal upgrading (HTU) will need larger scale demonstration to establish process and plant design. Hydrothermal deoxygenation (HDO) uses more conventional 'refinery based' process plant but needs significant catalyst development. Neste Oil technology is also a more refinery based process.

Overall, from the companies visited, there is an impressive amount of technology development under way in Europe, in particular based on modernising the old German coal technology. Development highlights presented to the mission team on various technologies and proposed commercial designs are summarised in Exhibit 4.4.

Company	Technology/topics covered	Process development highlights	Commercial-scale concept
VTT	Fast pyrolysis process to convert low value residue feedstocks	First phase: integrated thermal processing (ITP) for heat and power Second phase: biorefinery concept	10-20 MW_{th} biomass pyrolysis unit with bio-oil upgraded at biorefinery; claimed integrated efficiency of 80-90% may be optimistic
	Pressurised FB gasification (biosyngas) for a variety of applications	500 kW pilot unit operated up to 20 bar; new 30 bar unit under construction	200-300 MW_{th} FB gasifier (10 bar); fuel-flexible oxygen-based syngas plus FT synthesis for BTL, possibly integrated with manufacturing site, eg paper mills
Neste	NExBTL process (hydrogenation of vegetable oils and animal fats)	Building 170,000 t/y product unit at Porvoo Refinery; a joint venture (JV) with Total is in planning Hydrocracked products similar to FT diesel	Not raw biomass feed, but produces higher quality oil than first generation; Neste claims value where there is existing excess hydrogen production
ECN	BTL	Process design and economics for BTL plants Supply chain comparisons	Range of commercial plant sizes evaluated
	Biorefineries	Studies to meet ~150 million t/y (Europe 30% target by 2030)	Thermal biorefinery concept
	Microalgae, seaweed	Microalgae biomass production and concepts for onshore and offshore	Large scale seaweed production integrated with offshore wind farms and aquaculture in the North Sea
WUR	Biomass supply chain	System modelling for biomass supply chain (Biologics and Bioloco)	Supply chain options and optimisation
	Biorefineries	Chemicals production (adds more value) from biomass; small scale local preprocessing to retain functionality	Biomass for bulk chemicals production
	Microalgae	Biomass reactor development for increased algae production	Green cell factories – fatty acids and agricultural products
TNO	HTU (hydrothermal upgrading); technology developed and abandoned by Shell in early 1990s)	Wet feed (typical 25% wt biomass in water) to yield biocrude; pilot plant tests at 120-180 bar in multitubular reactor	Commercial plant size 130,000 t/y dry biomass feed; several HTU units will feed a central HDO plant
	HDO (Hydrothermal deoxygenation)	Some trials with Shell and Total; conventional hydroprocessing and hydrocracking	
	Fast pyrolysis PyRos	70% pyrolysis oil yield in cyclonic reactor design	Looking at FCC system for larger scale and adding zeolite to sand to help deoxygenation

Company	Technology/topics covered	Process development highlights	Commercial-scale concept
BTG	Fast pyrolysis	70% pyrolysis oil yield in rotating cone reactor design	Demonstration project in Malaysia on palm oil residues (50 t/d); multiple small units planned
Choren	BTL process (Carbo-V® gasification and Shell FT technology)	Beta demonstration plant 13,000 t/y (~350 bbl/d) product from 75,000 t/y biomass due to start mid 2007; oxygen gasification at 4 bar, FT at 30 bar	Gamma semi-commercial plant: 200,000 t/y FT diesel (~5,000 bbl/d); may be greenfield or brownfield site
Future Energy	GSP entrained flow gasifier (technology now owned by Siemens)	Pilot scale gasifier test facilities for feedstock testing and optimisation; bio-oil/char feed Demonstration unit at SVZ	GSP and MEGA-GSP; minimum 1,000 MW_{th} biomass feed
TUB-F	Methanol to gasoline (HTW gasifier + Lurgi MtSynfuel)	Looking to pilot at Total Leuna refinery	Commercial plant ~15,000 t/d methanol as energy carrier; fuel synthesis in refinery
	HP-POX (methanol based route)	With Lurgi, pilot plant (100 bar) to produce methanol directly; operated intermittently	
SVZ	Operating site for a number of gasifier technologies	Operating site with demonstration GSP entrained flow gasifiers (150 MW), a BGL slagging gasifier and seven Lurgi gasifiers processing a wide range of industrial wastes and biomass as pellets or briquettes; receives gate fee for waste feeds	Methanol (100,000 t/y) and power production since 1995; looking to add new conversion plant; gasification capacity is 85,000-175,000 t/y
FZK	TAMARA	Test facility for waste combustion system	Thermal waste treatment
	THERESA	Rotary kiln pyrolysis test unit, designed for MSW treatment, including flue gas cleaning	Thermal waste treatment
	Haloclean low temperature pyrolysis reactor	Rotary drum pyrolysis test unit; electrical waste (WEEE) initially; now biomass, mainly straw	Thermochemical conversion of straw
	Gasification and methanol synthesis	Tests using GSP pilot plant gasifier at Future Energy with slurry feed (biochar in bio-oil) from straw	Lurgi (LR) fast pyrolysis, GSP gasifier, Lurgi methanol demonstration plant planned (wood, straw biomass)
	VERENA pilot plant	Uses supercritical water at very high pressure	Gasification of wet biomass
Öko-Institut	Biomass energy strategies	Model and GEMIS model and database now integrates nearly all biomass flows in Germany and in the EU	Supply chain modelling

Exhibit 4.4 *Development highlights from mission*

4.4 Technical issues in BTL

Process efficiency is a key technical issue in developing BTL routes. In particular, thermal efficiency will determine overall net CO_2 emission reductions and a 'well-to-wheel' analysis is essential. In general, syngas-based routes to liquids are energy intensive and so have relatively low overall efficiencies. Some typical figures are shown in Exhibit 4.5.

Route	Typical efficiency (%)	
	Thermal	Carbon
GTL-FT	60-65	77-82
Methanol-DME	70	82
CTL	24	35

Exhibit 4.5 Typical process efficiencies for syngas routes

Choren claims an overall 45-55% efficiency for manufacture of diesel product will be possible in its Beta plant, depending on the operating method used. Maximum diesel mode requires some power input. Also, Choren avoids the reduction in efficiency that results from a local pyrolysis step followed by processing in a central plant. Data presented by ECN showed an overall 55% efficiency to FT liquids (note that a typical FT liquid (C_5+) product yield is 80%:20% diesel to naphtha by volume). Future Energy indicated an overall efficiency of ~20% biomass to fuel.

Biomass is a 'low density carbon' source, due to water and oxygen content in the feedstock, and also has a relatively low hydrogen content. By pretreating the biomass feed, carbon density is increased but carbon to hydrogen ratio is not improved. Pretreatment remains an area for further improvement.

As in CTL, the hydrogen to CO ratio in the syngas needs significant adjustment using the water gas shift reaction:

$$CO + H_2O \longrightarrow CO_2 + H_2$$

Choren appears to be adopting a different approach, in particular for its Beta plant, which is to add hydrogen from a separate plant. This is usually a very expensive option but may be justified for a small scale plant in order to reduce capital costs.

More developmental non-syngas routes should not be ignored as a potential means of improving overall process efficiency.

4.5 Catalysts

Successful implementation of a second generation biofuels project will rely heavily on the use of catalytic stages to accomplish several tasks. As has already been described, there are several different process routes being considered for production of second generation biofuels and these lead to different catalyst requirements.

If a fast pyrolysis process is used to produce a bio-oil then significant upgrading will be required to convert it to useful transport fuels. This may involve catalytic hydrotreating with reasonably conventional refinery hydroprocessing catalysts, or zeolite cracking (see Section 3.1.5). Or it may involve first a gasification stage to produce syngas.

If the biomass is converted to a synthesis gas stream, either by high temperature gasification with oxygen or conversion under milder conditions, the catalytic requirements are likely to be in three areas:

- Conditioning of the gas
- Removal of trace impurities
- Synthesis of products suitable for use as fuels

The exact combination of catalyst duties will depend on the chosen biomass feed, the thermal upgrading process employed and the chosen product.

4.5.1 Conditioning of the gas

The two most likely requirements for catalytic gas conditioning downstream of a biomass gasifier will be conversion of unreacted tars and adjustment of the $CO:CO_2$ ratio using the water gas shift reaction to achieve a suitable stoichiometry in the gas.

The process route recommended by VTT for biomass conversion involves relatively low temperature gasification and hence production of a gas with some unreacted tars. These tars can either be removed by filtering, scrubbing or by reaction over a catalyst to produce increased yield of synthesis gas. Although VTT has been investigating different catalyst options, these have met with some difficulties and a commercially viable solution may not yet have been realised.

Water gas shift catalysts are well proven commercially for driving the conversion of CO with water to produce hydrogen and CO_2. There are two types of water gas shift catalyst. The first of these is sour shift that is based on cobalt and molybdenum and operates in sour gas containing at least 300 ppm of H_2S. The sulphur is necessary to keep the catalyst in a sulphided form for maximum activity. The second type is so-called sweet shift that is widely used in synthesis gas plants based on steam reforming of sulphur-free hydrocarbons. Sweet shift catalysts are generally sensitive to sulphur and so careful sulphur removal is needed for these systems to operate effectively.

Most gasification applications that use shift reaction systems use sour shift catalyst because of the relatively high level of sulphur in the feedstock, which is normally coal, petroleum coke or asphalt. However, the level of sulphur in the syngas resulting from the gasification of most biomass feeds would not contain a high enough concentration of sulphur. Hence there is a choice to remove the residual sulphur (which is likely to be expensive) or to dope the gas with H_2S or some other sulphur compound.

4.5.2 Removal of trace impurities

Most synthesis catalysts, whether for FT or methanol synthesis, are relatively sensitive to trace impurities and so these must be removed from the gas:

- **Sulphur removal** – this can normally be done with simple fixed bed absorbents which effectively remove H_2S at a wide range of temperatures

- **COS conversion** – if the gas contains appreciable levels of carbonyl sulphide (COS) it may be necessary to convert this to H_2S using a hydrolysis catalyst prior to a bed of H_2S absorbent

- **Carbonyl removal** – some carbonyls may be formed in high temperature gasifiers and these can be removed on many high surface area absorbents

- **Halogen removal** – some biomass feeds may contain halogens which need to be removed; this can normally be done at a wide range of temperatures using activated alumina or mixed metal absorbents

4.5.3 Downstream synthesis

For most process schemes for BTL the expected synthesis technology is FT synthesis. The largest commercial operation producing FT liquids from gas derived via gasification is currently by Sasol in South Africa. This technology is well proven and, in the Sasol case, takes place over predominantly iron catalysts. In addition to the Sasol experience, several large GTL projects are currently under development or implementation, predominantly in the Middle East where gas is readily available at modest cost. These projects are generally being based around cobalt catalysis for the FT synthesis. The cobalt catalyst generally produces a narrower range of hydrocarbon products, but is considered to be more susceptible to poisoning than the older iron catalysts, and therefore more stringent upstream gas purification is required.

Both iron and cobalt catalyst systems for FT synthesis are considered to be commercially viable and hence no significant developments are needed to overcome issues that may be hindering the introduction of second generation biofuels.

As an alternative option, synthesis of methanol may be considered and the methanol either used as a chemical product or for further conversion to gasoline. Conversion of synthesis gas to methanol is well proven technology and developments are not needed to enhance implementation of biofuels.

The only plant operating at commercial scale that was visited as part of the mission was SVZ at Schwarze Pumpe. This plant is relatively complex as it uses three different types of gasification technology and its main product is methanol, although a significant proportion of the synthesis gas is used to generate power in a gas turbine. The feedstocks at SVZ are a mix of coal, sewage sludge and waste plastic. The catalyst systems used at SVZ are as follows:

- **Gas conditioning** – a single bed of sour shift catalyst is used to adjust the stoichiometry of the gas so it has the right balance of CO and CO_2 for methanol production. As the feedstock is rich in carbon there is an excess of CO_2 which is removed in a conventional wash system. The activity of the sour shift catalyst is high, and this would lead to excess conversion of CO to CO_2 and so a bypass is used to conveniently control the gas composition
- **Gas purification** – the wide mix of feeds leads to several different impurities in the final synthesis gas that would otherwise poison the downstream methanol catalyst, contaminate the final product or cause corrosion issues in the plant equipment. The purification system is operated downstream of the acid gas removal system which removes most of the CO_2 and H_2S from the synthesis gas. There are four purification catalysts and absorbents:
  - Carbon trap to remove carbonyls
  - Activated alumina to remove halogens (mainly HCl)
  - Precious metal hydrogenation and combustion catalyst to remove unsaturated hydrocarbons and some oxygen
  - Mixed metal sulphur guard to remove residual sulphur
- **Methanol synthesis** – after the gas conditioning and purification systems the synthesis gas is suitable for production of methanol and therefore there is a conventional methanol reactor using a standard copper/zinc catalyst

4.6 Risk sharing

The cost of developing second generation technologies is very high and extremely risky. One option, therefore, might be to form a consortium of stakeholders which would be helpful in reducing the individual cost and risk and might potentially accelerate development and give access to a greater spread of technologies. This should result in a higher probability that development of second generation biofuel technology will take place. However, it should be noted that traditionally this has not been the approach in developing process technology. New processes give commercial advantage and intellectual property rights (IPR), giving the inventors the ability to license the process and earn royalties.

4.7 Summary

Commercial BTL plants are some years away. Syngas from biomass and biomass pretreatment are areas that require larger scale process development. Biomass pretreatment for very diverse feed sources is a significant process challenge and there needs to be large scale demonstration and process integration for a wide range of potential feedstocks. Such developments are happening in Europe, in particular technology developments planned in Germany. FT synthesis designs should benefit from commercial developments in natural gas and coal based conversion to liquids. However, access to technology may be an issue for FT synthesis in future BTL projects. Other non-syngas routes should not be neglected and may provide overall improvements in process efficiency and cost if catalyst developments are successful. Risk sharing should be considered for biofuel implementation in the UK in order to accelerate development and give access to a greater spread of technologies.

5 IMPLICATIONS FOR ENGINE MANUFACTURERS

The internal combustion (IC) engine is probably most commonly associated with the cars and trucks seen on the roads every day, but its impact goes far beyond that. Diesel IC engines provide reliable power to the construction equipment used to build and maintain the UK's infrastructure, to the nation's farm machines and to many of the country's trains. Diesel engines also power stationary generators for stand-by and remote electrical supply. As well as providing reliable sources of power, the improvements in emissions both historically and as a result of upcoming legislation over the next decade mean that diesel and gasoline engines are increasingly low emission power providers.

5.1 The internal combustion engine's contribution to reducing CO_2 emissions

As work progresses on driving down NO_x and particulate emissions to 90% lower than today, attention is turning to reducing CO_2 emissions in response to concerns about GHGs. The CONCAWE/EUCAR/EC JRC well-to-wheel study (January 2004) showed that BTL diesel produced from plant matter yields well-to-wheel reductions in CO_2 emissions of up to 90%, which is comparable with the best possible hydrogen scenarios.

5.2 First generation biofuels

The existing, first generation, biofuels can be broadly divided into three groups:

- Biodiesel (fatty acid methyl ester (FAME)) from plant oils or animal fats
  – for diesel engines
- Bioethanol from starch or sugars
  – for petrol (gasoline) engines
- Biogas
  – for natural gas engines

Additionally there are those who advocate the use of unprocessed plant oils in diesel engines, although the available data shows that engine reliability is greatly diminished. There is as yet no standard for plant oil (eg rapeseed oil) as a transport fuel although the German Institute for Standardization (Deutsches Institut für Normung – DIN) is in the process of developing a standard for these oils.

FAME biodiesel (or first generation biodiesel), conforming to the relevant European Norm (EN) and American Society for Testing and Materials (ASTM) standards, can be burned in a standard diesel engine. Some material changes are required since biodiesel is known to impact negatively on natural and nitrile rubber polymers and some metals. Some diesel fuel system manufacturers use biodiesel compatible materials or provide option kits to make the fuel system compatible. However, the common position statement of the diesel fuel injection system manufacturers is still that they will only provide warranty for use with up to 5% biodiesel blends.

Apart from this need to change materials, the key engine related drawbacks that may be associated with FAME biodiesel use are:

- Power loss due to reduced calorific value (~8%-10% typically)
- Increased NOx emissions (~10% but dependent on the specific engine)
- Biodiesel has an increased tendency to oxidise compared to mineral oil diesel and can also biodegrade in storage; both of these degradation mechanisms of biodiesel in storage can result in engine failures

Another significant potential drawback with first generation biodiesel (FAME) is the potential for variability in product supplied to the market. The European standard for FAME biodiesel (EN14214) has done a lot to ensure that only good quality biodiesel is sold, but consistency remains an issue. Furthermore, because the exact properties of the end fuel can be affected by the choice of plant oil used as feedstock, this also contributes to variability in emissions, and performance remains an issue.

5.3 Second generation biofuels

By contrast, second generation biofuels relying on the BTL process should avoid the potential for variability due to feedstock choice and large numbers of small producers. This is because, as reported elsewhere in this document, the properties of the liquid fuel produced by FT synthesis are not affected by the biomass which is gasified at the beginning of the process. Furthermore, the need for large scale FT production facilities to ensure that BTL fuels can be produced economically means that, when full scale production commences, consistency of supply should be enhanced by virtue of production being located at a few large scale facilities.

BTL diesel also has similar stability to petroleum diesel and as a result will not be subject to the same problems of degradation in storage which afflicts FAME biodiesel currently. This means that no special handling requirements are needed, particularly for those customers who store their own fuel in bulk, or agricultural customers who may park a machine for several months at a time. The degradation to which FAME biodiesel is susceptible, if stored inadequately, may result in engine failures, particularly of fuel system components.

A benefit of the FT process is that it is possible to adjust the properties of the fuel produced and tailor it for particular characteristics. For example, diesel with a particular cetane number and/or evaporation curve could be produced. From the point of view of combustion in IC engines, the ability to produce fuels with properties tailored to different advanced combustion strategies is particularly beneficial.

5.4 Impact on conventional compression ignition (diesel) engines

A higher cetane number can be desirable for conventional diesel combustion since, in general, increasing cetane number results in improved autoignition and therefore reduces ignition delay with a consequent reduction in cylinder pressure rise rates and therefore reduction in NO_x formation. The same reduction in ignition delay has the effect of advancing ignition which results in increased NO_x and so these two effects may cancel each other out or tend towards one or the other depending on the engine in question.

Neste reported tests carried out by Scania on a heavy duty diesel truck engine showing that hydrotreated vegetable oil fuel (NExBTL in this case) resulted in decreased regulated emissions. Exhibit 5.1 shows the results reported compared to sulphur free EN590 petroleum diesel.

Emission	Measured reduction
NO_x	~18%
Particulates	~28%
Hydrocarbons	~22%
CO	~6%

Exhibit 5.1 *Decreased regulated emissions for hydrotreated vegetable oil fuel (NExBTL) compared to sulphur free EN590 petroleum diesel in a heavy duty diesel truck engine*

Choren, which produces BTL diesel at its pilot plant in Germany, report NO_x reductions of between 30% and 50% in light duty diesel engine tests by Volkswagen and DaimlerChrysler. Tests conducted at Argonne National Laboratory (ANL) on a Mercedes passenger car diesel engine and a Caterpillar single cylinder heavy duty diesel research engine showed NO_x reductions of up to 20% and particulate emission reductions of up to 50% for both engines.[7]

According to the analysis published in SAE paper 2005-01-3776 the BTL fuel produced by Choren (SunDiesel) has a cetane number of 80 and a lower boiling range than conventional US diesel (D2, ASTM D86). The cylinder pressure and heat release data presented in SAE 2005-01-3776 for the Caterpillar engine showed that there was no change in the ignition delay despite the difference in cetane number of the two fuels. SunDiesel's cetane number is 80 while D2 diesel has a cetane number of 47. The rate of heat release does change, with the peak heat release rate for SunDiesel being lower than for conventional diesel.

A final point worth noting about the BTL diesels described here is that the FT BTL diesel from Choren has a 3% higher energy content (lower heating value) than regular diesel while the NExBTL diesel was approximately the same. This is a distinct advantage for second generation diesel biofuels over FAME biodiesel which has about 10% lower energy content than conventional diesel. The fact that there should be no loss in power associated with switching to second generation diesel biofuels will be of benefit to end users.

5.5 Impact on compression ignition strategies for future emission standards

As mentioned above, researchers are investigating a number of strategies for meeting future heavy duty diesel NO_x emission standards. These bodies of research can be broadly divided into two categories:

- Conventional diesel combustion with after-treatment strategies such as Urea SCR (selective catalytic reduction), NO_x traps etc

- Advanced combustion strategies, such as homogeneous charge compression ignition (HCCI) with minimum after-treatment

By using an after-treatment device such as a urea SCR system it is possible to reduce the NO_x emitted at the exhaust exit. As with most real world situations, no after-treatment device will be 100% efficient. This means that advances are still required in combustion strategies to reduce engine-out emissions to a suitable level so that the particular after-treatment system chosen is able to reduce the NO_x emissions to the required level. The BTL fuels currently available have been demonstrated to reduce regulated emissions from conventional diesel combustion engines.

7 Ng *et al*, SAE 2005-01-3776

There may be further benefits to be gained from using the FT process to tailor the fuel still further.

By comparison, the principle behind advanced combustion strategies such as HCCI is to reduce engine-out emissions and avoid the need for NO_x removal after-treatment devices. HCCI combustion keeps in-cylinder NO_x formation to a minimum by avoiding the high temperature flame which is normally found in diesel combustion. This 'cool' combustion avoids the high temperature flame where NO_x is formed in conventional diesel combustion. The evidence published so far is mixed. Some research indicates that for HCCI combustion, fuel with lower cetane than conventional diesel is desirable in order to control the combustion. Other research has indicated that a higher cetane helps certain regimes of HCCI combustion.

5.6 Quantifying impact of new fuels

It is important for engine producers that BTL fuels are made available for testing in their engines at an early stage so that the impact of these new fuels can be quantified as soon as possible. The exact changes in emissions and performance with a new fuel may differ from one model of engine to another and so it may be necessary to assess BTL fuel performance on a wide range of engine platforms.

The fuel injection equipment such as pumps and injectors will be particularly susceptible to changes in fuel properties. From this point of view, the ideal scenario would be that any new fuel would not necessitate changes to fuel system components.

Based on the experience of first generation biofuels it is likely that the proportion of new fuels in the market as a percentage of the total fuel used will increase gradually over a period of time. If the second generation biofuels are uniformly blended into the national supply then the proportion of fuel entering a given engine will not be significant initially. In some instances though, local legislation or tax structures might make fuel blends with significant proportions of biofuel (>20%) desirable. Such legislation is already in place in some countries. Examples of this are:

- USA – diesel with 20% biodiesel (FAME) blended in (B20) qualifies as an alternative fuel for federal, state and public utility fleets that have targets for alternative fuel usage

- Germany – where tax incentives have meant that the pump price of biodiesel is lower than petroleum diesel, commercial operators were quick to demand biodiesel compatibility from the engines they use

With BTL fuels, the closer their similarity to conventional diesel from the point of view of chemical structure and energy content, any demand for high proportion second generation biofuel blends should pose fewer of the kind of problems outlined for FAME biodiesel previously.

6 FEEDSTOCK AND A SUSTAINABLE SUPPLY CHAIN

6.1 Introduction

Feedstock supply and logistics for the production of second generation transport biofuels is a vital component in the success of achieving the EU Biofuel Directive's guideline of 5.75% by 2010. The technologies seen in this mission have focused on the development of wastes and residues as the main feedstock, with some use of imported oils and indigenous forestry. Initially these technologies have been implemented using a feedstock that is readily available in sufficient quantities, such as industrial wastes and agricultural by-products. Future development will allow the supply to be refined and improved and to include dedicated, high yielding energy crops when demand increases.

6.2 Feedstock potential

The Biomass Task Force reported that 20 million t of biomass produced in the UK could be available to the energy sector. This biomass will come from wastes and crops not necessarily suitable for second generation transport fuel production, and selection of the most economic and suitable feedstock must be considered.

The Öko-Institut highlights a number of constraints in place which will affect feedstock production in Germany. It envisages that environmental restrictions will limit feedstock quantities. Biomass production will become a sustainable farming system, less intensive than food production, and more land will be taken for nature protection (biodiversity, and soil protection). Thirty per cent of organic farming will remain until 2030 and there will be no conversion of wetlands or extensive grassland into arable land. However, land will become available after the reforms of the EU sugar market have been implemented.

Land in the Netherlands is currently considered too valuable to produce indigenous energy crops and the government foresees that any dedicated crop feedstock will be imported.

Estimates of the quantities of feedstock available for renewable transport fuels (RTFs) are varied but it is considered that the EU will need all of the available biomass to make a significant difference in CO_2 reductions through the use of biofuel.

6.3 Available feedstocks

Selection of feedstock varied greatly between the countries visited by the mission, although choice within countries was more defined. Woodfuels were the preferred feedstock in Finland owing to the high level of forestry cover across the country. However, imported and indigenous oils were used for the production of NExBTL.

In the Netherlands, feedstocks were derived from imported wood products and waste, with some work being carried out on the more novel crops such as marine algae. It is considered that Germany envisages that the majority of the feedstock used for RTF production will be 'home grown', therefore the greatest variety of material selected for conversion processes was seen here. There was some development of dedicated energy crops such as short rotation coppice (SRC) and miscanthus in Germany but this was seen as the future rather than the current position.

6.3.1 Industrial waste

Industrial waste represents a vast, mostly untapped, resource of biomass feedstock for biofuels production. A wide range of biomass residues and waste materials are produced from a diverse spectrum of industries including the construction, food, medical, brewing and paper sectors.

In the UK this resource (municipal solid waste (MSW) and industrial wood waste) has been estimated by the Waste and Resources Action Programme (WRAP) to be of the order of 10 million t/y, and alternative outlets for these streams are needed to divert material away from landfill sites.

The combustion of refuse derived fuel (RDF), the high calorific element separated from MSW, is an established strategy for waste to energy in some EU member states. The use of RDF in the UK is limited due to concerns over flue emissions, public perception and the constraints of the waste incineration directive (WID).

The use of industrial wastes as feedstocks for second generation biofuels technology presents an alternative and valuable market for these feedstocks. Indeed, the use of MSW as a fermentation feedstock for the production of ethanol is close to being commercial; Loso Noco has recently announced its intention to build a large ethanol facility in the UK utilising this feedstock.

Improved pyrolysis and gasification technologies for the production of second generation biofuels being developed by the groups visited during this mission offer robust and flexible routes to process a wide variety of industrial wastes. The facility at Schwarze Pumpe in Germany gasifies industrial waste feedstocks to produce methanol, a potential feedstock for gasoline or diesel (MOGD process). Industrial waste streams considered for gasification and pyrolysis processes include MSW, debarking waste, sawdust, waste wood chips, paper mill residue, black liquor and spent grains from brewing. In the USA and Sweden considerable activity is being directed towards the pulp mill biorefinery concept whereby black liquor gasification technology and subsequent biofuels production is integrated within existing pulp mill operations.

6.3.2 Agricultural and forestry residues

The agricultural and forestry industries produce high levels of residue that can be used for RTF production. These feedstocks could be made available in the quantities required and, in some cases, already have a well developed supply chain. Agriculturally the amount of energy available from biomass by-products and dedicated crops is currently very similar, with the exception of oil-based feedstocks. This allows for the development of new technologies to first utilise these readily available residue products and then to introduce more refined dedicated crops when the industry becomes more established. This could reduce the problem of the 'chicken and egg' situation that has been currently holding up the biomass energy industry. However, some residues are currently being utilised for animal production and nature protection, and use of these 'wastes' will create a gap within the agricultural sector and environment.

6.3.2.1 Straw

Straw is a by-product of the production of arable crops such as wheat, barley, oats and rape. The UK currently produces 16 Mt/y of straw, 40% of which is chopped and returned to the soil. These crops require high fertiliser and pesticide inputs and need annual harvesting and establishment. However, they have a well developed market and established infrastructure which will allow the supply of an energy feedstock to run alongside an existing food market.

Most arable crops will yield up to 8 t/ha of straw which will require little drying for any of the technologies seen on the mission (moisture content <15%). However, it does contain a high level of corrosive elements such as potassium, chloride and silica. Gasification technologies using straw are highly likely to suffer expensive maintenance costs, and the waste materials such as ash will be heavily contaminated.

6.3.2.2 Woodfuel

The UK has the potential to supply 10 Mt of woodfuel from forestry waste.[8] The majority of the feedstock would come from forestry and woodland with 10% coming from processing products. This figure does not include use of recycled wood (solid recovered fuel – SRF), and WRAP estimates that there is up to another 10 Mt of wood waste available in the UK annually. Suitability of this waste relies heavy on the end product, and not all of the material would be used for RTF production. In some of the technologies seen on this mission, selection of wood has been an important influence on the quality and yield of desired product. Bio-oil yields at VTT were significantly reduced when the type of forest residue feedstock was altered.

Choren has selected woodfuel as the primary feedstock used in its Beta plant. These residues alongside SRF and straw will provide the plant with 75,000 t/y and will produce 18.5 million litres of Sunfuel. At its proposed Gamma plants, Choren envisages that the wood feedstock will come from a 30 km radius around the plants, and that each will be using 1 million t/y of biomass.

VTT has calculated that 6-10 Mtoe/y of biofuels could be produced from European forest residues, and considers wood residues to be the primary feedstock for energy production in Finland.

6.3.2.3 Wet agricultural residues

Disposal of agricultural wet residues has always presented problems. The costs of transportation to disposal sites are high due to increased weight of the biomass from high moisture content (MC). Any technology that could use these feedstocks as an energy resource must be highlighted. However, these technologies need to be relatively small to limit the need for feedstock transportation. These wet wastes can amount to 4,000 Mt/y (dry basis) globally and 200 Mt/y (dry basis) within the EU.[9] However, these figures include peat as a feedstock which may not be considered as a renewable fuel.

8 www.woodfuelresource.org.uk

9 TNO

At TNO, the development of hydrothermal upgrading (HTU) has enabled wet agricultural residues such as sugar beet pulp and onion pulp to be introduced as a feasible feedstock. These problematic feedstocks are also being addressed at FZK in Germany, where the use of supercritical water on wet agricultural wastes is being developed. At its pilot plant VERENA, silaged corn (maize) residues are being used with 70% MC.

In the UK, 3 Mt of animal slurries and manures are generated annually and these technologies could help utilise this waste. Also in the UK, one of the problems currently being addressed is the removal of the wet pulp produced during sugar beet ethanol conversion. The wet feedstock based technologies could not only utilise this wet residue but could increase the proportion of the crop used for energy production. This in turn would increase the carbon efficiency of the crop and improve the profitability.

6.3.3 Dedicated energy crops

The competition for land for energy production, including transport fuels, is strong and will increase in future years. The use of available land for feedstock production must utilise high biomass yielding crops.

6.3.3.1 Perennial grasses

Maximising the biomass production of the land area in the UK will require high yielding crops with minimal inputs. Miscanthus *(Miscanthus giganteus)* and switchgrass *(Panicum virgatum)* are the C-4 perennial grasses being considered in the UK as potential energy crops. By utilising the C-4 metabolic pathway, the crop requires very little fertiliser input and uses water more efficiently. This in turn means that the crop can produce high yields of biomass more economically and with lower carbon inputs than arable crops.

Exhibit 6.1 *Miscanthus*

Miscanthus and switchgrass are perennial grasses that once established can be harvested annually and have a lifetime in excess of 20 years. Research has shown that miscanthus can reach yields of over 15 t/ha in the UK without the need for nitrogen fertiliser and can maintain these yields consistently for over 13 years. In the UK, miscanthus is a commercially available option for feedstock supply and has been successfully established on 10,000 ha across the UK.

6.3.3.2 Short rotation coppice (SRC)

SRC in the UK mainly consists of willow *(Salix spp)*, with production of poplar SRC *(Populus spp)* currently being developed. These native tree species are relatively high yielding and require low levels of fertiliser. The agronomic knowledge of the crop is well established and an extensive breeding programme has been developed for willow. Current published willow SRC commercial yields are 7 t/ha (dry basis); however, these original plantations were grown on poor soils and a more realistic mean yield would be around 9-10 t/ha (dry basis). SRC has a high MC (50%) at harvest, and the crop will require drying during the preprocessing stage.

Willow SRC is commercially available, with well developed production chains. Currently ~5,000 ha of SRC willow has been planted in the UK, with a further 50,000 ha of planting contracts for miscanthus and SRC being offered in the next five years.

Parameter	SRC poplar *(Populus spp)*	SRC willow *(Salix spp)*	Miscanthus *(Miscanthus giganteus)*	Switchgrass *(Panicum virgatum)*	Reed canary grass *(Phalaris arundinacea)*
Current typical yield (t/ha dry matter)	7[a]	7[a]	12	10	8
Establishment time (y)	3+	3+	3+	2-3+	1-2
Pesticide requirements	Low	Low	Low	Low	Very low
Fertiliser requirements	Low/medium	Low/medium	Low	Very low	Medium
Agronomic knowledge	Good	Good	Reasonable	Low	Low
Establishment costs	High	High	Very high	Very low	Very low
Pest/disease problems	?	Beetle Rust	None serious	None serious	Possible insect pest problems
Plantation longevity (y)	20+	20+	20+ ?	20+ ??	10+ ??
Other issues	Resistant to lodging	Resistant to lodging	Resistant to lodging		

a SRC poplar and willow yields are estimates from farmers' willow fields and represent the fact that many crops are grown on low grade land; plot yields are greater (~10 t/ha dry matter)

Ref: Powlson DS, Riche AB and Shield I, *Biofuels and other approaches for decreasing fossil fuel emissions from agriculture*, Annals of Applied Biology 146(2):193-201 (2005): www.blackwell-synergy.com/links/doi/10.1111/j.1744-7348.2005.040056.x/abs

Exhibit 6.2 *Summary of information currently available on biomass crops in use or being researched in the UK*

In 2000, the UK Government had the foresight to see the need to develop dedicated biomass production in the UK to run alongside developing renewable technologies, and implemented an establishment grant for miscanthus and SRC. Four years later this development aid was increased further with the implementation of the Bioenergy Infrastructure Scheme that enabled the development of biomass crop supply chains. These schemes, together with the CAP reform payment (€45/ha ≈ £31/ha), have allowed the UK to become a market leader in the production of dedicated 'woody' biomass crops in Europe.

In Germany these crops are viewed as an important contributor of biomass in the future years. Choren has set up a company – Choren Biomass GmbH – dedicated to the development of energy crops such as miscanthus, SRC and switchgrass. The Öko-Institut will be proposing incentives for SRC development to the German Government in 2007, and foresees that the production of dedicated crops will be a vital component of the biomass supply chain.

6.3.3.3 Oil palm co-products

Unfortunately, conflicting pressures on land use in countries such as Indonesia have led to the association of palm oil with tropical rainforest destruction. Recently, the Roundtable on Sustainable Palm Oil (RSPO) was formed to draw together key stakeholders globally and agree environmental standards of production. Millions of hectares of land are available for expansion without the need for deforestation, and hardier varieties of oil palm are now also available, enabling production in areas where there is no competition with rain forest.

Within these parameters, the oil palm holds good potential for use as a multipurpose energy crop, spanning first and second generation biofuel production. Originating from tropical West Africa, it is most successful in areas within 10 degrees of the equator. Mature oil palms produce 20 t/ha/y of fruit bunches, 4 t of which is vegetable oil. This is four times the yield of oilseed rape grown in the EU. Oil palm is the highest yielding conventional crop in the world, in addition to which it produces palm kernel oil for oleochemicals and significant biomass that can be used for fuel production via second generation technologies.

BTG is working with a palm oil company in Malaysia to produce pyrolysis oil from the empty fruit bunches after the oil bearing fruit have been extracted. Their fibrous nature has caused some technical difficulties which the group is working to overcome. BTG is hoping in future to use discarded palm leaves in the same process, although other studies have shown these to be suitable for animal feed as an alternative.

In general, empty fruit bunches are currently stacked and composted to form a soil improving mulch around the base of oil palms, especially in parts of the plantation that have poorer soils. It is therefore important that alternative uses take into consideration the need for recycling of nutrients and organic matter in the production systems.

Because oil palm is a tree crop, it does not require the same intensity of cultivation as annual oilseed crops such as oilseed rape or soya beans. It is thus less energy and CO_2 intensive. According to Neste, its production results in less than half the CO_2 emissions of soya oil and less than a fifth of those of oilseed rape (see Exhibit 6.3), and it is a viable feedstock for its hydrogenation process. Palm oil sells at the equivalent of around $30-40/bbl (~£17-23/bbl), making it cheaper than crude oil at current world market prices.

6.3.3.4 Microalgae

Microalgae are tiny, sometimes single celled, aquatic plants that can often be found in seas, rivers, lakes and waterways. They thrive in water that is rich in nutrients, especially nitrogen, and can multiply rapidly, turning the water green.

In warm regions of the world they are cultivated commercially, often in raceway ponds with CO_2 injection to enable rapid, intensive growth. They are mostly used for nutraceuticals. For example, *Spirulina* is raised in this way and processed to make health tablets as dietary supplements.

Microalgae are potentially the most productive plants on earth, with very high photosynthetic efficiencies. Research has been undertaken, notably in the USA and Japan, to try to harness this for bioenergy production. Environmentally, this would have several distinct advantages over conventional biofuel feedstocks:

- They have productivities an order of magnitude higher than many conventional crops, enabling large amounts of fuel to be produced from a small area
- They do not require soil, which means that they can be grown in areas unsuitable for conventional agriculture

	Fossil diesel	NExBTL				RME
Raw material	Crude oil	Rapeseed oil	Palm oil	Soya oil	Animal fat	Rapeseed oil
Production		1.3	0.25	0.54	0.28	1.3
Transport		0.005	0.18	0.09	0.033	
Processing/ refining		0.2	0.2	0.2	0.2	
End use	3.2	0	0	0	0	0
TOTAL	**3.8**	**1.51**	**0.45**	**0.83**	**0.51**	**1.6-2.3**

Exhibit 6.3 *NExBTL CO_2 emission comparisons in kg CO_2 equiv/kgoe*

- There are varieties that can grow in seawater, which avoids conflicts with agriculture for precious freshwater resources; growth ponds could be constructed in coastal desert regions, using their abundant land, sunshine and seawater to produce clean, renewable biofuels

Production of methane, hydrogen, biodiesel and second generation biofuels from microalgae have all been considered. However, challenges remain with making it economical. ECN and WUR both estimated costs of around €2,000/t (~£1,400/t) dry weight, which is based on a simple, but standard production system. This is an order of magnitude too high for economical, stand-alone fuel production, which would require much cheaper production systems combined with consistently high productivities. Such systems have been designed, but further research and demonstration projects are needed in this area.

In the meantime, production of microalgae can be made more economical by using them to treat waste water. This is already being done commercially in warmer regions, such as California, where the algae convert the sunlight into bioenergy whilst absorbing the nutrients and oxygenating the waste water. By combining bioenergy production with water treatment and reuse, the economics are improved considerably. Fewer inputs are required (nutrients, CO_2) and the value of the outputs is increased. As the 'bio-economy' expands, there could be increasing opportunities for microalgae in waste water treatment as part of an integrated solution to biofuel production.

6.4 Supply chains

During this mission there was very little opportunity to investigate supply chains in depth. Demand for feedstock is currently quite low and feedstock is sourced either locally or imported using the established animal feed market. As demand increases,

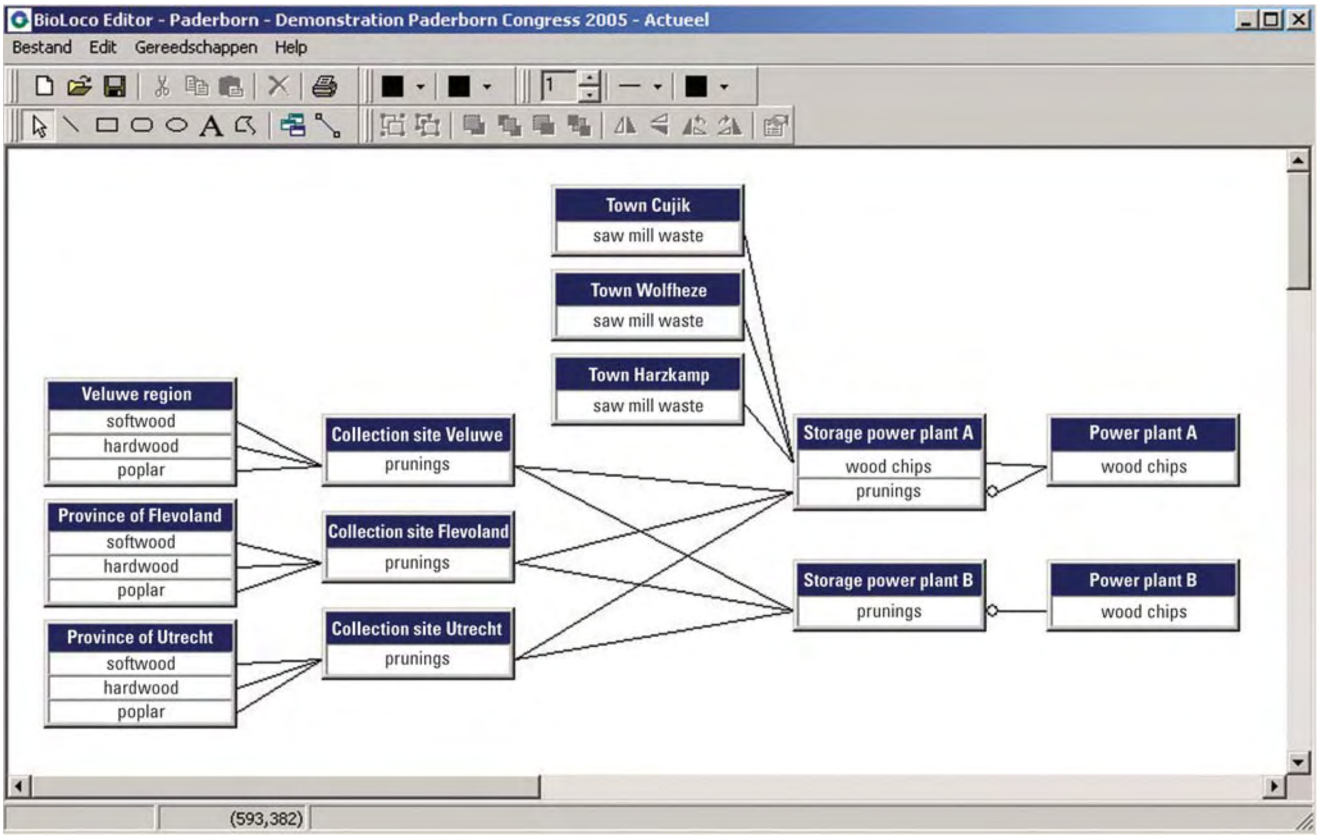

Exhibit 6.4 Screenshot of the Bioloco program (courtesy of WUR)

supply chains and biomass markets must be developed globally and within the EU.

Analysis of future potential supply chains has been carried out at WUR. Dr Bert Annevelink has developed an integrated framework to assess spatial and related implications of biomass delivery chains. The problem he identified was how the large global supply of biomass can be made available for biofuel conversion. He has broken down the biomass delivery chain into three links: biomass sources, logistics and storage, and biofuel production. He has identified the spatial impacts of each aspect of the delivery chain and has identified the technical and social interactions that are affected by the chain. Using the information collected concerning these three stages he has developed a biomass chain model, Bioloco. This model will suggest an optimum biomass chain based on a chosen optimisation criterion, financial or energetic, or to meet preset goals for each.

6.4.1 Biomass sources

Current feedstock selection is based on feedstock supply and availability. Future refinement and competition for individual feedstocks will mean that each technology will begin to select for different quality traits. Identification of these traits is being investigated by most of the institutes visited.

Information on the quality traits identified must be made available to feedstock producers. This link can benefit producers as well as the biofuel technologies. During this mission there were no visible links between feedstock producers and conversion technologies. The producers may be able to manipulate the feedstock to enhance a desirable characteristic or to reduce negative traits. This link must be established to increase the efficiency of a supply chain. In the UK, this knowledge transfer gap is being brought together with the SUPERGEN Biomass and Bioenergy Consortium. Funded by the Engineering and Physical Sciences Research Council (EPSRC), this consortium provides not only academic links between the two research areas but is aided and advised by industrial partners from both ends of the chain.

Physical properties of the feedstock are becoming an important characteristic in supply selection. Feed intake systems in most technologies are a major consideration when choosing a material. Feed blockages account for the majority of down time for most commercial plants.

Selection of feedstock on compositional quality has been made easier by the development of a feedstock biomass and waste composition database, Phyllis, hosted by ECN. This database contains information on ultimate and proximate analysis of over 60 different feedstock materials. This can be used as an important screening service to select feedstock suitable for conversion technologies.

6.4.2 Logistics and storage

The widespread implementation of second generation biofuels production technology will require the development of highly integrated and efficient biomass supply infrastructure to ensure secure delivery of competitively priced feedstocks to large pyrolysis and gasification facilities. In addition, this biomass supply chain must function at minimum energy inputs and environmental impacts. Feedstock supply chains are well established for both fossil transport fuel and first generation biofuel production, the latter exploiting established infrastructure for food supply. However, the development of efficient biomass supply chains presents a number of unique challenges:

- Low bulk and energy density of solid biomass
- High moisture content of biomass

- Physical and compositional heterogeniety
- Antiquated and innefficient harvesting techniques
- Seasonal variations in biomass supply
- Constraints on transportation distances for indigenous biomass feedstocks

To address these barriers, more R&D work is necessary to develop improved harvesting, drying and densification (baling, chipping, pelleting etc) technologies. The unoptimised nature of current biomass supply chains may constrain the scale of biofuel production plants such that they are economically disadvantaged against larger facilities that enjoy greater economies of scale. Choren has stated that its first full scale BTL biodiesel plant (200,000 t/y of diesel), planned for 2009/10, will require 1 million t/y of biomass feedstock, which will be sourced within a 30 km radius of the plant. The majority of the feedstock is likely to be based on forestry and agricultural residues. The output of this plant is relatively small compared to GTL plants in construction utilising natural gas feedstock.

A number of technologies in development, observed during this mission, are addressing these key barriers described above. ECN is developing torrefaction biomass pretreatment methodologies for densifying biomass and wood pellets prior to feeding into gasification processes. This torrefaction process, a mild thermal treatment, not only increases biomass pellet energy density, but also reduces the tendency of the material to absorb moisture from the atmosphere and improves its grindability and its fluidisation properties.

The various pyrolysis technologies observed during the mission could ultimately help to address existing biomass logistics issues by transforming solid material into pumpable, energy dense and easily transportable liquid. Such conversion technologies could be operated at satellite centres close to feedstock sources, eg forestry operations, for distribution of bio-oil to large centralised gasification facilities.

6.5 Summary

The use of residues as a feedstock for second generation transport fuels has been identified and exploited throughout the countries visited during this mission. Dedicated biomass crops are not currently widely being investigated. Development of these crops will be a vital issue in future years when feedstock composition and refinement is established. New technologies that utilise wet feedstock will be advantageous to enable the disposal of wet residues; however, it must be stressed that these technologies are in the development stage and may take some time to reach commercial status.

Global markets must be introduced for dedicated biomass crops to allow us to exploit more suitable climates and soils for increased biomass production. Exploitation of available land in the UK will require dedicated energy crops to increase in their land area and research into the development of these crops must continue.

7 ENVIRONMENTAL IMPACTS

7.1 Background

Amongst renewable energy sources, biofuels have a unique role to play, being the only direct substitute for fossil oil based fuels. Their popularity is growing rapidly due to factors such as increasing oil prices and concerns over future security of supplies. However, in the EU it is the environmental benefits that are most often cited as the key driver. Therefore, this chapter will examine the environmental implications of increased biofuel production as they relate to CO_2 emissions and the key resources of air, land and water. This is a complex subject, with limited scope in this report to do little more than raise general issues and make broad contrasts between first and second generation biofuel production.

7.2 CO_2 emissions

Modern agricultural methods have been developed for maximum food production rather than overall energy efficiency. Large amounts of energy are required for powering machinery and for artificial fertiliser production; less is required for perennial crops or trees that can be used as feedstocks for second generation biofuels and so the CO_2 benefits are generally better. If residues are used as feedstocks, the carbon and energy balances are even more favourable. This is made clear in Exhibit 7.1, which compares well-to-wheel CO_2 emissions from

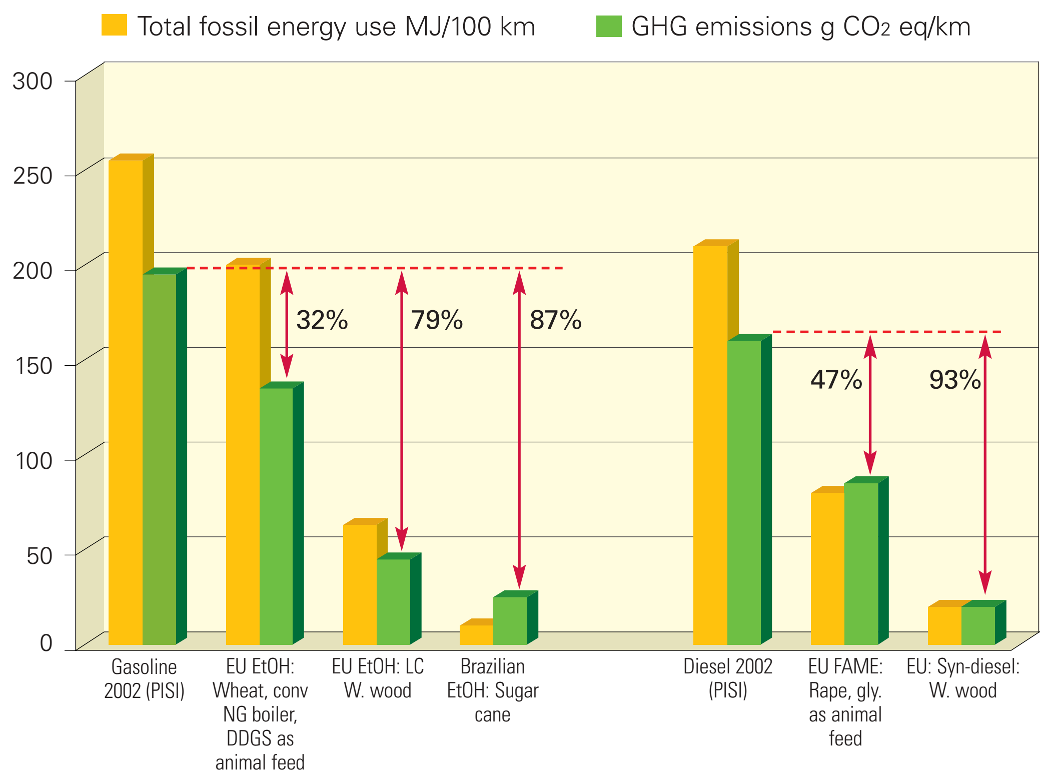

Exhibit 7.1 *Well-to-wheel energy content and GHG emission analysis*

various fuels with synthetic diesel from waste wood shown on the right hand side.

Since artificial nitrogen fertilisers are generally produced from natural gas, with the release of the substituted carbon, it is important to consider how nitrogen may be recycled in order to minimise CO_2 emissions. In thermal processes such as synthetic diesel production, most nutrients can be recycled by returning the ash to the soil, but nitrogen is often lost as gas. Avoiding this through nitrogen recovery would improve the energy balance and help to reduce overall GHG emissions.

Transportation of feedstocks and fuels is another important consideration and in this area there is an environmental trade-off between biodiversity and transport distances. For gasification and FT plants, economies of scale are significant so they require large amounts of biomass. For example, Choren is proposing plants that require 1 million t/y of biomass. It expects to derive all necessary feedstock from within 30 km of the plant using forestry residues. This would require an average biomass yield of around 3.5 t/ha/y from the whole area. High output energy crops can give significantly higher biomass output per ha and this could be used to reduce transportation distances. There is the potential for this to lead to loss of biodiversity, however.

Transportation by ship is much more energy efficient than by land, but the fundamental problem remains: woody plant matter is bulky and not very energy dense. Therefore, intermediate processes were considered that would increase the energy density prior to shipping. Pelletising wood is one currently used method for doing this. Torrefaction, developed by ECN, has a similar effect, creating a dried, smokeless fuel with similar mechanical properties to coal, making grinding far easier. The two processes can be combined to create torrefied pellets. Another potential technology is pyrolysis, which produces bio-oil, and methanol was also suggested as a suitable intermediate step. These more concentrated fuels have a lower

		Costs 2010	2020	Jobs	CO_2-equiv	SO_2-equiv
	Person transport	€cent/kWh$_{input}$		person/TWh$_{input}$	g/kWh$_{input}$	
Diesel car	**Fossil diesel with tax**	9.9	10.8	8.8	325.9	0.5
	Fossil diesel without tax	3.5	4.0			
	Rapeseed oil – DE, with credit	4.1	4.9	306	150.8	1.1
	RME – DE, no credit	8.0	8.5	342	174.9	1.2
	RME – DE, with credit	7.7	8.2	314	65.4	1.0
	RME – PL, no credit	7.6	8.2	537	188.8	1.2
	RME – PL, with credit	7.3	7.9	508	78.7	1.0
	BTL-wood-residue – DE	5.3	5.1	153	-131.2	0.6
	BTL-wood-SRF – DE	8.8	8.9	1757	-99.7	0.8
	BTL-wood-SRF – PL	4.1	5.2	–	-222.4	-0.6
Petrol car	**Fossil gasoline with tax**	13.0	14.2	9.1	342.8	0.5
	Fossil gasoline without tax	5.2	5.7			
	BioEtOH wheat – DE	7.2	7.8	217	197.3	0.7
	BioEtOH wheat – DE organic	9.5	10.2	518	130.4	0.2
	BioEtOH sugarbeet – DE	11.9	12.7	253	229.6	0.9
	BioEtOH wheat – PL	3.3	3.4	–	219.4	0.8
	BioEtOH sugar cane – BR	3.4	3.4	67	107.9	1.0
	Biogas (maize)	6.9	6.7	220	87.1	0.6
	Biogas (maize-organic)	8.8	8.7	360	71.1	0.4
	Biogas (double-cropping)	4.0	3.8	1870	88.8	0.5

***Exhibit 7.2** Typical outputs from Öko-Institut model (DE = Germany; PL = Poland; BR = Brazil; SRF = short rotation forestry) (courtesy of Öko-Institut)*

environmental impact from transportation and would then be taken to a centralised gasifier and FT plant for synthetic biofuel production.

Research is being undertaken internationally into the use of pyrolysis to extract energy from woody matter, whilst leaving behind a carbon rich biochar which can be safely stored in soil for hundreds of years.[10] Many of the world's soils have lost carbon and this replenishment actually improves their fertility, increasing biomass production and yields. Thus, second generation biofuels can theoretically be produced with additional carbon storage, making them 'carbon negative'.

Research undertaken at the Öko-Institut examined the carbon and employment benefits that could arise from different biofuel options in both diesel and gasoline substitution. The synthetic diesel option gave the greatest CO_2 savings, producing a negative figure due to carbon savings from electricity co-generation.

Thus second generation biofuel technologies have considerable potential for reducing greenhouse gas emissions from transportation. Since this is an important reason for adopting biofuel usage, it should be taken into consideration when tax incentives are set, rewarding lower carbon emissions rather than just giving a standard biofuel rebate per litre (see Chapter 9).

7.3 Other air pollutants

In addition to greater CO_2 reductions, second generation biofuels can offer solutions for improving local air quality owing to their cleaner burning properties. This topic is covered in greater detail in Chapter 5.

7.4 Land

To replace oil with first generation biofuels would require vast areas of land – roughly all of the world's crop land – to be dedicated to the task. There is disagreement over the amount of land remaining that could be converted for crop production, but even if large areas were available, the impacts of doing so would be considerable for the environment and biodiversity. Existing productive land is being lost internationally as a result of degradation and desertification and this encroachment is increasing rapidly. For example, the UN predicts that in 19 years' time, two thirds of Africa's crop lands will have become desert. Furthermore, as a result of population growth and increasing affluence, worldwide consumption of food is expected to have doubled from today's levels by 2050, and energy demand is expected to double or triple over the same period.

Clearly there are major challenges and, using first generation technologies alone, the scope for large scale biofuel production will be limited in the long term by land availability. There is justifiable concern that future biofuel production should be achieved with minimal impacts on food production and the environment.

As a result there is already interest in first generation crops that can be grown on unproductive land unsuitable for food crops. For example, Jatropha is a tough shrub being planted extensively in arid areas as a defence against spreading deserts. Its roots help prevent soil erosion and the fruit seeds contain vegetable oils with potential as a biodiesel feedstock.

Second generation technologies open up further possibilities in the UK and abroad:

- **Inedible agricultural residues, such as wheat straw, can be converted to fuel,** whilst the edible part is still used for human consumption. However, consideration must be given to the current uses of these residues (eg for animal feed or soil

10 Lehmann J, Gaunt J and Rondon M (2005), *Bio-char sequestration in terrestrial ecosystems – a review: mitigation and adaptation strategies for global change*

improvement) and the environmental implications of diverting them for bioenergy

- **Whole trees can be used as feedstock,** irrespective of variety. Trees can be grown on land too steep for cultivation or otherwise unsuitable for arable crops; because the whole biomass can be used, greater fuel outputs are possible per ha compared with purely first generation technologies, which only use a portion of the plant

The production of second generation biofuels and the impacts on the landscape and the environment is the subject of ongoing research. In the European context, perennial grasses such as miscanthus or short rotation coppice (SRC) willow are popular options already being developed for heat and power generation. Studies have shown them to be useful wildlife habitats, although they may impact the visual appearance of a landscape due to their height. Vast tracts of tall growing monocultures planted to feed large dedicated biofuel plants may cause controversy in sensitive rural areas, and additional traffic volumes resulting from the transportation of the biomass to the processing plants would also need to be considered.

Although there are high potential, carbon and energy efficient species selected for their suitability as energy crops there may also be exciting scope for multipurpose, sustainable forestry to be practised on a large scale with significant environmental benefits. Because second generation technologies are not exacting with respect to feedstock requirements, a wide variety of trees may be grown as mixed, multifunctional woodland, thus improving its biodiversity and environmental value. This could simultaneously achieve the twin goals of environmental gain and clean, renewable fuel production.

7.5 Water

Almost 70% of the freshwater resources used by human beings are for agricultural production.[11] In a world where demands for this precious resource are increasing, it is important that it is considered when contemplating future strategies. Ideally, where dedicated feedstocks are selected, they would be under rain fed agricultural systems, with minimal additional inputs. Applications of pesticides and fertilisers increase the risks of water pollution, and soils are especially vulnerable to leaching when they are left bare. Perennial crops and trees have the advantage of generally requiring fewer inputs and of maintaining soil cover, thus reducing the potential for water contamination compared with annual crops.

Therefore, long term feedstocks for second generation biofuel production can have significantly less impact on water resources than intensive annual crop production, provided that the right plant or tree is selected for the right situation.

7.6 General considerations

According to the European Environment Agency[12], there is sufficient biomass potential in the EU-25 to support ambitious renewable energy targets in an environmentally responsible way. In addition to this there are very significant opportunities for developing countries to become major producers, using biofuel production as a lever for economic and environmental development. Putting figures on the amount of biomass that could be produced worldwide is very complex, and studies vary in their estimations by a factor of nine.[13] However, second generation biofuel technologies could enable significant increases in biofuel production with minimal

11 FAO (2003) *World agriculture: towards 2015/2030*

12 EEA briefing, number 2/2005

13 Berndes G, Hoogwijk M and van den Broek, *The contribution of biomass in the future global energy supply: a review of 17 studies,* Biomass and Bioenergy 25:1-28 (2003): http://grove.ufl.edu/~bests/Net%20Energy/Berndes%20et%20al.%202003.pdf

environmental impacts. Indeed, there could even be environmental benefits achieved by making better use of residues and encouraging reforestation in areas where the environment has become degraded.

If environmental objectives are a prime driver, it is important that systems are put in place to ensure that feedstocks are produced sustainably. Well-to-wheel CO_2 emissions make up an important part of this. Using environmental economics, it is possible to factor positive and negative externalities into the costs of biofuels, with greater incentives for customers to buy fuels that are produced in the most environmentally responsible ways.

A complete life cycle analysis of environmental impacts associated with second generation biofuel production and consumption is beyond the scope of this report, but considerable work has been done in this area by the Öko-Institut. The GEMIS (Global Emission Model for Integrated Systems) model and other work it has done is freely available on line.[14]

14 www.oeko.de/projects_engl.htm, www.gemis.de

8 ECONOMICS, SOCIO-ECONOMIC BENEFITS AND COSTS

The current cost of most domestic and overseas produced biofuels is around twice that of conventional road fuels, as discussed in Chapter 2. As with first generation biofuels, the estimated cost of producing second generation biofuels from biomass feedstocks is high compared to conventional fuels. Consequently, the cost of avoided CO_2 is also estimated to be high (see Chapter 2).

In general, second generation technology for these biofuels is either still at the demonstration stage or developmental stage, as described in Chapter 4. Currently, there are no commercial plants in operation, nor integrated demonstration plants. Also, there is considerable uncertainty relating to feedstock supply and pretreatment costs. In fact, in view of this lack of maturity of economics, data for commercial scale biofuels production should be taken as indicative only.

8.1 Overall economics

Only very limited economic data were presented to the mission team. A summary of economic data on the larger scale plants and costs for various processes is given in Exhibit 8.1. Only ECN presented a breakdown of production costs and some indication of the potential benefits from economies of scale for the BTL route. ECN presented its costs on an energy basis, which is more common to the power industry, rather than on a weight or volume basis.

8.1.1 Comparison with GTL and CTL

In general, processes that produce a synthetic diesel (from gas, coal or biomass feedstocks via syngas and FT synthesis) have much better economics at high crude oil prices, ie higher product values. However, these syngas based process routes are very energy and capital intensive technologies compared to refining and petrochemical processes. For example, typical GTL and CTL

GTL	Typical current capital costs for a GTL plant producing 4 million t/y (~100,000 bbl/d) FT liquids are in the range €2.5–3 billion (~£1.7-2.1 billion), depending on location
CTL	A CTL plant producing a nominal 2 million t/y (~50,000 bbl/d) FT liquids is estimated to cost in excess of €2.5 billion (~£1.7 billion), excluding any carbon capture and storage (CCS) costs
BTL	Based on current views, a BTL plant with a nominal production capacity of 0.6 million t/y (~15,000 bbl/d) FT liquids is expected to cost around €1.5 billion (~£1.0 billion); a larger scale plant will give economies of scale, eg a BTL plant producing a nominal 3 million t/y (~75,000 bbl/d) FT liquids is expected to cost in the range €3–3.5 billion (~£2.1-2.4 billion)

Exhibit 8.1 *Typical capital costs of GTL, CTL and BTL plant*

plant costs are compared with a current view on biomass BTL capital costs in Exhibit 8.1.

For transport fuels, crude oil price is a good indicator of overall economics. With low feedstock costs and world scale production capacity (>4 million t/y FT liquids), GTL requires a minimum crude price in the range $25-30/bbl (~£14-17/bbl). With higher processing costs and typical production capacities in the range 2-4 million t/y, CTL is estimated to need crude oil prices in the range $45-60/bbl (~£25-34/bbl). Future requirements for carbon capture and storage (CCS) to minimise CO_2 emissions will add to the cost of CTL.

8.1.2 ECN economic data

For BTL, ECN presented estimated production costs for a range of plant capacities. At low production capacity, conversion plant production costs are high, but significant economies of scale are possible. Feedstock costs, including pretreatment, are high throughout and represent a high proportion of the production costs for the larger scale plant. ECN biomass costs at €4/GJ (~£2.8/GJ) appear to be comparable with UK estimates of £40/t (dry basis) for energy crops (Rothamsted Research), including fixed costs. However, the ECN claim that large scale BTL fuel production can be competitive with fossil fuels, at the current oil price, seems to be extremely optimistic.

8.1.3 Synthetic diesel from BTL

Overall, synthetic diesel from BTL is expected to be significantly more costly to produce compared to either GTL or CTL processes. Biomass BTL plants not only have high capital costs but also have relatively high feedstock costs. In addition, biomass feedstock availability and cost can limit the size of BTL conversion plant to much smaller production capacity than for either GTL or CTL. Therefore BTL production costs presented to the mission team are significantly higher than typical equivalent costs for either GTL or CTL processes.

8.2 Socio-economic benefits

Biomass production for use in bioenergy can bring socio-economic benefits, as presented by the Öko-Institut. Jobs from biomass can help to foster economic renewal in rural areas and encourage regional development. Most significant to job creation is energy crop cultivation, but production of power from biomass can also bring significant benefits. Öko-Institut estimates that, by 2030, in Germany over 200,000 jobs could be created, both direct and indirect (construction and infrastructure). However, jobs related to transport fuels from biomass play only a small part in this projection. Nonetheless, Öko-Institut is including job creation benefits as part of its overall supply chain modelling.

Also Choren is including job creation benefits in order to improve overall economics from its proposed commercial BTL plant. The Choren approach is a regional one, where its Gamma BTL plant (~200,000 t/y product) will require an intake of ~1 million t/y biomass. It is possible that the small BTL plant is also part of a regional green energy infrastructure, ie power and heat production, in order to maximise local biomass supply and socio-economic benefits. Recently, for each Gamma BTL plant, Choren has suggested that 150 direct and 700 indirect jobs could be created.

8.3 Commercial concepts

A number of concepts under consideration for commercial scale production of biofuels from biomass were presented to the mission team. These concepts basically fell into the following categories:

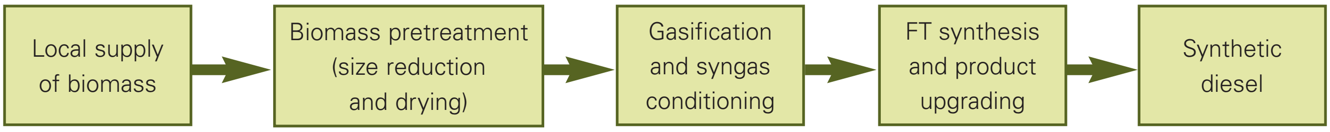

Exhibit 8.2 Small scale stand-alone conversion plant for BTL

8.3.1 Small scale production

This concept is based on using stand-alone production plants, close to local biomass supply (see Exhibit 8.2).

The capacity of the conversion plant is limited by local biomass supply. Dedicated biomass feedstocks are used, within a specified limited distance from plant to minimise feedstock costs and transportation. The use of an energy carrier is not required. There may be some local heat and power integration as part of a local bioenergy infrastructure.

A typical example of this approach is Choren's proposed Gamma plant. The planned capacity is 200,000 t/y product requiring a biomass intake of ~1 million t/y. Choren indicated that the biomass would come from within a 30 km radius. There are significant production costs associated with such a small capacity commercial BTL plant, in particular oxygen costs for the gasification step. In view of this, Choren is now considering two possible options:

- **Greenfield site** – located near Baltic Sea for regional biomass and imports
- **Brownfield site** – located in existing chemical park, with access to existing oxygen supply and possible utilities integration; it is also possible that a rapeseed oil plant will be built alongside, so that Choren could use the by-products

8.3.2 Large scale centralised conversion plant

This concept is based on using a large scale, centralised conversion plant with biomass feedstock supplied from distributed small scale local biomass sources (see Exhibit 8.3).

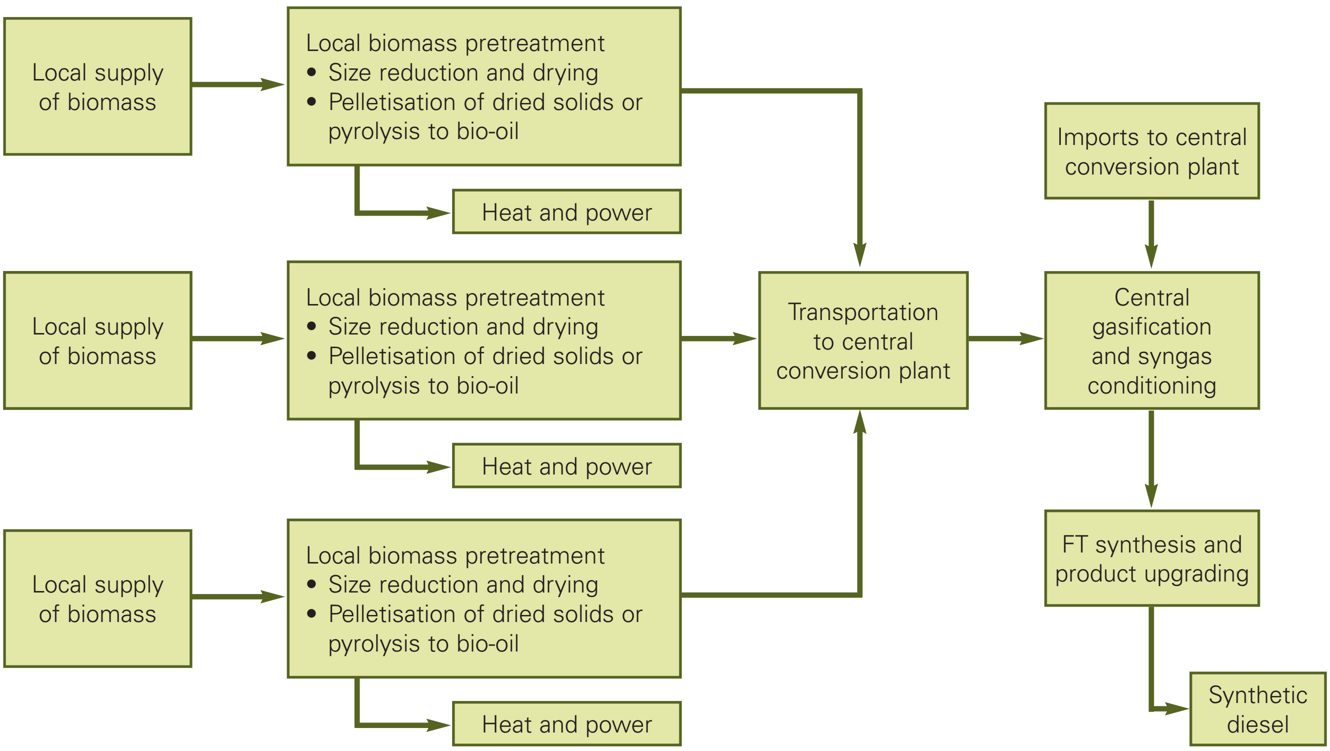

Exhibit 8.3 Large scale centralised conversion plant for BTL

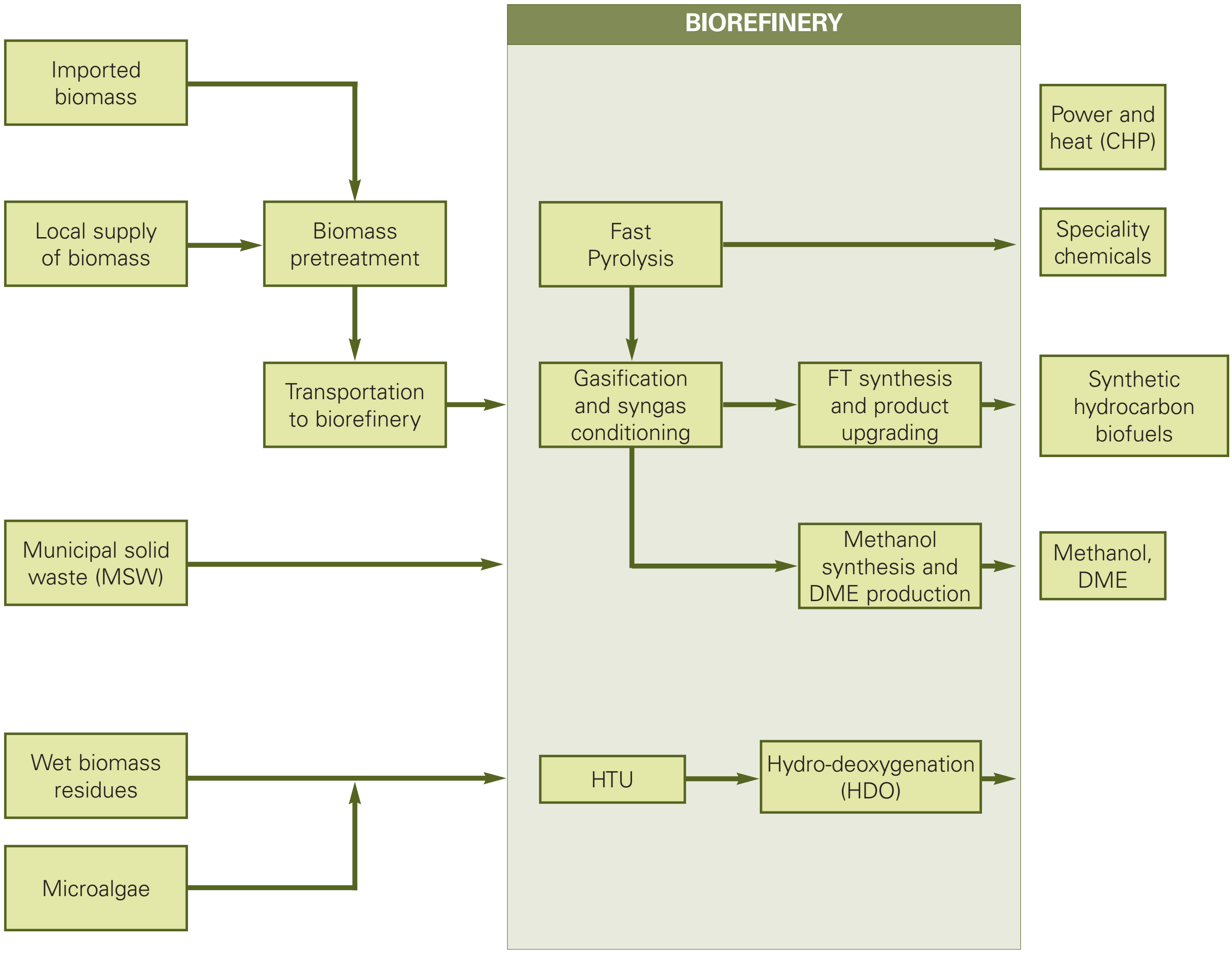

Exhibit 8.4 Biorefinery concept for second generation biofuels

Biomass pretreatment is done locally and may have heat and power integration. Transportation to the central conversion plant is by means of solid biomass pellets or by using an energy carrier such as bio-oil. Local and imported biomass feeds are envisaged, with probably a coastal location for the conversion plant in order to reduce imported biomass costs.

This is a typical approach being considered in the Netherlands. ECN sees dedicated biomass FT plants of several GW capacity with no polygeneration. A centralised BTL plant producing 0.6 million t/y liquids will require a biomass intake of ~3 million t/y. A very large centralised BTL plant, say producing ~3 million t/y liquids, will require a biomass intake of ~15 million t/y.

8.3.3 Biorefineries

Biorefinery concepts are not new but are creating renewed interest as a means of improving biomass economics. This approach involves a bioenergy system, as outlined in Section 3.5. A generic model is shown in Exhibit 8.4.

A large centralised facility with a number of integrated process routes is envisaged involving a wide range of potential biomass sources, with local and imported supply. Several different process routes are employed to give a wide range of products, eg chemicals, power and transport fuels. The objective is to:

- Maximise feedstock availability
- Optimise process integration for optimum efficiency and cost
- Maximise revenues from products

No economics or overall costs were presented to the mission team but ECN, WUR and VTT are developing concepts. Simple biorefineries could be just BTL plant integration into an existing site. In addition to a BTL plant, more complex biorefineries could also include:

- CHP from residues
- Methanol/DME
- Bioethanol, ie fermentation process route
- HTU and HDO processing wet feeds
- Industrial waste (MSW), possibly with separate gasification and syngas conditioning to the other biomass, but a common synthesis unit

8.4 Barriers and issues for second generation biofuels

Second generation biofuels are at an early stage of development, and estimated production costs for synthetic diesel from biomass are extremely high. Two factors, in particular, have a large influence on cost and hence future deployment:

- Biomass feedstock costs
- Small capacity BTL plant, limited by biomass supply

Although it is expected that commercial plant economics will become more defined through development of some of the commercial concepts presented to the mission team and supply chain development, significant barriers to commercial development are likely to exist from:

- Feedstock availability and cost
- Transport issues
- Conversion costs

8.4.1 Feedstock availability and costs

Fundamental issues include:

- Feedstock (growing and gathering) – there is a wide variety of types, availability and cost; what is the optimum combination of biomass feedstock and conversion?

- Availability of biomass feedstocks at competitive prices

- Lack of development of energy crops – are these too expensive?

- Pretreatment – what pretreatments and where? Biomass type and characteristics vary considerably and present a significant processing challenge

Both Neste and ECN saw barriers from insufficient biomass and the ‘wrong type’ of biomass for ambitious growth. Öko-Institut indicated that Germany is planning significant future R&D investment in the biomass supply side.

8.4.2 Transport issues

The low energy density of biomass and the low production rate from a given area present a fundamental challenge to biomass conversion. Energy carriers such as pyrolysis oil may help to concentrate supply and increase transportation distances, but how much will this be supported by cost and the overall CO_2 balance? How does this compare with converting to synthetic diesel closer to feedstock source, as in GTL, and transporting the finished product?

8.4.3 Conversion costs

Conversion through gasification and FT synthesis is a very capital intensive technology. Although significant development work is in progress, fundamental questions for commercial scale BTL application include:

- Can small capacity conversion plant be commercially viable, and how?
- Significant reduction in production costs through economies of scale are possible – what size of BTL plant can be supported? Will a wide variety of biomass feedstocks significantly improve viability?
- Will future improvements in developmental technologies offer alternative routes and lower costs?

Can BTL grow from a fledgling industry today to be commercially viable in the $40-70/bbl (~£23-40/bbl) crude oil price range, as for GTL and CTL processes? This currently appears extremely unlikely, and incentives and policy changes are needed if much larger scale BTL deployment is to become a reality. As outlined in Section 4.6, risk sharing should be considered for biofuel implementation in the UK in order to accelerate development and give access to a greater spread of technologies. Suggested policy measures relating to the UK are covered in Chapter 9.

8.5 Summary

Compared to commercial GTL and emerging CTL processes, BTL has significant barriers to commercial development in view of high feedstock costs, transport issues and small capacity conversion plant. These combine to make synthetic diesel by BTL very expensive to produce.

Significant improvements in commercial viability are likely as BTL developers, such as Choren, look for better commercial solutions on biomass availability and cost, as well as lower processing costs. Within Europe, such solutions are likely to include socio-economic benefits from job creation and rural development. Germany is likely to put significant future R&D investment into the supply side.

It appears unlikely that synthetic diesel from BTL will ever be directly competitive commercially with fossil fuels, and the challenge is to find policies and incentives that will encourage large scale BTL deployment from a renewables standpoint. Risk sharing should be considered for biofuel implementation in the UK in order to accelerate development and give access to a greater spread of technologies.

Company	Process	Capacity	Capital cost	Comments
VTT	BTL	300 MW_{th} biomass feed to plant	€210-235 million (~£145-162 million)	FB syngas production plus FT, possibly integrated with paper mill
Neste	NExBTL	170,000 t/y biomass product	€100 million (~£69 million)	Similar production costs to RME but superior product; oil hydrogenation rather than transesterification process
ECN	BTL	250 MW biomass feed to plant	–	Typical biomass scale: ~80,000 t/y FT liquids; production cost ~€27/GJ (~£19/GJ)
		1,750 MW biomass feed to plant	–	Central conversion plant: ~0.6 million t/y FT liquids; production cost ~€17/GJ (~£12/GJ)
		10,000 MW biomass feed to plant	–	Very large central conversion plant: ~3 million t/y FT liquids; production cost ~€15/GJ (~£10/GJ)
		1.3 million t/y FT liquids	€1.2 billion (~£0.83 billion)	Capital costs seem low for this scale
	Microalgae	25 million t/y dry biomass		Integrated production in North Sea? €50/t (~£34/t) (dry) onshore; €300/t (~£210/t) (dry) offshore
TNO	HTU and HDO	Commercial design for 130,000 t/y biomass	~€50 million for HTU plant (~£34 million)	Production costs ~€11-12/GJ (~£7.6-8.3/GJ) (including HDO); future plant ~€6-7/GJ (~£4.1-4.8/GJ); feedstock cost ~€1/GJ (~£0.69/GJ)
	HTU	25,000 t/y	€17 million (~£12 million)	
BTG	Fast pyrolysis	50 t/d	€7 million (~£5 million)	Installed and running
Choren	BTL	Beta plant ~13,000 t/y FT diesel		Ready 2007; Gamma plant target 2009/10
FZK	Gasification and methanol	2 MW demo plant (~4,000 t/y capacity) under construction	€22 million (~£15 million)	Lurgi (LR) fast pyrolysis, GSP gasifier, Lurgi methanol demonstration plant

Exhibit 8.5 *Economic data for second generation biofuels*

9 POLICY AND INCENTIVES

9.1 Scenarios

Biomass is an unusual renewable energy (RE) resource in that it can be used for a range of applications, including both heat and electricity on a non-intermittent, firm basis, as well as for production of a range of biofuels – solid, liquid and gaseous. It is, however, a resource limited by land use considerations, geographical distribution and resultant transport emissions, and consequently its use must be prioritised.

One of the primary benefits of second generation biofuels is the ability to make use of a far wider range of biomass than the first generation alternatives; however, the use of even biomass currently classified as residue or waste for transport fuel manufacture depletes the resource available for heat or power generation. The manufacture of biofuels, and therefore the steps taken to promote their uptake, must be undertaken in the context of all alternative uses for the biomass, and even the land required. This is discussed in greater detail in Chapter 7.

The potentially huge demand for biofuels nationally, in the EU and globally, if even relatively modest proportions of the current demand for transport fuels are replaced, coupled with the high capital cost of gasification and FT plant, mean that a relatively small number of centralised, very large scale facilities bring significant economies of scale and are the most realistic option. Such large plants, however, require high throughput of biomass feedstock to maintain economic operation. Owing to the typically low energy density of raw biomass, and the significant potential environmental damage associated with long distance transport of feedstock, especially over land, siting of biomass gasification and FT plants must be undertaken with great care and consideration of the feedstock supply chain. To take simply the UK demand for diesel, a 5% penetration by FT diesel would require around 1 million t/y, requiring about 5 million t/y of biomass feedstock. This is the scale of just five of the Gamma plants proposed by Choren.

It is therefore appropriate to consider various scenarios for the use of biomass for biofuels:

9.1.1 UK biomass for UK biofuel production

Under this scenario a small number of gasification and associated FT plants are set up in the UK using UK sourced biomass for feedstock. In order to make use of existing logistics infrastructure, the most likely siting for such plants would be associated with existing oil refineries. There are nine major UK oil refineries, each sited in close proximity to a major seaport and good rail access. If five 200 kt/y plants were constructed, co-located with existing refineries, they would each require 1 million t/y of feedstock, or over 100 t/h to be delivered 24 hours a day, 365 days a year. The total would represent over half of the total UK available wood resource from forest and woodland, arboricultural arisings, SRC and primary processing products, or, alternatively, around half the available recycled wood.

While it might be technically possible to transport such a large proportion of the UK's total wood resource to a small number of sites, even if maximum use were made of the railway, waterway and coastal shipping infrastructure there would also be a considerable requirement for road transport, and the pressure on the UK's transport infrastructure would be considerable. The transport costs would also dominate the feedstock costs, and the embedded energy and associated GHG emissions of the final fuel would escalate.

In addition, the impact on other industries currently making use of this resource, or intending to do so, would also be considerable. In particular it would be likely to have a significant negative impact on the deployment of biomass heat and power projects in the UK. At present a large proportion of the potentially available wood resource from UK woodlands and forestry not owned by the Forestry Commission is not harvested as the price available for thinnings, brash and small round wood does not make the process economically attractive for small scale private owners. It would be necessary either for the price of biomass to rise, or for the supply chain to become significantly more efficient (such as by making greater use of green wood, chipped in the forest directly into trucks, for transporting directly to point of use with no intermediate handling steps), if this potential resource is to become available. Without this resource it would be likely that the massive buying power and capital investment of biomass gasification and FT plants would dominate the domestic woodfuel market, leaving the less accessible resource for the local heat and power projects, pushing up the woodfuel price and dissuading future investment without significant further incentives.

Significant plantings of high yield energy crops could affect this position considerably, however. 1 million t of biomass could be obtained from within a 10 mile (16 km) radius if the average yield were 12 t/ha, within the capabilities of energy crops such as miscanthus under good, UK conditions. Although an average yield of this level would be unlikely to be achievable in the UK over such an extensive area, with the influence of factors such as road penetration, habitation and biodiversity concerns, it serves to illustrate how energy crops could play a valuable role.

Of course this scenario would be unlikely to evolve in this way in a free market as both the cost and embedded energy of low density biomass transported large distances over land in relatively small quantities would rapidly become less attractive than feedstock imported by the shipload. This becomes especially true for biomass residues that have very low, or even negative costs where disposal is a valuable service. In general, biomass is not time sensitive and is susceptible to large scale bulk handling and shipping, a relatively cost-effective and environmentally low impact transportation option. These options are already exploited by the biomass co-firing industry (whose combined demand is already on the scale of a million t/y) in the UK, and leads to the second scenario.

9.1.2 UK processing of imported biomass

An alternative to the scenario above is that a gasification and FT plant associated with a UK oil refinery would obtain its feedstock from a range of biomass sources overseas. It is likely that a proportion of this would be organic processing residues such as olive cake from the rim of the Mediterranean from the olive oil industry. Buying biomass on a global open market enables optimum prices to be paid; however, despite the relatively low CO_2 intensity of sea freight travel, it is desirable to minimise transport as much as possible.

Sea freight contributes about 14 grams of CO_2 per tonne kilometre (g CO_2/t km), while rail contributes 23 g CO_2/t km, road freight 123 g CO_2/t km and air freight 900 g CO_2/t km.[15] However, ships are fast becoming the biggest source of (non-CO_2) air pollution in the EU. By 2020 they are expected to emit more than all land sources combined.[16] It is therefore vital that if biomass is to be transported in bulk around the world it be done as efficiently as possible.

The various biomass densification technologies discussed during the mission offer the potential to reduce GHG emissions from feedstock transport in this way, and various organisations visited have developed sophisticated models to allow the analysis and optimisation of different options against environmental and financial criteria. ECN, FZK, WUR and the Öko-Institut have all done work developing models to help optimise the supply chain and choose the best combinations of plant siting and densification processes. Such processes range from chipping the biomass, through drying, pelletising and torrefaction to flash pyrolysis, each with different financial and energy costs and with the feedstock transported at different degrees of densification.

There is of course no universal solution. Different densification processes bring different processing costs, both financial and in terms of embedded energy. Different densified products too, such as pyrolysis bio-oil or torrefied pellets, bring different degrees of ease of handling and subsequent processing. Which is the most suitable for a particular combination of conditions will depend on the amount and type of biomass available, and its geographical distribution and distance from a potential processing plant and distance and nature of local transport infrastructure; the distance which it needs to be transported to a centralised gasification and FT plant; how many, and the geographical distribution of such feedstock densification plants; etc. For instance, if the majority of feedstock will be delivered from relatively local sources as either raw biomass or torrefied pellets, it may not be justified to build a dedicated facility at the gasification plant to handle pyrolysis oil from a single site.

Where there is sufficient availability of biomass remote enough from the gasification and FT plant to warrant a high degree of densification, flash pyrolysis can offer this; however, handling it and processing it at the gasifier will be different from that for solid biomass feedstock.

The option of establishing a pyrolysis bio-oil plant at the site of an available resource of cheap biomass, for densification for transport, is the one that BTG has been developing in Malaysia to make use of oil palm seed pod residues. At present this is not intended for subsequent gasification and conversion to biofuel, and the current plans are for co-firing in the Netherlands.

The ultimate extension of the process of biomass densification is:

9.1.3 UK import of synthetic biofuels

Instead of importing the biomass feedstock, the most energy dense form for shipping is

15 European Environment Agency indicator fact sheet TERM 2003 27 EEA 31

16 Clean Air for Europe impact assessment, p31 (2005)

the finished biofuel. Where there is sufficient supply of feedstock within a small enough distance to warrant a full scale gasification and FT plant, this is certainly the most efficient option in transport terms, and avoids the need for a pyrolysis stage. A gasifier and FT plant is, however, a complex and major installation, requiring significant infrastructure, in addition to transport links and access to feedstock. A (relatively large) skilled workforce, fire and security services and construction, engineering, consumable supplies etc, will all be required. While it is possible for all these to be brought in, it adds considerably to the complexity and expense of such a project.

Imports of second generation biofuels at scale are likely only to come from developing countries since developed countries such as the EU or the USA will preferentially consume the fuel at home. For developing countries to create the infrastructure and operate the processing plant will be a significant challenge, and the environmental and socio-economic impacts must be thoroughly assessed at the outset. However, the implementation of second generation technologies in these countries could offer substantial socio-economic gains.

9.2 Potential deployment of second generation technology

When considering the scenarios for the deployment of high temperature processes for second generation biofuels, the technology options are limited. However, the key advantage is the wide variety of feedstocks which potentially can be fed into these processes. As has been discussed in previous chapters, they can range from waste biomass and energy crops to sewage sludge.

The options are to convert the biomass into pyrolysis oil, or other densified form, in smaller satellite plants for feeding to a central gasifier, or preparing the feedstock for direct feeding to the gasifier. As is described in the technology sections, syngas is produced which will almost certainly need treatment to remove impurities. The syngas is then used to feed an FT process to convert the gas into diesel and other liquid fuels.

These technologies have existed for many years but they have not necessarily been connected together to produce diesel fuel from renewable biomass. However, Choren is building a small-scale version of this process to demonstrate its viability. This small plant will produce around 13 kt/y of diesel. It is estimated that a full-scale plant to reduce the unit cost of diesel, to produce 200 kt/y FT diesel, will cost around €0.5 billion (~£0.35 billion). Alternatively, this amount of capital could build around 10 conventional biodiesel plants of 250 kt throughput, in other words over 12 times the total production capacity. Of course there would be issues of vegetable oil availability but in a policy world only looking at volume of biofuels included in transport fuels clearly conventional biofuels win. However, the real aim of reducing GHG is not fully achieved.

We take the Choren model as our scenario for consideration as it is the most advanced and closest to market of all the second generation technology options available today.

9.3 Existing policy measures and impact on encouraging second generation technologies

There are a small number of policy options to encourage these technologies into the market. Typically, in the EU, biofuels are encouraged by tax incentives and the largest currently is in the German market at €0.47/litre (~£0.32/litre). The Choren plant visited in Germany using gasification and FT technology is only demonstration size although its annual production rate will be 13 kt. Even with this size of plant the very large tax incentive in Germany will still not cover the additional cost of production. The unit cost of production will inevitably reduce when the plant size is increased to 1 million t/y but the capital cost increases to around €2 billion (~£1.4 billion). Even with this size of plant it is unlikely that the current levels of tax incentives across the EU would sufficiently encourage investment of this scale.

Alternative mechanisms will therefore need to be considered to encourage these technologies into the market. However, due to the extremely high capital costs it may be that these technologies are never cost-effective for widespread use and are only used to dispose of specific waste or energy crops – in other words, niche applications at specific locations – and their throughput may be limited.

Due to the increasing cost of tax incentives to Finance Ministries across the EU, many member states are now implementing or considering biofuel obligations, sometimes called a flexible mandate. These set a volume requirement on fuel suppliers to include a percentage of biofuels blended with fossil fuels. In the UK the Renewable Transport Fuels Obligation (RTFO) is being introduced in April 2008. The detailed design and legislation necessary to implement the scheme is currently under development. This is almost certainly the most sophisticated scheme in the EU, but even this mechanism on its own does not have the potential to drive second generation biofuels into the market, since on a litre basis conventional biodiesel will always be cheaper than second generation biofuels. Therefore, if there are insufficient supplies to meet the obligation the fuel supplier pays an additional tax (buy-out price) and this will be passed on to the motorist. Therefore, potentially there may not be a driver to encourage second generation biofuels into the market. Therefore, an additional or alternative mechanism needs to be developed.

9.4 Proposals to encourage second generation biofuels

When investigating which mechanism could be used to encourage second generation technology, the best route appears to be understanding why second generation technology is necessary. Biofuels offer many advantages to society above fossil fuels but the key issue which drives the expansion of biofuels beyond the nominal target of 5.75% is climate change. If one only considers conventional crops then the current target probably meets the requirements of the agricultural sector in boosting the rural economy. If the aims of sustainable mobility and reducing GHG emissions from the transport sector are to be achieved then a tool needs to be used which credits technologies which are most efficient at reducing GHG emissions. Additionally this should not stop at the conversion technologies but should also include the feedstocks, ie the crops used to feed these processes.

This tool will need to be extremely sophisticated to model the energy inputs through the supply chain and the production process. Choren claims that its process route and feedstock give a 90% GHG saving compared with fossil diesel. This is very close to the savings achieved by burning woody biomass to produce electricity. It is also considerably more efficient than the production of FAME from vegetable oils which typically only reduce GHG by 55%. Therefore the dilemmas on where best to use the biomass created in the scenarios described above are no longer of such concern, since the GHG benefits of burning the biomass in a power station are similar to producing FT diesel from the same biomass. This is of particular significance as the options for reducing GHG emissions from the transport sector are extremely limited compared with other energy sectors.

9.4.1 Linking support to GHG benefits

A number of studies have produced well-to-tank and well-to-wheel analyses of GHG emissions from biofuels, but these studies differ in calculation methodologies and assumptions. They also do not offer an interface to allow the stakeholder to perform their own calculations for their particular supply chain. So the data on GHG benefits tend to be generic, rather than specific to the particular biomass, processing plants and transport logistics used. The generic data often reflect favourable options which are rarely employed in practice. Therefore there is a need to use a common methodology for quantifying the GHG benefits for various supply chain options.

The Low Carbon Vehicle Partnership (LCVP) is developing a methodology which could be used to calculate the GHG emissions from specific biofuel chains, as well as identify and promote chains with lower emissions. This tool could also be used for reporting on the carbon intensity of biofuel chains, and eventually for the precise certification of the carbon intensity of biofuels. Once developed and operational, this tool could be used to reward the lowest GHG emitting biofuels. Provided this tool is practical, user friendly and accepted by policy makers as the most appropriate and accurate mechanism for carbon certification then it could easily be linked to the policy mechanism.

Linking carbon certification to the policy objective of encouraging second generation biofuels with higher GHG benefits gives a few alternatives. However, the simplest policy could be converting the current Biofuels Directive targets from an energy basis to a GHG reduction basis. Therefore, the EU Biofuels Directive could set targets on member states of reducing the GHG emissions from road transport by say 4% by 2010. This would be a significant policy and conceptual change on behalf of the EC and member state governments. Such a change would need to specify the common tool to quantify the benefits from each alternative renewable transport fuel.

The probability of changing the EU Parliament and Commission's current policy during the current review period is extremely slim, but it is possible to influence UK Government policy, particularly in the second phase of the RTFO. This would involve the RTFO changing from a volume target to a GHG target for obligated parties. This sounds a very simple amendment, but the effort required by many stakeholders to achieve this policy change should not be underestimated. It is also likely to require the consensus of many conflicting stakeholders. As an example, some low efficiency conventional biofuel producers may see it as a threat to their process or feedstock.

This single policy change would immediately encourage R&D and eventually investment in full scale second generation technologies. Additionally, it would have the double effect of encouraging GHG efficiency improvements in existing conventional technologies.

10 CONCLUSIONS

10.1 General

Second generation transport biofuels offer a number of significant advantages over first generation products:

- Significantly greater GHG emission reductions are possible
- Potentially considerably reduced land requirements/increased yield
- Better diesel engine fuel than FAME with none of the negative material impacts associated with FAME biodiesel

FT based fuel synthesis also offers other major benefits:

- A cleaner fuel, with no sulphur or nitrogen
- Ideally suited to modern diesel engines without modification
- Totally compatible with existing diesel in any proportion and can be readily assimilated into existing fuel supply infrastructure

Biomass uniquely has the potential to provide a low carbon liquid transport fuel that is compatible with the existing user base and fuel supply infrastructure.

There are clear logistical and economic advantages in producing transport fuels that are completely compatible with existing transport fuels in any proportion.

10.2 Feedstock

Consideration of the feedstock supply chain and optimisation of biomass production are critical.

There are potential difficulties with obtaining sufficient feedstock for significant penetration of the transport fuel market from within the UK. Import of feedstock is one potential option.

A range of techniques for densification of biomass feedstock for transport are being developed which would be important in future production of these fuels in the UK. Pyrolysis and bio-oil stabilisation have some technical hurdles to overcome. Torrefaction seems an interesting process that may also offer processing and handling benefits.

Biomass feedstock supply logistics may limit the realistic scale of BTL plants in the UK and hence their cost competitiveness.

The majority of biomass feedstocks being evaluated in Europe are wood based or agricultural residues. There appears to be little focus on miscanthus or other dedicated energy crops. This may in part be a result of higher levels of forestry in many European countries.

If agricultural and forestry residues are to be considered as feedstock, existing uses must be considered to avoid double counting available volumes. Unintended impacts such as reductions in soil fertility and broader environmental issues must also be considered.

Germany is likely to put significant future R&D investment into biomass supply.

10.3 Process technologies

Gasification of biomass is very feedstock insensitive, allowing the use of a wide range of biomass. Viable feedstocks range from woody biomass to sewage sludge.

A wide range of bioenergy systems are being considered that include:

- European biomass and imported biomass
- Solid biomass gasification for synthesis gas
- Biomass pyrolysis to produce an energy carrier followed by centralised pyrolysis liquid (bio-oil) gasification for synthesis gas
- Synthesis of hydrocarbon fuels from synthesis gas via FT and via methanol
- Synthesis of other fuels that have transport applications
- Biorefineries for optimisation of products

The technology to produce second generation diesel from a clean syngas using high temperature processes has been available for many decades. Some demonstration work is required, however, to link all the elements together to build a full scale plant.

Large scale biomass gasification has not yet been demonstrated on a scale appropriate for FT technology. While there are no foreseen problems in cleaning up syngas for FT synthesis, this also has yet to be proven. Access to FT technology is currently restricted to a small number of providers and therefore could become a commercial issue.

A wide range of different renewable transport fuels are being considered in all the countries visited, of which high quality synthetic diesel and gasoline are the main focus. Other fuels being considered include methanol, DME and hydrogen.

There is no clear choice of process or technology for production of transport fuels from biomass. Some technologies are close to commercialisation whereas others are at early stages of development.

The biorefinery model is one in which there is significant interest; however, there has been very little development to date. It offers the potential to help the financial position of second generation biofuels and is a field in which the potential remains for the UK to establish a leading position.

The UK has no research facilities in second generation biofuel processing technologies; however, it has significant capability in underpinning technologies.

10.4 Economics

The very high capital cost of biomass gasification and FT plants is almost certainly the primary reason for their current extremely low level of deployment.

High delivered feedstock costs in comparison with coal and natural gas, of which harvesting and transport form significant components, also present a significant barrier.

Significant improvements in commercial viability are likely as BTL developers, such as Choren, look for better commercial solutions on biomass availability and cost, as well as lower processing costs. Within Europe, such solutions are likely to include socio-economic benefits from job creation and rural development.

There was significantly more medium sized and small entrepreneurial business activity in second generation biofuels technologies in the countries visited than in the UK (eg Choren, BTG).

10.5 Policy

There is no publicly funded activity in the UK to develop second generation biofuels, although individual companies in the UK are actively supporting activities in this area elsewhere in Europe and the world.

The current policy mechanisms operating in the EU are unlikely to be sufficient to encourage implementation of these technologies at any level of obligation. Alternative policy mechanisms are therefore required if these technologies are to be encouraged. If support mechanisms were adopted in which the net GHG reduction potential of products and processes were recognised, this would effectively differentiate between first and second generation products, allowing the environmental, performance and diversity aspects of the latter to be realised. It would also assist in making comparisons between alternative technologies.

The mission team saw no national incentive mechanisms to support either second generation biofuels specifically or to promote the production of energy crops.

The alternative uses of biomass need to be addressed in the UK and EU to ensure that these valuable resources are used in the most appropriate way to reduce GHG emissions.

There is a high level of interest and activity in second generation transport fuels in Europe with significant public funding. There is an appreciable level of industry support in Finland and Germany.

11 RECOMMENDATIONS

11.1 General

The nature of an integrated bioenergy chain for production of renewable transport fuels requires close integration of biomass production, biomass conversion and fuel synthesis. The relevant government departments – Defra, DTI and DfT – should place a high priority on establishing an effective cross-department task force to oversee this development and hence ensure that the UK meets its aspirations for climate change mitigation measures as well as capturing wealth creation opportunities.

11.2 Feedstock

Biomass producers need to develop feedstock supply chains and optimise biomass production to deliver maximum GHG benefits. Coordination by government and linking with the process technology and engine developers will be required.

International trade in biofuels and feedstocks is likely to be of great importance and should continue unhindered. Sustainability and environmental impact issues must be covered in accreditation criteria.

11.3 Process technologies

The UK should take a lead in implementing second generation technologies that offer high GHG reduction potential. One way to achieve this would be to establish a consortium involving industry, biomass producers and governments. The biorefinery model is one in which there remains the potential for the UK to establish an international lead with appropriate funding and prioritisation.

A comparative analysis of the alternative processing routes would help to identify the most promising technologies for transport fuels. The UK needs to build some capacity in understanding the S&T of transport fuel production from biomass.

R&D into technologies for economically viable transport fuel production at smaller scales to better match biomass resource availabilities in the UK should be funded.

11.4 Economics

The very high capital expenditure required for BTL plant presents major financial risk, making such major investments unlikely in the short to medium term without significant incentives. Government policies to mitigate such large investment risks should be investigated. Mechanisms such as grants or loans, with repayment schedules linked to success, to assist in the development of such technologies on a commercial scale, or enhanced capital allowances (ECAs), might be considered.

11.5 Policy

The UK has limited land resources that need to be optimised for food, materials and energy production. All decision making should be undertaken with consideration that available limited land resources need to be used as effectively as possible.

Government policy for encouraging biofuels needs to change from a volume/energy basis to a GHG reduction basis. In this way, optimum choices of feedstock and technologies will be preferred by the market. The UK should attempt to use its influence in the EU to ensure policy mechanisms focus on GHG reduction.

Policies to encourage the increased use of biofuels should be linked to environmental sustainability standards.

Government support for second generation biofuels should be considered in conjunction with other UK biomass heat and power initiatives to ensure optimum integration of infrastructure, including the feedstock supply chain. Consideration of alternative uses for the available biomass resource should always be included in any decision making process, and there should be meaningful discussion between UK government and industry on the role of second generation biofuels in the UK energy mix.

Appendix A

VISIT REPORTS

A.1 VTT (Valtion Teknillinen Tutkimuskeskus – Technical Research Centre of Finland)

A.2 Neste Oil Oyj

A.3 ECN (Energieonderzoek Centrum Nederland – Energy Research Centre of the Netherlands)

A.4 WUR (Wageningen Universiteit en Researchcentrum – Wageningen University and Research Centre)

A.5 TNO (Nederlandse Organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek – Netherlands Organisation for Applied Scientific Research)

A.6 BTG (Biomass Technology Group BV)

A.7 Choren Industries GmbH

A.8 Future Energy GmbH

A.9 TUB-F (Technische Universität Bergakademie Freiberg – Technical University Bergakademie Freiberg)

A.10 SVZ (Sekundärrohstoff-Verwertungszentrum Schwarze Pumpe) GmbH

A.11 FZK (Forschungszentrum Karlsruhe)

A.12 Öko-Institut eV

A.1 VTT (Valtion Teknillinen Tutkimuskeskus – Technical Research Centre of Finland)

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Including meeting with

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VTT is the largest contract research organisation in Northern Europe, with a turnover of €218 million (~£150 million), of which 70% is from external income. It has a staff of 2,661 and operates within a number of research themes including digital and communications technologies and environmental technologies.

Also present was Dr Jukka Leppälahti of Tekes (Teknologian Kehittämiskeskus – Finnish Funding Agency for Technology and Innovation). Tekes is the main public funding organisation for R&D, and is therefore highly attuned to Finnish Government policy objectives. It has a close relationship with VTT.

A presentation was given by Tuula Mäkinen on biofuels in Finland, based on the report presented by VTT to the Ministry Committee on Biofuels for Transport the previous week. The current situation for biofuels in Finland was reviewed, and a number of questions posed. The potential timescale and mechanisms by which a 5% target could be achieved, the optimum choice of vehicles and distribution channel and how much could be met based on indigenous raw materials were all addressed. It was concluded that 3% was a realistic target by 2010, but 5% could be achieved with an additional tax reduction of 2%. Current vehicles and distribution channels were felt to be the most appropriate. It was concluded that a proportion of 2-3% in 2010, and 7-8% in 2020, could be met from indigenous raw materials. Little benefit was seen for current generation biofuels; however, a development programme to introduce second generation biofuels, based largely on thermal processes, to markets by 2015 was suggested, to achieve a biofuel share of 8% by 2020. Lignocellulosic ethanol was not predicted to be competitive by the time thermal processes became available.

A presentation on pressurised FB gasification designed to be fuel flexible was given by Esa Kurkela, to handle woody biomass, straw, MSW and other wastes. The current development unit was 500 kW scale. Commercial scale of 200-300 MW_{feed} was envisaged, preferably integrated with energy consuming manufacturing plants, such as paper mills. In addition, work was being done on catalytic gas treatment. Lower heating value (LHV) efficiencies of different biosyngas conversion processes, including the use of off-gas and steam, and costings had been modelled. They consider the minimum economic scale to be about 150 MW_{feed} and calculate the front end as about 66% of the investment costs.

A presentation on pyrolysis of biomass to bio-oil was given by Dr Yrjö Solantausta. In the first phase, bio-oil was to be used in unmodified boilers for heat and power, in a process integrated with current installations (integrated thermal processing – ITP). In the second phase it would also be upgraded for biorefinery feedstock. Integration of the front end with current biomass users, and the back end with current conventional petrochemical refiners was felt to be important, with a stand-alone efficiency of 70% and an integrated efficiency of 80-90%.

A.2 Neste Oil Oyj

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Neste Oil is a major (conventional) oil company, the market leader in Finland, whose core business is oil refining, but with divisions in shipping, oil retail and components. The components division examines potential niche markets and includes biofuels work. It is owned 50.1% by the Finnish State.

A presentation was given by Jyrki Ignatius, giving an introduction to Neste Oil and its work in biofuels, and its view of biofuels. The company considers first generation biofuels to represent high cost of avoided CO_2; second generation offers better fuel quality and lower cost CO_2. It is building a €100 million (~£69 million), 170,000 t/y (product) plant to produce its next generation NExBTL biofuel at the Porvoo refinery and expects to start production from Q2 2007 as a JV with Total. Neste's vision for 2030 is that liquid fuels will still dominate, of which 20-50% will be liquid biofuels, the majority second generation biofuels. Gaseous fuels will be mainly used in dedicated fleets. It sees the biggest barriers to biofuels in the EU as the lack of mandatory, harmonised legislation, the availability of sufficient biomass feedstocks at competitive prices, lack of development of energy crops, current fuel quality issues and customer perception.

A presentation on the Neste NExBTL biofuel was given by Raimo Linnaila. The NExBTL process is one of hydrogenation of vegetable oils (or animal fats) to give pure C_nH_{2n+2} paraffins. It is a colourless, clear product that can be used directly in the current car pool without modification. It offers cetane numbers in the range 84-99, well above conventional EN590 diesel, and has LHV marginally higher than EN590 (significantly above RME). It also has zero oxygen, sulphur and polyaromatic content and physical properties (cloud point, viscosity etc) as good, or better than EN590 or RME. Neste calculates life-cycle emissions for NExBTL of 0.5-1.5 kg CO_2/kgoe fuel (depending upon feedstock) against 1.6-2.3 kg CO_2/kgoe for RME and 3.8 kg CO_2/kgoe for fossil diesel. It is working with multiple EU authorities for tests and approvals. Tests with Scania in heavy engines, and with VTT for passenger cars, show significant reductions in many emissions, particularly particulates, compared with EN590 diesel. By-products include water and a propane rich biofuel gas. It considers that it is a valid process where there is existing excess hydrogen production plant, as the cost of the hydrogen plant is not included in the €100 million (~£69 million) cost of the plant. 200,000 t of feedstock yields 170,000 t of product, which is close to the theoretical maximum. It sees no technical limits to the scaling potential, but currently all plants are integrated to existing sites. Current costs are comparable to RME but depend on feedstock prices as the plant investment is not a major component.

Finally, a presentation on NExBTL in the UK was given by Sami Oja. Neste is working with

DTI, DfT and HM Revenue & Customs (HMRC) to get NExBTL included in UK biofuel legislation and is a member of the steering group of a UK sustainability standard for biofuels.

A.3 ECN (Energieonderzoek Centrum Nederland – Energy Research Centre of the Netherlands)

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ECN has an annual turnover of around €105 million (~£72 million), employs about 900 people and is involved in many areas of research in energy and energy efficiency. It sees itself as bridging the gap between pure research and applications. Within the Biomass, Coal and Environmental Research Unit it includes clusters on Gasification and Gas Conditioning and Biofuels and Refinery Processes, as well as Heat and Power Production and its Environmental Research programme. Facilities include a range of gasifiers, gas cleaning and filters, a thermal cracker and an FT reactor.

A presentation on the technology options for synthetic biofuel production via syngas and product gas was given by Harold Boerrigter. The distinction between product gas, formed from low temperature gasification and containing CH_4 and other hydrocarbons and useful as a fuel, and (bio)syngas, obtained from high temperature gasification and containing only CO and H_2 and suitable for synthesis, was drawn. ECN's view is that SNG will supplement natural gas as a specialist, fleet transport fuel, for heat production and energy carrier over the next 40 years, with particular application for reduced local emissions. An indirect biomass gasifier using steam, optimised for nitrogen free product gas for SNG production was presented. Only 48% of product gas is suitable for FT synthesis, against 100% of synthesis gas. ECN therefore recommends the use of high temperature (entrained flow – EF) gasification and a high temperature tar cracker for FT. Although biomass is relatively low ash, it is not sufficiently low to use non-slagging gasifiers, so ECN uses a dry feed slagging design proven for coal, that can operate 1,200-1,600°C, 20-40 bar. Although optimum operating temperature is lower for biomass (1,200-1,300°C) than for coal (1,400-1,600°C), ECN believes co-gasification is the optimal choice, and has experimented up to 30% biomass with coal. The gasifier is fuel-flexible, suitable for solid woody biomass, bioslurry as well as coal. ECN sees dedicated biomass gasification FT plants, of several gigawatt capacity, with no polygeneration.

A presentation on optimum biosyngas production was given by Brem van der Drift. The observation was made that there is insufficient biomass, of the 'wrong' kind, for the ambitious goals. ECN therefore sees international shipping as significant. Scales for biosyngas processes it sees as 100 MW for the chemical sector, >100 MW for the gas and electricity sector, and >1,000 MW for transport fuels. Fifty per cent of worldwide biomass technical potential is woody, 20-40% grassy, so it sees these as key feedstocks. With the ECN slagging EF gasifier, remaining issues include ash melting, biomass feeding, gas properties, efficiency and economy. Experiments with a lab scale combustion/gasification simulator have shown the optimum flux/fuel mix (silica/alumina/fuel: 0.5/0.45 kg/kg) to keep >80% of the fuel ash in molten phase to allow flow. Optimum particle size for coal is <100 μm, for biomass <1 mm. Biomass can be fed with coal, requiring <100 μm particles, as a slurry, or in a dedicated feed. To grind fibrous biomass to fine dust as coal, ECN has developed the torrefaction process. This is a low temperature (200-270ºC) roasting process that results in a hydrophobic, zero moisture content (MC), high energy density fuel that can be ground very fine. Torrefied wood can also be pelletised while still hot at relatively good overall energy and economic efficiency. ECN sees torrefaction as preferable to flash pyrolysis for energy densification of biomass resources for shipping to centralised FT plant under many conditions. Finally, a consideration of the economics of a range of scenarios for the conversion of overseas biomass to FT products in Europe was presented from which it emerged that transport is crucial to final syngas costs, demanding high energy density for shipping.

Presentations on ECN work on biorefinery and microalgae were given by Hans Reith. Biorefineries are seen as assisting the economics of biofuel production and assisting the establishment of the supply chain, combined with CHP of residues. Processes include bioethanol and lactic acid production from lignocellulose and production of phenols from lignin using a modified organosolv pretreatment with high pressure CO_2. The full biorefinery cycle also includes the production of fine chemicals, solvents, fertilisers,

Exhibit A.1 *Dr Harold Boerrigter explaining the CFB biomass gasifier at ECN* elemental sulphur, base chemicals, gaseous and liquid fuels, electricity and heat. Work with microalgae suggests 30-60 t/ha/y (dry weight) biomass would be achievable in the Netherlands. With >30,000 species, different characteristics can be achieved. Up to 50% dry weight of oil accumulation, 50-80% wt polysaccharide, up to 80% wt hydrocarbons, or 200-350 Nm^3/t dry weight biogas production. In the Netherlands, 40% oil accumulation could be achievable, giving a potential of 8,200 litre/ha biodiesel, compared with 1,400 litre/ha for RME. Biomass production costs are predicted as >€2,000/t (>£1,400/t) dry weight, because of investment and harvesting costs, against a fuel value of €300-500/t (~£200-350/t), therefore co-products/processes (such as carotenoids, omega fatty acids, water purification) are necessary for economic production. The Bio-Offshore project proposes large scale seaweed production integrated with offshore wind farms and aquaculture in the North Sea. 5,000 km^2 (10% of the Netherlands' waters) is proposed. Costs of €50/t (~£34/t) dry weight are predicted near shore, and €300/t (~£210/t) offshore, with a potential of 350 PJ_{th} (25 million t dry biomass at >50 t/ha/y dry weight); however, dewatering at sea would be required.

A presentation on the economics of large scale biofuel production was given by Harold Boerrigter based on ECN's slagging EF gasifier, and FT synthesis based on the Shell SMDS plant. ECN sees the requirement for a relatively small number of large scale plants, associated with harbours and integrated with the existing chemical infrastructure, and using current, commercially available technologies. A breakdown of investment costs for a 200 MW_{th} (1,700 bbl/d FT products) scale plant shows the highest proportions for the air separation unit (ASU) oxygen plant (28%) and the Rectisol gas cleaning (22%), with the gasifier at 19%, the FT synthesis 16%, product upgrading 9% and H_2 manufacturing and syngas conditioning 6%. Scaling costs for a number of plants suggest a scale-up factor of 0.7. At 10 MW_{th} the FT fuel product cost is estimated as €40/GJ (~£28/GJ), of which €30 (~£21) is conversion costs. At 10,000 MW_{th} these figures fall to €15/GJ (~£10/GJ) (or €0.55/litre (~£0.38/litre)) and €4 (~£2.80) respectively, for the same biomass and pretreatment costs, though higher transport costs. ECN believes this would be competitive at current ($60/bbl (~£34/bbl)) oil prices.

A.4 WUR (Wageningen Universiteit en Researchcentrum – Wageningen University and Research Centre)

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WUR is a collaboration between Wageningen University, which specialises in the life sciences, Van Hall Larenstein School of Higher Professional Education and a number of research institutes of the Dutch Ministry of Agriculture. WUR has 5,600 staff, 8,500 students and specialises in food and food production, plants and animals, environment and climate and economics and society. Bioenergy, biorefinery, and biobased products are key research areas within the Agrotechnology and Food Sciences Group.

A presentation on WUR's work on microalgae was given by Professor René Wijffels. The theoretical maximum photosynthetic efficiency is 21%, while 16% has been achieved using flat panel reactors. Different reactor designs were described by Prof Wijffels, including flat panels which incorporate dilution of light, tubular reactors which offer large surface area to volume ratio, hybrid flat panel/tubular with stacked array of tubes, and flat panels with high biomass density in which the cells are constantly moved instead of diluting the light, giving a flashing illumination effect on a 0.2 s timescale. The work was motivated to manufacture omega-3 fatty acids and antioxidants for the aquaculture industry, which is limited by the catch of fish for feed for these nutrients.

A presentation was given by Bert Annevelink on work to asses the biomass supply chain and its implications, covering biomass sources, logistics and storage and biofuel production for electricity, heat and transport. Spatial impacts including water demands (quantity and quality), biodiversity, soil (nutrients, erosion, carbon), landscape, climate change, alternative land uses etc are all included. The project has led to a biomass logistics computer simulation (Biologics) and a biomass logistics computer optimisation (Bioloco). Bioloco can optimise on a financial or energetic basis, or work within goals for both. It includes combinations of drying, comminution and transport alternatives, and considers seasonal fluctuations of both supply and demand. It is currently only available for WUR's own use and is intended for strategic planning, rather than day-to-day operations. It is intended to address such questions as optimum choice of biomass feedstock and source, what pretreatments and where they should be performed, optimum scale and location of conversion plants, and the resultant financial and energetic costs of the whole chain. The IEA Bioenergy Assessment Model (BEAM) includes similar elements.

A presentation on the valorisation of lignum for chemicals and products was given by

Richard Gosselink. Lignin (typically 20-30% of biomass) is currently viewed as a waste product and burned; however, it can be converted to phenols. Lignin depolymerisation under supercritical conditions was described.

A presentation on biorefinery processes was given by Professor Sanders. The relative values of heat (€4/GJ ≈ £2.80/GJ), electricity (€22/GJ ≈ £15/GJ), transport fuel (€10/GJ ≈ £6.90/GJ) and bulk chemicals (€75/GJ ≈ £52/GJ), and their fossil raw materials costs – €3 (~£2), €6 (~£4), €8 (~£6) and €30 (~£21)/GJ respectively – were given, showing the justification for integrated chemical production. A processing model in which initial preprocessing is local and small scale (eg farm based, especially removing water to minimise shipping costs) was proposed. This also allows the return of nutrients to the soil. Processing to retain the functionality of functional chemicals, rather than ground up synthesis were felt to be key.

A.5 TNO (Nederlandse Organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek – Netherlands Organisation for Applied Scientific Research)

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TNO is a contract research and consultancy organisation operating in five core areas: quality of life; defence, security and safety; science and industry; built environment and geosciences; and information and communication technology. TNO was established in 1930 to support companies and government, has around 5,000 employees and annual turnover of €550 million (~£380 million) and receives approximately 25% government funding. It also undertakes testing and certification and generates its own IPR which it licenses. In the 1980s it started looking at coal combustion technologies, and in the 1990s oil.

A presentation on hydrothermal processing, including supercritical water gasification (SWG) and hydrothermal upgrading (HTU) of biomass was given by Dr Jan Zeevalkink. SWG uses water at high temperature and pressure (above its critical point) to yield an H_2 rich (60%) product gas from aqueous biomass slurry at typical levels of 10-20% biomass. Use of supercritical ethanol or methanol can allow transesterification of vegetable oils without using water or lye to yield clean biodiesel. HTU typically uses 25% biomass in liquid water at 300-350ºC and 120-180 bar, with a reaction time of 5-20 minutes to yield 45% biocrude, 25% gas (>90% CO_2), 20% water and 10% dissolved organics with a thermal efficiency of 70-90%. The biocrude can be separated into light (50-70%) and heavy fractions by flashing or extraction. The light biocrude contains no minerals, is soluble in organic solvents such as acetone and can be upgraded by hydrothermal deoxygenation (HDO). The heavy fraction solidifies below 80ºC. Shell and Delft University have done some work on upgrading biocrude. They regard it as a cheaper alternative, at higher energetic efficiency than FT, which can be optimised at small scale (though larger than pyrolysis plant). HTU allows the use of high MC organic waste material like sugar beet pulp and onion pulp or domestic waste at low, zero or negative cost. Production costs of the pilot plant (including HDO) are €11-12/GJ (~£8/GJ), though a future (2015) plant would be about €6-7/GJ (~£4-5/GJ), which would be competitive with fossil diesel without subsidy. The capital cost of an HTU plant would be around €50 million (~£34 million), and it would be envisaged that several HTU plants would feed a central HDO plant.

A presentation on flash pyrolysis of biomass and the TNO PyRos technology was given by Professor Gerrit Brem (a part-time professor at the University of Twente). TNO views flash pyrolysis as a simple method for increasing the energy density of biomass by a factor of 4-5 times, decoupling the production and application of pyrolysis oil. Reaction parameters of 500ºC, 1 bar, no added oxygen and a reaction time of around 1 s to avoid cracking give around 70% oil ('liquid wood' containing 20-30% water), 15% gas and 15% char. TNO has looked at a wide range of different reactor designs. The PyRos design is based on a commercial cyclone dust filter operating at 500ºC. Sand is used as a volumetric heat carrier (in combination with a heated wall) and is injected at the top with the biomass in proportion 10:1 sand to biomass. The sand and char drops out of the bottom of the cyclone for reuse. Waste electronics or sewage sludge could also be used as feedstock with modifications to the design. The cyclone reactor allows compact design and quick quenching. It is also very efficient at catching oil aerosols. TNO is looking at replacing some of the sand with zeolite catalyst. Further research will include upgrading the oil and controlling the oil quality and composition within the reactor.

A.6 BTG (Biomass Technology Group BV)

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BTG is an independent private research and consultancy company formed in 1979 that works on technology and project development to increase bioenergy in primary energy supply.

A presentation was given by Dr Wolter Prins on BTG and its biomass pyrolysis process. The pyrolysis technology is based on a rotating cone reactor design with a sand heat carrier developed in the early 1990s at the University of Twente, and further developed subsequently by BTG to give 70% pyrolysis oil, 15% gas (that has been used to run a gas engine) and 15% char. BTG built at 1 MW pilot plant then delivered a 10 MW plant to Malaysia for pyrolysis of oil palm residues. It was installed in April 2005. In this design the feedstock is fed in near the bottom of the unit and carried up by the rotation of the cone. The Malaysian plant is currently operating at half capacity owing to the difficult ('fluffy') nature of the feedstock. It also has problems with sand circulation owing to sticky ash, with oil filtering and with the ash content of the oil. BTG intends to use excess heat for drying feedstock and ash for the soil. Current costs are €6-7/GJ (~£4-5/GJ). There has been an application from Electrabel for co-firing the oil in Holland. Investment in the plant was €3 million (~£2 million), including feeding unit; maximum output is 30 t/d. It has no refractory lining so start-up time is around 4-5 h, allowing 5 d/wk operation. Seasonally running out of feedstock is a current problem.

BTG is also working on an FB gasifier and a reverse flow tar cracking unit for gas cleanup to allow gasification of bio-oil for operation of a gas engine. Successfully injecting bio-oil into an FB can be difficult, and efficiency is relatively low. Incorporation of a catalyst into the FB gasifier allows the temperature to be reduced. BTG is also working on upgrading the bio-oil (decarboxylation and dewatering) to reduce transport costs, and also hydrotreating and partial deoxygenation. It has tried running a standard diesel engine on pure bio-oil (having started on ethanol); however, the standard injectors corroded within 10-15 minutes. Stainless steel replacements work well, though.

Exhibit A.2 *Rotating cone pyrolysis reactor at BTG*

A.7 Choren Industries GmbH

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Choren is a private company set up in the early 1990s (initially in 1990 as UET GmbH), since 1992 for the gasification and refining of organic raw materials for energy. The name is derived from Carbon Hydrogen Oxygen RENewable.

An introduction to the company and its technology was given by Dr Carlhans Uhle. The three phase gasification technology originally came from the old GDR, and yields 35% CO, 35% H_2, 25% CO_2. The yield of FT liquid fuel corresponds to about 4,000 litre/ha, about 3-6 times as much as first generation biodiesel.

Choren currently has an Alpha plant in operation and is working on a Beta plant at 45 MW_{th}, 75,000 t/y biomass (18.5 million litre/y) at 85% capacity and using FT technology from Shell. The Beta plant is expected to be in production by mid 2007; however, this is also only an intermediate stage, and a Gamma plant is planned for 2009/10, and four more by 2015, each yielding 200,000 t/y of fuel, from 1 Mt biomass, sourced from within a 30 km radius of each plant, by which sites will be selected.

At present, Choren is using forestry residues. It can use agricultural residues but cannot at present use 100% straw without modification. Energy crops are not yet seen as necessary.

There is currently a total tax exemption on all biofuels until 2009; however, the new government prefers to stop exemptions and move to an obligation. Until this has been finalised, Choren will not make a decision on future investment, which will be sited where the economic conditions, as well as the feedstock availability, are optimal; however, they require sufficient industrial infrastructure.

Choren buys in oxygen, and currently buys in hydrogen, but does not intend to do this in the long term.

To achieve 20% biofuels in Europe, only 300 Gamma scale plants would be required in the EU.

Choren has tried running a gas engine on the product gas, and is considering CHP to assist cash flow.

Choren buys biomass directly from farmers rather than through brokers, and defines the MC it wants. Very little waste is produced; the ash is used for road building.

Exhibit A.3 *Beta plant under construction at Choren*

A.8 Future Energy GmbH

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Future Energy has been involved in entrained flow gasification for more than 30 years, developing technology from the Deutsches Brennstoffinstitut Freiberg (Freiberg Fuel Research Institute) in the 1970s for gasification of brown coal. The first pilot plant (3 MW_{th}) was commissioned in 1978/9 and has been used with a wide range of feedstocks including coals, sewage and industrial sludges, oils, slurries, chemical wastes and biomass. The technology was commercialised in 1984 (200 MW scale) at Gaskombinat Schwarze Pumpe (GSP – now SVZ Schwarze Pumpe). Future Energy, along with SVZ Schwarze Pumpe, was a member of the Sustec Group; however, the coal gasification business of the Sustec Group (including Future Energy) has since (May 2006) been acquired by Siemens.

A presentation was given by Friedmann Melhose on Future Energy and its GSP and MEGA-GSP entrained flow gasifier technology. The entrained flow gasifier range, with a pressurised water cooling screen, can handle a wide range of feedstocks without pretreatment for coals, heavy oil, chemical residues, or with pretreatment for heterogeneous wastes and biomass. It gives >99% conversion of carbon, the raw syngas is 100% tar free and there is no dioxin or furan formation. It features 2.5-3.5 s reaction time and has low thermal mass so needs only about 1 h start-up time. Operating pressure is 24-40 bar and temperature 1,100-1,600°C for coal, or 40-60 bar and 1,400°C for biomass.

A key feature is the pressurised water cooling screen which runs at 250°C, which is protected by a (13 mm) silicon carbide (SiC) 'ramming mass' layer and a (5.5 mm) layer of solid slag, over which liquid slag at 1,400°C flows. A stable thermal gradient is maintained by monitoring the water temperature and adjusting flow. The cooling screens show operating lifetimes >10 y. The liquid slag flows down into a water quench at the bottom of the reactor where it granulates.

Modifications to the design are necessary for feedstocks with different characteristics, as ash free (<1%) feedstock requires a refractory lining as there is insufficient slag to protect the cooling screen. High (>20%) salt content feedstock also requires modified design. The reactor design allows good mixing from back flow, and the cooling screen design makes incorporation of additional apertures much easier than with a refractory lining.

Biomass gasification yields 27% H_2, 50% CO, 14% CO_2, 6.3% N_2 (from the carrier gas), so a 350°C CO shift stage, as well as separation of the sour gases from the syngas, are required. Using recycled CO_2 as carrier gas, purging etc, allows the N_2 level to be reduced; also a high density feedstock flow to minimise carrier gas. The granulated slag produced is of very similar chemical constituency to the local native rock. Biomass has to be fed as a bio-char/oil slurry; fast pyrolysis bio-oil is ideal, although some initial work on torrefaction and pulverisation of biomass has been done with ECN.

Large scale operation is required for biomass (eg 1,000 MW_{th}), suggesting a centralised gasifier, sited at a refinery, with a few distributed, fast pyrolysis units for local

Exhibit A.4 *Top of entrained flow gasifier at Future Energy*

feedstock processing. Biomass could be supplemented seasonally with fossil feedstock.

The total efficiency of the whole process from biomass to fuel is 15-20%.

Future Energy has an in-house test facility to perform experiments on feedstock preparation, optimisation of gasification conditions and reactor design.

A.9 TUB-F (Technische Universität Bergakademie Freiberg – Technical University Bergakademie Freiberg)

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TUB-F is the University of Mining and Technology. It was formed as the Saxony State Lignite Research Foundation in 1918 and has 4,616 students. The IEC is the largest Institute. It was originally involved in studying the gasification of brown coal, but has been looking at gasification of biomass in the last few years.

A presentation on a number of activities was given by Professor Bernd Meyer. TUB-F is the coordinator of the DeZeV (Deutsches Zentrum für Vergasungstechnik – German Centre for Gasification Technology), of which Choren, Future Energy and Sustec Schwarze Pumpe are also members. IEC is working on a commercial, HTW, 10 bar FB gasifier combined with a Lurgi MtSynfuel process methanol synthesis plant for the production of 15,000 t/d of methanol as an intermediary for 5,438 t/d diesel, 685 t/d gasoline (plus 579 t/d light products) using a zeolite catalyst. It sees this as a decentralised biomass preconditioning step with methanol as energy store/vector, with fuel synthesis in a large, central refinery.

IEC is also working on a 1,000 MW_e IGCC (integrated gasification combined cycle) generating demonstration plant with E.ON, featuring polygeneration of power, basic chemicals and fuels, based on (extremely cheap) brown coal. It sees centralised gasification, with decentralised power generation, as optimum and is also working on biomass gasification.

Another project is HP-POX (high pressure partial oxidation), initially of oil and gas residues, and also biomass pyrolysis oil and char slurries, with FZK supplying the bio-oil slurries. This operates at 100 bar, 1,200-1,500°C, 5 MW_{th}, 500 litre/h oil and produces methanol directly. Formic acid and acetic acid are also formed, and IEC is looking at slagging, fouling corrosion, and the paths of heavy metals and impurities.

Work is being done on partial oxidation of aromatic hydrocarbons, thermal and catalytic cracking of crude oil and FT products, and hydrogenation of vegetable oils by Dr Mathias Olschar. IEC believes the economics of the methanol route to diesel fuels is comparable with FT, and offers some advantages and some disadvantages. About 10-20% of IEC's research effort is biomass related, with about 80% still on coal.

A.10 SVZ (Sekundärrohstoff-Verertungszentrum Schwarze Pumpe) GmbH

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SVZ, formed on the site of a brown coal gasification plant, was part of the (Swiss) Sustec Group. However, in May 2006 it was bought by (German) Siemens. It has been an independent company since 1995, has 260 employees, and gasifies 400,000 t/y solid and 50,000 t/y liquid waste in 10 gasifiers to run a 44.5 MW_e gas turbine, a 30 MW_e steam turbine and a 100,000 t/y methanol plant.

A presentation on SVZ was given by Dr Lutz Picard. SVZ was established on the site of the Schwarze Pumpe gasification plant that produced town gas from lignite briquettes from 1964. There are now three types of gasifiers on site: two GSP entrained flow gasifiers, seven rotating grate FDV (Lurgi) gasifiers, and one BGL slagging gasifier. These handle used plastics, including WEEE, sewage sludge, contaminated wood, treated domestic waste, pellets from tar and sewage sludge, shredder residue, contaminated oils and oil/water mixtures, and solvents. High levels of impurities can be accepted because of the high operating temperatures.

After gas cleaning, the output of the BGL gasifier is 64% H_2, 19.6% CO, 6.3% CO_2, 8.4% CH_4 and 1.4% N_2. The syngas constituents can be adjusted by incorporation of a coal component. All wastes are pelleted or briquettes.

The methanol plant was added in 1995 and operates at 45 bar and 250ºC with a copper catalyst. The methanol is sent out for a wide range of applications, including to DaimlerChrysler for its fuel cell car development.

Synthetic biofuels are of increasing interest, and SVZ expects FT fuel production to start in the next 2-3 years, though probably derived from coal. SVZ is retaining the same gasification capacity but gradually replacing old plant as part of a €30 million (~£21 million) investment. It receives a gate fee of up to €150/t (~£100/t) for waste handling.

Exhibit A.5 *Part of SVZ site*

A.11 FZK (Forschungszentrum Karlsruhe)

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FZK undertakes precommercial R&D in areas of public interest. It is a part of the Helmholtz Association of National Research Centres and undertakes research in five areas – structure of matter; earth and environment; health; energy; and key technologies – and runs 11 programmes. FZK has more than 3,800 employees, with 1,420 scientists, and it has an annual budget of €406 million (~£280 million), of which €75 million (~£52 million) is self generated. State ownership is 90% Federal and 10% the State of Baden-Württenberg.

FZK collaborates with universities and industry in Germany and internationally, and with other Helmholtz Centres. It includes a number of institutes, including the Institute for Technical Chemistry (ITC), which includes the Thermal Waste Treatment Division (ITC-TAB) and the Chemical-Physical Processing Division (ITC-CPV).

An introduction was given by Dr Helmut Seifert to the Thermal Waste Treatment Division (ITC-TAB). This handles different wastes, with a range of thermal processes including combustion (including the TAMARA combustion system), pyrolysis (including the THERESA rotary kiln and Haloclean pyrolysis units) and gasification, and covers a range of aspects including thermal processes, material flows, aerosols and particles, and pyrolysis and gas treatment.

A presentation was given by Dr Andreas Hornung of ITC-TAB on the Haloclean enhanced low temperature pyrolysis process. It uses a screw drive and relatively long timescale pyrolysis with chopped, milled or pelletised feedstock with steel balls for heat transfer. The temperature is chosen to optimise solid, oil or gas proportions, as required. One application is for the production of activated carbon (eg for water purification) combined with electricity generation where there is abundant waste biomass, such as in areas of olive production around the Mediterranean. Gas treatment following gasification is a major topic. The intention is to install a three stage line at FZK with a fast pyrolysis unit, gasifier and gas treatment. Because of the long residence time, tars are broken down and do not leave the system; however, the phenol and water levels are too high for the product gas to be used directly in a gas engine without gas cleaning and a condenser. There are currently problems with using food crops as feedstock in Germany as it is illegal to burn them, though rape is feed, not food. A new building is currently under construction to house a new fast pyrolysis unit which will use sand for heat transfer. It will cost €22 million (~£15 million) including a gasifier and synthesis unit (probably methanol).

Exhibit A.6 *Dr Andreas Hornung explaining the Haloclean screw pyrolysis reactor at FZK*

A presentation on BTL work was given by Professor Edmund Henrich of the Chemical-Physical Processing Division (ITC-CPV). They are working with a GSP entrained flow gasifier, oxygen blown to minimise nitrogen dilution, operating at 50-100 bar, 1,200ºC in slagging mode and with a residence time of a few seconds. They are considering feedstock supply strategies for a 5 GW scale central syngas plant with local pyrolysis plants, comparing use of road and rail. They conclude that a combination of tractor (up to 30 km) and rail is far more energetically efficient than truck haulage. Different pyrolysis reactor types have been studied and the well established twin screw design (LR Lurgi-Ruhrgas) chosen. The FZK system works with a biomass throughput of 5-10 kg/h; the only heating is through the sand heat carrier, though other heat carriers are being studied, including steel shot and SiC as some sand can be carried out with gas. In experiments with gasifying slurries at Future Energy with their 3-5 MW EF gasifier operating at 26 bar and 1,200-1,600ºC, they have achieved about 45% CO and 25% H_2 with a suitable slurry and atomisation. They need a 2:1 liquid to char ratio because of 50-80% porosity of the char. Anything that can be pumped and with a heating value >10 MJ/kg can be used. They are also working with the 130 MW_{th} GSP gasifier at Schwarze Pumpe and with Lurgi on a 20-25 t/h pyrolysis plant on the FZK site looking at methanol or DME output. They are also looking at methods for estimating capital investment and simplified estimation of total production costs.

A presentation on gasification of wet biomass was given by Dr Nikolaos Boukis of ITC-CPV. The technique employs biomass in supercritical water at above 250 bar at 600ºC (much higher temperature than HTU process) with a residence time of around 1 minute for the treatment of sewage sludge, 'wine trash' and other wet organic wastes. The pilot plant VERENA employs a 100 kg/h high pressure pump at 350 bar, a preheater fired with flue gas, and a main heat exchanger for heating prior to the 35 litre reactor to 700ºC. The feedstock must be ground to <1 mm. Product gas from corn silage with 9.2% dry matter by weight consists of 45% H_2, 37.6% CH_4, 9.3% C_2H_6 with low levels of other hydrocarbons, CO, CO_2 and N_2, with a total carbon yield of 90% and thermal efficiency of 80%. Sulphur, nitrogen and chlorine leave the process with the aqueous effluent. The product gas is produced, and maintained, at high pressure. Work is continuing to address plugging from salt deposits, corrosion and yield and to optimise reaction temperature, H_2:CH_4 ratio, reliability and economics. Work to operate at a lower temperature (~350ºC) using a zirconia catalyst has led to their CATLIQ process, which is being commercialised by a Danish company.

A.12 Öko-Institut eV

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Öko-Institut (Institut für Angewandte Ökologie – Institute for Applied Ecology) was founded in 1977 as a non-profit environmental research institute with income from project based funding. It is sponsored by the German Environment Ministry, has a turnover around €7 million (~£5 million) and strives to make its findings as widely disseminated as possible. It has more than 100 staff from a range of disciplines at three locations.

A presentation on their work on sustainable biomass energy strategies for Germany was presented by Dr Uwe Fritsche. The Öko-Institut has developed GEMIS (Global Emission Model for Integrated Systems) to analyse the needs of the biomass energy sector. This model incorporates an integrated analysis of 99.5% of all biomass flows in Germany and 95% of biomass flows in the EU, current technology options, together with technology learning curves, analysis of land use implications, human labour flows (direct and indirect employment) and consideration of the demands of all sectors and environmental constraints. It makes use of transparent, reviewed, freely available data.

GEMIS starts with energy use scenarios and works back to the resource (feedstock) use implications. The model and database of data used in the model is freely available on the web via www.gemis.de. The model includes both economic and carbon benefits of scenarios, and interlinkages between markets are factored in, though carbon trading is not. Wage costs are assumed to be equilibrated across the EU-25 after 2010, though not before, while land use cost differentials remain. Financial (and carbon) implications of geographical siting of parts of a project (from Germany's perspective) can be assessed using the model.

At present, publicly available 'typical' technology performances are used, though there is work to incorporate data from the RENEW Project on specific technologies. Options such as 'double cropping' are available. Lignocellulose derived ethanol is not included in the model. Life cycle comparisons of biomass technologies for electricity, heat and transport can be compared.

Assumptions for land availability include figures for nature protection, organic farming and set-aside. Demand side efficiency gains are also included, and considered a very important component. Cogeneration is seen as key, requiring heat users, and co-firing seen as cost effective with CO_2 trading.

The project can be used to analyse trade-offs between scenarios, effects over time and inform policy recommendations.

Appendix B

MISSION TEAM AND ITP

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Johnson Matthey Catalysts Division has three business units, of which Process Catalysts and Technologies provides catalysts and refining technologies to many market sectors, including GTL processing. It offers a portfolio of products, services and manufacturing capability for syngas generation, gas treatment, FT synthesis, hydroprocessing and hydrogen production.

Dr David Bown
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A major international project management, services and process engineering company, AMEC Oil & Gas is involved in the implementation of new technologies, such as GTL and CTL. AMEC has a long-standing relationship with Syntroleum, and has experience with the design and engineering of licensed Syntroleum GTL technology on a number of projects for the production of synthetic liquid fuels from natural gas and coal.

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Professor Tony Bridgwater is founder of the Bio-Energy Research Group (BERG) at Aston University which carries out research into thermal biomass conversion including fast pyrolysis of biomass and solid waste and advanced gasification and bio-energy systems analysis, design and evaluation.

BERG is a member of the EPSRC SuperGen Biomass and Bioenergy project, the European Bioenergy Network of Excellence and the European ThermalNet which includes the PyNe Biomass Pyrolysis Network, GasNet for gasification technologies and CombNet for combustion.

Craig Jamieson
Next Generation
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Next Generation is a start-up company formed as spin-out from research into mass production of microalgae for fuels and chemicals etc. The company was invited to be the UK's first and only representative on the IEA International Biofixation Network, which brings together researchers of microalgae for CO_2 mitigation.

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BP International is one of the world's largest energy companies. As well as its traditional petrochemical businesses, it invests heavily in a wide range of alternative and RE technologies.

Bob Saunders is part of the BP International Future Fuels Group looking at next generation fuels. He is Chair of the BSI Committee on Liquid Fuel Specification, a member of the Low Carbon Vehicle Partnership (LCVP) Fuels Working Group and a member of the Renewable Energy Association (REA) Renewable Transport Fuels Group. He is a past secondee to DTI during initial discussions on the Renewable Transport Fuels Obligation (RTFO).

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The National Non-Food Crops Centre (NNFCC) provides an independent source of information on the use and implementation of non-food crop products and technologies in the UK. It disseminates scientific and technical information as widely as possible to help facilitate technology uptake. NNFCC covers all aspects of the use of plant derived materials, derivatives and by-products for non-food purposes, including for energy.

Nicola Yates
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Rothamsted Research offers scientific R&D of agricultural crops for enhanced quality and production, more sustainable production, increased environmental benefits, protection and remediation of soil quality, enhancement of biodiversity and new, sustainable products and applications for crops. The development of improved strains of energy crops for combustion and other energy applications is one key area of research.

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For 80 years, Caterpillar Inc has been building the world's infrastructure and, in partnership with Caterpillar dealers, is driving positive and sustainable change on every continent.
A Fortune 100 company, Caterpillar is a technology leader and the world's leading manufacturer of construction and mining equipment, diesel and natural gas engines and industrial gas turbines. In 1998 Caterpillar acquired the British based Perkins Engine Company. Caterpillar Engine Research Europe is located at Perkins's Peterborough site.

Dr Geoff Hogan
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ERIN Research Ltd is a small, specialised company that undertakes information gathering and activities to promote technology transfer in fields of low carbon and RE technologies and sustainable materials and technologies. It aims to assist UK organisations in both the industrial and academic sectors to learn about the development and use of sustainable, low carbon and RE technologies, and to share best practice between experts around the world.

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The DTI Global Watch International Technology Promoter (ITP) network assists UK companies to identify overseas technology partners, develop or transfer technologies, products, processes or management practices.

Nicola Smoker is ITP for Europe specialising in environmental, sustainable energy and process technologies.

Appendix C

CURRENT UK BIOFUEL SUPPORT INSTRUMENTS

Renewable Transport Fuels Obligation (RTFO)

The RTFO was announced in November 2005 as a mechanism that will require that 5% (by volume) of all UK transport fuels sold on UK forecourts must come from renewable sources by 2010. This would be a 20 fold rise on current sales. The RTFO will be introduced in early 2008. It will work by a system of certification by which oil companies will receive certificates from the scheme administrator for biofuel sold. These certificates will be tradable, and work in a similar way to the current system of ROCs (Renewables Obligation Certificates) for electricity generation, by which companies that exceed their statutory obligation may sell additional certificates to companies that have not met their obligation.

The UK RTFO reflects the EU Biofuels Directive 2003/30/EC of May 2003 that sets indicative targets for the sale of biofuels at 2% by energy content for 2005 and 5.75% by 2010. The UK figure of 5% by volume is equivalent to about 3.8% by energy content.

The RTFO is predicted by the Government to lead to 1 million t of CO_2 emission saving in 2010.

Reduced duty rate for biodiesel

The UK Budget 2001 announced a new duty rate for biodiesel set at 20 pence per litre below that for ULSD, and this was introduced in the 2002 Budget. In Budget 2003 a duty rate for bioethanol of 20 pence per litre below that of unleaded petrol was announced and introduced in January 2005. These duty differentials are guaranteed to stay in place until 2007-8.

This measure has resulted in current sales of biofuels of about 10 million litres per month, about 0.25% of all road fuel sales.

Enhanced Capital Allowance (ECA) for biofuels production plant

In the 2005 Pre-Budget Report the Government announced that, subject to state aids approval, it would go ahead with a 100% first year allowance for biofuels plant that meet certain qualifying criteria and which make a good carbon balance inherent in the design, to help support innovation. This would allow companies investing in such qualifying biofuel production plant to write off 100% of the capital cost of the investment against their taxable profits for the period during which they make the investment, assisting cash flow and shortening the payback period.

Appendix D

GLOSSARY

~	approximately
≈	approximately equal to
<	less than
>	greater than
%	per cent
€	euro (€1 ≈ £0.69 ≈ $1.2)
£	pound sterling (£1 ≈ €1.45 ≈ $1.75)
$	US dollar ($1 ≈ £0.57 ≈ €0.83)
µm	micrometre = 10^{-6} m
ANL	Argonne National Laboratory (DOE, USA)
are	= 100 m^2
ASTM	American Society for Testing and Materials (USA)
ASU	air separation unit
atm	atmosphere ≈ 1.013 bar = 1.013 x 10^5 Pa
BABFO	British Association for Bio Fuels and Oils (now part of REA)
bar	= 10^5 Pa
bbl	barrel
BEAM	BioEnergy Assessment Model (IEA)
BERG	Bio-Energy Research Group (Aston University, UK)
BGL	British Gas Lurgi
BR	Brazil
BSI	British Standards Institution
BTG	Biomass Technology Group BV (Netherlands)
BTL	biomass to liquid
°C	degrees Celsius
C	carbon
C_2H_6	ethane
C_3H_8	propane
CAP	Common Agricultural Policy (EU)
CCS	carbon capture and storage
CEN	Comité Européen de Normalisation – European Committee for Standardization (HQ Belgium)
CFB	circulating fluidised bed
CFPP	cold filter plugging point
CH_4	methane
CHP	combined heat and power
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CONCAWE	Conservation of Clean Air and Water in Europe (association, HQ Belgium)
COS	carbonyl sulphide
CPV	Chemical-Physical Processing Division (ITC, FZK)

cP	centipoise = 0.01 P = 0.001 N s/m^2 (Pa s)
CTL	coal to liquid
d	day = 86,400 s
DDGS	distillers dried grains with solubles
DE	Germany
Defra	Department for Environment, Food and Rural Affairs (UK)
DeZeV	Deutsches Zentrum für Vergasungstechnik – German Centre for Gasification Technology (TUB-F)
DfT	Department for Transport (UK)
DIN	Deutsches Institut für Normung – German Institute for Standardization
DME	dimethyl ether
DOE	Department of Energy (USA)
DTI	Department of Trade and Industry (UK)
d/w	dry weight
EC	European Commission
ECA	enhanced capital allowance
ECN	Energieonderzoek Centrum Nederland – Energy Research Centre of the Netherlands
Ed	editor
EEA	European Environment Agency (HQ Denmark)
EF	entrained flow
EN	European Norm (standard)
EPSRC	Engineering and Physical Sciences Research Council (UK)
ETBE	ethyl tertiary butyl ether
EtOH	ethanol
EU	European Union
EU-25	the 25 member countries of the EU
EUCAR	European Council for Automotive R&D (HQ Belgium)
F	fax
FAME	fatty acid methyl ester
FB	fluidised bed
FCC	fluid catalytic cracking
FDV	festbettdruckvergasung – fixed bed high-pressure gasification
FFV	flexible fuel vehicle
FT	Fischer-Tropsch (process)
FZK	Forschungszentrum Karlsruhe (Germany)
g	gram = 0.001 kg
GDR	(former) German Democratic Republic/East Germany
GEMIS	Global Emission Model for Integrated Systems (developed by Öko-Institut)
GHG	greenhouse gas
GJ	gigajoule = 10^9 J
GSP	Gaskombinat Schwarze Pumpe
GTL	gas to liquid
h	hour = 3,600 s
H	hydrogen (atomic)
H_2	hydrogen (molecular/gas)
H_2S	hydrogen sulphide
ha	hectare = 100 are = 10,000 m^2

HCCI	homogeneous charge compression ignition
HCl	hydrogen chloride
HCN	hydrogen cyanide/hydrocyanic acid
HDO	hydrothermal deoxygenation
HGCA	Home-Grown Cereals Authority (UK)
HHV	higher heating value
HMRC	HM Revenue & Customs (UK)
HP POX	high pressure partial oxidation
HQ	headquarters
HTU	hydrothermal upgrading
HTW	High Temperature Winkler (process)
IC	internal combustion
ICE	internal combustion engine
ICCEPT	Imperial College Centre for Energy Policy and Technology (UK)
IEA	International Energy Agency (HQ France)
IEC	Institut für Energieverfahrenstechnik und Chemieingenieurwesen – Institute of Energy Process Engineering and Chemical Engineering (TUB-F)
IGCC	integrated gasification combined cycle (gas turbine)
IPCC	Intergovernmental Panel on Climate Change (UNFCCC)
IPR	intellectual property right(s)
ISBN	International Standard Book Number
ITC	Institute for Technical Chemistry (FZK)
ITP	(1) integrated thermal processing; (2) International Technology Promoter (network, DTI)
J	joule = 1 N m = 1 W s
JRC	Joint Research Centre (EC)
JV	joint venture
kg	kilogram
kgoe	kg of oil equivalent = 42 x 10^6 J = 42 MJ
km	kilometre = 1,000 m
kt	kilotonne = 1,000 t = 10^6 kg
kW	kilowatt = 1,000 W
kWh	kilowatt-hour = 1,000 Wh = 3.6 x 10^6 J = 3.6 MJ
L	left
LCA	life cycle assessment
LCVP	Low Carbon Vehicle Partnership (UK)
LHV	lower heating value
LPG	liquified petroleum gas
m	metre
m^2	square metre
m^3	cubic metre
MC	moisture content
MJ	megajoule = 10^6 J
mm	millimetre = 0.001 m
MOGD	methanol to olefins, gasoline and diesel
MSW	municipal solid waste
Mt	megatonne = 10^6 t = 10^9 kg
MTBE	methyl tertiary butyl ether

MTG	methanol to gasoline
Mtoe	million tonne (megatonne = Mt = 10^6 t) of oil equivalent = 42 x 10^{15} J = 42 PJ
MW	megawatt = 10^6 W
MW_e	megawatt (electrical output)
MW_{th}	megawatt (thermal output)
NNFCC	National Non-Food Crops Centre (UK)
N	(1) nitrogen; (2) newton = 1 kg m/s^2
N_2	nitrogen
NH_3	ammonia
Nm^3	normal (0ºC, 1 atm) cubic metre
NO_x	nitrogen oxide(s)
odt	oven dried tonne
p	pence
P	poise = 0.1 N s/m^2 (Pa s)
Pa	pascal = 1 N/m^2
PAH	polycyclic aromatic hydrocarbon
pH	potential of hydrogen (measure of acidity or alkalinity)
PISI	port injection spark ignition
PJ	petajoule = 10^{15} J
PJ_{th}	petajoule (thermal output)
PL	Poland
PO	Post Office
pp	pages
ppm	parts per million
Q1, Q2…	first quarter, second quarter… (of year)
R	right
R&D	research and development
RCEP	Royal Commission on Environmental Pollution (UK)
RDF	refuse derived fuel
RE	renewable energy
REA	Renewable Energy Association (UK)
RME	rape methyl ester
ROC	Renewables Obligation Certificate (UK)
RSPO	Roundtable on Sustainable Palm Oil (Secretariat: Malaysia)
RTF	renewable transport fuel
RTFO	Renewable Transport Fuels Obligation (UK)
s	second
S&T	science and technology
SAE	Society of Automotive Engineers (USA)
SCR	selective catalytic reduction
SiC	silicon carbide
SMDS	Shell Middle Distillate Synthesis (process, Shell)
SME	small and medium sized enterprise
SNG	synthetic natural gas
spp	species
SO_2	sulphur dioxide
SRC	short rotation coppice
SRF	(1) solid recovered fuel; (2) short rotation forestry

SVZ	Sekundärrohstoff-Verwertungszentrum Schwarze Pumpe (Germany)
SWG	supercritical water gasification
syngas	synthesis gas
t	tonne (metric ton) = 1,000 kg
T	telephone
TAB	Thermal Waste Treatment Division (ITC, FZK)
tC	tonne of carbon
TGA	thermogravimetric analyser
Tekes	Teknologian Kehittämiskeskus – Finnish Funding Agency for Technology and Innovation
TNO	Nederlandse Organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek – Netherlands Organisation for Applied Scientific Research
toe	tonne of oil equivalent = 42 x 10^9 J = 42 GJ
TUB-F	Technische Universität Bergakademie Freiberg – Technical University Bergakademie Freiberg (Germany)
TWh	terawatt-hour = 10^{12} Wh
UK	United Kingdom
ULSD	ultra low sulphur diesel
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US(A)	United States (of America)
UVO	used vegetable oil
VOC	volatile organic compound
vol	volume
VTT	Valtion Teknillinen Tutkimuskeskus – Technical Research Centre of Finland
vs	versus
W	watt = 1 J/s
WBCSD	World Business Council for Sustainable Development (HQ Switzerland)
WEEE	waste electrical and electronic equipment
Wh	watt-hour = 3,600 J
WID	Waste Incineration Directive (EC)
wk	week
WRAP	Waste and Resources Action Programme (UK)
wt	weight
WUR	Wageningen Universiteit en Researchcentrum – Wageningen University and Research Centre (Netherlands)
y	year

Appendix E

SOME FIGURES AND CONVERSION FACTORS

Fuel	Lower heating value (MJ/kg)	Cetane number	Density at 15ºC (kg/m^3)	bbl/t
Fossil gasoline (EN228)	44	–	730	8.6
Fossil diesel (EN590)	42.8	>49	820-845	7.6-7.3
Synthetic diesel	40	73-81	740	8.5
Ethanol	27.0	–	789	7.9
FAME (EN14214)	37	>51	860-900	7.3-7.0
Woody biomass (dry)	19-22	–	500-700	–

Exhibit E.1 Properties of selected fossil fuels and biofuels

	MJ	GJ	kWh	toe
MJ	1	10^{-3}	0.278	24×10^{-6}
GJ	1,000	1	278	0.024
kWh	3.6	0.0036	1	86×10^{-6}
toe	42,000	42	11,700	1

Exhibit E.2 Conversion factors for selected units of energy

Appendix F

LIST OF EXHIBITS

Other DTI products that help UK businesses acquire and exploit new technologies

Grant for Research and Development – is available through the nine English Regional Development Agencies. The Grant for Research and Development provides funds for individuals and SMEs to research and develop technologically innovative products and processes. The grant is only available in England (the Devolved Administrations have their own initiatives).
www.dti.gov.uk/r-d/

The Small Firms Loan Guarantee – is a UK-wide, Government-backed scheme that provides guarantees on loans for start-ups and young businesses with viable business propositions.
www.dti.gov.uk/sflg/pdfs/sflg_booklet.pdf

Knowledge Transfer Partnerships – enable private and public sector research organisations to apply their research knowledge to important business problems. Specific technology transfer projects are managed, over a period of one to three years, in partnership with a university, college or research organisation that has expertise relevant to your business.
www.ktponline.org.uk/

Knowledge Transfer Networks – aim to improve the UK's innovation performance through a single national over-arching network in a specific field of technology or business application. A KTN aims to encourage active participation of all networks currently operating in the field and to establish connections with networks in other fields that have common interest.
www.dti.gov.uk/ktn/

Collaborative Research and Development – helps industry and research communities work together on R&D projects in strategically important areas of science, engineering and technology, from which successful new products, processes and services can emerge.
www.dti.gov.uk/crd/

Access to Best Business Practice – is available through the Business Link network. This initiative aims to ensure UK business has access to best business practice information for improved performance.
www.dti.gov.uk/bestpractice/

Support to Implement Best Business Practice – offers practical, tailored support for small and medium-sized businesses to implement best practice business improvements.
www.dti.gov.uk/implementbestpractice/

Finance to Encourage Investment in Selected Areas of England – is designed to support businesses looking at the possibility of investing in a designated Assisted Area but needing financial help to realise their plans, normally in the form of a grant or occasionally a loan.
www.dti.gov.uk/regionalinvestment/

The DTI Global Watch Service provides support dedicated to helping UK businesses improve their competitiveness by identifying and accessing innovative technologies and practices from overseas.

Global Watch Information
Global Watch Online – a unique internet-enabled service delivering immediate and innovative support to UK companies in the form of fast-breaking worldwide business and technology information. The website provides unique coverage of UK, European and international research plus business initiatives, collaborative programmes and funding sources.
Visit: www.globalwatchservice.com

Global Watch magazine – distributed free with a circulation of over 50,000, this monthly magazine features news of overseas groundbreaking technology, innovation and management best practice to UK companies and business intermediaries.
Contact:
subscriptions@globalwatchservice.com

UKWatch magazine – a quarterly magazine, published jointly by science and technology groups of the UK Government. Highlighting UK innovation and promoting inward investment opportunities into the UK, the publication is available free of charge to UK and overseas subscribers.
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Global Watch Missions – enabling teams of UK experts to investigate innovation and its implementation at first hand. The technology focused missions allow UK sectors and individual organisations to gain international insights to guide their own strategies for success.
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