DTI New and Renewable Energy Programme

EXECUTIVE SUMMARY TO:

TECHNOLOGY STATUS REVIEW AND CARBON ABATEMENT POTENTIAL OF RENEWABLE TRANSPORT FUELS IN THE UK

B/U2/00785/REP
URN 03/982

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First Published 2003

dti
Department of Trade and Industry

Executive Summary

Objectives

This study reviews the technology status for the production of renewable transport fuels (RTFs), discusses the possible progression in technologies required for the production of increasing quantities and different types of RTFs, and analyses the costs of the different RTF options and their potential contribution to reducing greenhouse gas emissions from the UK transport sector.

Introduction

The primary drivers behind introducing RTFs into the UK are to: reduce transport sector dependency on non-renewable fuels; reduce GHG emissions from transport fuel chains; reduce the impact on air quality and health of transport fuel use; improve energy security in the transport sector; and contribute to rural development through domestic production of biomass-based fuels. A market for RTFs exists today based on ethanol from the fermentation of sugar and starchy crops and biodiesel from oil crops. The market for these fuels has developed mainly as a result of air quality and energy security issues, and to support the agricultural sector. Hence, ethanol and biodiesel use, mainly blended with petrol and diesel, respectively, is common in several countries (e.g. the US, Brazil, France and Germany). It is estimated that 25 Billion litres (Bl) of bioethanol for fuel and about 3 Bl of biodiesel were consumed globally in 2002 (Chapter 2). However, the contribution of RTFs remains very small in relation to the global energy use in road transport. Globally, the market for RTFs, especially bioethanol as a fuel oxygenate, is showing strong signs of growth in response to national programmes stimulated by air quality, global warming, energy security and rural development agendas. In particular, mitigating global warming may require a significant contribution from renewable transport fuels. Interest is also increasing from industry and policy makers in advanced technologies for the production of biodiesel and bioethanol, Fischer-Tropsch and hydrolysis based processes, respectively, and in renewable hydrogen from renewable electricity and biomass. These could deliver larger quantities of RTFs compared to traditional biodiesel and bioethanol routes based on efficiency and resource base considerations.

Renewable energy potential

The UK potential for renewable transport fuels production is large (Chapter 3), as illustrated in table E1. Assuming a conversion efficiency to transport fuel of 50%, UK renewable resources could provide about 40% of current UK transport energy consumption (about 55% of road transport energy consumption).

However, other energy end-uses such as electricity and heat, would also be competing for the renewable energy resources, with trade-offs in terms of economics and the environment that need to be carefully addressed. Also, given the finite availability of renewable resources and the competition for alternative uses, efficiency in energy use for transport will be paramount to its sustainability.

Table E1: Summary of indicative practical energy potentials from the different renewable energy resources.

Resource	Practical potential (PJ)	Share of primary UK transport energy (2001) [a,b] (%)
Biomass resources		
Energy crops[c]	360	14%
Residues	400	16%
Waste vegetable oils	10	0.4%
MSW	370	15%
Direct renewable electricity resources		
Wind offshore	360	14%
Wind onshore	290	12%
Wave	180	7%
Tidal	7	0.3%
Hydro	10	0.4%
Photovoltaic	130	5%
Total	2117	84%

a – primary transport energy in the UK (2001) = 54.9 Mtoe (2.51 EJ). DTI, 2002.
b – values do not account for conversion of the resource to potential RTFs. The actual contribution of RTFs would then be lower.
c – energy crops grown on 2 Mha and achieving annual yields of 10 oven dry tonnes per ha.

RTF options and fuel chains

The diversity of options for producing transport fuels from renewable resources is very wide. In total, a realistic sub-set of 88 fuel chains has been identified for the UK, resulting in the production of eight different end-fuels from a range of resources and conversion technologies. These end-fuels are: bioethanol, biodiesel, methanol, hydrogen, DME (di-methyl ether), biogas, bio-oil and electricity.

Of the 88 chains, there are potentially 21 chains for hydrogen production, 12 for ethanol and 10 for biodiesel. The chains chosen are those chains that are at an advanced R&D stage, near-market or mature, and include both biomass and non-biomass renewable energy-based routes of relevance to the UK. However, many more potential chains exist and surprise technologies and pathways cannot be ruled out. The eight potential ‘end-fuels’ highlighted are also a simplification as a number of them are potential intermediaries in the production of other end-fuels; e.g. all the end fuels could be used to produce electricity or hydrogen.

Thirteen renewable transport fuel chains were chosen for detailed evaluation (Chapter 5 and Annexes 1 and 2) following consultation with a range of stakeholders (Annex 3), and extensive literature reviews were carried out in order to assess the technology status and obtain data for each stage in the chain to be evaluated (Chapter 4). The normalisation unit on which the comparison of economic, energy and environmental parameters across different fuel chains is based is a ‘GJ of end-fuel’. Costs, energy inputs, and CO2 equivalent emissions are calculated for the full fuel chains (well-to-tank) and for each of their main stages:

1. production of feedstock or primary energy carrier;
2. transport of feedstock or primary energy carrier to conversion unit(s);
3. conversion of feedstock or primary energy carrier to end-fuel;
4. distribution of end-fuel to refuelling station.

Direct energy inputs and CO2 emissions associated with the different stages of the fuel chain are considered. Indirect energy inputs and CO2 emissions are considered only in a few cases, e.g. agro-chemical inputs to crops, where the contribution is estimated to be significant.

Several RTF chains result in co-products at various stages of the chain. Base case calculations do not consider allocation of costs, energy inputs and CO2 emissions to co-products. This approach has been adopted because of the uncertainty associated with both the methodology to be used in accounting for co-product credits and in the data available to carry out a co-product allocation. In practice, the importance of co-products can only be ascertained when a commercial scale industry is in place and good time series data is available for end uses of co-products, including possible substitution effects of the co-product. However, the influence of possible revenue from co-products and the allocation of energy inputs and CO2 emissions to co-products could have substantial beneficial impacts as discussed in the main text of the report.

Because renewable supply options for the production of transport fuels are diverse and generally less commercially mature than the conventional alternatives, the parameters used in the assessment of the fuel chains are presented in a 'low' to 'high' range of values that reflect the variety of the fuel chain options and the uncertainty in knowledge. It must be noted that a 'low' value for one parameter does not correspond to the 'low' value of another parameter, for example, the 'low' cost value does not necessarily correspond to the 'low' GHG value. A detailed discussion of the ranges of values is also provided in the main text of the report.

The 'well-to-tank' comparison does not consider differences in conversion efficiencies between different RTFs and conventional fuels once on-board the vehicle (well-to-wheel). The on-board conversion efficiency could have a significant influence in comparing the costs, energy inputs, and CO2 equivalent emissions of different fuel chains and, therefore, would need to be considered as part of a more exhaustive comparison than provided here.

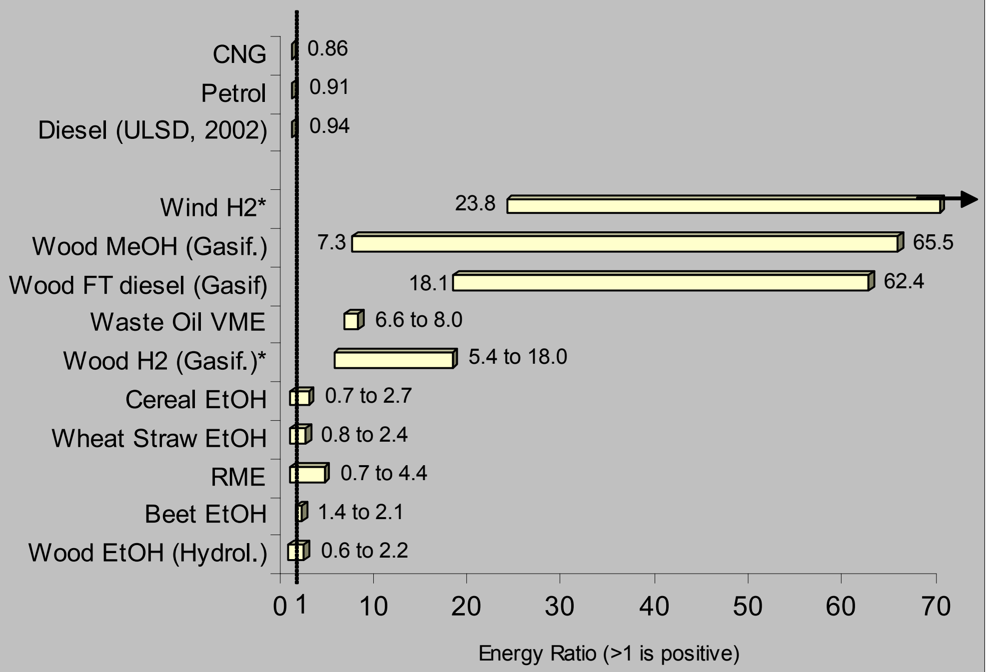
Full fuel chain summaries, a breakdown of the calculations for the different stages of the fuel chains, and the assumptions underlying the calculations are provided in Annex 1 of the report.

Energy balances

Energy balances are critical to evaluating the net energy outputs from RTF chains. An indication of the efficiency of a fuel chain is provided by the energy input required to produce a unit of energy in the form of RTF. This generally has an effect on the economics of the fuel chain. Fuel chain efficiencies are assessed in the tables in Annex 1.

However, in terms of non-renewable energy substitution it is the amount of non-renewable energy input required to produce a unit of RTF that is of interest. This is also related to the CO2 emissions of the fuel chain. The energy balance in this study is therefore defined as the amount of RTF energy produced per unit of direct non-renewable energy input. A 'negative' energy balance (<1) means that more non-renewable energy is used to produce an RTF than is in the final renewable fuel itself.

Figure E1: Energy Balances for Selected RTF Chains



Note: * - large range primarily due to different energy requirements for each of the transport modes for hydrogen i.e. pipe, compressed or liquified.

Direct non-renewable inputs are assumed in all cases for the production of biomass feedstock and transport and for the transport of the RTF. This provides a base case, however, it could be envisaged that in the future these inputs could be substituted, in part or entirely, by renewable energy inputs. The energy inputs to the conversion process could be renewable, where process residues are used as fuel, or non-renewable and, together with the process type, will have a significant effect on the range of values for the energy balance of a particular fuel chain.

All the RTF chains evaluated show a positive energy balance, except under the worst case assumptions and then only for a few of the chains. Energy balances between 0.2 (strongly 'negative') and 66 (strongly positive) have been calculated for the non-wind RTF chains, and greater than 28 for the four hydrogen from wind chains, as shown in figure E1.

Biodiesel and bioethanol routes are generally energy intensive. Significantly favourable energy balances are only achieved when renewable fuels, mainly residues from the biomass resource used, are used to produce energy for the process, and when energy is allocated to co-products, in which case the energy in the RTF can be between 2 and 5 times that of the non-renewable energy input. In the case of biodiesel from waste vegetable oil, the energy balance is more favourable, with the energy in the biodiesel estimated at between 6.6 and 8 times that of the non-renewable energy input.

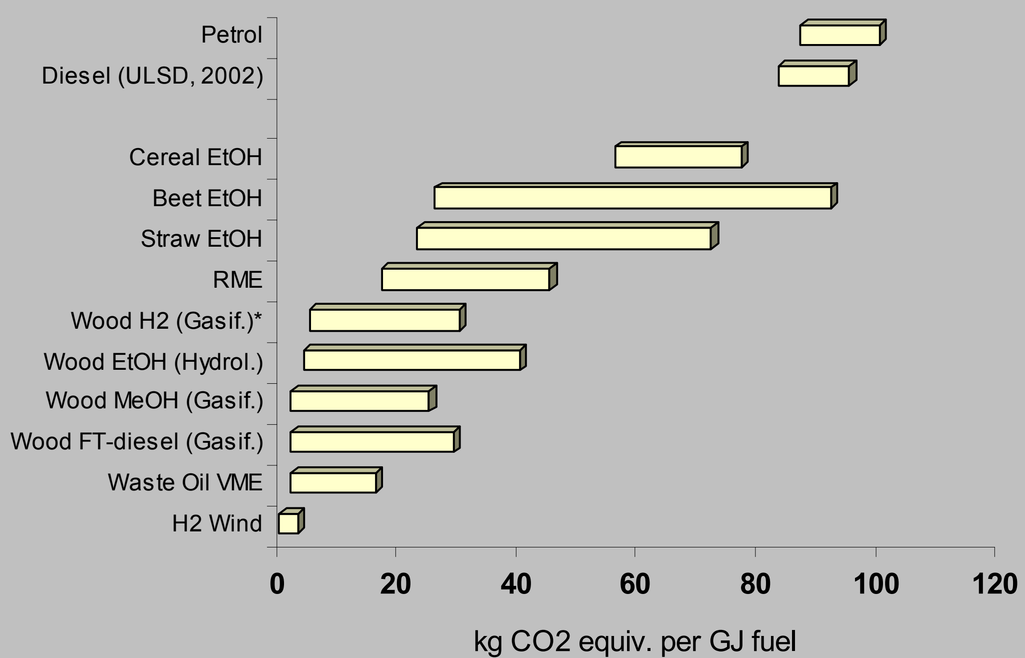
Gasification-based routes (FT diesel, methanol and hydrogen) using woody crops present strongly favourable energy balances. This is a result of less energy intensive processes compared to conventional biodiesel and bioethanol routes and heat and power requirement of the conversion process being generated within the process using part of the biomass resource. The lower energy balance for hydrogen compared to FT diesel and methanol is mainly a result of the energy consumed by transporting the hydrogen by road in compressed form, which has been assumed for the case illustrated.

Hydrogen production from direct renewable electricity is assumed not to require any direct non-renewable input expect for the transport of the hydrogen. This results in very favourable energy balances for wind-to-hydrogen routes.

GHG balances and abatement

Generally, all renewable transport fuel chains considered could result in substantial emissions reductions compared to conventional fossil fuels. All of the RTF chains evaluated show net reductions in fuel chain GHG emissions compared to petrol or diesel (per GJ fuel), except ethanol produced from sugar beet and then only under the worst set of assumptions. GHG emissions ranged from virtually zero for two of the offshore wind hydrogen scenarios (pipeline transport and on-site electrolysis, where fossil energy input for the road-based hydrogen distribution is avoided) to 106 kg CO_2 (equivalent) per GJ of fuel for ethanol from sugar beet, in its worst case scenario, as shown in figure E2.

Figure E2: GHG Emissions from RTFs and Conventional Transport Fuels



* The range in emissions results from the different modes of hydrogen transport.

The sugar beet to ethanol chain also exemplifies the range in potential GHG emissions that are possible from each chain, depending on: the yields achieved; inputs required to achieve those yields; the technologies chosen at each stage of the chain and the origin of their direct energy inputs. The biomass-to-ethanol chains show the greatest range, primarily because of the large amounts of energy required in the extraction of the sugars and in distillation. As a result, the combination of poor yields and older, less efficient, technologies fuelled with fossil fuels can result in very poor energy balances and relatively high GHG emissions. However, choosing efficient modern technologies and using good crop growth management practices can result in real benefits.

Conventional biodiesel and bioethanol routes could provide significant GHG benefits per unit of fossil fuel substituted, and could potentially reduce GHG emissions by about 80% compared to petrol and diesel. However, the relatively low efficiency of these chains and the limited number of feedstocks on which they currently rely, constrains their role in providing a potentially substantial source of RTF. Therefore, achieving a significant contribution of RTFs in road transport energy provision will need to rely on a greater variety of biomass (residues and dedicated energy crops) and non-biomass energy sources.

Advanced FT diesel and bioethanol conversion technologies are likely to expand the scope for RTF production from biomass. The use of woody crops for ethanol could lead to greater GHG reductions. Although based on a less efficient process, the resulting emissions could be close to those of RTFs based on woody crop gasification. However, although gasification and lignocellulosic hydrolysis technologies could result in greater efficiencies and GHG reductions, they remain to be technically and economically proven at commercial scales. Commercial scale production facilities using these technologies are unlikely within 5 years, and it may take 10 to 15 years to achieve commercial maturity, with supporting policies.

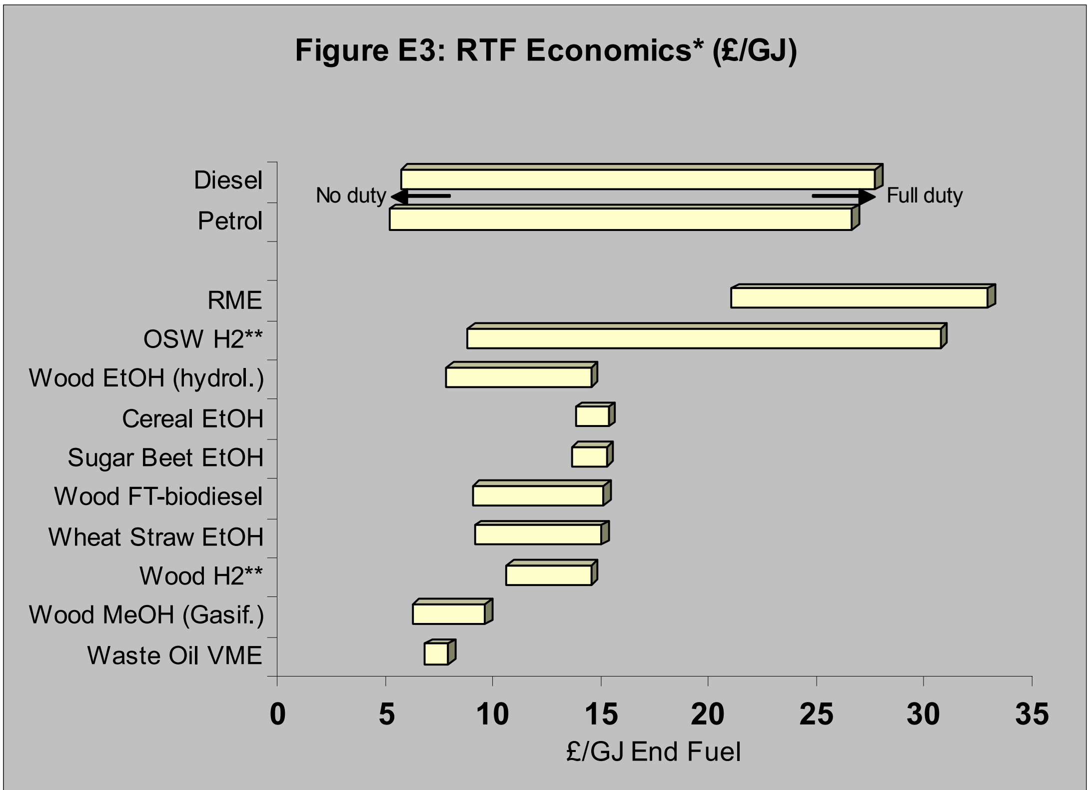
Hydrogen appears to provide a convergence point for RTF production, being able to exploit the entire range of renewable resources, efficiently and with potentially very low emissions. Wind hydrogen supply routes offer the potential for virtually zero emissions. However, the hydrogen option faces important barriers in relation to an establishment of an infrastructure for its distribution. Also, trade offs between the direct use of electricity produced from renewables compared to its use for hydrogen production will need careful consideration.

Further reductions in GHG emissions can be expected where RTFs lead to greater energy efficiency on-board the vehicles, for example possible improvement in combustion efficiency of ethanol blends or use of hydrogen in fuel cells.

Economics

None of the RTF chains evaluated could produce fuels at lower costs than the current (2002) cost of conventional fuels when subsidies/taxes and co-product values are excluded, although a number of chains are close to being competitive on this basis (figure E3). The consideration of co-products from RTF production and external benefits (e.g. environmental benefits) would generally enhance the competitiveness of RTFs compared to petrol and diesel. It is estimated that all the chains, assuming the technologies achieve commercial status, could produce fuels at lower costs (excluding tax) than the current price of conventional fuels (including tax).

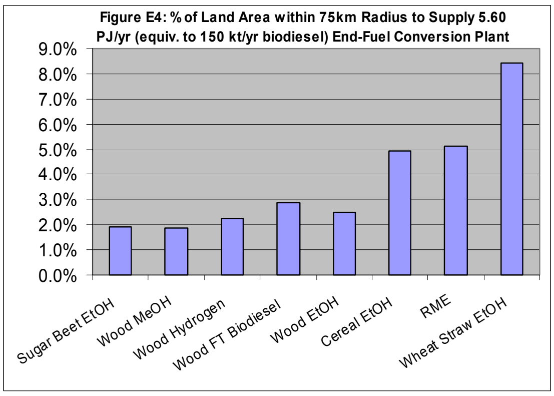
The cheapest RTF options are likely to be those produced using wastes (e.g. waste vegetable oil, organic fractions of MSW) and residues (e.g. forest and agricultural residues) as feedstocks. However, such resources will generally be limited. Wood-based (short rotation coppice, in the case of this analysis) ethanol, methanol, biodiesel and hydrogen production are likely to have good prospects for relatively low cost RTF production. Electrolysis-based hydrogen production could also result in relatively low cost RTF production where low cost sources of renewable electricity are available (at or below 2p/kWh), and advantage of electrolytic hydrogen production being that it could be produced at the point of vehicle refuelling.

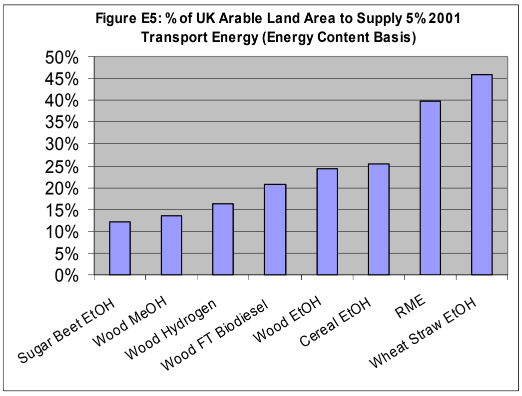


* Production costs for the renewable transport fuels are all exclusive of tax (duty + VAT).
** The range in costs is primarily due to the range in costs arising from the different modes of hydrogen transport.

Resource requirements

Whilst a relatively small percentage of the land area within an economically viable distance to a commercial scale conversion plant is required for crop production (e.g. between 1 and 7%), a significant share of total UK arable land would be required to meet a notional 5% substitution of road transport fuels by biomass-based RTFs (e.g. between 9 and 60% or more depending on crop type and conversion efficiency). This is illustrated by figures E4 and E5 below. Less energy may be required from those end-fuels where their use is associated with higher vehicle efficiency (e.g. the use of hydrogen in fuel cell vehicles).





The substitution of 5% of road transport fuels by hydrogen generated from renewable electricity would require between 0.12 and 0.17EJ of electricity, depending on the efficiency of the electrolysis process and the whether the hydrogen is compressed or liquefied following its production. The electricity requirement corresponds to between 18% and 26% of practical onshore and offshore wind energy potential and between 12% and 18% of practical direct renewable energy potential.

Conclusions

Renewable transport fuels could indicatively substitute over half of road transport fuel in the UK based on the estimated practical renewable energy potential and an average assumed conversion efficiency from renewable resource to transport fuel of 50%. The practical renewable energy resource is roughly equally divided between biomass and waste and direct renewable electricity sources. In practice, there will be a number of technical and economic constraints, and competition between renewable resources for different end uses, that may reduce the potential for RTF production from renewables. On the other hand, competition for land for food production is likely to continue to decrease as subsidies to food crops are reduced and global competition in agricultural commodities grows, particularly for cereals. Also, supplies of renewable transport fuels from abroad may also be cheaper than home production. Therefore, a UK RTF industry will need to make gains in efficiency and cost reductions if it is to become and remain competitive.

Emerging RTF technologies hold the promise of reducing costs, energy inputs and GHG emissions, but they remain to be proven on a commercial scale. R&D activities are occurring in most of the technologies discussed in Europe and the USA, with very little activity in the UK at the moment. In the case of biomass-based RTF chains, the development of suitable feedstocks, including energy crops, and suitable supply logistics will prove critical to their success, and much experience is yet to be acquired.

Traditional biodiesel and bioethanol routes are relatively inefficient and significant GHG emissions reductions require significant amounts of renewable resources. More advanced conversion routes allow for important gains in efficiency. Assuming woody biomass from SRC were used to produce RTFs such as Fischer-Tropsch diesel, methanol and hydrogen via a gasification route, an average GHG saving compared to petrol and diesel could be about 76kg CO2 equivalent per GJ of fuel. The total abatement of a 20% substitution of petrol and diesel by these biomass-based RTFs would be equivalent to about 38Mt CO2 equivalent. Assuming the direct renewable electricity sources were used to produce hydrogen via the electrolysis route, an indicative average GHG saving compared to petrol and diesel could be about 90kg CO2 equivalent per GJ of fuel. The total abatement of a 20% substitution of petrol and diesel by hydrogen from renewable electricity could be about 45Mt CO2 equivalent. The GHG abatement potential of RTFs could be greater in the case it involved increases in on-board vehicle efficiencies.

All RTF chains could bring about reductions in GHG emissions from road transport. However, conventional biodiesel and bioethanol production routes in the UK, although significant gains in efficiency and emissions reductions are possible, are relatively inefficient in economic and environmental terms, but could be used as stepping stones to prove and develop supply chain and distribution logistics on the road to lower carbon and more cost effective RTF chains. Novel biodiesel and bioethanol routes based on Fischer-Tropsch and hydrolysis processes, respectively, could lead to lower costs, greater CO_2 reductions, and open-up potentially larger markets. These chains could provide fuels for advanced ICE and hybrid ICE vehicles, and have attracted recent interest and investment from automotive and energy companies.

Hydrogen appears to have the ultimate potential for use in fuel cell vehicles, the development, testing and demonstration of which is being actively pursued by the automotive industry. Hydrogen could also be used in ICE vehicles, which may provide a stepping-stone to fuel cell vehicles and could prove to be an interesting future option for high power vehicles. Energy companies are involved in the implementation of the first hydrogen refuelling stations in association with hydrogen-fuelled vehicle demonstrations fleets in Europe and elsewhere. However, a significant renewable hydrogen penetration is likely to be at least two decades away, as it will take time to develop the demand for hydrogen and related infrastructure. Early action with regard to developing hydrogen demand and supply remains though important in ensuring a low carbon transport future.

Other renewable transport fuels such as methanol, biomethane, DME and direct use of renewable electricity attract limited interest. Methanol is not regarded as a likely fuel for ICE vehicles and, while it could still be an option for fuel cell vehicles, the direct use of hydrogen appears increasingly likely to be the preferred choice. Biomethane could have some potential use in niche markets, in particular in association with the development of a market for CNG vehicles. The direct use of renewable electricity appears as an unlikely prospect given the fading interest in battery electric vehicles outside niche applications.

Minimising the costs, energy inputs and GHG emissions from all RTF chains requires careful technological choices and adequate fuel chain management within a framework of targeted incentives and good regulation.

Recommendations

Based on the findings of this study, a number of recommendations are made with regard to further work.

Develop detailed scenarios for ‘best practice’ biodiesel and bioethanol chains based on conventional processes that could serve as industry standards.

Develop more detailed analyses of the technical and economic potential of hydrolysis and gasification-based fuel chains.

Develop a better understanding of the trade-offs between biomass use for the production of heat and electricity or transport fuels and the role biomass could have as a future primary energy source for the power and transport sectors.

Develop a better understanding of solutions and policies that could reduce GHG emissions from transport, the role of different renewable transport fuels and the policy mechanisms that would lead to their market introduction.

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Annexes:

Glossary:

Term	Description
Bl	10^9 (billion) litres
BtL	Biomass to Liquids- generally refers to thermal processes for the production biodiesel, DME and ethanol.
C5	Five carbon monomer e.g. fructose (a pentose)
C6	Six carbon Monomer e.g. glucose (a hexose)
CMG	Compressed Methane Gas
CNG	Compressed Natural Gas
CO_2	Carbon dioxide (global warming potential = 1)
DME	DiMethyl Ether
DDGS	Distillers Dry Grains with Solubles
End-fuel	A fuel that can be used directly to power a vehicle
EJ	Exa Joule (10^{18} joules)
ETBE	Ethyl Tertiary Butyl Ether
EtOH	Ethanol
FCEV	Fuel Cell Engine Vehicle
FCV	Fuel Cell Vehicle
Fischer Tropsch	A catalytic system for reformulating gasifier-derived syngas. The process is most widely known for the production of ethanol from coal in South Africa by SASOL
FT	Fischer Tropsch (see above)
GJ	10^9 Joules
H2	Hydrogen gas
Ha	Hectare = 10 000m^2
Hexose	Six carbon (C6) sugar e.g. glucose
IC	Internal Combustion
ICEV	Internal Combustion Engine Vehicle
MeOH	Methanol
Mha	10^6 ha
MJ	10^6 Joules
Ml	10^6 Litres
MSW	Municipal Solid Waste
MTBE	Methyl Tertiary Butyl Ether
Mtoe	Million tonnes of oil equivalent
MW_{th}	MW energy input (rate x energy content of feedstock)
MW_e	MW electricity produced
N_2O	Nitrous Oxide (global warming potential = 310 x CO_2 (IPCC, 2001))
Odt	Oven dry tonne (1000kg)
Pentose	Five carbon (C5) sugar e.g. fructose
SRC	Short Rotation Coppice
R&D	Research & Development
RTF	Renewable Transport Fuel
RME	Rape Methyl Ester
SME	Soya Methyl Ester
t	Metric tonne (1000 kg)
VME	Vegetable Methyl Ester
WDS	Wet Distillers Grains
WVO	Waste Vegetable Oil

Definitions:

‘Biomass’ – all organic matter of vegetable and animal origin that has not undergone fossilisation.

‘Biodiesel’ – general term describing the production of diesel substitute fuels based on pressing of oil crops and esterification e.g. RME, VME.

‘FT-Biodiesel’ – diesel substitute fuel produced from different possible biomass feedstocks using the gasification-based Fischer-Tropsch route.

‘Co-products’ – all non-transport fuel outputs from a renewable transport fuel chain that have an economic and/or energy value. For example, sugar beet pulp is produced in significant quantities when sugar beet is processed for ethanol or crystalline sugar production. The pulp has economic value as animal feed or could be used to produce process heat and electricity in the sugar beet mill.