Railways and Biofuel

First UIC Report

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Produced in co-operation with

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Executive Summary

The use of Biofuels (fuels produced from organic sources, i.e. crops, waste organic material or oil) is currently being promoted as a transport fuel, as they have the potential to reduce emissions of greenhouse gases, gases that contribute to climate change. They can also increase energy security, i.e. reducing a country's reliance on imported energy products.

The principal forms of Biofuel are Biodiesel, which can be blended with, or replace diesel, and Bioethanol, which can be blended with, or replace petrol. In the European Union (EU), an indicative target of 5.75% (by energy content), set in the Biofuels Directive (2003/30/EC), is stimulating the increased use of biofuels, in particular Biodiesel, for EU road transport. There are also discussions on increasing the proportion beyond 5.75% to say 10%-20% *(Source: EC 8/9 March Presidency conclusions).*

Many countries are responding to this Directive by introducing tax incentives and obligations on manufacturers to produce Biofuel and add it to conventional transport fuels. Outside of the EU, many countries are taking similar policy actions. There is also the possibility of using one of the so-called 'flexible mechanisms' of the Kyoto Protocol, the Clean Development Mechanism (CDM), to stimulate the development of biofuel technology in developing countries.

This Report was commissioned by the UIC from the UK Association of Train Operating Companies (ATOC), who were assisted by AEA Energy & Environment. The purpose of the report is to build on the previous paper (ERRI, 1997) from the UIC on biodiesel and indicate what has changed in this time. In particular:

- Is there sufficient ***supply of Biodiesel for the EU railways***?
- How are the issues associated with the higher ***costs*** of the fuel being addressed?
- Are Biofuels ***technically feasible***?
- Are Biofuels really ***sustainable***?

Railways already have an environmental advantage over other forms of air and road transport as seen in various reports *(Source: ATOC Baseline Statement April 2007).* This is diminishing, due to rapid progress in the other transport sectors. Biofuels offer an opportunity to help rail to maintain or improve its green credentials and hence promote modal shift, as an environment conscious society may choose rail over other modes of transport. This should increase rail usage and indeed, transport market share. Biofuels can also provide an alternative source of transportable energy and this may help to increase the security of supply for the rail industry.

There is also scope for potential cost savings if sufficient tax exemptions and incentives could be applied by Member States to railways. Finally these items all contribute to meeting the requirement of the EEA TERM paper:

"a shift to more environmentally friendly modes should be sought 'where appropriate'. "

And the Kyoto Protocol which pledges to:

"cut EU-15 GHG emissions by an 8% reduction on 1990 levels by 2012"

Although, there are, significant advantages to be realised, there are important issues and risks, that need to be considered and addressed such as:

- **Supply:-** The Biofuels Directive has resulted in an increase use of biofuel from virtually nothing in the 1990s, to an estimated 3500 million litres in 2005. Planned or recent increases in production capacity suggest that earlier predictions of Biodiesel supply in 2012 of 14,000 million litres (Source: *IEA (2004)*) might be an underestimate.

- **Demand:-** Compliance with the EU target on increasing transport biofuel using Biodiesel alone, will potentially require 16,000 million litres by 2012. However, given the likely increased demand resulting from the various policy initiatives around the world, the railway sector is likely to face global competition for biodiesel.
    - Biomass to Liquid or Second Generation Biofuel (see section 6.3.1) will offer a higher yield and can help increase supply to help meet the rising demand. However, the processes and technologies for the production of second generation Biodiesel are still being developed and are uncertain.

- **Costs:-** Currently, Biodiesel costs significantly more than diesel and this is a disincentive to using Biodiesel *(See table 5).* The costs and prices are volatile, being related to the biofuel source and supply and demand market forces.
    - Governments could subsidise Biodiesel production, but a complication is that currently it is difficult to guarantee that the fuel being subsidised is not coming from an unsustainable source, which may be worse in terms of GHG emissions than the substituted fossil fuels.
    - A worldwide / EU *(See section 5.3)* certification scheme, could give governments the confidence to offer discounts to reduce costs to the end user. A potential alternative is for governments to legislate and consumers pick up the costs.

- **Technical:-** Initial engine results from desk top analysis and test bench work *(See section 6*) shows that Biodiesel is feasible for use in railway traction units engines in lower percentage blends. However, there are potential disadvantages such as increased fuel consumption and decreased power. Blends in excess of B30 (30% biodiesel content) may increase maintenance costs, although, it is expected that second generation Biofuels will be of a higher specification and indeed may prove to be better than fossil fuels.
    - Biodiesel can influence the emissions from engines as shown in figure 18 and this needs to be considered in light of EU Directive on Non-Road Mobile Machinery stage IIIB or equal legislation. For example using Biodiesel is likely to increase NOx emissions but lower Particulate emissions, even if tests results vary from railway to railway.
    - In Germany and UK, some road transport is currently using blends of up to 50%. To meet the expected rail demand, MTU have already developed an engine that is capable of running on B100, *(Source: MTU, section 6.2)* and undoubtedly, others are under development.

- **Global Sustainability:-** This report shows Biofuel are able to reduce GHG emissions by up to 80% *(see section if 5)* considering the whole life cycle of production, transport and combustion. But there are still some uncertainties about the sustainability of Biofuels and it is still difficult for customers to be sure of the environmental credentials of the Biofuels they are buying and to be certain of the benefits they provide. With certification schemes in place that are supported by the NGOs, it would be possible for customers to be confident that their Biodiesel was produced in a sustainable manner and know what GHG savings the fuel actually delivers.

Contents

Glossary

Anaerobic digestion	Anaerobic digestion (AD) is the harnessed and contained, naturally occurring process of anaerobic decomposition – i.e. biological decomposition in the absence of air/oxygen. AD processes can be used to produce *biogas*/*biomethane* biofuels.
B5, B10, B20, etc	Coding used to identify fuels in which *Biodiesel* has been blended with conventional diesel; the number indicates the proportion of the blended fuel that is Biodiesel, i.e. B10 contains 10% *Biodiesel* and 90% regular diesel
Biobutanol	Butanol may be used as a fuel in an internal combustion engine and is more similar to gasoline than ethanol. It can be produced from biomass as well as fossil fuels; when produced from biomass (via a similar fermentation process as *Bioethanol*) it is often referred to as *Biobutanol* to reflect its origin, although it has the same chemical properties as butanol produced from petroleum.
Biodiesel	Biodiesel is a synthetic fuel derived from biological sources (such as vegetable oils), which can be used in unmodified diesel-engine vehicles. Biodiesel fuels are currently typically produced by *esterification* of vegetable (or other) oils to produce *FAME*, however advanced/second generation biodiesel fuels are under development that use other feedstocks and methods, such as *BtL diesel*.
Bioethanol	Bioethanol is a *Biofuel* alternative to gasoline obtained from the conversion of a biomass feedstock (such as sugar beet in Europe, corn in the USA and sugar cane in Brazil). Agricultural feedstocks used to produce Bioethanol are considered renewable because they get energy from the sun using photosynthesis.
Biofuel	Biofuels are derived from biomass *feedstocks* – plants or other organisms or their metabolic by-products, such as manure from cows. Crops specifically grown for biofuel production include sugar beet and rapeseed (primarily in Europe); corn and soybeans (in the USA); sugar cane in Brazil; palm oil in South-East Asia; and *jatropha* in India. Biodegradable waste outputs from industry, agriculture, forestry and households can be used, which can be converted to biogas through *anaerobic digestion*, *esterification* or *BtL* processes.
Biofuels Directive	EU legislation (Directive 2003/30/EV), applicable in all 27 EU Member States, that sets indicative targets for the introduction of biofuels in the EU
Biogas	Biogas typically refers to a (*biofuel*) gas produced by the *anaerobic digestion* or fermentation of biodegradable organic matter under anaerobic conditions. Biogas is comprised primarily of methane and carbon dioxide and can be used as a vehicle fuel (where it is upgraded to higher quality *biomethane*) or for generating electricity.
Biomethane	Biomethane is another name for *biogas*. However in Europe the

	Natural Gas Vehicle industry makes an important distinction between unrefined biogas as the first output of processes such as anaerobic digestion (and commonly used in heating/electricity generation) and biomethane, the upgraded/more tightly specified product for use in vehicles. Biogas is typically a mixture of 50-75% methane, 25-50% carbon dioxide and other compounds, with biomethane being typically greater than 97% methane.
BtL / BtL diesel	Biomass-to-Liquid (BtL) processes involve high temperature gasification of grassy or woody biomass *feedstock*, followed by a *Fischer-Tropsch* type gas-to-liquid process for creating synthetic fuels such as BtL diesel (also known as *second generation Biodiesel*).
Carbon dioxide (CO_2)	The main *greenhouse gas* released in the course of the combustion of fossil fuels.
Cetane number	A measure of diesel fuel ignition characteristics. Like the octane number used for petrol, the higher the value, the better the fuel performance.
E5, E85, etc	Fuel in which *Bioethanol* has been blended with conventional petrol; the number indicates the proportion of the blended fuel that is bioethanol, i.e. E85 contains 85% Bioethanol and 15% petrol
Energy security	Increasing *energy security* refers to reducing the reliance on imported energy products
Esterification	An alkali-catalysed chemical process using methanol (or other alcohols) to convert *feedstock* oils into *FAME* (*Biodiesel*) and other products.
FAME	Fatty Acid Methyl Ester (FAME) is created by *esterification* of oils. The molecules in current *Biodiesels* are primarily FAMEs and so the *Biofuel* produced by such *esterification* processes are often referred to as FAME biodiesel, or simply FAME.
Feedstock	The biomass source (e.g. crops or waste oils, waste wood, etc.) from which *Biofuels* are produced
Fischer-Tropsch process/synthesis	The Fischer-Tropsch (FT) process is an established technology and already applied on a large scale by Shell in Malaysia and Sasol in South Africa. The process uses natural gas or coal as a feedstock to produce low-sulphur diesel fuels and other synthetic petroleum products. The synthetic diesel fuels produced by such processes are referred to as FT diesel or GtL diesel, and related *BtL diesel*.
Greenhouse gas (GHG)	A gas that enhances the planet's natural greenhouse effect, thereby contributing to global warming and climate change.
Jatropha	A *feedstock* for *Biodiesel*, the use of which is currently being developed in India.
PAH	Polycyclic Aromatic Hydrocarbons, also known as PAH, are chemical compounds formed by the incomplete combustion of hydrocarbons and also contained in small amounts in diesel, other

	fuels. Many of them are known or suspected carcinogens and are consequently restricted in content in diesel.
Second generation Biofuels	Advanced *Biofuels* currently under development and not yet commercially available, such as *BtL diesel* and lingo-cellulosic ethanol, are often referred to as second generation Biofuels as they mark an expansion of the potential feedstocks for biofuel production, a step-change in the overall process efficiency, and in the case of *BtL diesel*, a fundamentally different production process.
SunFuel or SunDiesel	Commercial names for types of prototype *second generation Biodiesel* fuels - produced by biomass-to-liquid (see *BtL*) processes.

1 Introduction

1.1 Background to the study and report

The International Union of Railways (UIC) plans to hold a workshop on Biofuels in July 2007. To provide background information for this workshop, UIC commissioned ATOC to produce a study on 'Railways and Biofuels to identify experience with the use of Biofuels on the railways of selected European and other countries. ATOC in turn commissioned AEA Energy & Environment, an operating division of AEA Technology plc, to assist. This document is the Draft Final Report of this study. It will be circulated by ATOC and the International Union of Railways (UIC) for comment. The report will be finalised in May 2007, taking into account any comments received.

1.2 Methodology and progress to date

The project's methodology included a review of literature and internet-based sources, such as the websites of relevant organisations, and a survey of UIC members, and was based on the Terms of Reference given in Appendix 1. The literature review and survey were undertaken between February and April 2007.

The ***literature review*** included documentation supplied by ATOC, as well as documents and information supplied by or obtained from other stakeholders, such as the IEA and the European Biodiesel Board.

The ***survey of UIC members*** was based on a questionnaire that was circulated to selected operating companies in EU Member States, as well as those in a number of other European countries and countries elsewhere in the world. Of these, ATOC identified fifteen key countries that should be the focus of the work, seven of which are EU Member States that already had a reasonable level of Biodiesel use[1], and eight of which are from elsewhere in the world[2]. The questionnaire was drafted by AEA and subsequently finalised by taking into account comments from ATOC and UIC. Where questionnaire responses were not received from key countries, interviews with relevant stakeholders were undertaken to obtain the necessary information.

1.3 Structure of the report

The structure of the report is as follows:

- Section 2 gives a brief introduction to Biofuels and how they are produced.
- Section 3 reviews the emerging policy framework that encourages the use of Biofuels.
- Section 4 outlines the potential for using Biodiesel on the railways.
- Section 5 outlines the environmental issues associated with the use of Biofuels on the railways.
- Section 6 reviews the technical issues associated with increasing Biofuel use on the railways.
- Section 7 summarises the key findings of the report.

[1] Italy, France, Spain, Germany, UK, Denmark and the Czech Republic
[2] USA, Canada, Southern America, Russia, China, India, Australia and South Africa

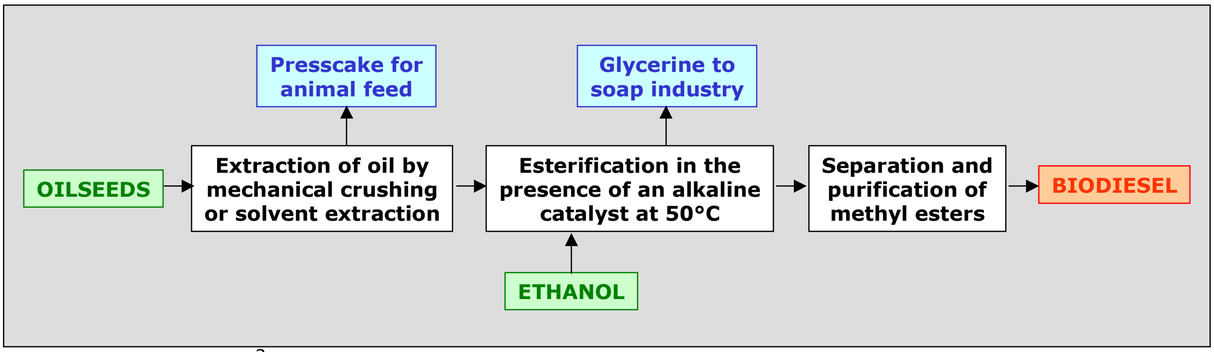
2 What are Biofuels?

Biofuels are produced from organic sources, usually from plant biomass (from crops or waste material or oils). Using them can generally result in a net reduction in greenhouse gas emissions compared to conventional fossil fuels. The main type of Biofuel most likely to be relevant/useful for use on the railways is Biodiesel, however other types of Biofuel might also find niche uses on the railway, including bioethanol (and the related biobutanol) and biogas (and the related biomethane).

The potential reduction in greenhouse gas emissions is one of the main reasons that the use of Biofuels is being promoted as an alternative to conventional transport fuels, particularly in Europe. In other countries, e.g. the US, Biofuels are supported more for their potential to increase energy security, i.e. reducing reliance on imported energy products, than for environmental reasons. Biofuels can either be blended with conventional fuels or used in a pure form to replace these fuels. Biodiesel, therefore, can be blended with or replace conventional diesel, while bio-ethanol replaces petrol (i.e. gasoline). Biofuel blends are referred to by a combination of a letter and a number indicating the fuel and percentage blend. For example, diesel mixed with 5% Biodiesel is referred to as B5, while petrol blended with 85% bio-ethanol is called E85. Given that Biodiesel is the Biofuel with the most potential for the railways (given the large amounts of diesel the railways currently use and its high flash point), the discussion of the report focuses on this fuel, although other Biofuels are covered where relevant.

A schematic representation of the way in which Biodiesel fuels are produced from energy crops is given in Figure 1. At present, rapeseed is the feedstock used for over 80% of global Biodiesel production, with sunflower oil providing 13% and small contributions from other vegetable oils. However, other feedstock's are likely to be used in the development of Biodiesel in the future, e.g. Jatropha in India. Such Biodiesel fuels produced from oils (usually vegetable oils) are also known as FAME (Fatty Acid Methyl Ester) and are the predominant type of Biodiesel currently produced worldwide.

Figure 1: Production of Biodiesel by esterification of vegetable oil



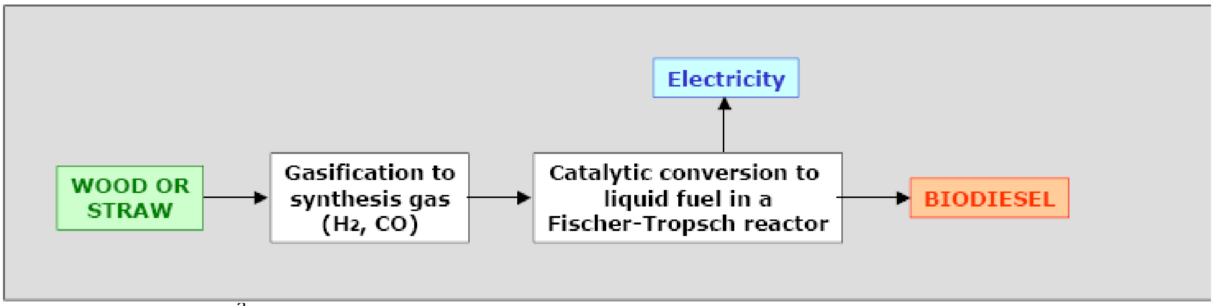
Source: AEA, 2003 [3]

However, BtL (Biomass-to-Liquid) diesel is a promising alternative for the future. BtL is a form of synthetic Biodiesel produced by gasification of biomass followed by a Fischer-Tropsch (gas-to-liquid) process. It is also known as advanced or second-generation Biodiesel, or commercially as 'SunFuel' or 'SunDiesel'. A simple schematic summary of the BtL production process is provided in Figure 2. BtL Biodiesel is anticipated to be of superior

[3] "International resource costs of Biodiesel and bioethanol", as study by AEA Technology Environment for the Department for Transport, March 2003. Available in HTML format at: http://www.dft.gov.uk/pgr/roads/environment/research/cqvcf/internationalresourcecostsof3833 and in PDF at http://www.senternovem.nl/mmfiles/Costsofbiobioethanol_tcm24-187060.pdf

quality to both existing FAME and conventional fossil diesel fuels - it is a sulphur-free fuel with a higher average cetane number and energy content. More information on BtL diesel is provided in a later chapter (see Section 6.4.1).

Figure 2: Production of Biodiesel by gasification and Fischer-Tropsch – Biomass to Liquid (BtL) process



Source: AEA, 2003 [3]

Biogas (and Biomethane) can be used in natural gas powered engines and are typically produced by anaerobic (in the absence of air) digestion of organic material by bacteria - a process that occurs naturally in digestive systems, marshes, rubbish dumps and septic tanks. Railway applications of natural gas have been used mostly in demonstration projects, but could still be a potential niche market, perhaps in urban settings where the lack of particulate emissions and quieter running engines would be advantages. Identification of experience specifically in biogas rail operation is limited to that in Sweden (see Box 5 in Section 6.4.2).

Bioethanol and biobutanol are best suited as a spark ignition engine fuels as they have a low cetane number. Ethanol is used extensively in the United States and increasingly in Europe as an additive to petrol. However, extensive use has been made of bioethanol in buses in Sweden, where ignition improvers make the combustion of ethanol practical in diesel engines. They are currently produced from fermentation of sugar-rich crops, such as sugar cane, sugar beet (and in the United States, corn), but may in the future be produced from a wider range of biomass types.

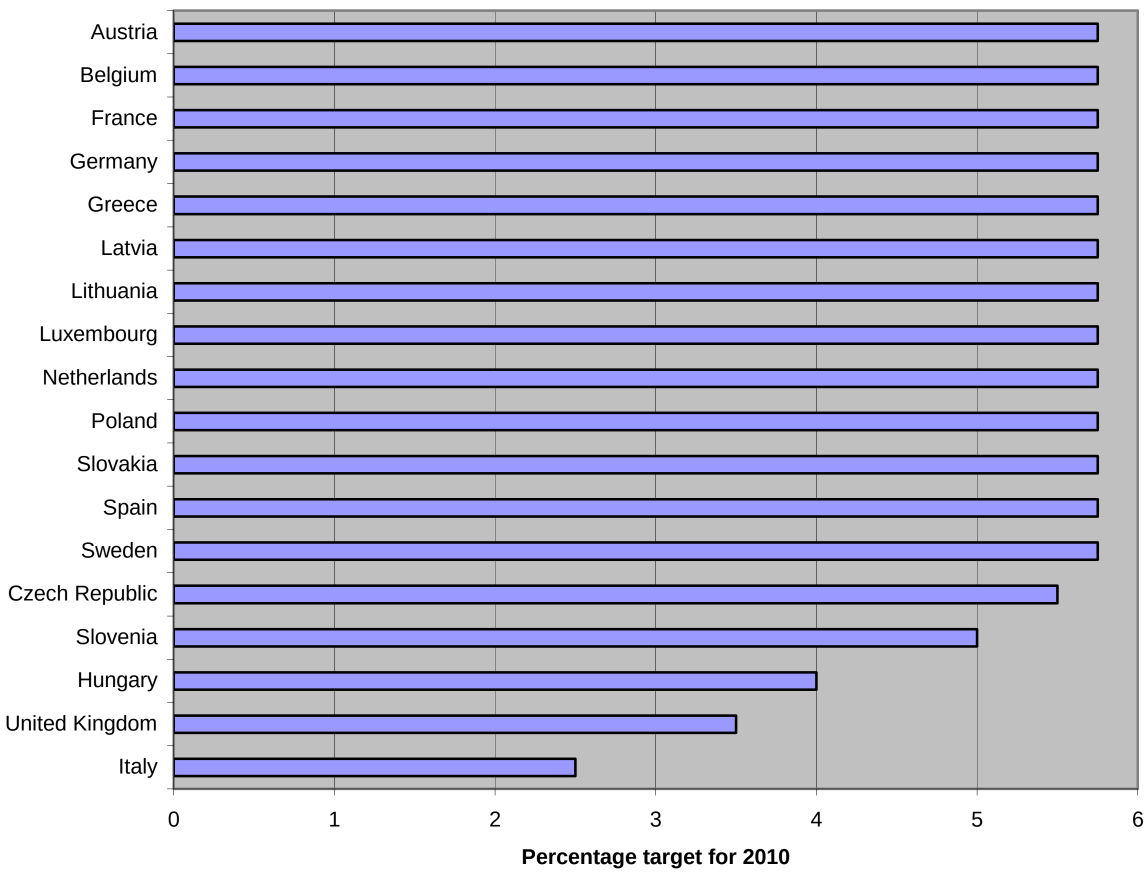
More information and discussion on the relative merits of advanced BtL diesel and the alternatives to Biodiesel are provided in Section 6.4.1.

3 The emerging policy framework

3.1 Targets, obligations and tax exemptions

In the EU, the main policy instrument to promote the use of Biofuels by transport is the Biofuels Directive (Directive 2003/30/EC), which is arguably the most important instrument in the world that has stimulated the recent increases in the production of Biodiesel (see Section 4.3). Even though the Directive does not explicitly prefer one Biofuel to another, the use of Biodiesel in the EU has increased as a result of the Directive, more than the use of bioethanol. Although the Directive does not set legally binding, i.e. mandatory, targets, it does require Member States to set national targets for the introduction of Biofuels and proposes 'reference values' that the Member States should take into account. These reference values are effectively indicative targets and the Directive proposes that these should be set at 2% by 2005 and 5.75% by 2010. According to European Environment Agency (2007)[4], most Member States have set a target for 2010 for increasing the use of Biofuels in transport that is in line with that suggested by the Directive (see Figure 3).

Figure 3: Target for increasing transport Biofuel use in EU Member States*



*Cyprus, Denmark, Estonia, Finland, Ireland, Malta, Portugal had not yet fixed their targets
Source: Table reproduced from EEA (2007)

[4] EEA (2007) *Transport and Environment: On the way to a new common transport policy. TERM 2006* Copenhagen

More recent information has suggested that some Member States, e.g. France, Germany and the UK, have subsequently increased their targets, and are also using other mechanisms to encourage Biofuel use (see Table 1).

Table 1: EU Member States' actions in response to the Biofuels Directive[5]

	National targets for 2010 (cf 5.75%)	**Tax exemption; rate for Biodiesel**	**Other comments**
Czech Republic	5.5%	100% reduction in excise duty for blended Biodiesel containing at least 31% RME; i.e. €0.329 less than the duty on diesel	Support programme for Biodiesel production in place
Denmark	Decision yet to be taken	From the Danish CO_2 tax	A 0% indicative target was set for 2005 as government sceptical of Biofuel benefits
France	7.00%, mandatory	100% reduction in excise duty for Biodiesel; i.e. €0.33 less than the duty on diesel; extra tax for fuel suppliers if target not met	Tax exemption applies to an annual quota
Germany	6%, mandatory	Previously, Biodiesel exempt from tax; no longer tax exemption for blends; exemption for 100% Biodiesel to be phased out	When tax exemption removed, the mandate (i.e. 6% by 2010) was introduced
Italy	5.00%, legal requirement	Level of taxation only 20% that of fossil diesel	Tax exemption applies to an annual quota of 250,000 tonnes
Spain	5.75%	100% reduction in excise duty for Biodiesel; i.e. €0.30 less than the duty on diesel	
UK[6]	5%, impact of the Renewable Transport Fuel Obligation (RTFO)	£0.20 (€0.30) per litre; RTF certificates will be tradable; suppliers without sufficient RTFCs will have to pay 'buy-out' price	From 2008, the RTFO will oblige fuel suppliers to ensure that a certain % of the fuel they supply is Biofuel

At the moment, there are no EU targets or reference values for subsequent years, but it is very likely that such targets will soon be set. Indeed, at their meeting in March 2007, EU leaders endorsed a 10% minimum binding target to be achieved by all Member States by 2020, which had been proposed by the European Commission in January 2007[7]. Such an endorsement does not count as a legal requirement, but it can be expected that the European Commission will soon bring forward the relevant proposals.

It is worth noting that another EU Directive, the so-called Taxation of Energy Products Directive (Directive 2003/96/EC), sets the rules governing Member States application of taxes and excise duties to energy products, including transport fuel. This Directive requires Member States *inter alia* to apply the same level of excise duty to the same energy product; exemptions to this requirement are specified, one of which allows exemptions to be offered for Biofuels. When Member States apply reductions or exemptions from excise duty to Biofuel, they are taking advantage of this option, but must obtain approval from the European Commission.

For some of the countries that are the focus of this project, e.g. USA, Brazil and China, the focus to date has been on producing bio-ethanol rather than Biodiesel, and therefore

[5] Sources: Country reports submitted under the Biofuels Directive, see http://ec.europa.eu/energy/res/legislation/Biofuels_members_states_en.htm; Pelkmans *et al* (2006) *Impact Assessment of measures towards the introduction of Biofuels in the European Union* Report of WP4 of the PREMIA project; questionnaire responses; EEA (2007)
[6] http://www.dft.gov.uk/pgr/roads/environment/rtfo/aboutrtfo
[7] Brussels European Council 8/9 March 2007, Presidency conclusions; see http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf

bioethanol tends to have been given more policy attention in these countries. However, this is changing. For example, Brazil is now taking steps to translate its success with introducing bioethanol to Biodiesel. The Brazilian government has introduced a requirement that all diesel fuel should be mixed with 2% Biodiesel, a proportion that will increase to 5% by 2013. The Biodiesel will be sourced primarily from domestically-produced soybean oil. In 2006, neighbouring Argentina also introduced a requirement that all diesel sold in the country should consist of 5% Biodiesel by 2009[8]. South Africa is currently finalising a Biofuels Industrial Strategy for the country. The draft strategy proposed that 4.5% of liquid road transport fuels should be Biofuel by 2013, consisting of E8 blends for petrol and B2 blends for diesel. The strategy should be finalised in the course of 2007 and should be supported by a number of measures, including fuel duty exemptions and agricultural support[9].

In India, the government has established a National Biodiesel Mission, which consists of two phases. In the first phase, which ran from 2003 to 2007, a demonstration project was set up with the aim of laying the foundations to the country's Biodiesel industry. Eleven million hectares of land in the country has been identified for growing energy crops, such as Jatropha and Pongamia and technology for the transesterification of oilseed has been developed and utilised. Stakeholders have also bought into the mission with oil companies declaring that they will buy Biodiesel at a price equivalent to that of diesel. Discussions on the possible introduction of subsidies and tax incentives to encourage the production and use of Biodiesel are ongoing. Phase II of the mission, which runs until 2012 aims to produce sufficient Biodiesel to be able to achieve a 20% Biodiesel blend. A National Biofuels Development Board has been set up to assist with the mission[10].

In 2006, the US state of Washington became the country's second (after Minnesota) to require that 2% of the diesel sold in the state should be Biodiesel. In the US, more generally, tax credits are available to Biodiesel producers. In Canada, the National Climate Change Action Plan has a target production rate for Biodiesel of 500 million litres a year by 2010, which would be equivalent to around 2% of the country's diesel needs. A similar approach has been taken in Australia, where the government has a target of producing 350 million litres of Biofuel (both bio-ethanol and Biodiesel) by 2010[11].

The situation in Germany is particularly interesting, as it produces more than half the world's Biodiesel and has now scrapped its tax exemption for Biofuel blends. Biofuels in Germany had benefited from tax exemptions since the 1990s, as they were not covered by the national Mineral Oils Tax, so had a comparative advantage over fossil fuels. Additionally, Biofuels were also exempt from the German eco-tax measures introduced in the late 1990s. Coupled with this 100% Biodiesel was promoted at filling stations and for use in particular transport segments, e.g. taxis, buses and pleasure boats[12]. Some reports suggest that the high level of German Biodiesel use is directly linked to the existence of the earlier tax exemptions[13]. However, in 2006, a decision was taken to remove the tax exemption for Biodiesel blends and introduce the requirement that 6% of transport fuels should be Biofuels by 2010[14].

In France, the development of Biodiesel also benefited from a tax reduction, although only Biodiesel produced up to a certain quota benefits from this incentive. The success in developing Biodiesel can also be attributed to the development of a plan into which all the

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[8] RNCOS (2006) *Biofuels Market Worldwide (2006)* New Delhi

[9] Department of Minerals and Energy *Draft Biofuels Industrial Strategy of the Republic of South Africa* November 2006

[10] Questionnaire response; Gonsalves, J (2006) *An Assessment of the Biofuels industry in India* United Nations Conference on trade and Development, UNCTAD/DITC/TED/2006/6

[11] RNCOS (2006)

[12] ABI (2003) *Worldwide review of Biodiesel production* prepared for IEA Bioenergy Task 39 Austrian Biofuels Institute

[13] NOVEM (2003) *Biofuels in the Dutch market: a fact-finding study* Report 2GAVE03.12, Netherlands Agency for Energy and the Environment, Utrecht

[14] Pelkmans *et al* (2006)

main stakeholders were able to buy[15]. In France, there has also been a lot of political support for increasing the use of Biodiesel on the national railway network. In January 2006, French President Jacques Chirac declared that in 30 years time French railways would not be using fossil fuels. To this end, SNCF has been undertaking a number of trials on B30 and plans to test B100 (see Box 1 in 6.1.1)[16]. Tax exemptions for Biodiesel are also common in other European countries, e.g. Biodiesel is free from energy taxes in Norway and Sweden, receives a comparative reduction of 15% in Romania[17] and receives a €0.50 reduction per litre compared to zero sulphur diesel in Austria[18].

In Italy, a similar system to that used in France, i.e. of allowing tax reductions on the use of Biofuels up to a certain quota, is in place. Until 2005, the majority of the quota, and therefore the main fuel that benefited from the policy, was Biodiesel. However, 2005 budget cut the quotas for Biodiesel in favour of bio-ethanol. The logic behind this move is that most Biodiesel feedstock was imported, while bio-ethanol feedstock is available locally. Hence, a decision was made to promote bio-ethanol production to be produced mainly from wine alcohol, sugar beet and grains[19].

In relation to the use of Biofuels on the railway, Indian Railways (IR) is taking an active interest in the development of Biodiesel and intends to increase its use of the fuel (see also Box 2 in 6.1.1). IR is offering around 44,000 hectares of surplus land to private companies and farmers to grow oil seed crops. Additionally, it is also planning to buy Biodiesel for blending with diesel for use on diesel locomotives and has a Memorandum of Understanding with the Indian Oil Corporation, under which the latter is to supply a 10% Biodiesel blend to IR for large-scale utilisation on diesel locomotives (questionnaire response). Additionally, Virgin Trains in the UK is interested in the use of Biodiesel and has been undertaking tests (see Box 3 in 6.1.1).

3.2 Possibility of Clean Development mechanism with Biodiesel for railways: case study

The Clean Development Mechanism (CDM) is one of the flexible mechanisms that the international community is using to help reduce greenhouse gas emissions. It involves a partnership between a company in the industrialised world and a company (or country) in the developing world, whereby the party from the industrialised world helps the party from the developing world introduce low greenhouse gas emitting technology. The party from the industrialised world is then able to receive a credit – in the form of a Certified Emission Reduction (CER) – which can go towards meeting its domestic emissions reductions targets. In the case of EU companies, the CER can contribute towards meeting a company’s target to reduce emissions within the EU emissions trading scheme.

Hence, a CDM project involving Biodiesel would involve the production of Biodiesel and its use as a substitute for fossil fuel diesel in a developing country. However, to date, the Methodological Panel of the CDM Executive Board, which has to agree how the greenhouse gas emissions saved by a CDM project are translated into CERs, has not approved a methodology for switching fossil diesel for Biodiesel. There are therefore currently no Biodiesel CERs on the market. However, there are some methodologies for Biodiesel projects in the project pipeline that may be approved. A number of CDM projects for the use of Biodiesel on railways are currently being considered, such as in India and Brazil.

[15] ABI (2003)
[16] SNCF, personal communications
[17] Respective questionnaire responses
[18] Pelkmans *et al* (2006)
[19] RNCOS (2006)

3.3 Increasing the use of Biofuels on the railways

As noted above, the main mechanism to encourage increased use of Biofuels by road transport is to introduce fuel duty differentials (e.g. Biodiesel compared to fossil diesel) and obligations on fuel suppliers. Railways are in a different position to road transport, as fuel duties for road transport are high, whereas rail often pays relatively less duty on its fuel. Hence, for the purposes of the use on railways, conventional diesel is often cheaper than Biodiesel (see also Section 4.4). Hence, currently there is sometimes little scope to introduce a duty differential to encourage the increased use of Biodiesel without first increasing duty on conventional diesel, which would, at least in the short-term, increase the cost of fuel used by the railways. Similarly, obligations on suppliers of fuel to railways to use a certain proportion of Biodiesel in their fuel would also increase the costs of the fuel, as long as the costs of Biodiesel remain higher than those of conventional diesel.

Where railways do pay fuel duty, it is possible to reduce the duty on Biofuels, for example, in proportion to the percentage blend used. However, whether it is possible to introduce a sufficiently large differential that would encourage the use of Biofuels will depend on the various costs and tax levels in any particular country.

For governments to reduce duty levels on Biofuels, they will require confidence that Biofuels are less harmful to the environment than fossil fuels. At the moment there is little that can be done to prove the credentials of any litre of purchased biofuel. A Biofuels certification scheme would allow a customer to buy sustainable Biofuel and know the measurable benefit it will deliver. With such a scheme you could argue duty rates could be set based on the credentials of the Biofuel.

4 Potential for Biofuel use on the railways

4.1 Characterisation of the fleet

Before identifying the potential for the use of Biofuels on railways, it is first useful to characterise the locomotives and railcars that are used on the rail network. For Europe, this was undertaken as part of a previous study in which AEA was involved for UIC[20]. This study was also based on a survey of UIC members, but focused on the potential to reduce emissions of conventional pollutants from the diesel-powered rolling stock of European railway fleets.

The study found that, on average, diesel traction accounted for only 20% of European railway operations and that the characteristics of the diesel fleet vary between countries, e.g.:

- In the Baltic States, Ireland and Greece, there is almost no electrified track, so diesel rolling stock makes up the overwhelming majority of the fleet.
- In contrast, countries such as Germany and France use diesel traction typically for feeder traffic on sparsely used lines, rather than on the main network.
- In a fully electrified country like Switzerland, diesel traction is only rarely used for some maintenance and shunting operations.

As diesel traction in many countries is widely used for shunting and civil engineering processes and on lines with low traffic density, the average utilisation of diesel locomotives is much lower compared to electric traction. The main exceptions to this are the heavy haul diesel freight trains in the Baltic countries. UIC's European members operate around 17,000 locomotive and 14,000 railcar diesel-powered engines, while non-UIC members have a further 2,700 locomotive and 2,600 railcar diesel engines. The average age of diesel railcar engines was found to be 16 years, while the equivalent figure for locomotives was 27 years, although there was a very large range of values for different European railway companies. Indeed, the survey found that one third of locomotives and 7% of railcar diesel engines are older than 35 years.

When asked about expectations for the future development of their diesel fleets, UIC members assumed that on average there would be a decline in the total numbers of vehicles in their entire diesel fleets, but that there would be an increasing number of diesel railcars. On the basis of the data received, and making assumptions on the life expectancy of the vehicles, scenarios for the future development of European diesel fleets were developed. These made rough estimates that around 8,500 railcars and between 9,000 new locomotives will be purchased in Europe between 2005 and 2020.

4.2 Volume of diesel fuel consumed by railway operators

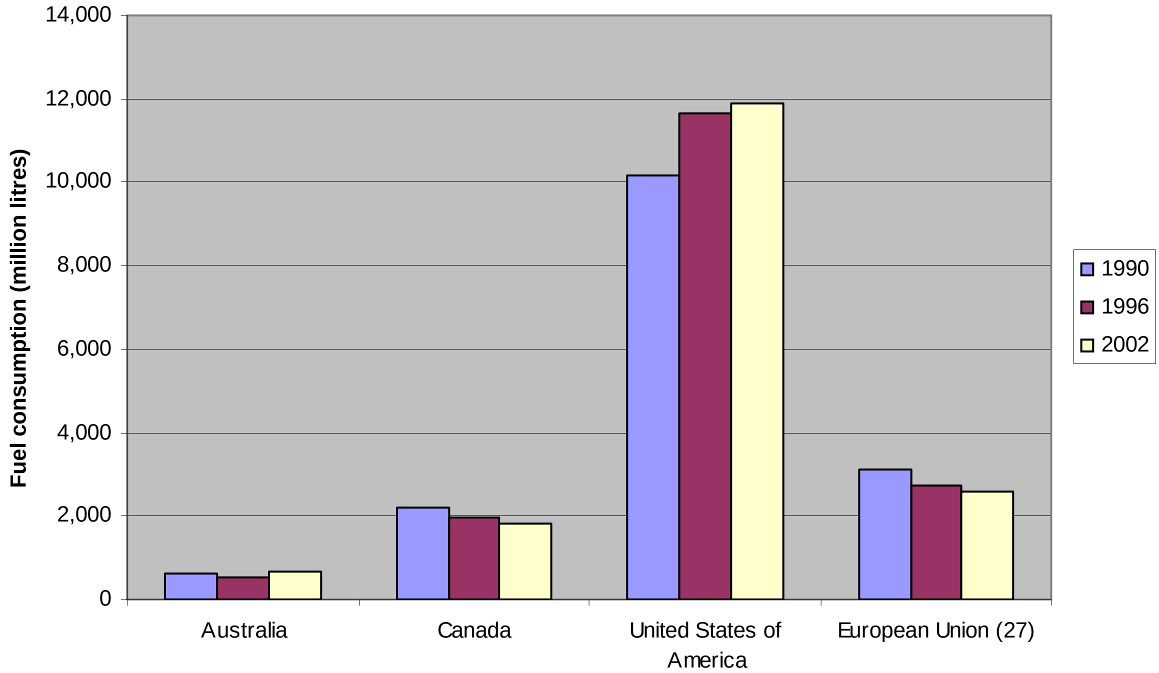
Globally, the consumption of liquid fuel, which is mostly diesel, by the railways is equivalent to at least 690,000 TJ, or 17,000 million litres[21]. This figure only includes fuel consumption by countries included in Annex I of the UN Framework Convention on Climate Change (i.e. industrialised countries), so excludes all developing countries, as well as the Russian Federation[22]. Hence, the total global consumption of liquid fuel by the railways is likely to be significantly higher – possibly double. For example, as part of the survey undertaken for this

[20] AEA (2006) *Rail diesel Study* produced for UIC, in association with UIC, UNIFE and Euromot
[21] UNFCCC
[22] Data was not available for the Russian Federation, even though it is an Annex I country.

project, Indian Railways reported that it used 2,000 million litres of diesel in 2005. As can be seen from Figure 4, the level of consumption of liquid fuels on the railways in industrialised countries is dominated by consumption in the United States (70% of the total), where consumption is growing, whereas in the EU[23] and Canada liquid fuel consumption by the railways is decreasing.

The EU only accounts for 15% of the industrialised countries' use of diesel on the railways. By Member State, liquid fuel consumption on the railways is, not surprisingly, dominated by the large countries. However, an additional factor in this figure, which probably accounts for the lower figures in France, Italy and Spain compared to the UK, for example, is the extent of the electrification of the railways in a country, e.g. the UK has only 31% of its track electrified compared to around half in France, Germany and Spain and 69% in Italy[24]. In 2002, the highest consumption of liquid fuels on the railways of the EU was in Germany, the UK and Romania. It is interesting to note that for most countries there has been a general reduction in fuel consumption since 1990 (see Figure 5).

Figure 4: Liquid fuel consumption by railways: EU compared to others countries (1990, 1996, 2002)

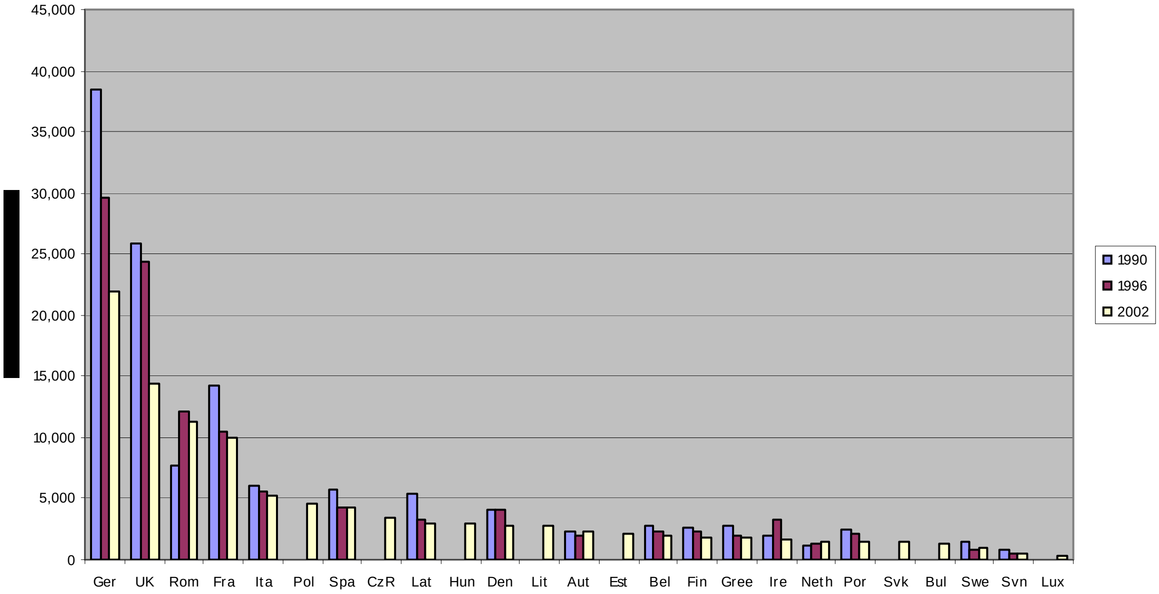


Source: UNFCCC database

[23] EU figures for 1990 and 1996 include information on only 19 Member States, as they do not include data for Poland, Czech Republic, Hungary, Lithuania, Estonia, Slovakia, Bulgaria, Luxembourg, Cyprus or Malta; figures for 2006 include data on 25 Member States, i.e. all but Cyprus and Malta.

[24] Transport Statistic Great Britain 2006

Figure 5: Liquid fuel consumption by EU 27 railways (1990, 1996, 2002)



Source: UNFCCC database
Note: The drop in railway fuel consumption in the UK was caused by changes in reporting rather than real reductions in use

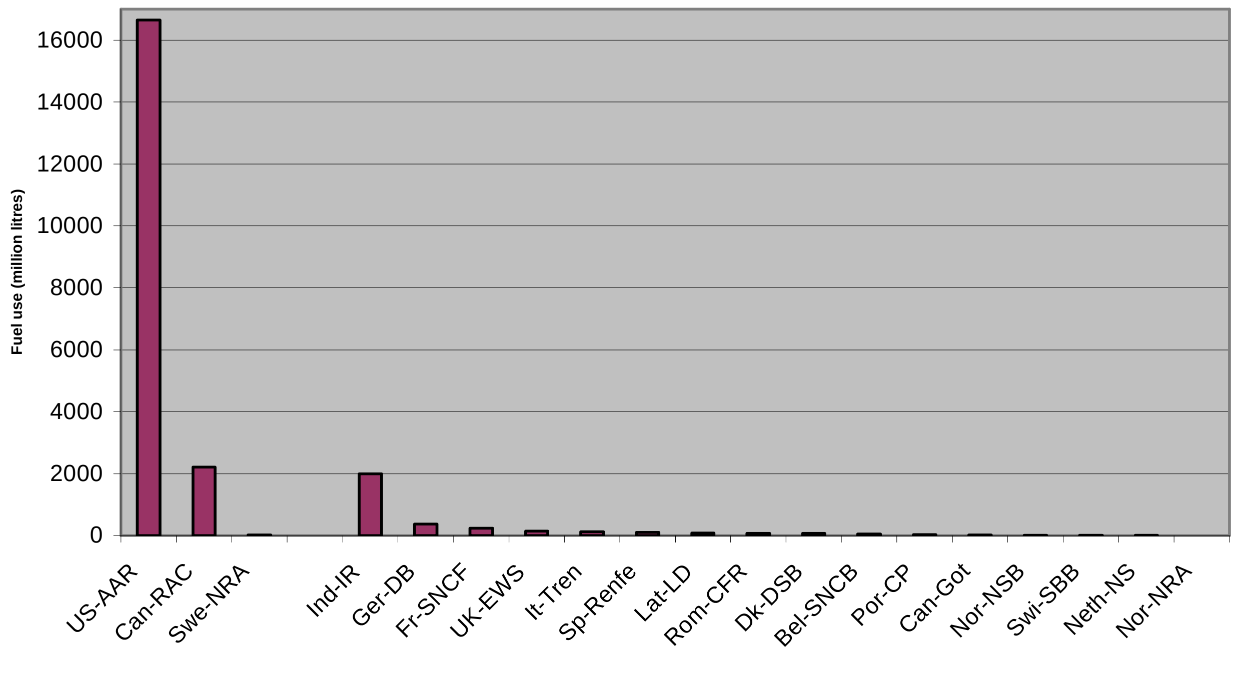
As part of the survey undertaken for this project, UIC members supplied data on annual fuel consumption (see Table 2 and Figure 6). In our survey, only Indian Railways reported any use of Biodiesel. Currently two trains are operating in the southern part of the country using a 5% Biodiesel blend. In 2005, half a million litres of Biodiesel was used, but this amount is expected to increase rapidly in future years, as a result of the policies of the Indian government and Indian Railways (see Section 3.1).

Table 2: Use of diesel by surveyed railways (2005)

Country	Company/organisation	Fuel use	Biodiesel use
National administrations (total figures for members)			
US	Association of American Railroads (AAR)	16655.8	Unknown
Canada	Railway Association of Canada (RAC)	2209.0	0.0
UK	Association of Train Operating Companies	600.0	0.0
Sweden	National Rail Administration (NRA)	23.0	0.0
Companies/administrations (own use)			
India	Indian Railways	2000.0	0.5
Germany	DB	368.8	0.0
France	SNCF	238.0	0.0
UK	EWS (freight)	150.0	0.0
Italy	Trenitalia	119.1	0.0
Spain	Renfe Operada	100.7	0.0
Latvia	Latvijas Dzelzcels	77.7	0.0
Romania	Romanian Railway Company for Freight Transportation	70.4	0.0
Denmark	DSB	68.0	0.0
Belgium	SNCB	49.9	0.0
Portugal	CP	30.2	0.0
Canada	Go transit	24.8	0.0
Norway	NSB	16.1	0.0
Switzerland	SBB	10.1	0.0
Netherlands	NS	5.7	0.0

Norway	Jernbaneverket - the National Rail Administration	1.2	0.0

Figure 6: Use of diesel by surveyed railways (2005)



4.3 Actual production of Biodiesel and future trends

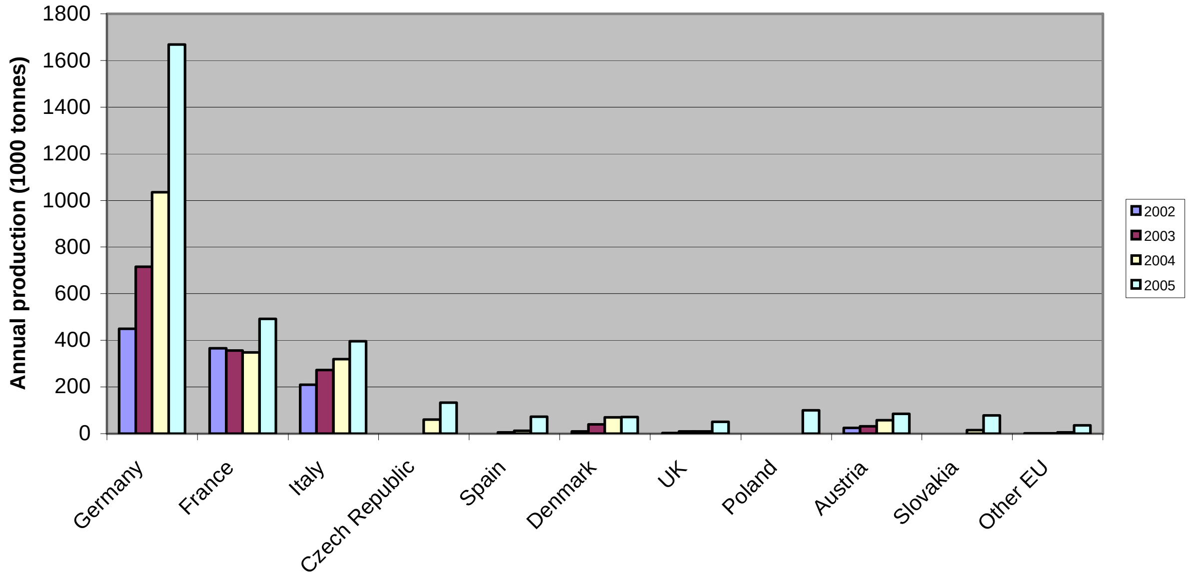
While Biodiesel is the focus of this report, it is worth noting that Biodiesel is not the most popular Biofuel produced globally. Levels of production of bio-ethanol, which is generally mixed with petrol for use as a transport fuel, are 10 times those of Biodiesel, i.e. in 2005 production of bio-ethanol exceeded 35,000 million litres, whereas only 3,500 million litres of Biodiesel were produced[25]. For some of the countries that are the focus of this study, e.g. USA, Brazil and China, efforts to date have been on developing the production and use of bio-ethanol rather than Biodiesel, although, as was be noted in Section 3.1, this is changing.

The vast majority – 89% – of the global Biodiesel production is in the EU, with Germany producing more than half of the total.

Furthermore, the production of Biodiesel has been growing rapidly with a fourfold increase between 2000 and 2005[26]. As can be seen from Figure 7 and Figure 8, below, there has been significant growth in many EU countries and in the US in recent years with production quadrupling in Germany alone in only three years. Total EU Biodiesel production stood at 3.2 million tonnes in 2005, while the US produced around 250,000 tonnes. Production figures for other parts of the world are not comprehensively available, but China is estimated to have produced 60,000 tonnes of Biodiesel in 2004[27].

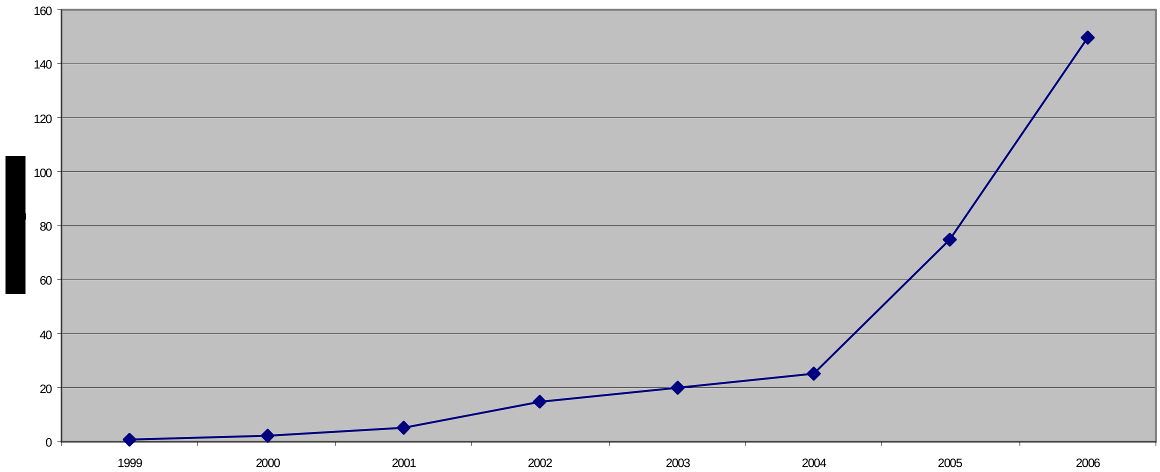
[25] Worldwatch institute (2006) *Biofuels for Transportation: global potential and implications for sustainable agriculture and energy in the 21st century* Washington DC
[26] Worldwatch institute (2006)
[27] RNCOS (2006)

Figure 7: EU Biodiesel production (selected countries)



Source: European Biodiesel Board (2006)[28]

Figure 8: US estimated Biodiesel production

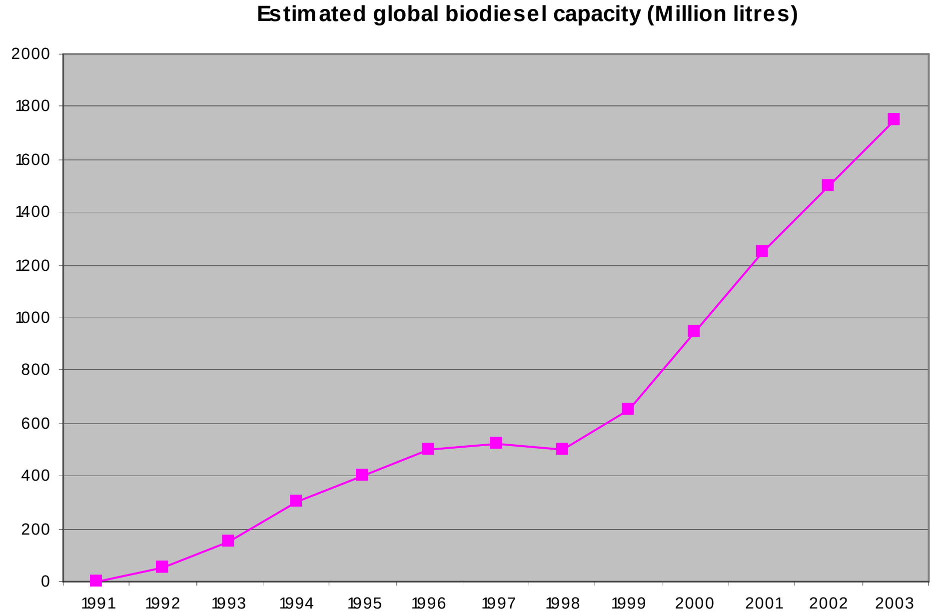


Source: National Biodiesel Board (2006)[29]
Note: 2006 figure estimated

Globally, Biodiesel capacity has been increasing significantly (see Figure 9). Lichts (2003) is the most widely quoted for global production capacity, but more recent figures for countries and regions suggest that growth has continued to 2006 and is likely to continue to do so with the number of Biodiesel production plants either under construction or being planned.

[28] European Biodiesel Board (2006) *EU Biodiesel production growth hits record high in 2005: EBB publishes annual Biodiesel production statistics* Press release, 25 April 2006; www.ebb.eu.org
[29] National Biodiesel Board (2006) *US Biodiesel Production Capacity;* see www.nbb.org

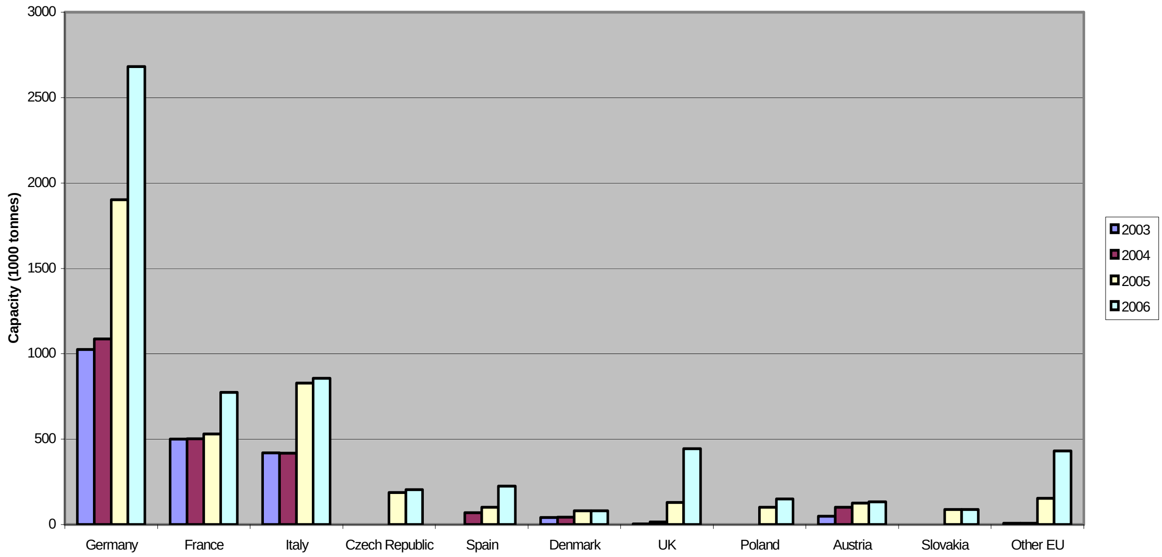
Figure 9: Estimated global Biodiesel capacity (in million litres)



Source: IEA (2004)[30], taken from Lichts (2003)

In the EU, Biodiesel production capacity is increasing at a similar rate to production itself. By mid-2006, the EU's Biodiesel production capacity was estimated to be over 6 million tonnes (i.e. 6,800 million litres), an increase of 44% over the previous 12 months and a trebling of output since 2003[31]. As can be seen in Figure 10, nearly half of this capacity is in Germany, with a significant proportion in France and Italy. However, it is also worth noting that there have been significant increases in the production capacity of many EU countries in recent years.

Figure 10: Biodiesel production capacity (selected EU countries)



Source: European Biodiesel Board (2006)[32]

[30] IEA (2004) *Biofuels for transport: An international perspective*
[31] It should be noted that some of the differences between production capacity and actual production can be accounted for by the fact that some plants will have begun operation in the course of the year, and therefore would not have been able to produce their maximum potential annual production capacity in that year.
[32] European Biodiesel Board (2006)

The high German production is linked to a high demand and it has been suggested that a major stimulus for biofuels in Germany was the onset of the 1990 Gulf War[33]. Eight years later - Leer (in the north-western comer of Germany) had approximately 100,000 cars running on biodiesel in mainly Germany, but also Sweden, the Netherlands and some other countries, they all run on **connediesel** from Leer.

In 2006, the US National Biodiesel Board (NBB) estimated that the combined production capacity of US Biodiesel plants was 580 million gallons (i.e. 2,200 million litres), which is significantly more than actual US production (see above). The NBB notes that additional Biodiesel plants are under construction and that some of the existing plants are being expanded, which has the potential to increase US Biodiesel production capacity by 1,400 million gallons (i.e. 5,300 million litres). Biodiesel production capacity is also increasing in Australia, where capacity will increase by 170% once those production plants that are either under construction or planned begin production (see Table 3).

Table 3: Biodiesel Capacity in Australia (million litres), 2006[34]

	Total Capacity	***Number of plants***	***Notes***
Operating plants	367	8	Total for seven plants only; capacity for other not given
Under construction	446	6	One plant (of 147 million litre capacity) was due to come into operation in Nov 06
Planned	174	2	
Total	**987**	**16**	

As described in Section 3.1 the Indian government is actively developing Biodiesel production capacity and use in the country. Hence, many projects are developing Biodiesel production capacity in the country. In 2006, BP announced that it was going to fund a $9.4 million project to cultivate 8,000 hectares of land currently classified as wasteland with Jatropha. The project, which is expected to take 10 years, aims to ultimately produce nine million litres of Biodiesel per annum[35]. In late 2006, a 10,000 tonne per annum Biodiesel plant operated by Southern Online Biotechnologies (SOB) began commercial production of Biodiesel in the Indian state of Andhra Pradesh[36].

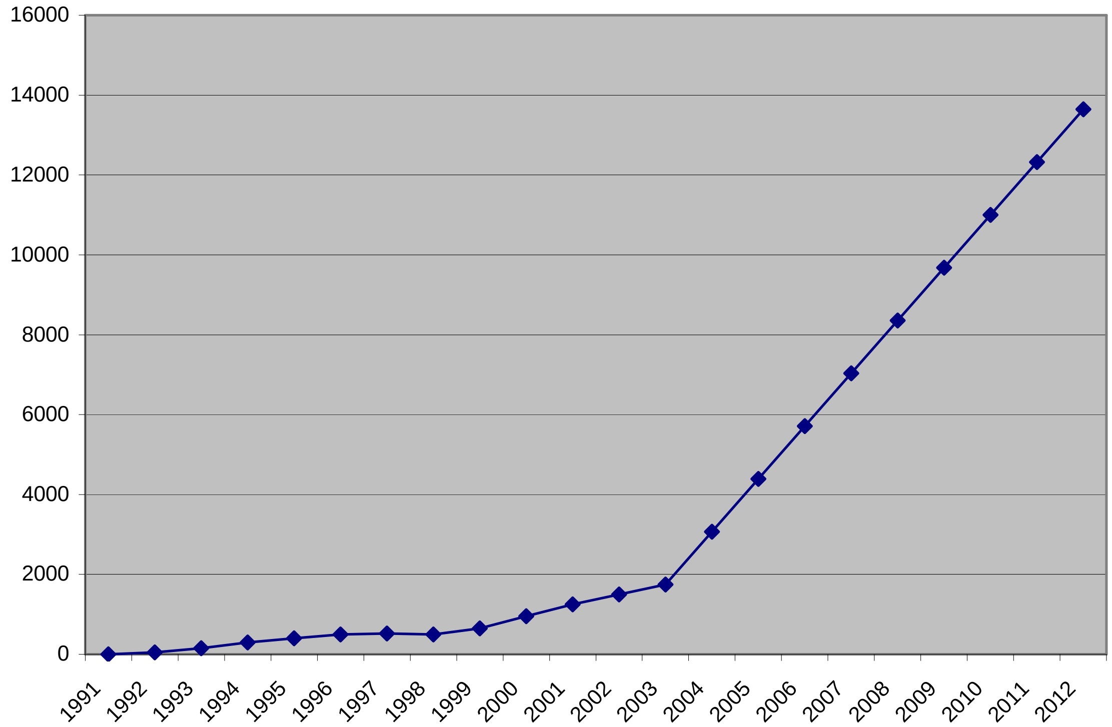
As of 2005, Brazil has three Biodiesel production plants with the capacity to produce 45.6 million litres of Biofuel per year; seven more plants are planned. China is planning to increase production of Biodiesel from the relatively small amounts that it currently produces, as it sees Biodiesel as an alternative to imported foreign fuel. In Canada, prior to 2006 only small-scale, Biodiesel production facilities were operational, but two larger facilities began production in 2006[37].

The IEA has projected that Biodiesel production will increase into the future (see Figure 9). The projection assumes that the EU's 5.75% Biofuels target would be met proportionately

[33] The paper "Biodiesel in Europe 1998 Biodiesel Processing Technologies" produced by JConnemann, J.Fischer Oelmuhle Leer Connemann GmbH & Co., D-26789 Leer (Ostfriesland), Federal Republic of Germany.
[34] Biodiesel Association of Australia, http://www.Biodiesel.org.au/ see Biodiesel production
[35] BP (2006) *BP to fund Indian Biofuel production study by the energy and Reosources Institute* Press release dated 2 February 2006; see http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7014607
[36] Express News (2006) *Bio-diesel production to begin in a fortnight* Express News Service, Hyderabad, 3 October 2006; *see* http://www.sol.net.in/bio/Expressnews031006.jpg
[37] RNCOS (2006)

with Biodiesel and ethanol and that demand would largely be met by domestic production rather than import. This assumption is the main driver of the trend. However, as noted above, many countries are expanding their Biodiesel production capacity, so there is the potential for significant increases in future years.

Figure 11: Global Biodiesel production projections (Million litres)



Source: Replicated from IEA (2004)

From the information presented above, therefore, it can be seen that Biodiesel production capacity is growing significantly in Europe, where 89% of the world's Biodiesel is currently produced, and elsewhere in the world. In 2006, EU Biodiesel production capacity was estimated to be 6,800 million litres – a trebling of output in three years. By 2012, it has been estimated that there will be around 14,000 million litres of Biodiesel production capacity, worldwide (IEA, 2004). However, given the recent increases in capacity in the EU and elsewhere, this figure appears to be an under-estimate and it is likely that by 2012 global production of Biodiesel will be in excess of 14,000 million litres. However, in the EU, meeting the targets for increasing the amount of Biofuels used by road transport is likely to absorb much of the increased production of Biodiesel. For example, if all EU countries met the proposed 5.75% target for 2010 with Biodiesel alone, 16,800 million litres would be required[38]. It should be noted, however, that it is unlikely that the EU biofuels target would be met by using biodiesel alone, as it can be expected that bioethanol will make some contribution in light of the fact that petrol made up a third of transport's final energy consumption in 2004, compared to diesel's 49%[39].

The figure of 16,800 million litres is roughly the volume of diesel currently used by the railways of the EU-27, Canada, the US and Australia. The most recent data available suggests that these countries use around 17,000 million litres of fuel a year, of which around

[38] Calculation based on figure from EEA (2006), which suggests that replacing 1% of transport fossil fuels would require 119PJ of energy for transport fuels to be produced from Biofuels. Therefore meeting the 5.75% target would require 684 PJ or 16,800 million litres of Biodiesel.
[39] Eurostat (2006) *Energy Transport and Environment indicators* 2006 edition, Eurostat pocketbook; kerosene and alternative fuels accounted for a further 13% and 4%, respectively.

2,600 million litres is used in the EU. Globally, the use of diesel by the railways is likely to be significantly higher than this – possibly as much as double. If the diesel fuel used by the railways of the EU were required to meet the same target as road transport fuels by 2010, i.e. 5.75%, then an additional 150 million litres of Biodiesel would be needed. If, as an example, the same proportion of Biodiesel were required to be used in all the railways of the EU, Australia, the US and Canada, 976 million litres of Biodiesel would be needed.

4.4 Market and production costs

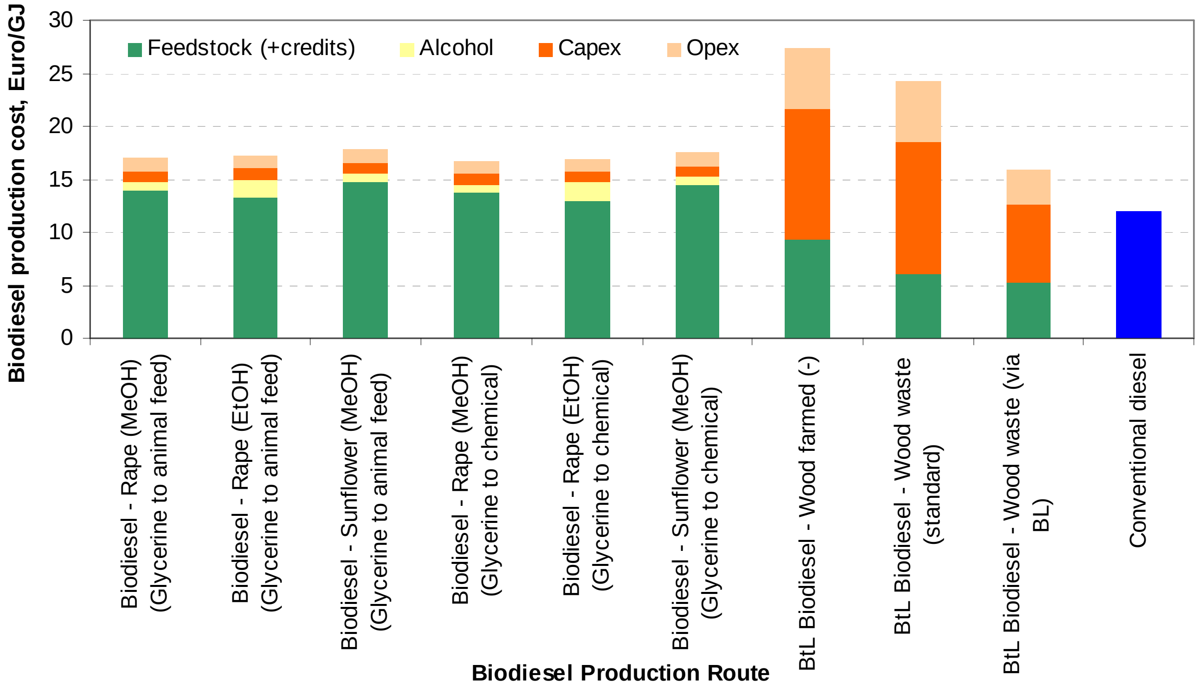
The market and production costs of Biodiesel result from a combination of technological, geographical and economic factors. Figure 12 and Table 4 from the JRC/EUCAR/ CONCAWE Well-to-Wheels report (2006) illustrate the overriding importance of the cost of oil seed feedstock for the current generation Biodiesel fuels, which comprise about 80% of the overall cost of Biodiesel production. Conversely the advanced BtL diesel fuels currently under development can use much less expensive (and more intensively produced) feedstock. In this case the feedstock cost is only expected to comprise 25-35% of the overall production cost, as capital and operating expenses are also much higher. The figure also illustrates that Biodiesel produced in Europe is expected to remain significantly more expensive than the untaxed cost of fossil diesel in 2010.

Table 4: European Biodiesel feedstock costs in 2010 (JEC 2006)

Feedstock	LHV[40] GJ/tonne	Delivered cost to processing plant	
		Euro/tonne	Euro/GJ
Rapeseed	23.8	248	10.4
Sunflower seed	23.8	278	11.7
Wheat straw	14.4	37	2.6
Waste wood	18	53	2.9
Farmed wood	18	81	4.5

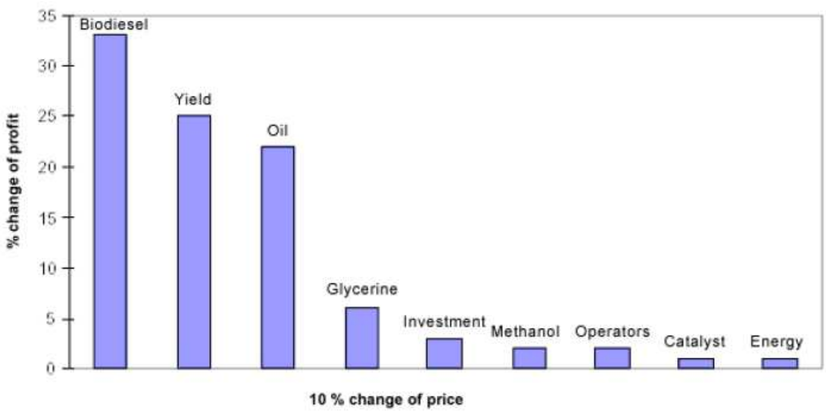
[40] LHV = Lower Heating Value, which is a measure of the energy content of a fuel. It is defined as the amount of heat released by burning a specified quantity of the fuel and returning the temperature of the combustion products to 150 degrees C. LHV is also referred to as the Net Calorific Value.

Figure 12: European breakdown of Biodiesel production costs in 2010 (JEC 2006)



On a micro-economic basis, the profitability of Biodiesel production depends on a number of factors with sensitivities that are illustrated in Figure 13. On a macro-economic basis the profitability is affected by import prices, employment, taxes and subsidies[41]. These factors can all vary significantly between different regions.

Figure 13: Profitability factors on a multi-feedstock basis[42]

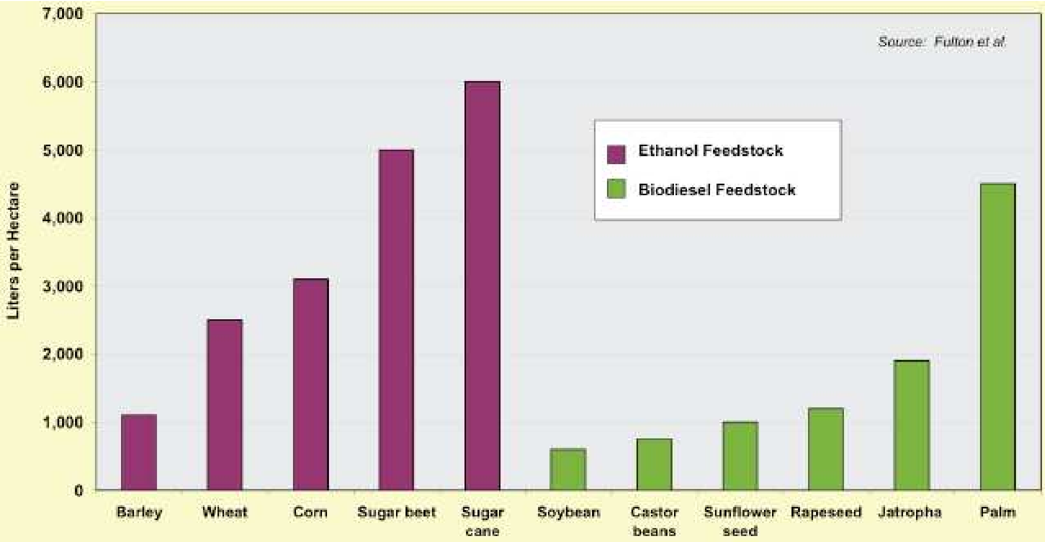


It can be seen in Figure 14 that (after market price) feedstock yield is the single largest factor in affecting the profitability of Biodiesel production. This is because the feedstock cost accounts for the major component of production costs, as already discussed. Figure 14 shows that the per hectare yields of oil seed crops such as Jatropha (favoured in India) and palm (favoured in SE Asia) are significantly higher than those for the typical vegetable oil crops grown in Europe and the US (rape, sunflower and soya), acting to lower the production costs of Biofuels produced from these crops.

[41] A World Wide Review of the Commercial Production of Biodiesel – A technological, economic and ecological investigation based on case studies, Stephan Friedrich, Institut für Technologie und nachhaltiges Produktmanagement der Wirtschaftsuniversität, Wien, 2004

[42] Austrian Biofuels Institute (ABI): World-wide Trends in Production and Marketing of Biodiesel; presented at the ALTENER – Seminar "New Markets for Biodiesel in Modern Common Rail Diesel Engines", University for Technology Graz, Graz 2000

Figure 14: Biofuel yields of selected bioethanol and Biodiesel feedstock[43]



The costs of production of Biodiesel produced outside of Europe in places like India and the US are in fact already lower than predicted for 2010 in the EU (Table 5 and). In Brazil and Malaysia prices are already considerably lower than European Biodiesel due to a combination of the factors already discussed. However, due to significant local demand for such Biofuels, this is unlikely to translate to significantly lower import costs. Increasing competition for imported Biofuels from countries such as China will also act to limit the possibilities in terms of potential imports to Europe into the future.

Table 5: Worldwide production costs of different Biofuels

Production costs:	EUR/toe[44]	Year	Source
Biodiesel from Rapeseed (EU)	780	Current	IEA WEO 2006
Biodiesel from Soya (US)	670	Current	IEA WEO 2006
Biodiesel from Soya (Brazil)	380	Current	BMW 2006[45]
Biodiesel from Jatropha (India)*	600	Current	India Railways, 2007
Biodiesel from Palm Oil (Malaysia)	300	Current	BMW 2006[45]
Fossil diesel (EU)	498	2010	PREMIA / JEC 2006
Biodiesel (EU)	720	2010	PREMIA / JEC 2006
BTL diesel from straw (EU)	1008	2010	PREMIA / JEC 2006
BTL diesel from farmed wood (EU)	1147	2010	PREMIA / JEC 2006
Fossil petrol (EU)	498	2010	PREMIA / JEC 2006
Ethanol from sugar beet (EU)	716	2010	PREMIA / JEC 2006
Ethanol from wheat (EU)	649	2010	PREMIA / JEC 2006
Cellulosic ethanol from straw (EU)	957	2010	PREMIA / JEC 2006

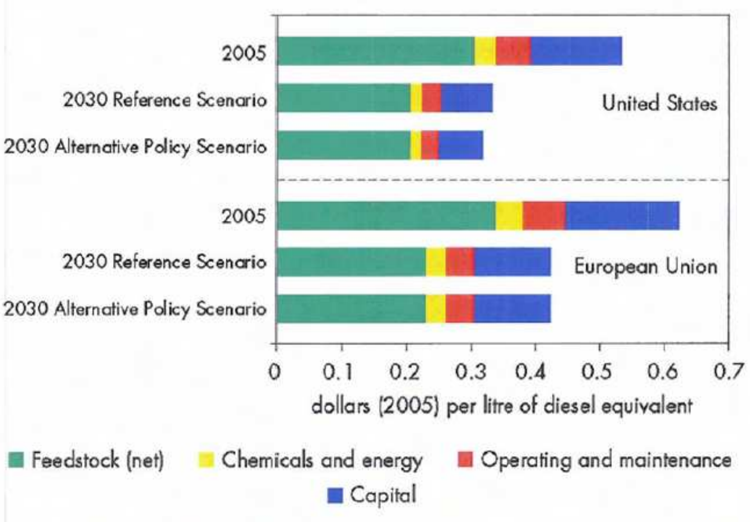
* Market price rather than production cost

For BtL diesel PREMIA assumes that costs will be between 10% and 20% below 2010 values by 2020. Prices of Biodiesel are currently 20% higher in Europe compared to the US

[43] "Biofuels for Transportation Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century", Prepared by the Worldwatch Institute for the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), in cooperation with the Agency for Technical Cooperation (GTZ) and the Agency of Renewable Resources (FNR), June 2006
[44] toe = tonnes of oil equivalent
[45] Data converted from data from the Brazilian Association of Vegetable Oil Industries (ABIOVE) provided in: "Biofuel Market Worldwide 2006", RNCOS, November 2006

(where the base feedstock is soya bean) according to the IEA[46], and are projected to fall in cost 30-40% by 2030 (see from IEA WEO 2006). This would imply that the relative cost of conventional Biodiesel and BtL diesel might not change significantly in future years, however the additional technical and greenhouse gas reduction benefits of BtL diesel fuels (discussed in a previous section) need to be weighed against this, together with the potential for increased production volumes per hectare.

Figure 15: Production costs of Biodiesel in the European Union and United States



46 Chapter 14 – The Outlook for Biofuels, World Energy Outlook 2006, IEA.

5 The use of Biofuels and the environment

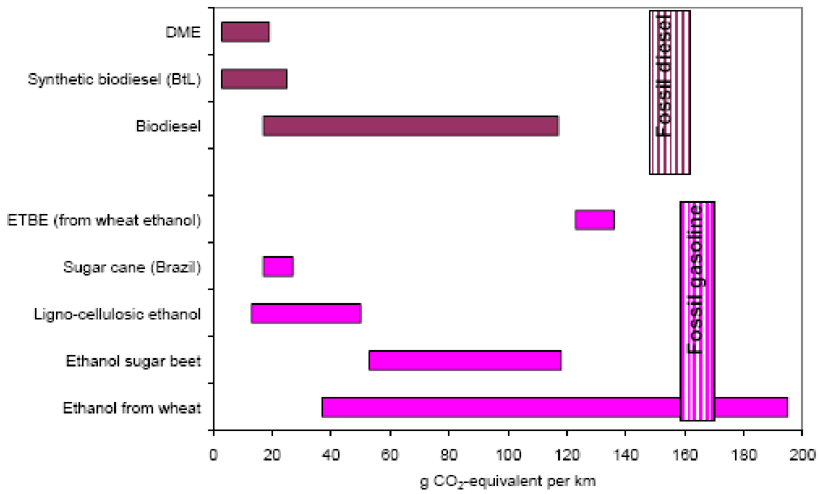
5.1 Atmospheric emissions comparison between Biodiesel and conventional fuel

Combustion of fuel can give rise to a range of emissions to the atmosphere with impacts at the local, regional or global levels. For example, the emissions of oxides of nitrogen (NO_x) and particulate matter can adversely affect local air quality, whilst carbon dioxide (CO_2) is a major greenhouse gas. In the European Union, the Air Quality Framework and Daughter Directives require the effective management of local air quality, including the impacts of transport, for protection of public health. Air quality limits are applied for several pollutants (including the oxides of nitrogen, sulphur dioxide and particulate matter), which are emitted by the transport sector. International agreements such as the UNFCCC, the Convention on Long Range Transboundary Air Pollution (CLRTAP) and Stockholm Convention provide a framework for regional and national legislation to control emissions of greenhouse gases, acidifying emissions and persistent organic pollutants respectively. Furthermore, European legislation sets emission limit values for transport vehicles, including rail locomotives and diesel multiple units, and fuel quality standards for fuel used by transport.

The main environmental driver for the increased use of Biofuels is the potential for the displacement of greenhouse gas emissions by replacing the use of fossil fuels with Biofuels. Biodiesel can have lower overall life-cycle CO_2 emissions than conventional fossil fuels, but the benefit is strongly dependent on the production methods used to produce Biodiesel. Recent research (JEC, 2006) [47] has indicated that conventionally produced Biofuels are energy-intensive compared to conventional fossil fuels, but that there are some overall CO_2 benefits to be achieved. With respect to CO_2 emissions, using Biodiesel (FAME) produced from rape or sunflower oil can result in reductions of 53% to 78% in CO_2 emissions when taking into account the full fuel cycle and combustion of the fuel. The range represents both variations in production-distribution route maps, and also a degree of uncertainty in estimates. The research also indicated that the second-generation of Biofuels (e.g. BtL diesel) are likely to lead to greater CO_2 benefits. This is summarised in the following Figure 16 from the PREMIA project[48] (based on information from JEC, 2006), which includes a wider range of different feedstock and production routes for regular Biodiesel.

[47] JEC (2006), carried out by the EC Joint Research Centre (JRC), the European Council for Automotive Research (EUCAR) and CONCAWE, and funded by the European Commission,
[48] PREMIA D4, Report of WP4: Impact Assessment of Measures Towards the Introduction of Biofuels in the European Union, by CERTH/HIT and VITO. Produced for European Commission DG TREN, September 2006.

Figure 16: Range of Well-to-Wheel emissions of greenhouse gases for different Biofuels and fossil fuels in 2010 (from JEC (2006))



However, caution must be applied in considering the net emissions of Biodiesel produced in other parts of the world, where the net balance may not be as favourable when land use change is factored in. Even in Europe, planting Biofuels crops on grazing land would probably not pay off in greenhouse gas terms for decades (JEC 2006) and there are similar concerns regarding Biodiesel production from palm oil in South East Asia where rainforest has been cleared to make way for palm oil plantations. Carbon storage in a hectare of tropical forest may be almost 5 times that in a hectare of palm plantation[49]. In this case some studies have suggested the potential net well-to-wheel greenhouse gas savings of the Biodiesel produced may consequently be negated for many years[50]. The European Commission and several countries (including the UK) are therefore currently working on Biofuel sustainability certification schemes in order to guard against the possibility such scenarios resulting from imports to Europe.

Research on the impacts of Biodiesel on air pollutant emissions is less conclusive. Emissions of the pollutant sulphur dioxide (SO_2) may be reduced where the introduction of Biofuels replaces fuel with a high sulphur content, as Biodiesel is of sulphur-free quality (i.e. contains <10ppm sulphur). However, given that the introduction of sulphur free fuels will soon be required by EU legislation, and indeed sulphur-free fuel is being used in many EU countries already, this potential benefit is unlikely to have a significant impact in the EU. In other countries with less strict fuel standards, however, reduced SO_2 emissions from the use of Biodiesel would result from increasing the use of Biodiesel.

However, emissions of NO_x from vehicles can be higher when using Biodiesel; emissions of particulate matter are difficult to evaluate, but some studies suggest they are significantly reduced. Much of the available European data does not show significant differences between Biofuels and conventional fuels as regards emissions of particulate matter[51]. Current UK estimates assume that Biofuels would not lead to significant changes /reductions in NO_x or PM_{10} emissions[52] compared to conventional diesel. Previous tests run by SNCF on Biodiesel blends seem to confirm this (see Box 1).

[49] Reijenders, L. and Huijbregts, M.A.J., 2006. Palm oil and the emission of carbon based greenhouse gases. Journal of Cleaner Production, doi:10.1016/j.jclepro2006.07.054

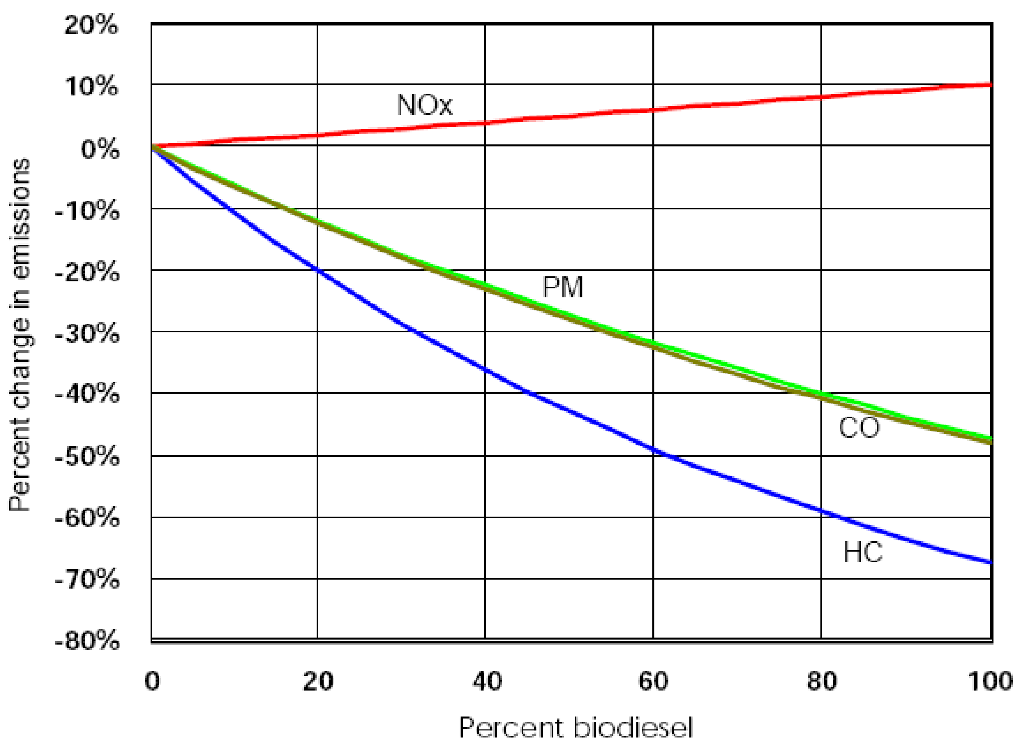
[50] "Audit of UK Greenhouse Gas emissions to 2020: will current Government policies achieve significant reductions?", UCL Environment Institute: Environment Policy Report Number 2007:01, Commissioned by Channel 4 for Dispatches, 2007.

[51] Gerie Jonk, *European Environmental Bureau (EEB) background paper: On the use of Biofuels for transport* (18 March 2002): http://www.eeb.org/publication/EEB-Biofuels-background-18-03-02.pdf

[52] AEA Energy & Environment, National Atmospheric Emissions Inventory

However, research by the US Environmental Protection Agency (EPA) indicates that emissions of most pollutants might be reduced more significantly. The US EPA carried out in 2002 a review of previous research in this area to identify the general trends in air pollutant emissions with increases in the percentage Biodiesel blend for Heavy Duty vehicles and engines[53]. A summary of some of the findings from this study is presented in Figure 17 and Table 6, which have been taken directly from the EPA study. This appears to be the most comprehensive analysis into the area at the moment – no more recent analyses have been identified. The results of this study should, however, be treated with caution when considering diesel fuels outside of the US – for example European conventional diesel fuels are generally of superior specification which may lead to important differences in relative engine emissions when comparing fossil diesel with Biodiesel. It is also not clear how well such results derived for heavy-duty road vehicles would compare with the performance of the higher-powered rail vehicle engines, which also have very different duty cycles. Information from existing rail experience (e.g. from SNCF tests and from the Norwegian National Rail Administration) at least seems to agree that Biodiesel gives higher NO_x emissions than conventional diesel.

Figure 17: Average emission impacts of Biodiesel for heavy-duty highway engines (Source: US EPA[53])



[53] A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions, US EPA, October 2002, http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf

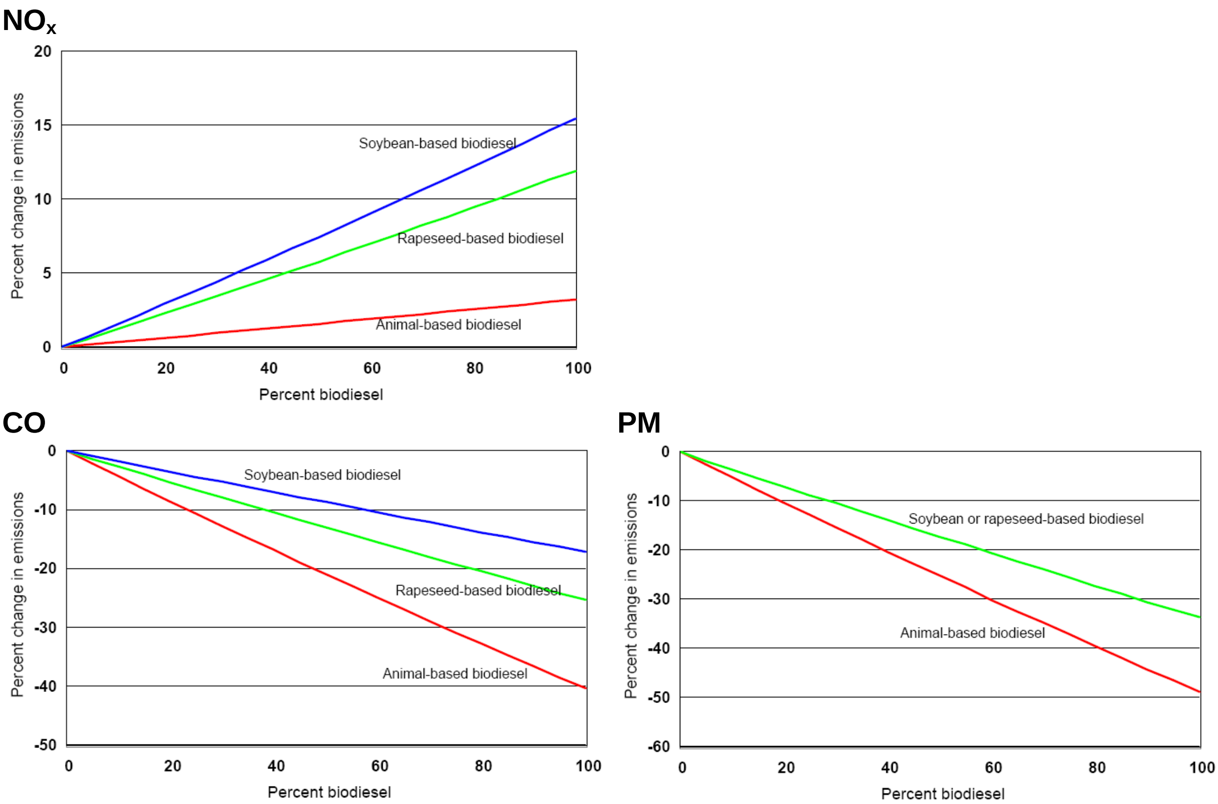
Table 6: Emission impacts of Biodiesel compared to conventional fuel (US EPA)

Emission Type	B100	B20
Regulated Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
NOx	+10%	+2% to -2%
Non-Regulated Sulphates	-100%	-20%*
PAH (Polycyclic Aromatic Hydrocarbons)**	-80%	-13%
nPAH (nitrated PAH's)**	-90%	-50%***
Ozone potential of speciated HC	-50%	-10%

* Estimated from B100 result
** Average reduction across all compounds measured
*** 2-nitroflourine results were within test method variability
B100 = 100% Biodiesel, B20 = 20% Biodiesel and 80% conventional diesel

In terms of unregulated pollutant emissions, the available evidence indicates that the use of Biodiesel can lead to substantial reductions in some pollutants compared to conventional rail diesel fuel, e.g. for sulphur dioxide (SO_2) and PAHs (Polycyclic Aromatic Hydrocarbons). Little information appears to be available on other pollutants such as metals, POPs (Persistent Organic Pollutants) and on speciated particulate emissions (e.g. PM_{10}, $PM_{2.5}$, etc).

Figure 18: Biodiesel source effects for NO_x, PM and CO



The US EPA study does also highlight that there can be important differences in the relative emissions performances of Biodiesel produced from different source oils, as illustrated in Figure 18. It could be expected that such variation will be somewhat reduced as a result of the definition of Biodiesel standards, such as the European Standard EN 14214 for Biodiesel produced from vegetable oils.

The UK is currently conducting bench tests on a number of diesel rail engines using different Biodiesel blends. Initial results from the tests on a single rail engine (the Cummins NTA855R3) include comparisons of impacts on power delivery, specific fuel consumption and emissions of nitrogen oxides (NO_x), hydrocarbons (THC), carbon monoxide (CO) and particulate matter (PM). These results indicate that the optimum combination of effects on engine performance probably occurs at blends between B10 and B40/50. With the exception of emissions of NO_x (which decrease from a peak of +6% relative to Ultra-Low Sulphur Diesel (ULSD) for B50 blends), all other negative impacts increase significantly for blends between B40/50 and B100. At this early stage the results are useful indications, however because of significant differences between different engines, firm conclusions cannot be drawn until other engine models have been tested. The study and initial results are discussed in greater detail in Box 3 in Section 6.1.1. The bench testing will be used to design suitable in-service trials, anticipated to start in mid-2007 for one year.

The overall conclusion for Biodiesel (FAME) is that for blends up to B5 the impacts on toxic air emissions are likely to be insignificant. For intermediate blends (up to B30) there may be very small increases in NO_x emissions, but potentially larger reductions in other important regulated and unregulated emissions compared to conventional diesel. Potential reductions in net emissions of greenhouse gases (principally CO_2) are significant - between 50 and 80% reduction for B100 and typical European production. The degree of greenhouse gas reductions depends on the Biodiesel blend and the combination of feedstock source and production and distribution routes.

5.2 Wider sustainability issues

The most important issues in relation to the sustainability of Biofuels relate to their impact on energy use/CO_2 emissions and the emission of other conventional air pollutants, such as oxides of nitrogen (see Section 2.4, above). However, there are other issues that will contribute to determining whether Biofuels are sustainable or not, such as land use, impacts on biodiversity and ecosystems, impacts on water and the production and disposal of waste products.

The main way in which the impact of Biofuels on ***energy use*** is measured is by assessing the energy balance of fuels, i.e. the ratio of the energy contained in the Biofuel to the energy used to produce the Biofuel[54]. Generally, energy crops grown in tropical climates have better energy balances than crops grown in temperate climates, partially because of the better conditions, but also because they are often cultivated manually and use less fertiliser and pesticides. While the energy balance of temperate Biofuel crops has improved, they are likely to continue to have lower yields than tropical crops[55]. A summary of the energy balances of Biodiesel crops is given in Table 7 (the higher then number the better the energy balance).

Table 7: Energy balances of Biodiesel crops

Fuel	Ratio of energy content to energy used to produce the fuel
Palm oil	Around 9
Waste vegetable oil	5 to 6
Soybeans	Around 3
Rapeseed	Around 2.5
Diesel (crude oil)	0.8 to 0.9

Source: Worldwatch Institute (2006) summarising the results of various studies

[54] Energy inputs considered relate to the amount of energy derived from fossil fuels. There is an alternative measure that includes energy from biomass in the estimation of the energy inputs, but this is not as widely measured.
[55] Worldwatch Institute (2006)

The ***greenhouse gas emissions*** associated with the use of Biofuels is linked to both the combustion of Biofuels, but also to the cultivation of the feedstock and the production of the Biofuel. Carbon dioxide can be emitted in the course of the cultivation and production of Biofuels, either if fossil fuels are used in the course of the process or if land previously used for other purposes (particularly if it was previously uncultivated) is converted to Biofuel production, and nitrous oxide (N_2O) is emitted in the course of the production of the feedstock[56]. As was noted in Section 2.4, the CO_2 balance of any Biofuel also depends on the feedstock used and the mode of production, including the way in which the waste products are used[57]. Additionally, it should be noted that biogas (e.g. biomethane), can be a greenhouse gas, thus any leakages that occur would release a greenhouse gas into the atmosphere.

The issue of ***land availability***, particularly competition between food and energy crops for agricultural land, and the potential conversion of currently unspoilt natural habitats to produce energy crops, is a potential cause for concern. Currently, the EU-15, Canada and the US have 5 billion hectares of arable land or land dedicated to pastures. For the Biofuel crops with the highest yields, i.e. sugar cane and palm oil, between 650 and 700 million hectares (i.e. around 13% of current total farm land) would be needed to replace all the transport fossil fuels by Biofuels. By 2020, with improved yields, it can be expected that only around 6% of existing farmland would be needed for energy crops. However, if this is not to result in an increase in the amount of land devoted to farming, then agriculture will have to become more intensive[58].

The use of land for the intensive production of Biofuel crops could also have adverse environmental impacts, as with the cultivation of land for food crops. There is the potential to ***degrade soil*** and put pressure on potentially scarce ***water resources***, if good agricultural practices are not used; the use of fertilisers and pesticides has the potential to ***pollute both soil and water resources***, if used excessively; and the demand for land may increase the pressure on existing ***natural environments*** with knock-on adverse impacts ***on biodiversity*** (WWF, 2006; ECCM, 2006)[59].

Many environmental NGOs recognise that Biofuels have the potential to reduce greenhouse gas emissions, but are concerned that the current approach to increasing the use of Biofuels will not be an environmentally-sustainable option for many of the reasons noted above[60]. Indeed, in 2006 a group of European environmental NGOs, including Friends of the Earth Europe, Birdlife International, the European Environmental Bureau (EEB) and the European Federation for Transport and Environment (T&E), wrote a joint letter to the European Commissioner with responsibility for the environment asking the Commission to develop sustainability criteria for Biofuels to ensure that they deliver greenhouse gas emissions and do not accelerate the destruction of biodiversity in the EU and developing countries[61]. More recently, Birdlife, EEB and T&E have come out in support of a technologically-neutral approach of setting ‘decarbonisation’ targets for transport, rather than setting targets for Biofuels due at least in part to some of their concerns about the need to guarantee that Biofuels are sustainable. The European Commission has recently proposed to focus on

[56] Worldwatch Institute (2006)
[57] ECCM (2006) *Draft environmental standards for Biofuels* A report commissioned by the LowCVP by Edinburgh Centre for Carbon Management, IIED, ADAS and Imperial College; see http://www.lowcvp.org.uk/assets/viewpoints/LowCVP%20-%20Draft%20Environmental%20Biofuels%20Standards%20-%20July%2006.pdf
[58] CE (2007) *Biofuels and their global influence on land availability for agriculture and nature: A first evaluation and a proposal for further fact finding* Delft.
[59] WWF (2006) *WWF Position paper on Biofuels in the EU* September 2006; see http://assets.panda.org/downloads/wwf_position_eu_Biofuels.pdf; ECCM (2006)
[60] For example, see Greenpeace’s website: http://www.greenpeace.org/international/campaigns/climate-change/solutions/bioenergy
[61] http://www.foeeurope.org/publications/2006/joint_letter_Dimas_biomass_19_January_2006.pdf

decarbonising transport fuels, but it is not yet clear how this will interact with the proposed Biofuels target (see Section 3.1).

5.3 Towards Biofuels standards

In order that the potential benefits of increased Biofuels use can be maximised, a number of recent studies have been investigating the form that potential sustainability standards for Biofuels might take. A study for the UK Low Carbon Vehicle Partnership proposed draft standards for the environmental assurance of Biofuels covering the production of Biofuel crops, and the storage, transport and processing of the Biofuel. The report proposes the following ‘principles’ (e.g. the conservation of carbon stocks) and ‘criteria’ (i.e. protection of above ground carbon and the protection of soil carbon):

- “Conservation of carbon stocks
    - Protection of above-ground carbon
    - Protection of soil carbon
- Conservation of biodiversity
    - Conservation of important ecosystems & species
    - Basic good biodiversity practices
- Sustainable use of water resources
    - Efficient water use in water critical areas
    - Avoidance of diffuse water pollution
- Maintenance of soil fertility
    - Protection of soil structure and avoidance of erosion
    - Maintain nutrient status
    - Good fertiliser practice
- Good agricultural practice
    - Use of inputs complies with relevant legislation
    - Use of inputs justified by documented problem
    - Safe handling of materials
- Waste management
    - Waste management complies with relevant legislation
    - Safe storage and segregation of waste”

The report also suggested that additional mechanisms should be put in place, i.e.

- Development of a set of indicators to monitor the impact on the environment and identify any subsequent risks caused by Biofuel production. Corrective actions could then be taken.
- Work with Biofuels investors to ensure that sustainability considerations are integrated into investment plan at the earliest possible stage.
- A fund to ensure the protection of the most important ecosystems in the areas where Biofuels are being produced.

In the Netherlands, an Energy Transition Task Force was set up to inform Dutch policy on incorporating sustainability criteria into national policy to promote the use of biomass. Its report identified criteria and indicators within six themes, three of which (the first three in the list below) were particularly relevant for biomass and three that were the starting points for corporate social responsibility, i.e.:

- Greenhouse gas balance;
- Competition with food, local energy supply, medicines and building materials;
- Biodiversity;
- Economic prosperity;
- Social well-being; and

- Environment.[62]

For the greenhouse gas balance, a criteria of a net emission reduction of greenhouse gases of 30% was proposed, while for other themes, a dialogue was required with national and local stakeholders, e.g. to determine potential competition with local needs or the potential impacts on regional and national prosperity. With respect to both the well-being and the environment themes, the criteria were no negative effects on the social well-being of the workers and local population and no negative impacts on the local environment, including impacts on soil, water resources and air quality, the use of fertilisers and waste management.

These two reports take slightly different approaches and it remains to be seen the type of standards that will be put in place. While it is clearly useful for national organisations to develop such criteria, given the global nature of the Biofuels market, an internationally-recognised certification system is clearly needed. The UK is investigating a similar scheme and Within Europe, such a system could be developed by the European Union, for example. As discussed earlier an additional feature of such a scheme may be to allow member states to provide additional funding towards the production of certified Biofuels. This could be done via a number of methods such as special duty rates or funding to assist customers with the purchase costs.

5.3.1 NGOs position on biofuels

WWF produced a Position Paper on Bioenergy, which included the following quote:

"*Modern and carbon-neutral biomass fuels have the potential to become a key source of electricity and heat in the next twenty years[63]. Compared to other intermittent renewable energies such as wind and solar, they offer the advantage that they can be stored and therefore used when needed. This increases the application of biomass fuels as a valuable alternative to replace coal in power plants. Research shows that there is an opportunity for OECD countries to generate up to 15% of their electricity requirements from sustainable biomass sources by 2020[64]. The potential global contribution of bioenergy in 2050 will be substantial with a input estimated at 50%[65].*

Developing sustainable production and use of biomass is also key for many communities in developing countries. Many still rely on unsustainable use of firewood, dung and inefficient cookers generating large environmental and health problems. Whilst this position paper covers the global situation, the context and focus is particularly on industrialised countries and sectors and it should therefore be interpreted accordingly.

On the role of bioenergy WWF believes that:

- *When creating an economic level-playing field, biomass fuels are cost-effective and easily accessible sources of energy to replace fossil fuels.*

[62] Energy Transition Task Force (2006) *Criteria for Sustainable Biomass Production* A report from the Project Group on the Sustainable Production of Biomass, July 2006; see http://www.senternovem.nl/mmfiles/Criteria_voor_duurzame_biomassa_productie_Eindrapport_Engelse_versie_tcm24-205854.pdf
[63] This paper focuses on modern bioenergy uses, e.g. conversion of biomass in heat, electricity or transport fuels through an industrial process.
[64] Bauen et al, 2003, Biopower Switch: a blueprint for achieving 15% of electricity from biomass in OECD countries by 2020, Imperial College London and E4tech Consulting, available on www.panda.org/climate.
[65] UNDP, UN Department of Economic and Social Affairs, World Energy Council, 2000, World Energy Assessment

• Presently, preference should be given to the production of highly efficient combined heat and power production applications over dedicated electricity only and transport fuels.

• Stimulating bioenergy requires a cross-sectoral approach at government level, involving Ministries of Agriculture, Forestry, Environment, Trade & Industry, Transport, Finance.

• Governments have a key role to play in stimulating bioenergy demand through a package of measures including inter alia: preferential tariffs or quotas for biomass."

This is generally a positive message, however recently NGO concerns of how sustainable the biofuels are, has led to a Coalition of NGOs, including WWF, Greenpeace, Friends of the Earth and RSBP launching an advertising campaign[66]:

"A misjudged push for the wrong kinds of 'green' fuels could damage the climate and destroy some of the world's last remaining rainforests".

While acknowledging that Biofuels can be used in place of petrol and diesel and that they can be produced from crops and as a result, could reduce greenhouse gas emissions, the NGO coalition is warning that governments risk implementing ill-thought-out policies which lack the appropriate safeguards. In other words, governments could be creating more problems than they solve. This is because businesses producing biofuels could destroy fragile rainforests and wetlands for fuel production (as noted above).

The groups are demanding that the biofuel producers must

"meet minimum greenhouse gas and sustainability standards, with environmental audits of the whole life-cycle of the fuels, from growing the crop to burning it in the car."

A well developed certifcation system has the potential to address these concerns.

[66] see WWF news archives May 9th 2007

6 Technical aspects

6.1 Technical feasibility for railway use

Whilst there is considerable experience and understanding of the impacts of Biodiesel use in road vehicles, there is limited experience on the railways. Information on Biodiesel tests carried out by the engine manufacturers is not readily available (their position is discussed in a subsequent section of this report). However a number of European rail operators have carried out their own bench and field trials on rail vehicles and engines - these include French railway operator SNCF, German railway operator DB, the Czech Operator CD, and the Hungarian operator MAV. Tests by these operators yielded mixed results - Deutsche Bahn (DB) tested rape oil (pure and blended) in railcars and locomotives, with the result that there were no benefits in terms of emissions other than CO_2. This contradicts the results shown in figure 18 from EPA however test results are dependent on the type of fuel used and the particular engine used so it is possible for the results to be different. Results of earlier tests on B20 by SNCF also yielded similar conclusions (see Box 1), however further trials are currently underway on B30 and B100. Outside of Europe, following successful trials of their own, Indian Railways has made a major policy decision to utilise Biodiesel on their railways, see Box . Furthermore, according to the Go transit (Canada) questionnaire response, a transit commuter rail system called Rail Runner is presently using B20 in its service in Albuquerque New Mexico USA.

Because of the relatively lower energy density (energy content per litre of fuel) of FAME Biodiesel compared to conventional fossil diesel, a 5% greater volume of Biodiesel is needed to maintain vehicle performance and range relative to conventional diesel. There may also be odour problems associated with Biodiesel combustion from some sources, such as vegetable oils, however these are more minor considerations. Other drawbacks arise due to the aggressive behaviour of FAME, which results in all materials that come into contact with the fuel having to be FAME-resistant. Fuel hoses and rubber joints, for instance, swell and become brittle if they come into contact with FAME. Before a vehicle can run on pure FAME or high percentage blends of FAME with diesel, therefore, it is necessary to replace any “at-risk” components with ones that are FAME-proof. This has to be checked in each individual instance. The review for ATOC by Interfleet (2006)[67] provides the following useful list of parameters identified as particularly important in consideration of the utilisation of FAME Biodiesel on railways:

Beneficial aspects:	***Adverse aspects:***
• Reduced gaseous (except nitrogen oxides) and particulate emissions • Minimal sulphur content (<10ppm) • Higher cetane number and flash point • Higher density/viscosity • Improved lubricity • Biodegradable and low toxicity	• Reduced energy content (by approximately 8-10%) • Increased fuel consumption • Increased nitrogen oxide • Poor low temperature starting and operation • Poor oxidation stability and water absorption characteristics • Incompatibility with certain elastomers and natural rubbers • More rapid lubricating oil degradation • Degradation during long-term storage

The Interfleet report suggests that for blends greater than B5, as the blend ratio increases, deteriorating effects on performance and reliability could be expected, although these might

[67] “An Examination of Biodiesel Fuel and the Implications of its Potential Use on UK Railways”, Report Number: ITLR-T18618-001, by Ian Silver, Interfleet Technology Ltd, 8 August 2006.

still be acceptably small up to B20. Some of these adverse aspects for blends higher than 5% may be reduced or overcome by fine-tuning of engines or minor equipment replacements (e.g. fuel hoses and rubber joints). Other issues may require more significant changes but might be largely overcome by the engine (and oil) manufacturers if there is sufficient demand for engines compatible with the higher blends. For any given engine fleet, the warranty situation with the OEM (Original Equipment Manufacturer) or overhauler may be compromised for existing engines with the higher blends.

Biofuels may also influence the implementation of stage IIIB of the NRMM. For example, if we use figure 18 from EPA we can see that the PM reduction associated with biodiesel will make compliance with the PM limits easier whereas compliance with the NOx limits will become harder.

It is worth noting that advanced/second generation Biodiesel currently in development does not share these limitations. However, this fuel is unlikely to be widely available for a number of years (more information is provided in a later section).

6.1.1 Case Studies

We contacted European Railways and other railways from around the world and received responses from the following railways. The five case studies in Boxes 1 to 5 provide details on the railway experiences of SNCF (France), DB (Germany) and Indian Railways in the testing and use of Biodiesel blends, information on ongoing tests in the UK and the experience of a US train operating on B20.

Box 1: Evaluation of Biodiesel for rail by SNCF

SNCF has previously carried out tests on B20 Biodiesel (20% Biodiesel mixed with regular diesel) with a DMU engine (see Figure 1 below). Testing assessed the engine's emissions performance over the ISO 8178 test cycle F. Results showed no significant emission benefits, and in some cases even reductions in performance (CO, HC and NO_x) and an increase in fuel consumption.

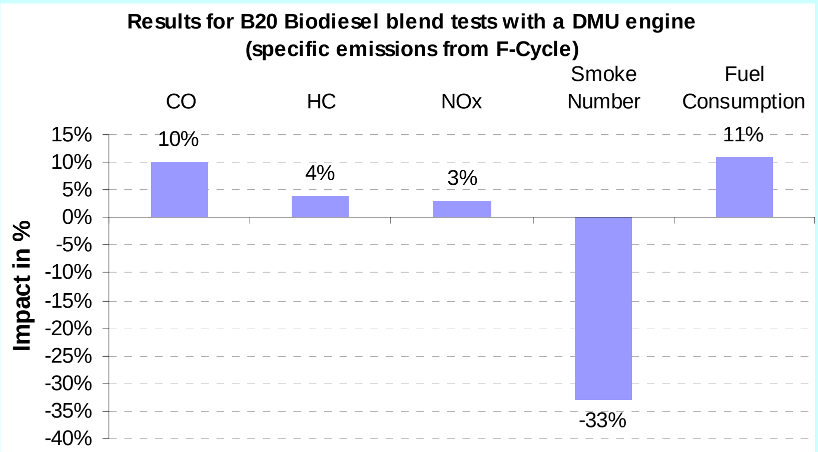


Figure 1: Biofuel test results (80% diesel and 20% Biodiesel) relative to diesel, DMU engine

Despite these results further trials are underway. This is largely due to a statement in January 2006 by President Chirac that said "the RATP and the SNCF will not have to consume one oil drop any more within twenty years", i.e. by 2025. A stated objective towards this goal is 70% of the SNCF locomotive fleet running on B30 Biodiesel by 2010. A quote from the French Transport Minister admitted that these higher Biodiesel blends were likely to cause problems. This has raised the importance of Biofuels for rail up the agenda and further trials are now being conducted with the aim of introducing Biodiesel to the French railway system. These trials started in autumn 2006, with SNCF carrying out Biodiesel trials in specific locations across France. Three specific programmes are being implemented, as follows:

1. A 2-year trial with B30 Biodiesel blend (consisting of 30% Biodiesel and 70% conventional diesel) used in two Regional Express Trains (TERs) of type X73500 railcar traction units (with 2 x MAN D2866LUH, 257kW engines) in two regions of France;
2. The same B30 fuel trialled in a shunting yard. This is with Y7100 (POYAUD 6PYT, 152kW engine) and Y8000 (POYAUD, RVI, 219kW engine) shunting locomotives;
3. 100% Biodiesel trialled in two locomotives running on a test track. These are a BB67400 loco (with a PIELSTICK 16PA4-185 1765kW engine) and a BB460000 shunting loco (with a CAT 3508B, 1000kW engine).

According to the oil company Total, B30 would be twice as expensive to produce compared to conventional diesel. ADEME, the French Agency for the Environment and Energy Management, has estimated that production costs of Biodiesel are approximately €0.30 per litre higher than the production costs of the conventional gas oil.

Initial results of the bench tests on B30 seem to indicate there is nothing in particular to be worried about in the use of B30 in unmodified engines. The engines being tested so far have been subject to preventive measures in order to isolate the causes of any problems that might arise due to the use of Biodiesel. It is anticipated that by early May 2007 actual "on-rail" application trials of B30 will be carried out. Bench testing of B100 is not anticipated to start before the end of 2007/start of 2008.

Box 3: Introduction of Biodiesel onto Indian Railways

Indian Railways (IR), the prime mover for passenger and freight traffic in India, have a fleet of about 4000 diesel electric locomotives that consume about 1.7 million tonnes of petro-diesel fuel annually. Medium speed, large bore heavy-duty diesel engines having power levels ranging from 560-3000 kW are used for these locomotives. With a view to reduce the operating costs, enhance service performance, increase economic competitiveness and reduce the environmental impact of diesel locomotive emissions, use of Biodiesel as an alternate fuel for traction purposes was actively investigated by Indian Railways.

In order to evaluate the performance of diesel electric locomotives with Biodiesel and its various blends as fuel, laboratory tests and field trials were carried out on the 16 cylinder ALCO DLW 251 series engines (2315 kW). The field trials were carried out on the Shatadbi Express diesel locomotives between New Delhi and Amritsar. Certain equipment manufacturers like the MICO who supply the fuel injection equipment to IR have raised certain conditions on warranty in case Biodiesel is used as a traction fuel on diesel locomotives. Indian Railways carried out detailed engine testing of the ALCO engine with imported soya based Biodiesel and its blends. The tests were conducted with B10, B20, B50 and B100 blends of Biodiesel. The engine power output, specific fuel consumption, exhaust gas temperatures, firing pressures, emissions and injection pressures were some of the parameters monitored during the tests.

Summary of main results of Biodiesel trials[68]

It can be seen in the following Figure 1 that the maximum engine power is not affected significantly by changing to Biodiesel blends and the engine power remains within ± 1% of that of mineral diesel (B0).

[68] Extracts from "Utilization of Biodiesel for Rail Traction on Indian Railways", by A. K. Kathpal and Anirudh Gautam (Engine Development Directorate, Research Designs & Standards Organisation, Lucknow), Avinash Kumar Agarwal (Department of Mechanical Engineering, IIT Kanpur)

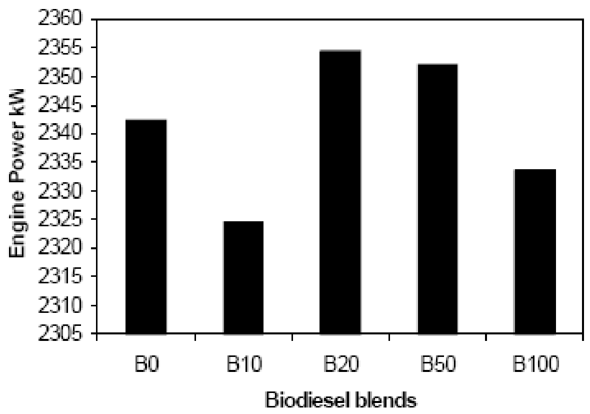


Figure 1: Maximum engine power for different Biodiesel blends

The specific fuel consumption was higher with higher blends of Biodiesel: as anticipated, the fuel consumption is highest with B100, followed by B50 and the lowest is obtained with conventional diesel (B0). However, the IR trials also showed no appreciable difference in fuel consumption with B10 and B20 blends as compared to the regular diesel, suggesting that using these blends may have limited penalties in terms of volumetric fuel consumption.

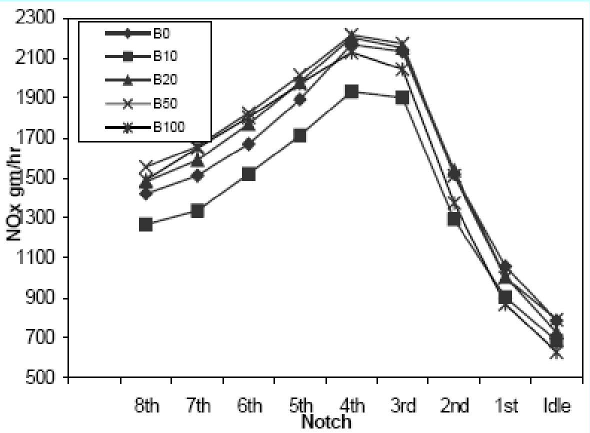


Figure 2: NOx emissions for Biodiesel blends

Figure 2 shows the results of tests on NO_x emissions. The emissions are lowest with the B10 followed by conventional diesel whereas emissions were highest with B50. IR has noted that previous research has established that NO_x formation for Biodiesel and its blends is not purely a function of temperature and depends on a number of factors such as fatty acid composition, chain length of fatty acids, number of double bonds, cetane number, type of engine and the density of the Biodiesel. Thus the NO_x emissions behaviour of the ALCO 251 engine is a matter for further research, using different feedstock-based Biodiesel and their blends. Emissions of hydrocarbons (HC) decreased on moving from B0 to B100 in the tests.

In the field trials a locomotive was used to haul the prestigious Shatabadi Express from New Delhi to Amritsar fuelled with B05. No adverse effects were observed during the test-run in terms of haulage capacity, abnormal engine performance etc. After the completion of nearly 700 km return trip, no unusual deposits were noticed in the fuel filters. The fuel injection pumps and injector nozzles were also found to be in satisfactory condition and free from any gum or resinous deposits.

Resulting actions

The success of the trials has led to the Indian Railways making a policy decision to promote the use of Biodiesel across their rail network. Utilisation of Biodiesel has just started on Indian Railways (IR), and they are currently only running two trains with B5 on the Southern Railway with a total consumption of Biodiesel of about 0.5 million litres in 2005. However, this is expected to increase substantially in the coming years. India has plans to utilise B20 on all its diesel vehicles. For this the Government has already identified about 11 million hectares of land for oil crops, which should be sufficient to make the utilisation of Biodiesel sustainable. The Chhattisgarh government, which is promoting jatropha plantations in all 16 districts, has set up a jatropha Biodiesel plant near Raipur. The Biodiesel sells at Rs.28 per litre, at least Rs.10 less than traditional imported diesel[69].

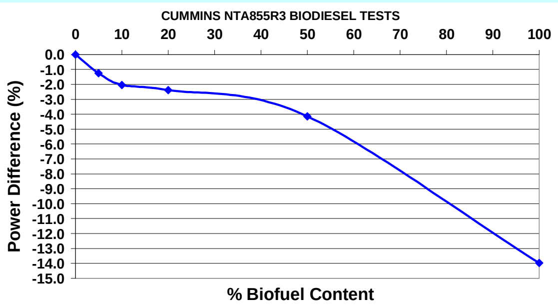
Box 4: Initial results of UK Biodiesel trials

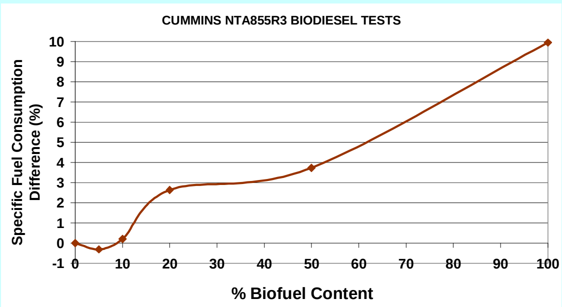
Interfleet Technology Ltd is currently undertaking UK trials of Biodiesel for ATOC. Virgin are also exploring the possibility of running their fleet of class 22X trains on a biodiesel blend in excess of 5 as they believe that this will reduce their carbon foot print and increase their environmental benefit over other modes of transport the aim of this is to encourage passengers to use trains instead of air or road.
The trials will consist of a series of tests using the ISO 8178 F Duty Cycle on a number of different rail engines fuelled with different Biodiesel blends. The initial test bed work will examine blends of 5%, 10%, 20%, 50% and 100% on a number of engines. The results are to be used to set the blend for service trials so that the maximum possible blend ratio that does not prevent the train from running to timetable can be used. The final report from this study will aim to make recommendations that will minimise the cost to the fuel industry while giving the maximum environmental benefit through reductions in emissions of sulphur, carbon dioxide, particulate matter and oxides of nitrogen. The engines identified as priorities for testing for UK applications are highlighted in red in Table 1 below, together with a Class 66 Freight engine.

Sum of Engines			
Engine	**Total**	**Percentage**	**Priority**
NT855	912	32.83%	1
QSK-19	549	19.76%	2
MTU 6R183	529	19.04%	6
LT-10	274	9.86%	5
Perkins 2006 TWH	256	9.22%	4
Paxman VP185	150	5.40%	7
MTU 16v 4000 R41 R	108	3.89%	3
English electric	0	0.00%	8
Grand Total	2778		

Table 1: Engines as a proportion of UK rail fleet and priorities for Biodiesel trials

The initial results of tests on the Cummins NTA855R3 engine are presented in the figures below. Results are presented as percentage changes relative to ultra-low sulphur diesel (ULSD) and include comparisons of impacts on power delivery, specific fuel consumption and emissions of nitrogen oxides (NO_x), hydrocarbons (THC), carbon monoxide (CO) and particulate matter (PM). These initial results indicate that the optimum combination of effects on engine performance probably occurs at blends between B10 and B40/50. With the exception of emissions of NO_x (which decrease from a peak around B50), all other negative impacts increase significantly for blends between B40/50 and B100. Similar results have also been obtained with initial tests of B10 and B20 on the Cummins QSK19 engine, except that NO_x emissions dropped significantly below those of ULSD for B20. At this early stage the results are useful indications, however because of significant differences between different engines, firmer conclusions cannot be drawn until other engine models have been tested.





[69] See news story at New Kerala.com: http://www.newkerala.com/news3.php?action=fullnews&id=29257

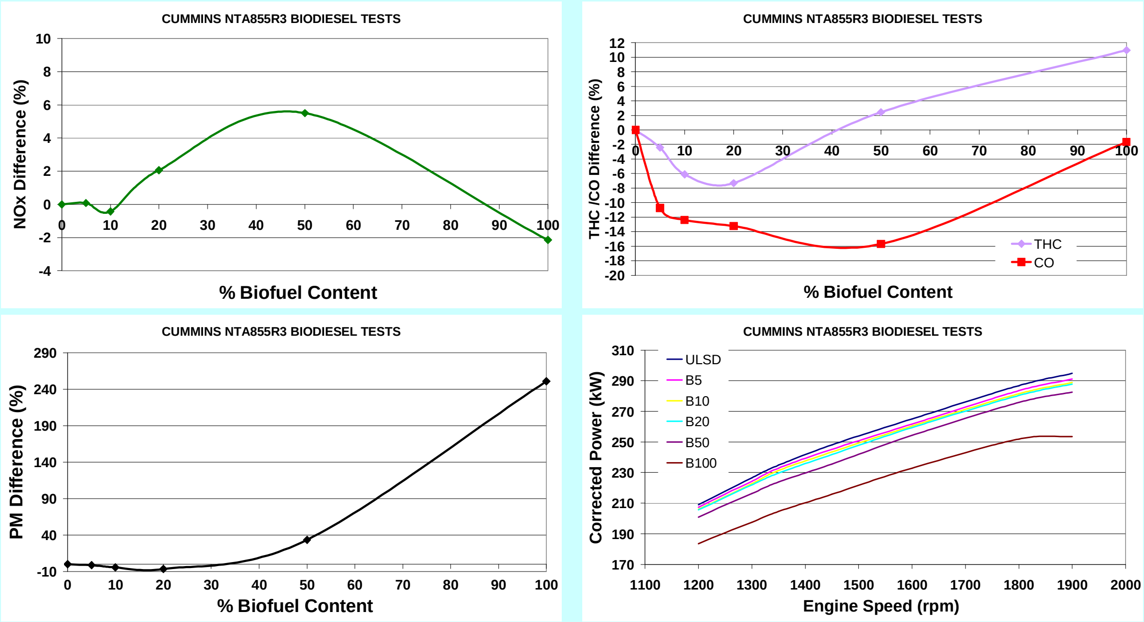


Figure 1: Initial results of UK bench trials of Biodiesel with the Cummins NTA855R3 engine, [Results are presented as % changes relative to ultra-low sulphur diesel fuel.]

It is currently proposed that, following the bench testing work, four engines of each of the finally selected engine types will be tested in a service trial for one year. This test would have two purposes.

1. To examine the long term effects on the engines due to the use of Biodiesel.
2. To compare results with the test bed on fuel consumption

The service trials are currently expected to start in mid-2007, with the final reporting on the work due in 2008.

Box 5: New Mexico commuter train running on B20 Biodiesel

New Mexico has a new commuter train ('Rail Runner') that started running on a B20 blend of Biodiesel in 2006 – it was one of the first commuter rail systems in the country to use Biodiesel. The Rail Runner's five locomotives are diesel-electric MP36PH-3Cs built by Motive Power Inc.[70]. These produce about 3600 horsepower each and are capable of running at speeds in excess of 100 mph. The express service is operating initially only between New Mexico's largest city Albuquerque and Bernalillo, a distance of about 20 miles. Eventually, it will run between Belen, south of Albuquerque, and to Santa Fe by 2008. The ten double-decker passenger cars are built by Bombardier in Quebec and can carry up to 200 passengers each (140 seated, 60 standing). Each train consists of 2-3 passenger cars, for a capacity of up to 400-600 commuters[71].

[70] "New Mexico Commuter Train to Run on B20 Biodiesel Blend", Green Car Congress website, 28 July 2006. Article available at: http://www.greencarcongress.com/2006/07/new_mexico_comm.html
[71] "Meep! Meep! Here Comes the Rail Runner", article and photo available on the EVWorld website at: http://www.evworld.com/article.cfm?storyid=1045

Figure 1: The New Mexico 'Rail Runner' Express train, operating on B20

Box 6: Queensland, Australia: Feasibility Study for QR Biodiesel Trial 2006/7

A study carried out for Queensland Rail (QR) in 2006 examined the feasibility of biodiesel as an alternative locomotive fuel in QR freight operations and assessed the effect of biodiesel on the environment.

The Government had already set a fuel quality standard for neat biodiesel (B100) in September 2003 and is currently working on management options for standardising diesel/biodiesel blended fuels. In Adelaide, all metro trains are now already running on biodiesel. The project was launched on 1 March 2005, and saw the city's 95 metro rail cars operating on B5 biodiesel, with the blend set to be progressively increased to B20 in the future.

There are currently two major suppliers of biodiesel in Australia - Australian Biodiesel Group (ABG) and South Australia Farmers Fuel (SAFF). They were both contacted as part of the QR feasibility study to provide the typical physical properties of their biodiesel products. The SAFF biodiesel specifications supplied were found to be within the limits of both EMD locomotive manufacturer specifications and Australian federal fuel guidelines fuel recommendations. It was recommended in the study report that QR trial a blend of 5% biodiesel with ultra-low sulphur diesel in the initial stage, with blends up to B20 (20% biodiesel) also considered. Although the findings indicated biodiesel fuel offers significant environmental and health benefits in the form of reduced emissions, a number of project risks were also identified, such as fuel filter plugging and somewhat reduced fuel economy. However, these were judged as manageable. B5 and B20 fuels were judged as 'low risk' for application in trials.

Among the other recommendations of the study for the proposed biodiesel trials were:
- Risk management and minimisation using fuel quality monitoring, risk awareness and regular maintenance.
- Obtain biodiesel complying with Australian Standards, checking supplier warranties and with original engine manufacturer, EMD, on the engine warranty statement in relation to the supplied fuels.
- Upgrade natural rubber fuel system components over time to be compatible with biodiesel and with new ultra-low sulphur diesel.
- Keep thorough records and develop processes for the purpose of establishing whether engine failure is due to use of biodiesel.
- Closely monitor engine cooling system as circumstantial evidence suggests biodiesel may lead to some cooling system issues.
- Prior to commencing trials, the test locomotive should undergo servicing, including replacement of the fuel injectors, changing the lubricating oil and engine intake air filters, and the lubricating oil itself.
- Fuel filter plugging is likely to occur when biodiesel is initially introduced and more frequent inspections must therefore be carried out.

Following on from the feasibility study and its recommendations, testing on biodiesel by QR began in October 2006 with two control tests and one biodiesel B20 emission and loadbox tests being performed. No engine problems have been encountered so far, however some minor technical issues were identified with the emission testing, though nothing too serious. Initial results show that using B20 biodiesel can to reduce carbon monoxide (CO) emissions with an average reduction across notches of 22% observed. Oxides-of-nitrogen (NOx) emissions were up on average of 10%, whilst average engine power output was down by almost 1% and fuel consumption increased by an average of 4%. However, QR have noted that these initial test results are not statistically significant. Although some oil was thrown out of the exhaust during the first B20 test, QR have concluded this may have been due to prolonged engine idling before the test and has not occurred in any subsequent tests. Further tests are ongoing.

6.2 Position of rolling stock producers and engine manufacturers and fuel suppliers

The recent report for ATOC by Interfleet (2006)[72] provides a useful starting point to assess issues such as warranty cover for new power units and engines, which are subject to maintenance agreements. Such issues are key to the use of Biofuels and we have contacted manufacturers to confirm their positions on use of Biofuel; to date we have only had a response from Cummins who confirmed their position is unchanged. An EU-wide standard for Biodiesel was introduced in 2004 (EN 14214), which has become the reference for all Biodiesel producers and engine/vehicle manufacturers.

Whilst most engine manufacturers appear to be willing to include 5% (by volume = about 4.6% by energy) Biodiesel blends (also known as B5) within the fuel specifications, engine manufacturers appear to be less willing to include use of higher blends (such as B10, B15 and B20) or 100% Biodiesel (B100). As such motor problems caused by the use of higher Biodiesel blends can lead to insurance problems if used according to the Norwegian National Rail Administration. The main reasons for the position of engine manufacturers include: lower energy content (reduced power and fuel economy), elastomer incompatibility, microbial growth, possible cold starting problems and increased oil change intervals (generally at least halved). The Euromot position paper as part of NRMM review[73] states:

> *"Biofuels shall be used only as a blend with conventional fuel. The amount of FAME shall not exceed 5 % by volume. For diesel engines, concentrations of Fatty-Acid Methyl Esters (FAME) beyond 5% by volume can have an adverse effect on the engine's performance and the fuel system's integrity or durability. Areas of concern are low-temperature operability (filter plugging), heat content (poor fuel economy) and storage/thermal stability (filter plugging, injector deposits, microbial decomposition). Higher volume blends can only be accepted for BTL (Biomass to Liquid) due to its superior quality (this applies also for GTL (Gas-to-liquid) though it is not a Biofuel)."*

In light of these comments it would be advisable to undertake some comprehensive research to assess the impact on the engine's performance and the fuel systems' durability and integrity prior to the rolling out of blends with a FAME content of greater than 5%. The merit of a 5% Biodiesel warranty by engine manufacturers may itself be limited as diesel fuel in the EU can be supplied with up to 5% Biodiesel without declaration according to the European diesel fuel quality standard (EN 590) that applies. It is understood, according to the PREMIA[74] project, that the CEN technical group responsible for maintaining and revising the standard has accepted a proposal from Germany to increase the community norm for diesel in order to allow a 10% Biodiesel blend. This could have significant implications for railway operators in those European countries where the railways use the same fuel as for road transport (e.g. Germany).

[72] "An Examination of Biodiesel Fuel and the Implications of its Potential Use on UK Railways", Report Number: ITLR-T18618-001, by Ian Silver, Interfleet Technology Ltd, 8 August 2006.
[73] 'Considerations on diesel fuel quality required for non-road mobile machinery', May 2005
[74] The EC funded PREMIA project aims at supporting the European Commission's on-going work on alternative fuels and provides input to the revision of the Biofuels directive, as well as investigating longer-term policy options. More information (including reports and meeting minutes) can be found at www.premia-eu.org

Blending is already common in France and Germany where 5% blends are used, but unblended Biodiesel may be used in some older existing rail engines, after slight modifications have been made to the engine[75].

In terms of compatibility with higher blends, the Caterpillar engine range is divided into two, with most of the range stated as being able to be run on Biodiesel blended with diesel fuel in any proportion, provided that the undiluted Biofuel satisfies the specification given (Interfleet, 2006). The remainder of the fleet is restricted to operation at 5% Biodiesel, beyond which it is suggested that premature failures could occur, not covered by warranty. A limited number of MTU engines are also approved for use with FAME according to the European Biodiesel Standard EN 14214. In fact the MTU 1800 is B100 compliant. MTU developed this engine due to rising customer demand for such engines due to freight trucks in the UK and Germany already running on biodiesel blends up to B50.

Cummins announced in the US in March 2007 the approval of Biodiesel B20 blends for use in its 2002 and later emissions-compliant ISX, ISM, ISL, ISC and ISB engines (including the recently released 2007 products). Cummins upgraded its previous position on the use of Biodiesel fuel, which limited the use to B5 blends only, up to B20 for three key reasons:

1. The American Society of Testing Materials specification ASTM D6751 now includes an important stability specification for B100 Biodiesel.
2. The availability of quality fuels from BQ-9000 Certified Marketers and Accredited Producers is growing rapidly;
3. Cummins has completed the necessary testing and evaluations to ensure that customers can reliably operate their equipment with confidence using B20 fuel.

Cummins has announced that they will continue their efforts to ensure that future products will be compatible with Biodiesel fuels, and will continue to participate in industry efforts aimed at the development of consistent quality throughout the Biodiesel industry[76]. The US announcement does not cover any engines currently in use in volume in the UK railways, however.

6.2.1 FUEL INJECTION EQUIPMENT (FIE) MANUFACTURERS.

A common position statement was issued in June 2004 by five of the principal FIE manufacturers[42]. This fully supported the development of alternative fuels, but stated that their agreed position was to limit the release of injection equipment to a maximum of 5% FAME content. For blended fuels above this level, a primary concern is oxidation stability and the lack of sufficient safeguards against blend quality. A comprehensive table is included in the position statement listing FAME fuel characteristics, their effect on FIE and potential failure mode.

6.2.2 ENGINE MANUFACTURERS ASSOCIATION (EMA).

EMA is an international organisation representing the interests of engine manufacturers, to which most of the above mentioned OEMs belong. A position statement on biofuels was issued as far back as 1995, with the most recent technical position being issued in February 2003[39]. This is a fairly comprehensive six-page document, and its conclusions are worth outlining below, as it usefully summarises a lot of the preceding discussion: -
- EMA members expect that blends up to 5% biodiesel should not cause engine or fuel system problems, provided that the B100 fuel meets the requirements of one of the three relevant international standards.

[75] Rail Diesel Study, Work Package 2 Final Report: "Technical and operational measures to improve the emissions performance of diesel rail", by AEA Technology, UIC, EUROMOT and UNIFE, December 2005.
[76] Further information about the use of Biodiesel for both on-highway and off-highway Cummins products can be found on the Web at: http://www.everytime.cummins.com/every/

- For blends in excess of B5, the individual engine manufacturer should be consulted.
- Biodiesel additives may be required to improve storage stability and allow use across a wide ambient temperature range.
- The condition of seals, hoses and gaskets should be monitored regularly.
- Increasing power loss is likely with increasing biodiesel percentage, culminating in a loss of approximately 5-7% at maximum power.
- PM, CO and HC emissions are all reduced, and NOx increased, compared with diesel fuel. Additionally, it is stated that biodiesel should not be used as a means to improve air quality in ozone non-attainment areas.
- Biodiesel fuels are non-toxic and biodegradable.
- Individual OEMs should decide the implications of biodiesel use on commercial warranties.
- The average cost of biodiesel exceeds that of conventional diesel fuel.

Two further documents have been issued by EMA since that time. The first of these was a statement issued in March 2006 distancing the organisation from the use of raw or processed vegetable oil as fuel, instead of correctly processed biodiesel. The second document, issued in May 2006, is a biodiesel specification [40] for blended fuel up to B20. This specification attempts to address known biodiesel deficiencies to the industry's satisfaction, for example lubricity and cetane numbers are defined consistent with that expected from diesel fuel, and an oxidation stability test is included to ensure that a minimum six-month storage period is achievable. However, for low temperature operation, reference is simply made to the possibility of improving blending practices or deriving alternative low temperature operability test methods. Notwithstanding that, this document is an important step forward in defining set biodiesel blend standards.

6.2.3 PETROLEUM SUPPLIERS.

Approaches were made to six other major fuel suppliers for their views and comments. Of these, only Total responded. They considered that the major issue was one of cost, with the current road duty rebate on ULSD of 20 pence per litre being effectively equal to the extra cost of producing a litre of biodiesel. Much of the interest that they had received centred on how much cheaper biodiesel might be. The view was that in the short term (i.e. approximately the next 3-5 years), there was more of a future for them in marketing low sulphur gas oil to the non-road industry (required from 1st January 2008 to have the sulphur level of gas oil reduced from 2000 to 1000 ppm), unless there was a change in the duty regime from the UK government.

6.2.4 UNITED KINGDOM PETROLEUM INDUSTRY ASSOCIATION (UKPIA).

UKPIA represents the interests of its nine member companies supplying petroleum products within the UK. It has a statement on its website [43] identifying its position regarding biofuels in the UK. In summary, this states that:

- Biomass is a limited resource and delivers the greatest CO_2 reduction when used to generate heat and power.
- Duty differentials have effectively introduced alternative fuels to the UK.
- Duty incentives should be targeted only to those biofuels complying with BS EN 14214, to avoid poorer quality biodiesel fuel coming onto the market.

Contact was made with a representative of the UKPIA for further discussion. He reaffirmed the view that diesel fuel can be expected to include 5% FAME by April 2008, but also added that this could rise to 10% by around 2015. He also added that FAEE might be used as a biodiesel component in the future (see section 4.5).

6.3 Position of car manufacturers

In order to assess the situation for the railway sector regarding biofuels it is also helpful to have a view on the automotive sector. An initial internet inquiry has shown that almost all major car manufacturing companies have invested significant efforts in research and development to provide technical solutions for the use of biofuel in their cars already. It can be assumed that these efforts are dependent on the markets operated on and the political framework for the use of biofuel in these markets:

- South America/ Brazil: All car manufacturers operating on the Brazilian market offer models with flexi-fuel to be able to use both ethanol as well petrol since the use of ethanol has a long tradition in Brazil.
- United States: There is a strong commitment by US car manufacturers on the use of biofuel - mainly ethanol (e.g. General Motors and Daimler Chrysler). The US government strongly supports the use of biofuels and the development of a distribution infrastructure as part of the US strategy to increase energy security/ lowering the dependency on fossil fuels and to subsidize the national agricultural industry. There are significant sales of flexi-fuelled vehicles, mainly due to current fiscal incentives on the price of the vehicles.
- Europe: In general the activities and commitments of European car manufacturers for the use of biofuels are lower compared to the US. It seems that also plenty of efforts are made to develop hybrid or hydrogen engines.

Company Examples[77]:

- General Motors: Sets priority to Ethanol and the provision of E85 ethanol capable vehicles. GM announced last year that they will double their production of vehicles capable of running on renewable fuels by 2010 and plans to make half of their annual vehicle production biofuel-capable by 2012, provided there is ample availability and distribution of E85 ethanol, as part of an overall national energy strategy.
- Chrysler Group: Promotes the use of "Clean, Renewable, Home-Grown Fuel". The company has produced more than 1.5 million Flexible Fuel Vehicles (FFVs) capable of running on E85 fuel. The company will produce an additional 250,000 FFVs in 2007 and 500,000 in 2008. The Chrysler Group's diesel vehicles – the Dodge Ram pickup and Jeep® Grand Cherokee SUV – are approved for use with B5 fuel, composed of 5 percent clean, renewable biodiesel and 95 percent conventional diesel fuel. These vehicles are delivered to customers running on B5.
- Volkswagen: Has quite a lot of experience with the development of cars capable to run on biofuels, especially ethanol, due to their production site in Brazil. Volkswagen is also working on solutions for the use of second generation biofuels. Volkswagen's proposal for the long-term, technologically neutral promotion of biofuels in Europe is to introduce a market-economy-based fuel-taxation model which focuses on CO_2 efficiency and sustainability criteria versus a simpler quota system.
- PSA Peugeot Citroen: Produces flex-fuel cars for the Brazilian market. It seems that PSA gives higher priority to the development of hybrid cars and fuel cell engines.
- BMW: Has no statement about the use of Biofuel (ethanol or biodiesel). BMW's priorities seem to be to bring cars with hydrogen-fuelled internal combustion engines to the market.

The initial internet survey has shown that for most of the car manufacturing industry biofuel plays an important role in the company's technology strategy. Whereas companies from North and South America seem to prefer ethanol blends (E85), biodiesel and second generation biofuels as well as alternative engine concepts such as hydrogen-fuelled engines seem to have priority for European car manufacturers.

[77] Results of an internet survey on May 24th 2007 using the following websites: www.gm.com, www.daimlerchrysler.com, www.volkswagen-umwelt.de, www.psa-peugeot-citroen.com, www.bmwgroup.com

6.4 Other Biofuels

Diesel engines burning a liquid fuel oil (gas oil, diesel oil) provide the most common type of power unit used by railway vehicles for propulsion and other uses. There are many reasons for this, such as the high flash point which prevents the fuel igniting, the high energy content and the ease with which it can be stored and transported. The rail vehicles typically have a long life (compared to road vehicles) and consequently substitution of mineral oils by Biodiesel blends and 100% Biodiesel are typically assumed as the most convenient Biofuel. However, other Biofuels are available and in development, for example Sweden has operated a railcar fitted with an engine modified to burn a gaseous Biofuel (Box 7) and, bioethanol is available and commonly blended with petrol in road vehicles at both low (5% ethanol and 95% petrol by volume, or E5) and high levels (85% ethanol, or E85). The use of petrol-engined rail vehicles is not common but such bio-ethanol fuel could be used by railways, where appropriate, for example in maintenance and support equipment. There is also the future potential of so-called 'second generation' Biofuels, such as BtL (Biomass-to-Liquid) diesel (also known as synthetic diesel). The following subsections discuss these other fuels, including their advantages and disadvantages, in more detail.

6.4.1 BtL (Biomass-to-Liquid) and HTU (Hydrothermal Upgrading) Diesel

Gas-to-Liquid (GtL) diesel is a mature technology producing synthetic diesel by the Fischer-Tropsch synthesis of natural gas. When a similar process is carried out using gas derived from the gasification of biomass it is referred to as Biomass-to-Liquid (BtL) diesel, also known as 'SunFuel', 'SunDiesel'[78], or 'second generation Biodiesel'. Biodiesel produced by a BTL process holds significant potential to produce very high quality Biodiesel fuel (superior in many respects to conventional fuel) with significantly lower net CO_2 emissions (up to 90% or even higher claimed[79]) than existing Biodiesel fuels (FAME). This fuel can generally be used in all diesel engines, as the make-up and especially the purity of the synthesis gas is able to meet the highest quality standards. However, BtL technology is in an early stage of development at the moment, compared to the relatively mature Biodiesel/FAME production.

The Fischer-Tropsch process was pioneered for the purpose of converting solid fuels, mainly coal, to liquid fuels in countries where there was a very limited indigenous supply of oil. The first stage of the BtL process involves the gasification of the feedstock to a "synthesis gas", which is primarily a mixture of hydrogen and carbon monoxide. This gas can, in turn, be converted to liquid fuel and in the produces significant heat that can be used to generate electricity as a significant co-product of the process.

There is little information in the literature about Fischer-Tropsch processing of Biofuels, although the process should be very similar to the fossil fuel process. The key challenge for Biofuels is to adapt and optimise the whole system to a scale that is appropriate to the availability of the biomass feedstock. A large refinery would not be practical, as it would require wood to be transported long distances to the processing facilities.

78 As developed by CHOREN Industries, see: http://www.choren.com/en/
79 VW Mobility and Sustainability report: http://www.mobility-and-sustainability.com/

Table 8: Comparison of properties of conventional diesel, FAME and BtL diesel

Property	Conventional diesel	FAME Biodiesel	BtL diesel
Energy density, Net CV in GJ/tonne	43.4	37.2	44.0
Physical density, litres/tonne	1203	1124	1282
Volumetric energy density, MJ/litre	36.1	33.1	34.3
Typical cetane number	52 to 54 in EU[80] (with additives)[81]	56 to 58[82] (no additives)	75[83] to 99[84] (no additives)
Viscosity @40°C (mm^2/s)	3.5	4.5	2.9 – 3.5
Cloud Point, °C	Less than -5	+3 to -7[85]	-5 to -30
Oxygen content, % by mass	0	~11	0
Carbon content, direct emissions in gCO_2/litre	2.63	2.50	2.43
Net CO_2 reduction over fuel cycle over conventional diesel	-	Typically 40-60%	>90%
Sulphur content, ppm	Currently <50ppm	<10 ppm	<10 ppm
PAH content, % by mass	2 to 5 in EU[86]	0	0

The market requirement for cetane number is about 45-50[83]. Due to this high cetane number, BtL diesel can be blended with conventional diesel of lower quality which otherwise would not have been utilized as an automotive fuel. An overall a summary of the advantages and disadvantages of BtL diesel include the following:

Advantages	***Disadvantages***
• Potential for very high net CO_2 emissions reductions (greater than current Biofuels) • Potential for significant net emissions reductions of toxic air pollutants compared to diesel and Biodiesel • Grassy or woody biomass feedstock is less expensive and can be produced both more intensively than existing oil crops and on a wider range of land types • BtL diesel can be used at all blends in existing engines without modification • Superior cetane levels to fossil diesel • Sulphur-free grade fuel is produced • Improved performance compared to FAME's limiting areas, such as freezing point, energy content, …	• Very high capital and overall production costs • Technology is still in development and yet to be proven

[80] In the US the typical range is lower, minimum 40, with an average of 43 according to: http://www.boulderBiodiesel.com/Glossary/
[81] Commonly available diesel fuels have a cetane index of 50 to 52, and values of 53 to 54 are achieved by the addition of ignition accelerators, according to: http://www.biopowerlondon.co.uk/Biodiesel.htm
[82] Or even as high as 70, depending on the vegetable oil base.
[83] "Production of synthetic Biodiesel via Fischer-Tropsch synthesis - Biomass-To-Liquids in Namdalen, Norway", Project report by Norwegian University of Science and Technology, December 2006. Report available at: http://www.zero.no/transport/bio/BtL%20Namdalen.pdf
[84] "NExBTL – Biodiesel fuel of the second generation", a report by Neste Oil Corporation and Technical Research Centre of Finland, January 2005. Available at: http://www.nesteoil.com/binary.asp?GUID=6D18F58B-6CBB-456E-B781-64DEB22DD54D or at http://www.greencarcongress.com/2006/10/neste_oil_in_la.html
[85] For soya oil based FAME, according to the Biodiesel Association of Canada - http://bcbiofleet.ca/Website%20Documents/Biodiesel%20Users%20Guide/Fleet%20Manager%20Manual%20Version%201%20Apr05.pdf
[86] The limit value for PAH content in the EU is 11% by mass (current proposals are to reduce this limit to 8%), however in reality the vast majority of the fuels sold are of significantly lower PAH content.

Hydrothermal Upgrading (HTU) diesel can be produced from residual organic feed with high water content, as opposed to dry residues for BtL (CE Delft, 2005[87]). The hydrothermal upgrading process is based on depolymerisation and deoxygenation of biomass by means of hydrolysis and decomposition. This process has to be followed by a catalytic hydrodeoxygenation (HDO) to produce the final diesel fuel. The process can use dry or (lower cost) wet biomass (such as forestry, agriculture and food processing residues). Greenhouse gas emission reduction potential is claimed to be 65-90%. The HTU process is still in a relatively early stage of development (more so than BtL diesel), so it is hard to make estimates of cost, however because it can utilise wet biomass streams otherwise that would otherwise not be used, future costs might reach levels below those of current conventional diesel[87]. Current indications are that fuel quality will be equal to or better than conventional diesel fuel.

6.4.2 Biogas and Biomethane

Railway applications of natural gas have been used mostly in demonstration projects, but could still be a potential niche market, perhaps in urban settings where the lack of particulate emissions and quieter running engines would be advantages. Some trains have been run on compressed natural gas (CNG), but large volumes of CNG cylinders are required to store an adequate amount of fuel, so liquefied natural gas (LNG) may provide a more practical application for long distance transport. Identification of experience specifically in biogas rail operation is limited to that in Sweden (see Box 7).

As far as the engine manufacturers are concerned, Cummins has stated that they are working on many types of alternative fuels, however variable fuel quality is a problem (as it is for Biodiesel). For the example of biogas, fuel quality is very variable – it is typically used in stationary power plants where a low power density is acceptable. This would be an issue on the railway. However, according to the NGV (Natural Gas Vehicle) industry[88] supporting renewable methane makes an important distinction between unrefined biogas (a mixture of methane, carbon dioxide and other compounds) as the first output of processes such as anaerobic digestion[89] that is then upgraded to 'biomethane' (with typically greater than 97% methane) and used in vehicles. This is a distinction from biogas that is typically considered as an electricity generating fuel and has a much more variable methane and energy content. This seems to be borne out by Swedish experience with a biogas (biomethane by the NGV definition) powered railcar that has been running successfully since autumn 2005 (see Box 7). However Methane is 24 times a more powerful GHG than CO2. Since transporting and storing Methane is difficult as shown below the leakage of methane would need to be carefully controlled to prevent further release of GHG and net disbenefits.

Box 7: Swedish biogas powered railcar

Background
Swedish companies Euromaint and Svensk Biogas have developed a prototype train that runs exclusively on biogas. They converted a Fiat Y1 diesel engine railcar to run on two Volvo bus biogas engines (Volvo Bussar AB). The train is equipped with eleven canisters that give it a range of 600 kilometres (375 miles), a power output of 286 hp and a maximum speed of 130 kilometres (80 miles) per hour. The single carriage prototype cost €1.08 million to develop and can carry a maximum of 54 passengers. The train, when used between Linkoping and Vastervik, was estimated to cost 20% more

[87] "Biofuels under development - An analysis of currently available and future Biofuels, and a comparison with biomass application in other sectors", report by CE Delft and commissioned by Netherlands Petroleum Industry Association (VNPI), May, 2005
[88] European Natural Gas Vehicle Association, see: http://engva.org/
[89] Anaerobic digestion involves the decomposition of micro-bacteria in organic material in an oxygen-free environment, a natural process that occurs in swamps, and marshes, for example. In biogas plants, this takes place under controlled conditions in a digestion chamber.

to run on methane than on the usual diesel.

Biogas is a mixture of methane and CO_2 and the CO, NO_x and PM emissions performance of the prototype is significantly better than diesel powered traction (see table below[90]).

Table 1: Emissions from the Swedish railcar biogas engines compared to the old diesel engines

G/kWh	*New biogas engines*	*Old diesel engines*	*% Change*
CO carbon monoxide	0.01	0.6	-98%
NOx nitrogen oxides	2	6.15	-67%
NMHC hydrocarbons	0.1	0.35	-71%
Particles	0.01	0.16	-94%
Complying with	Euro 5	Euro 1	

Biogas is generated when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion. Almost any organic material can be used to produce biogas since the process occurs naturally in digestive systems, marshes, rubbish dumps and septic tanks. The gases formed in the anaerobic digestion process, mostly methane and carbon dioxide, are collected. For use as an engine fuel, the methane content has to be boosted to around 97%, which is done by removing most of the carbon dioxide[90].

The biogas (/biomethane) prototype (named "Amanda") entered service in Sweden in June 2005, and initially has been operated by SJ on Sweden's 80km scenic east coast line between Linkoeping and Vaestervik. However, Euromaint and Svensk Biogas hope to eventually roll out the concept across the Swedish network and have already begun preliminary discussions to export the technology to countries as far a field as India.

A key driver for the project was the European Commission's Biofuels Directive that sets indicative targets for the Biofuel share of all transport fuels at 2% by 2005 and 5.75% by 2010. Sweden's ambitious target to replace 3.0 percent by the end of 2005 was the highest among European Union member states, most of which set a target of 2.0 percent. However, in Sweden's favour is their history of embracing biogas as an alternative to petrol or diesel. According to the Swedish Environment Ministry in 2005 there were 779 biogas buses in Sweden and more than 4,500 bi-fuel cars that are able to run on petrol and either biogas or natural gas. In 2006 the NGV fleet experienced very positive growth.

- light-duty cars 10420 (+48 %)
- heavy-duty trucks 338 (+22 %)
- heavy-duty buses 757 (+34%)
- Total 11515 (+46 %)

There were, at the end of the year, 68 (+10 %) public CNG filling stations and 27 (+23 %) bus filling stations. Total CNG sales during 2006 were:

- 20,140 million Nm^3 of natural gas (+ 4 %)
- 23,716 million Nm^3 of biomethane (+ 48 %)
- = 43,856 million Nm^3 total methane (+ 24 %)

Note: units of Nm^3 are cubic metres of gas at standard temperature and pressure conditions (i.e. 25 degrees C and 1 atmosphere)

[90] Information from Svensk Biogas AB, "Biogas train Environmentally friendly and cost effective", available at: http://www.svenskbiogas.se/sb/docs/english/Biogastrain_produktblad_2005.pdf

There are also other examples of diesel rail vehicles converted to run on natural gas, that may also indicate the possible technical opportunities for biomethane/biogas on the railway, these include the following[91]:

- **OAO RZD converting diesel locomotives to gas propulsion[92]:**
  OAO Russian Railways (OAO RZD) aims to have converted 250 diesel locomotives to gas propulsion by 2010, with work on the project beginning in 2004. According to the President of RZD, Gennady Fadeev, top priority is to be given to locomotives with gas propulsion in the future procurement of rolling stock. The Sverdlovsk railway (a division of RZD) planned to convert all its diesel locomotives to gas traction by 2007, with the first set to take up service in 2006.
- **Natural-gas conversion at the Peruvian Central Railway[93]:**
  The Peruvian Central Railway has had a freight and passenger train converted from diesel to gas propulsion by General Electric and now works the 4,800m high Andes line between Lima and the Huancayo region. Reasons cited for the conversion were cleaner combustion and the significantly lower cost of gas.
- **Pilot project for natural gas traction in DB's shunting operations[94]:**
  Deutsche Bahn AG has placed the first Class 360 diesel-hydraulic locomotive converted to run on liquefied natural gas (LNG) into service, which powers complete passenger trains at Munich Central Station on a daily basis. The pilot project being run by DB's Munich Research and Technology Centre primarily seeks to investigate the machine's energy consumption, range, fuel provision, emissions of both noxious substances and noise, and life cycle costs. The gas engine delivers 472 kW and is a D 3508 Caterpillar diesel engine converted to gas propulsion and spark ignition. The tank system by Linde carries max. 872 litres of liquefied natural gas at a pressure of around four bar and a temperature of minus 138°C. Before the gas is fed to the engine at 2.5 bar, the heat exchanger warms it up to +20°C.

An overall summary of the advantages and disadvantages of biogas/biomethane include the following:

Advantages	***Disadvantages***
• The highest potential net reduction of CO_2 emissions of any Biofuel • Significant reductions of all toxic air pollutants relative to fossil diesel • The lower noise engines may be favoured in urban conditions	• Requires the use of specially adapted engines to operate on the gas • Storage as either a compressed gas or as a liquid adds significant additional space and weight (and cost) to the rail vehicle. • Rail vehicle operating range will almost certainly be sacrificed to minimise fuel storage • Requires a new gaseous refuelling infrastructure to be installed • Higher operating costs due to inexperience and possibly higher fuel costs

[91] Information from the Pro-Rail Alliance document "First Comparison of the Environmental Performance of Rail Transport", May 2006, available at: http://www.allianz-pro-schiene.de/cms/upload/pdf-Dateien/English_documents/Einzelmanahmen-engl_Fassung2006-Endg.pdf
[92] Source provided by Pro-Rail Alliance was: Gudok 24/05/04; Railway Gazette International 08/05 p467
[93] Source provided by Pro-Rail Alliance was: Reuters 17/06/05, International Railway Journal 08/05 p4; Lineas del Tren 325
[94] Source provided by Pro-Rail Alliance was: BahnTech 01/2001, p17; zev 4/01, p148

6.4.3 Bioethanol and Biobutanol

Bioethanol is best suited as a spark ignition engine fuel as it has a low cetane number. Ethanol is used extensively in the United States and increasingly in Europe as an additive to petrol. However, extensive use has been made of bio-ethanol in buses in Sweden, where ignition improvers make the combustion of ethanol practical in diesel engines. In 1999, Scandia Corporation reported that one out of six of their buses sold was an ethanol bus. Beyond the greenhouse gas emission benefits of bio-ethanol (which are similar to conventional Biodiesel), using bio-ethanol fuel results in very low particulate emissions. According to Sorensen (2005)[95], a recent study on ethanol using Exhaust Gas Recirculation (EGR), an oxidation catalyst and a particle filter show that emissions levels corresponding to Stage IIIB of the EU's non-road mobile machinery Directive were readily attainable.

Bioethanol is easily transportable, however to maintain vehicle range its requires around a 60% increase in fuel tank size. Diesel engine modifications could be expected to be limited with the use of an ignition improver, as can be seen with the engines on the ethanol buses produced. Pump and nozzle capacity would have to be increased and a lubricity additive would be needed for the fuel, as is the case for conventional low sulphur diesel fuel with low aromatic content[95].

Bioethanol is commonly used in blends with petrol in existing road vehicles worldwide, in a similar way to Biodiesel – for example as a 5% blend (E5) in Germany and France, and a 20% blend (E20) in Brazil. At these levels no engine modifications are required, although blends with petrol to use in conventional petrol vehicles in Europe are currently limited to 5% (although recent proposals are to allow separate blends up to 10% in the future). It can also be used at higher levels up to 85% bioethanol (E85) in specific flexi-fuel vehicles - with relatively little modification (and extra cost) needed compared to regular models. As such bio-ethanol may prove a more attractive proposition to use in train operating companies support and road vehicle fleets, rather than as a fuel for rail vehicles.

Bioethanol may also be used as a possible alternative for natural gas derived methanol in Biodiesel production, producing FAEE (Fatty Acid Ethyl Ester) to further enhance the net greenhouse gas emissions reductions of Biodiesel.

Biobutanol is an advanced Biofuel produced in a similar way to bioethanol, from the same feedstocks and offers a number of advantages that may help accelerate Biofuel adoption. It can be blended into standard grade gasoline or gasoline containing ethanol, is compatible with existing vehicle technology and has the potential to be incorporated into the existing fuel supply infrastructure. Advantages over bioethanol (BP, 2006[96]) include:

- It can be easily added to conventional petrol, due to its low vapour pressure.
- It has an energy content closer to petrol than bioethanol (so a greater distance can be travelled per litre of fuel).
- It can be blended at higher concentrations than bioethanol for use in standard vehicle engines. This is currently up to 10%v/v in the EU (compared to 5%v/v for bioethanol), with the technical potential in the future to increase up to a 16% volume.
- It is less susceptible to separation in the presence of water than ethanol/petrol blends, and therefore allows it to use the industry's existing distribution infrastructure without requiring modifications in blending facilities, storage tanks or dispensing pumps.

[95] Rail Diesel Study, Work Package 2, "Third party assessment of the UIC report entitled 'Technical and operational measures to improve emissions performance of diesel rail'", By Spencer C. Sorenson (Technical University of Denmark), November 2005.
[96] Biobutanol fact sheet, available from the BP website at: http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/B/Bio_biobutanol_fact_sheet_jun06.pdf

- Is expected to be potentially suitable for transport in pipelines, unlike existing Biofuels; as a result, biobutanol has the potential to be introduced into petrol quickly and avoid the need for additional large-scale supply infrastructure.

Biobutanol can also be utilised in synergy with bioethanol in blending with petrol and existing bioethanol facilities could potentially be cost-effectively converted to biobutanol. British Sugar announced collaboration with BP and DuPont in starting production of biobutanol in 2007 at their Wissington bioethanol plant, currently being converted to biobutanol production[97].

6.4.4 Others

Besides the fuels already covered, biomass may be used for electricity generation potentially in CHP (combined heat and power) systems in railway stations to reduce net carbon dioxide emissions. Trenitalia (Italy) are also studying the possibility of producing electrical energy from pure vegetable oil. However in terms of fuels for rail vehicles, biomass derived methanol and DME (dimethly ether) are alternatives that have the potential to reduce emissions of greenhouse gases and other gaseous air pollutants. Much information on methanol and DME is available in the third party assessment of the Rail Diesel Study WP2 report (2005)[95], with further information in the recent Well-to-Wheels report from JEC (2006). This information is summarised in the following paragraphs.

<u>Methanol</u>
Methanol has a low cetane number, and is best suited as a spark ignition fuel, but a methanol diesel engine was developed and produced in the 1990s, with emissions of especially NO_x and particulate matter reported to be substantially lower than any diesel engine of the time. Special consideration must be taken with regard to combustion, but successful operation was achieved, and the engine operated successfully for a time in buses in Los Angeles and New York (NYSERDA, 1997[98]). The use of methanol in an engine would require fuel system modifications including a larger pump and nozzles, and a roughly twofold increase in tank capacity, due to a lower heating value. Certain material modifications would be needed to ensure fuel system compatibility with methanol. The fuel is also very toxic, so handling issues may also arise. Methanol synthesis from methane is a well-established process and bio-methanol can also potentially be produced from syngas resulting from biomass (e.g. farmed or waste-wood) gasification, resulting in significant net CO_2 reductions over diesel. Such production would be expensive, although potentially lower than the costs of producing BtL diesel, but with the added disadvantage of the necessary engine, vehicle and infrastructure modifications required to use the fuel. However this may be to an extent offset by reducing the need for complex, expensive and heavy after-treatment systems to comply with forthcoming NO_x and PM emission limits.

<u>Dimethyl Ether (DME)</u>
DME was first presented as a possible diesel fuel alternative only recently (Sorenson & Mikkelsen, 1995[99]; Fleisch, *et al*.,1995[100]). It has been shown that DME has very desirable

[97] Press release on British Sugar's website at: http://www.britishsugar.co.uk/RVEa326524311fa46e3827a286a3c57aaaa,.aspx

[98] NYSERDA, Website of the New York State Energy Research and Development Authority. http://www.nyserda.org/programs/transportation/AFV_fleetdemo_rpt.asp. Alternative Fuels for Vehicles Fleet Demonstration Program. Final Report 97-4, 1997. Of special Interest Vol 3, sec 3, Heavy Duty Vehicles, available at: http://www.nyserda.org/programs/pdfs/VOL3SC22.PDF

[99] Sorenson, S. C., Mikkelsen, Svend-Erik, "Performance and Emissions of a 0.273 Liter Direct Injection Diesel Engine Fuelled with Neat Dimethyl Ether", SAE Transactions, SAE Paper 950064, 1995.

[100] Theo Fleisch, Chris McCarthy, Arun Basu, Carl Udovich, Pat Charbonneau, Warren Slodowske, Svend-Erik Mikkelsen, Jim McCandless, "A New Clean Diesel Technology: Demonstration of ULEV Emissions on a Navistar Diesel Engine Fueled with Dimethyl Ether". SAE paper 950061, 1995.

characteristics from a combustion and air quality emissions point of view[101]. The first DME engine to be used in a vehicle was in a Volvo bus (Hansen, *et al*., 2000), using a first generation DME engine. A common rail system was built to more closely take into account DME properties, with much lower injection pressure. EURO IV exhaust emissions were achieved with little development of the combustion system, without EGR and with only an oxidation catalyst and no further NO_x optimisation. A 15% fuel penalty was encountered relative to a EURO II engine, although a diesel powered EURO IV engine would also suffer a fuel consumption penalty. More advanced recent engines show a fuel consumption penalty for low NO_x similar to that of diesel for the same NO_x level, with CO and HC emissions readily controlled with an oxidation catalyst. No particle filter or NO_x after-treatment systems are needed. Fuel system durability remains to be proven.

Replacing diesel oil with DME requires the fuel volume to be almost doubled due to lower heating value and a vapour space requirement in the tank. Safety and handling considerations close to those of LPG are appropriate. It is readily transported by rail today, and the infrastructure is close to that of LPG (Hansen, *et al*, 2000). There is a need for technical improvements in the areas of fuel lubricity and seal compatibility.

One of the main problems with DME is its availability. It is currently produced directly from natural gas derived methanol in a relatively simple process, but in only small volumes. There is no commercial experience with bio-DME produced directly from natural gas (via synthesis gas from biomass gasification), according to JEC (2006). Development of such processes on a large scale would be likely to lead to process improvements and higher energy efficiency in the long run. The price for DME has been predicted by several sources to be comparable to that of diesel fuel on an energy basis, when produced from methanol via natural gas (Sorensen, 2005). Using methanol produced via biomass gasification offers significant greenhouse gas emissions reductions, but would substantially increase the price of DME towards BtL diesel levels. This again has the added disadvantage of the necessary engine, vehicle and infrastructure modifications required to use the fuel. However, as with bio-methanol, this may be to an extent offset by reducing the need for complex, expensive and heavy after-treatment systems to comply with forthcoming NO_x and PM emission limits.

[101] A collection of information about DME is available from the International DME Association at the website: http://www.aboutdme.org

7 Principal findings

The principal findings of the study are:

- **Supply and demand**
    1. The EU's Biofuels Directive has arguably been the most important policy measure to stimulate the growth of Biodiesel production and use in the EU. In Germany, the tax exemptions granted to Biodiesel in the late 1990s and early 2000s are also credited with the growth in Biodiesel production and use in that country.
    2. Many EU Member States have more or less adopted the targets for increasing Biofuels use proposed by the Biofuels Directive and many are requiring fuel suppliers to achieve the targets. Tax exemptions are the principal mechanism that Member States use to incentivise the use of Biofuels. In France and Italy, a quota system was also in place, and support has also been given for the production of oilseed crops, e.g. in the Czech Republic.
    3. In other countries, e.g. Brazil, Argentina and a couple of US states, fuel suppliers are also being obliged to blend a certain proportion of Biodiesel with conventional diesel. In India, a National Biodiesel Mission engaging all stakeholders aims to increase production of Biodiesel to levels that will enable blends of 20% Biodiesel to be sold in the county by 2012.
    4. Global production of Biodiesel is increasing rapidly and recent or planned increases in production capacity in many countries around the world – not only in the countries of the EU – are likely to ensure that this trend continues.
    5. Global production of Biodiesel in 2005 stood at 3,500 million litres, of which 89% was produced in the EU.
    6. If the diesel fuel used by the railways of the EU were required to meet the same target as road transport fuels by 2010, i.e. 5.75%, then an additional 150 million litres of Biodiesel would be needed.
    7. Understandably, few railway companies have yet committed themselves to using Biodiesel, although Indian Railways has signed an agreement with an oil company for the supply of 10% Biodiesel blends.
- **Costs**
    8. The main determinant of the cost of a Biofuel (around 80%) is the cost of the feedstock. For the second generation of Biofuels currently under development, the proportion of the total cost determined by the cost of the feedstock is likely to decline significantly, as other costs, such as capital and operating costs increase.
    9. After market price, feedstock yield is the next most significant determinant of the price of Biofuels. Yields vary significantly between crops with crops preferred in India and South East Asia (e.g. palm and Jatropha) typically having significantly higher yields than crops grown in the EU and US (e.g. rape, sunflowers and soya).
    10. The profitability of Biofuel production depends on import prices, taxes and subsidies, which vary between countries.
    11. The costs of Biofuel production in India are already less than those predicted for the EU in 2010. Increased competition for any Biofuels that come on to the international market, e.g. from China, means that the low production costs elsewhere may not translate to an equivalent reduction of prices in the EU.

- **Technical suitability**
  12. There is relatively little experience with using Biodiesel on the railways. Trials undertaken in Germany and France suggest that emissions of some pollutants actually increase, although there might be some reductions in emissions of carbon dioxide. Further trials are underway in France on which we are trying to obtain more information.
  13. Trials undertaken by Indian Railways suggest a small (less than 1%) variation in maximum engine power between different Biodiesel blends (from 10% up to 100%) compared to conventional diesel; the specific fuel consumption increases and the emissions of hydrocarbons decrease as the proportion of Biodiesel increases; and emissions of the oxides of nitrogen were lowest for the 10% blend, followed by emissions for conventional diesel.
  14. Initial results from UK trials suggest that the optimum combination of effects on engine performance probably occurs at Biodiesel blends between B10 and B40/50. With the exception of emissions of NO_x (which decrease from a peak around B50), all other negative impacts increase significantly for blends between B40/50 and B100.
  15. There are potential beneficial and adverse effects of using Fatty Acid Methyl Ester Biodiesel on the railways; one important impact is the adverse effect that this type of Biodiesel can have on certain materials that are commonly used in engines. These materials have to be replaced with components that are resistant to these effects.
  16. As the Biodiesel blend increases, there might be adverse impacts on performance and reliability, but these might be acceptably small up to blends of 20%. Second generation Biofuels are unlikely to have the same limitations.
  17. Most engine manufacturers appear to be willing to include 5% Biodiesel blends within the fuel specifications that can be used in their engines, they are generally less willing to accept the use of higher Biodiesel blends.

- **Sustainability**
  18. In the longer-term, second generation Biofuels, produced by converting biomass to liquid are likely to offer more benefits in terms of a reduction in carbon dioxide emissions. However, the technology is at a relatively early stage of development.
  19. Biofuels have the potential to reduce transport's greenhouse gas emissions and improve a country's energy security.
  20. Apart from the life cycle emissions of Biofuels, there are wider sustainability issues associated with the cultivation of Biofuels, as there would be with any crop. Hence, it is important for good agricultural and management practices to minimise these impacts.
  21. Certification standards are being developed to ensure that the potential adverse sustainability impacts of Biofuels would be minimised as far as possible, while enabling the benefits of Biofuel use, e.g. reduced greenhouse gas emissions and increased energy security, to be realised.
  22. There does not appear to be a significant impact on pollutant emissions if diesel is replaced with low Biodiesel blends. As the percentage Biodiesel content of a fuel increases, there may be small increases in emissions of the oxides of nitrogen, whereas emissions of other pollutants, such as carbon monoxide and particulate matter might be reduced.
  23. Replacing diesel with Biodiesel has the potential to reduce significantly emissions of the greenhouse gas carbon dioxide. However, the extent of the reductions depends on the specific Biodiesel blend and the production and distribution routes used.

The report concludes that Biofuels can form part of the solution to GHG emissions but there are important issues that must be addressed;

- The supply of Biofuel, and Biodiesel in particular, is rapidly increasing. Planned or recent increases in production capacity suggest that earlier predictions of Biodiesel supply in 2012 (Source: *IEA (2004))* might be an underestimate. However, given the likely increased demand resulting from the various policy initiatives around the world, the railway sector is likely to face competition for Biodiesel on the global market. BtL or Second Generation Biofuel (see section 6.3.1) will offer a higher yield and can increase production to help meet the rising demand but the processes for the production of second generation Biodiesel are still being developed
- Currently Biodiesel costs significantly more than diesel and this is a disincentive to using Biodiesel. Governments could subsidise Biodiesel production but there is currently no way they can guarantee that the fuel they are subsidising is not coming from an unsustainable source and may in fact be worse than fossil fuels. A worldwide /EU (see section 5.3) certification scheme can give governments the confidence to offer discounts to reduce costs to the end user. The alternative is that governments legislate and industry picks up the costs.
- Initial results from desk top analysis and test bench work shows Biodiesel is technically feasible for use in railway traction unit engines in lower percentage blends, but there are still disadvantages such as increased fuel consumption and decreased power. Blends in excess of B30 may increase life cycle costs. Again second generation Biofuels can meet a higher specification and in fact may prove to be better than fossil fuels.
- This report clearly shows Biofuels can reduce GHG emissions but it is still difficult for customers to be sure of the environmental credentials of Biofuels they are buying and to be certain of the benefits they provide. With certification schemes in place, it would be possible for customers to ensure their Biodiesel was produced in a sustainable manner and know what GHG saving the fuel actually delivers.

If used together, Second Generation Biofuels and a Biofuel Certification scheme can help to resolve these issues.