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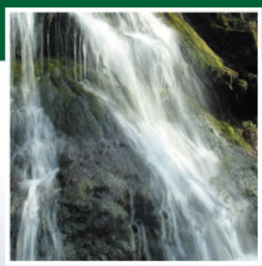

Chapter 11
Liquid Biofuels

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11 Liquid Biofuels

Bernard Rice, Teagasc, Oakpark.

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Table of Contents

List of Tables

List of Figures

11.1 Objectives

Having completed this section of the training course and manual, learners should:

- Understand the different technical approaches available to produce liquid biofuels.
- Be aware of current production of liquid biofuels in Ireland and future potential.
- Be able to identify benefits and barriers to the production of liquid biofuels.
- Be aware of relevant EU and Irish policy and legislation.
- Understand the key components of financial viability.
- Be aware of aspects of a liquid biofuels project in Ireland through a case study.

11.2 Definitions and Classification

In the original proposal from the European Commission for a directive on biofuels three principal categories of alternative fuels were identified:

- Biofuels i.e., fuels derived from biomass crops or by-products that are suitable for use in vehicle engines or heating systems;
- Natural gas, with future large-scale use likely to be based on purpose built cars;
- Hydrogen, with natural gas or electrolysis being the most likely initial large-scale production methods[1].

Biofuels can be considered as potential replacements or extenders for mineral fuels such as diesel or petrol. They can be sub-divided into a number of categories, the principal two being:

- vegetable oils / animal fats which can be used in unprocessed form or converted to biodiesel;

[1] Hydrogen being classified as a renewable fuel will depend on how it is produced. Biomass is a potential source of hydrogen and developments in technology (thermal gasification, etc.) will be important to facilitate its exploitation in this way.

- bio-ethanol produced from the fermentation of organic materials such as sugar beet, cereals, etc..

Vegetable oils include oil from purpose grown oil seed crops (oil seed rape, camelina sativa, etc.). They also include waste vegetable oil (or recovered vegetable oil – RVO) such as waste cooking oil from the catering industry. Animal fats include tallow produced by the rendering industry.

Other biofuels, which will not be discussed here include the following:

- Biogas (principally composed of methane), which is collected at landfill sites or from anaerobic digestion systems, could be used in vehicles in compressed form.
- Bio-methanol and dimethylether (DME), which are produced from biomass derived methane, offer limited attraction compared to alternatives.
- Bio-oil produced from the pyrolysis of biomass materials continues to be the subject of extensive research, although commercial uptake is limited as yet.

Vegetable oil and bio-ethanol technologies are now well developed and have reached commercial acceptance in many countries.

11.3 Liquid Biofuels Technology

11.3.1 Vegetable Oils / Animal Fats

Vegetable oils and animal fats can provide a high-quality source of renewable fuel for use in either diesel engines or central heating system boilers. Some of these uses are already well developed; others are still under development. Use of these fuels would result in reductions of greenhouse gas emissions, given that they are considered to be carbon neutral[2]. It is recognised, however, that there are greenhouse gas emissions associated with the production of these fuels, resulting from the use of fossil based energy in their production. This needs to be taken into account in calculating emissions on a life cycle analysis basis.

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[2] Carbon emitted on combustion is taken up in new plant growth, resulting in no net addition to the atmosphere.

These fuels have no sulphur, which improves exhaust emissions, and they are biodegradable, which reduces pollution risks from spillages. They could therefore be considered to be premium fuels whose use could be directed to applications that make best use of their health and environmental advantages. There are issues with the quality and stability of these fuels and therefore specification standards for both rapeseed oil and the biodiesel derivative are being developed in Europe and at a Member State level.

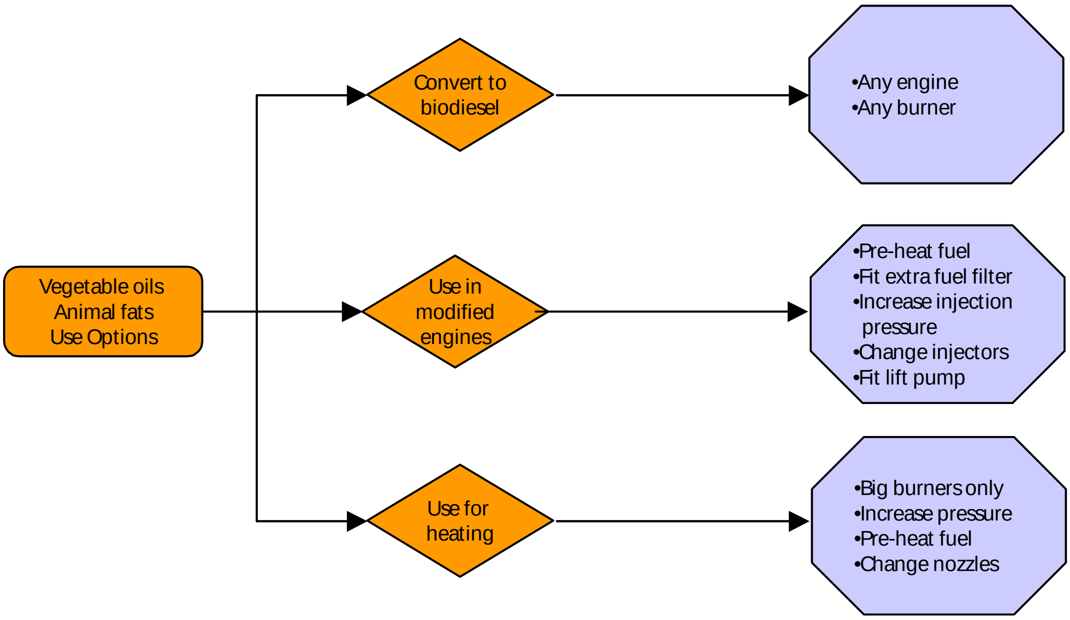

Figure 11.1 Options for the use of oils and fats as fuels

11.3.2 Feedstock Materials

Oil Seed Crops

Currently, the main fuel use of vegetable oils in the EU is as biodiesel. The vegetable oil is produced from oilseed crops grown on set-aside land. These crops are mainly rapeseed in Northern Europe, and sunflower in Southern Europe.

Irish farmers can achieve satisfactory yields of rapeseed, and many cereal farmers could produce it with their existing complement of farm machinery. Farmers would probably welcome the opportunity to use it as a break crop in

a mainly-cereals crop rotation and at least 30,000 hectares could be grown in Ireland without significant disturbance to existing crop production practice.
Oilseed crops could also provide, as a by-product, a native source of genetically modified organism (GMO) free animal feed protein, which should be readily marketable because of a positive public image.

Recovered vegetable oil

A less expensive raw material would be recovered vegetable oil (RVO) from the catering industry. About 7,000 tonnes is collected in Ireland at present, while waste management companies indicate that about 10,000 tonnes could be collected with a better collection service and a more economically viable end use. The use of this material in animal feeds has been disrupted since the 1999 Belgian dioxin-in-chickens incident, which was traced to RVO. Teagasc research, together with research and practical experience in Austria, is showing that it can be used to make good quality biodiesel.

Animal fats

Beef tallow from the rendering industry, whose market as an animal feed has been disrupted by the onset of the BSE[3] crisis, is another possibility that could be exploited. The disposal of tallow from the rendering of SRM[4] (approximately 3,000 tonnes per year) has been resolved by its use in the boilers of the rendering plants. Total tallow production in Ireland (in all rendering plants) is approximately 60,000 tonnes per year, two-thirds of which goes to animal feed. The long-term future of tallow as animal feed is in some doubt, and alternative outlets need to be developed. Its use for heating is already being demonstrated, but its application as a fuel for transport or in a CHP plant would have a higher potential value.

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[3] BSE - Bovine Spongiform Encephalopathy
[4] SRM (specified risk material) consists of animal parts (brain, spleen, spinal cord, etc.) considered as most likely locations of the BSE agent (prion).

11.3.3 Technologies

Use in engines

Vegetable oils can be used as engine fuels in two ways (Figure 11.1):

- In unprocessed form, with some peripheral modifications to the engine.
    - This use is relatively new but developing rapidly in some parts of Germany. The engine conversion consists of some combination of fuel pre-heating, extra filtration, increased injection pressure and replacement injectors (Figure 11.1). Fuel processing cost and industry start-up costs are kept to a minimum. Production plants in these cases require low capital investment and the by-product cake can be used locally. It is possible to start at a small scale and expand later. This approach has particular relevance in Ireland.
- Converted into biodiesel, (for example rape methyl ester – RME) and used in any diesel engine without modification
    - Figure 11.2 shows a schematic of the biodiesel (methyl ester) production process.

In France biodiesel is used as a minor ingredient (5%) in blends with mineral diesel which is sold to the general public. In Germany and Austria it is mainly used in undiluted form. Efficient production requires large scale conversion plant, and processing adds about €0.05 – 0.1/litre to the final cost of the fuel. The main by-product of biodiesel production is glycerol. European oleochemical producers are becoming concerned at the distorting effect of large quantities of "subsidised" glycerol coming on the market (APAG, 2002).

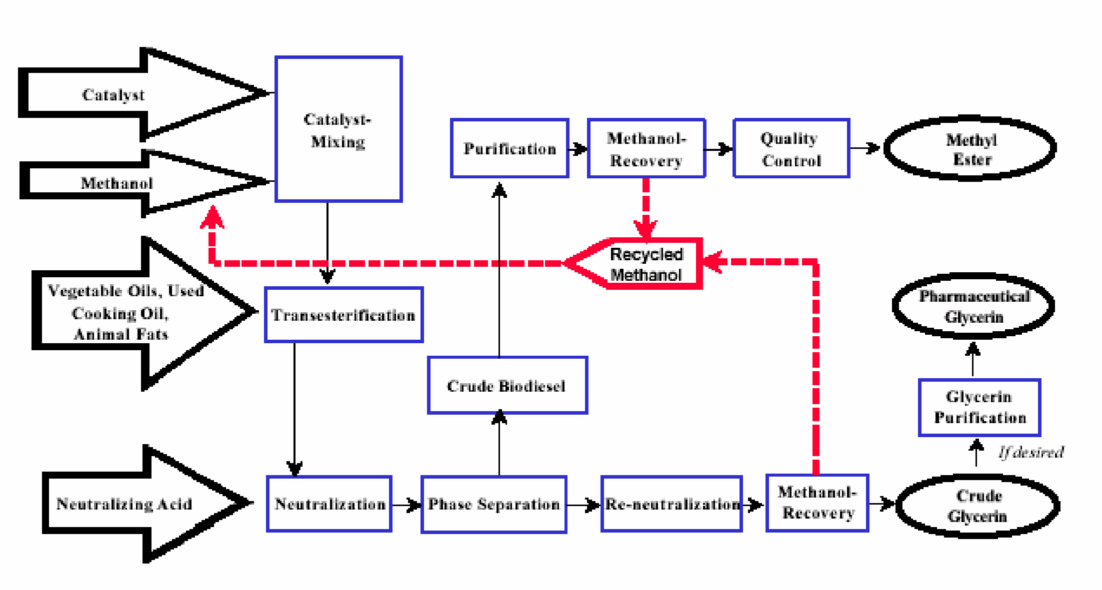

Figure 11.2 Schematic of a biodiesel production process[5]

Use for heating

The use of vegetable oils and animal fats for heating in large-scale burners is also technically feasible. Economic viability, however, depends on a raw material price that is competitive with heavy-grade mineral oil. Use in domestic-scale heating units might be more profitable, but the availability of suitable small burners at a reasonable price remains a deterrent.

11.3.4 Bio-Ethanol from Sugar Beet, Cereal or Wood Waste

Bio-ethanol is produced by the fermentation of sucrose and glucose, the most abundant sugars in agricultural crops. It can be used as a motor fuel as shown in figure 11.3.

[5] Biodiesel Production and Quality by the National Biodiesel Board, www.biodiesel.org/pdf_files/prod_quality.pdf.

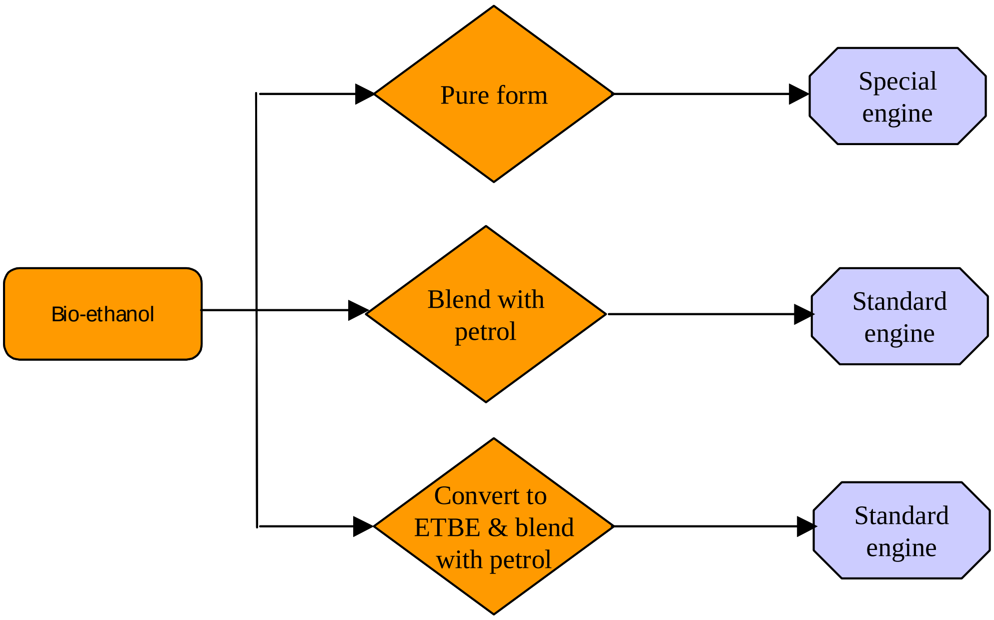

Figure 11.3 Different approaches to use of bio-ethanol as a transportation fuel.

Apart from its value as an oxygenate when blended with petrol, bio-ethanol use results in reductions in emissions of CO_2. The National Renewable Energy Laboratory (NREL) in the US suggests a saving of 7 – 10 kg CO_2 per US gallon of petrol displaced[6], or 1.85 – 2.65 kg per litre[7] of petrol displaced.

11.3.5 Feedstock materials

With many raw materials, fermentation may have to be preceded by the extraction and preparation of fermentable carbohydrates. Fermentation is always followed by the recovery of bio-ethanol by distillation, for which heat input is necessary.

To date, the most widely used raw materials for ethanol production are maize (USA), sugarcane (Brazil), sugar-beet (France) and wheat (France). Cheaper cellulose materials such as straw and wood may be used in the future as processing technology is developed. The production of bio-ethanol from wood , in particular, is the subject of significant research effort in Europe and North America. In an Irish context, grass would be an interesting possibility, as it is by

[6] Bioethanol – the Climate Cool Fuel – www.ott.doe.gov/biofuels/pdfs/bioenvro.pdf.
[7] One US gallon equals 3.78 litres.

far the most widely grown crop and its production is well suited to Ireland's climate.

The crop areas required to produce the quantity of ethanol equivalent to 2% of petrol consumption in Ireland (53,000 tonnes per year) vary from about 15,700 ha of sugar beet to 47,000 ha of barley and possibly up to 86,000 ha of grass. For grass, two alternative scenarios are possible:

- In the first, only the water-soluble carbohydrates are converted;
- In the second the cellulose is also utilised.

Two alternative processes are also possible for wood-chips: one assuming that only cellulose is utilised, the other assuming that both cellulose and xylose are converted.

11.3.6 Technologies

Most commercial bio-ethanol is produced by the fermentation of sucrose and glucose (the latter usually obtained from starch). Some bio-ethanol is also produced by the fermentation of lactose. Fermentation of maltose is the source of bio-ethanol in beer and many spirits, but is rarely used for the production of industrial bio-ethanol. A typical bio-ethanol production flow diagram is presented in figure 11.4.

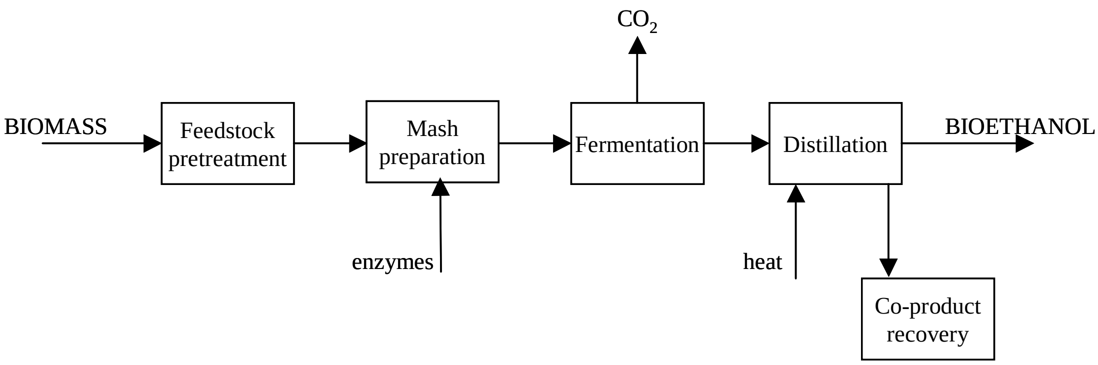

Figure 11.4 Typical biomass to bio-ethanol production flow diagram.

The technology for the production of industrial bio-ethanol has improved considerably in the past twenty years. However, the underlying principles remain the same:

- extraction of fermentable carbohydrate from the feedstock (hydrolysis if it is a polysaccharide such as starch or insulin), followed by
- fermentation and recovery of ethanol in a three-stage distillation.

Fermentation and recovery of bio-ethanol is the same for all raw materials. The individual processes differ in the pre-treatment (extraction and preparation) of fermentable carbohydrates. For example, sucrose in molasses can be fermented directly, sucrose in sugar beet needs to be extracted, while feedstocks with polysaccharides need to be pre-treated and hydrolysed before fermentation can take place.

There are three ways in which bio-ethanol could be used as engine fuel in Ireland (refer to Figure 11.3):

I. In pure form, for which special vehicle engines would be necessary. This approach is unlikely to be attractive in Ireland because, in addition to needing special engines, fuel specific distribution infrastructure would need to be put in place.

II. Petrol / ethanol blends[8] could be used in conventional unmodified spark-ignition engines, up to about 20% ethanol. An EU Directive permits the use of up to 5% ethanol in blends with petrol (Commission of European Communities, 1985). This approach is widely applied in the US, where E10 is commonly used, but has not been favoured in the EU. Petrol / ethanol blends have a higher vapour pressure than either fuel on its own, and this leads to technical problems with the handling and storage of the fuel.

III. Blends of the ethanol derivative ethyl tertiary butyl ether (ETBE - produced by the reaction of 45% ethanol with 55% isobutylene) and petrol may also be used in unmodified engines. The 1985 Directive authorises up to 15% ETBE in blends. This has been the most

8 A blend of 90% petrol / 10% bio-ethanol is designated E10 while a blend of 80% petrol / 20% bio-ethanol is designated E20.

favoured approach to ethanol use in the EU. Additional plant for the conversion of ethanol to ETBE, which does not exist in Ireland at present, would be required.

11.4 Benefits

11.4.1 Vegetable Oils and Animal Fats for Liquid Biofuels

The benefits from the development of vegetable oils and animal fats as diesel engine or heating fuels include:

- *Ecological implications*: Life Cycle Analyses indicate that biodiesel has an overall ecological advantage over mineral diesel oil (Franke, 1998).
- *CO_2 abatement:* There is considerable variation in the literature in terms of the CO_2savings on a life cycle basis. For example, Scharmer & Gosse (1996) report an abatement level of 3.25 kg of CO_2 per litre of mineral diesel replaced, while estimates based on a DEFRA report (2003) would indicate a more modest 1.84 kg of CO_2 per litre of mineral diesel replaced. Some of these variations may be explained by the degree to which co-products and their associated carbon credits (or debits) are included in the calculations. Based on a CONCAWE (2002) review of the literature, it is estimated that the use of 20,000 hectares of set-aside land (producing 1.3 tonnes of biodiesel per hectare), available waste vegetable oil, and tallow could produce 44,000 tonnes of biodiesel. This represents an amount equal to 2% of the road transport diesel consumption. Further, the resulting annual CO_2 savings (using the DEFRA report figures) would be approximately 97,000 tonnes[9].
- *Other emissions:* The main improvements would be in reduced smoke, particulates, carbon monoxide (CO) and unburned hydrocarbons. Oxides of Nitrogen (NO_x) levels, however, are unlikely to be reduced

9 This estimate is based on biodiesel with a density of 0.88 kg / litre and an emission factor of 0.81 kg CO2 / litre (based on life cycle analysis and with account taken of use of the straw and rape meal), low sulphur diesel with a density of 0.85 kg / litre and an emission factor of 3.03 kg CO2 / litre (based on life cycle analysis) and an energy ratio of 0.91 (biodiesel/low sulphur diesel) on a volume basis.

(United States Environmental Protection Agency, 2002 ECOTEC, 1999).

- *Water protection:* Vegetable oil is non-toxic and biodegradable. In the event of an oil spillage reaching a waterway, the effect on aquatic life would be very slight in comparison to mineral diesel.
- *Employment:* On the basis of French studies, the total employment generated by this type of industry would be about 1 job per 100 tonnes of vegetable oil produced (Vermeersch, 1994). However, the potential employment impact in Ireland would require further research.

11.4.2 Bio-ethanol from Sugar Beet, Cereals or Wood Waste for Liquid Biofuels

The contribution of a bio-ethanol industry to the abatement of CO_2 emissions would depend on the raw material selected as well as the efficiency of processing. Using sugar-beet, Bignon (1996) quotes an energy ratio[10] of 1.18 for ethanol and 0.93 for ETBE. The ETBE figure should be compared with 0.73 for MTBE. Poitrat (1999) claims a saving of 0.66 tonnes of CO_2 per tonne of ETBE when it is used as a substitute for MTBE. As noted above, NREL suggests a CO_2 saving of 1.85 – 2.65 kg per litre of petrol displaced.

The energy balance of bioethanol is controversial, as some (mainly older) studies have suggested that more energy is needed to produce the bioethanol than the net energy in the bioethanol produced. Net energy balance calculations are complex and the efficient utilisation (or non-utilisation) of by-products as process fuel or animal feed often determines whether the net energy balance is positive (Henke et al., 2003; Shapouri et al., 2002), although the EU directive on the promotion of biofuels does not mention this aspect. Use of by-products is also crucial to commercial viability.

Modern bioethanol production has a more positive energy balance than previously realised. While some studies are sceptical about the benefits to be

10 The ratio between the energy in the ethanol produced and the sum of the energy to produce the feedstock and the energy to convert the feedstock to ethanol.

gained, others estimate significant environmental, social and economic benefits from the production and use of bioethanol (Urbanchuk, 2001).
Other advantages of bio-ethanol as an additive to petrol would include:

- Its oxygenating effect, leading to a reduction of carbon monoxide (CO) in vehicle emissions and a reduced potential for ground level ozone formation;
- Its value as an octane enhancer;
- The absence of sulphur;
- Reduction of unburned hydrocarbons in the emissions.

11.5 National Potential

Ireland currently uses approximately 1.8 million tonnes of road transport diesel. To achieve the 2% substitution rate for this fuel which is proposed as a target for 2005 by the EU Directive, production of 44,100 tonnes of biofuel would be required. One possible way of achieving this target would be from:

- 7,000 tonnes of RVO (all the material currently collected) converted to biodiesel or used in converted engines;
- 25,000 tonnes of rapeseed oil (from 20,000 ha of set-aside land and based on the more optimistic oil productivity levels suggested by a CONCAWE [2002] review) used in converted engines or to produce biodiesel;
- 12,000 tonnes of tallow converted to biodiesel.

To achieve the 2010 target of 5.75% substitution, biofuel crops would have to be produced on arable (i.e. currently food-producing) land. At current prices for vegetable oil used in food, this would require subsidy in addition to the reduction in excise duty. However, advances in crop production over the coming years should help to mitigate the cost disparity.

11.6 Barriers to Adoption

Barriers to adoption include the following:

- Profitability – the recent initiatives from the Department of Finance to exempt excise duty on liquid biofuels has been of considerable benefit to the development of the sector. However those who have not qualified under the exemption scheme will struggle to be profitable.
- With current technologies, liquid biofuels can be produced from annual arable crops only.
- Availability of arable land in Ireland is limited.
- Oilseed rape needs a rotation period of about four years further limiting potential.
- The distribution network for liquid biofuels is very limited in Ireland at present.

11.7 Relevant Policy and Legislation

11.7.1 EU Directive on Biofuels (2003)

The Directive is designed to contribute to the reduction of EU dependence on imports of transport fuels, to contribute to the EU's Kyoto Target on reducing green house gas emissions and to meet the target of substituting 20% of traditional fuels by alternative fuels by 2020. The Directive requires that the share of biofuels in the EU transport fuel market is 2% by 2005 and 5.75% by 2010.

11.7.2 Mineral Oil Tax (MOT) Relief on Biofuels I&II

Under the 2004 Finance Act the Department of Finance launched the "Pilot Programme for Mineral Oil Tax (MOT) relief on Biofuels". Under the programme MOT relief for pilot biofuel projects in a number of categories (as follows) were awarded:

Pure plant oil	6 million litres
Biodiesel	1 million litres
Bioethanol	1 million litres

Under the scheme MOT relief was awarded through a competitive process in which applicants were invited to submit proposals for consideration. The scheme concentrated on the pure plant oil category in particular.

This pilot scheme was followed up with a second scheme called the "Biofuels Mineral Oil Tax Relief Scheme II" which was announced in the 2005 budget. This scheme will also operate as a competitive process with applicants submitting proposals by August 28th 2006. This scheme aims for 2 per cent of the fuel market to be taken up by biofuels by 2008. The level of excise relief will start at €20 million in 2006 and will be increased to €35 million in 2007 and to €50 million in each of the following three years. This relief is expected to support the use and production in Ireland of some 163 million litres of biofuels per year. This is 20 times the current level of biofuels that is excise-relieved. The volumes anticipated in each category are as follows:

Year	Biodiesel / other biofuels blended with diesel in compliance with EN590 Litres	Bioethanol 5% - 85% blend Litres	PPO 100% blend Litres	Biofuels used in captive fleets Litres	Total Litres
2006	44m	11m	nil	9m	64m
2007	57m	40m	3m	12m	112m
2008	60m	85m	6m	12m	163m
2009	60m	85m	6m	12m	163m
2010	60m	85m	6m	12m	163m

Table 11.1 Biofuels Mineral Oil Tax Relief Scheme II Anticipated Volumes
Source - Department of Finance

11.8 Government Supports

Government supports are primarily though the Mineral Oil Tax (MOT) Relief on Biofuels. Grant aid has been received from some project developers from local LEADER companies. Research into liquid biofuels has been ongoing in a number of academic institutes, while Teagasc (Ireland's Agriculture and Food Development Authority) have been actively researching in this area for many years.

11.9 Financial Viability

11.9.1 Vegetable Oils / Animal Fats

Rice (2002) has estimated the total cost per litre of oil produced from rapeseed in a small extraction plant for two cases, assuming seed prices to the grower of:

€150/tonne and

€180/tonne.

The net oil cost is set out in Table 11.2

In his analysis for the case of using unprocessed oil (vegetable oil not transformed to biodiesel) in converted engines, in order to recover the cost of the engine conversion the oil would need to be approximately €0.1/litre cheaper than mineral diesel. In addition, to allow for the associated reduction in fuel economy the unprocessed oil would need to be a further €0.06/litre lower.

In biodiesel form, having added in a production cost of €0.1/litre and a fuel economy reduction of €0.05/litre, the total cost would be similar to raw vegetable oil. The equivalent price of mineral diesel would therefore need to be at least €0.52/litre, exclusive of excise duty, for either form of biofuel to be competitive.

Production & Extraction Cost of Rapeseed Oil		Option1	Option2
Seed price to grower	€/tonne seed	€ 150.00	€ 180.00
Seed transport	€/tonne seed	€ 5.00	€ 5.00
Seed drying / storage	€/tonne seed	€ 10.00	€ 10.00
Cost subtotal	€/tonne seed	€ 165.00	€ 195.00
Dryer losses	%	6%	6%
Seed cost at mill, allowing for losses	€/tonne seed	€ 175.53	€ 207.45
Seed pressing process cost	€/tonne seed	€ 36.00	€ 36.00
Pressed seed cost	€/tonne seed	€ 211.53	€ 243.45
Oil yield	%	32%	32%
Gross oil cost, based on oil yield	€/tonne oil	€ 661.04	€ 760.77
Oilseed cake income			
Cake yield	%	63%	63%
Cake price	€/tonne cake	€ 130.00	€ 130.00
Cake transport cost	€/tonne cake	€ 4.00	€ 4.00
Net cake value	€/tonne cake	€ 126.00	€ 126.00
Cake income per tonne of oil produced	€/tonne oil	€ 248.06	€ 248.06
Net cost of oil (Gross oil cost less cake income)	**€/tonne oil**	**€ 412.97**	**€ 512.71**
Net cost of oil	**€cent/litre oil**	**€ 0.35**	**€ 0.44**

Table 11.2 Total cost of rapeseed oil produced in a small decentralised plant in Ireland (Rice 2002)

With RVO and tallow, the feedstock price might be expected to be considerably lower – probably €0.2 – 0.3/litre. This would reduce the equivalent price of mineral diesel to about €0.35 – 0.45/litre.

The current price of mineral diesel before distribution or taxation has fluctuated between €0.3 and €0.4/litre. Some excise duty reduction would be needed, at least for an initial period, to allow any vegetable oil / animal fat based fuel to compete with mineral fuel in diesel engines.

11.9.2 Bio-Ethanol from Sugar Beet, Cereals or Wood Waste

Total production costs have been estimated for conventional and lignocellulose material based bio-ethanol (Table 11.3 from Rice et al, 1996). Since there are as yet no commercial lignocellulose plants, the cost estimates for this process are speculative.

Table 11.3 shows a range of production costs from €0.47 – 0.73/litre, depending on the feedstock materials, feedstock price and transformation process. More recent studies, however, indicate lower costs for bioethanol produced from sugar beet compared to wheat (CONCAWE, 2002; Henke et al., 2003).

The calorific value of ethanol is about two-thirds that of petrol. If one assumes a current petrol cost of €0.4/litre before tax or distribution, the value of bio-ethanol as a replacement would be no more than €0.26/litre[11]. Its value on the basis of the price of MTBE from mineral sources would also be low. If viewed in this way, virtually all the current excise of €0.4/litre[12] would have to be remitted to make even the lowest-cost ethanol scenarios competitive. However, MTBE has been associated with water contamination in some US states and is being phased out in California. This should enhance the status of ethanol and ETBE as fuel oxygenates free from environmental problems and could lead to an increase in their price.

	Feedstock less by-product	**Processing**	**Transport**	**Total**
Feedstock	**Cost (€cents/litre)**			
Sugar beet	24	24	5	53
Wheat	22	29	1	52
Barley	22	29	1	51
Grass	18-24	25-32	7-17	50-73
Straw	20	36	5	61
Wood-chips	10-14	36	1-2	47-52

Table 11.3 Estimated production costs of ethanol from conventional and lignocellulosic feed-stocks
(Rice et al., 1996)

11.10 Case Study

See PDF file “Chapter 11 Wexford Pure Plant Oil Case Study”

11 Bioethanol has a calorific value which is about two thirds that of petrol and to have the same value per unit of energy, its value per litre would need to be approximately €0.26 when compared to a petrol value of €0.40 / litre.

12 Excise duty on unleaded petrol is €401.36 / 1,000 litres – Finance Bill 2003.

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*List of references are those that appear in the SEI Briefing Note on Liquid Biofuels. The original document can be found at http://www.sei.ie

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