

The Production and Use of Biodiesel Derived from Used Frying Oil in Scotland



**A Pre-feasibility Study prepared on behalf of Forward Scotland
and Scottish Water by SISTech and the Scottish Agricultural
College
April 2002**



SISTech

Scottish Institute of
Sustainable Technology



The Production and Use of Biodiesel Derived from Used Frying Oil in Scotland: Pre-feasibility Study

April 2002

Tim Darlow^a, Kerr Walker^b and Michael MacLeod^a

^aSISTech, Heriot-Watt University, Riccarton, Edinburgh, EH14 4AS

^bScottish Agricultural College, Craibstone Estate, Aberdeen, AB21 9YA

Prepared by the Scottish Institute of Sustainable Technology (SISTech) and the Scottish Agricultural College on behalf of Forward Scotland and Scottish Water.

Acknowledgements

The authors would like to acknowledge the help of the following organisations that provided information during the preparation of this report: the staff of Scottish Water, BABFO, MacLennan Oils, ACORN and A and B Oils.

Cover Photo: *Two 20 litre drums of used frying oil await collection in central Edinburgh.*

EXECUTIVE SUMMARY

Biodiesel can be produced from vegetable oils or their derivatives by a process called esterification. In comparison to mineral diesel, biodiesel has important environmental benefits.

- Its use produces significantly lower emissions of pollutants such as carbon monoxide, sulphates and particulates.
- The carbon dioxide produced during combustion of biodiesel is, to a large extent, offset by the carbon dioxide absorbed during growth of the crops used to produce the oil.
- Biodiesel has a very low toxicity and quickly biodegrades in the natural environment. This is in comparison to mineral diesel which is highly toxic and will remain in the environment for long a time before fully degrading.

Biodiesel can be used in existing diesel engines without major engine modification and can be economically produced. As a result biodiesel is now widely used in several countries in Europe and around the world. The importance of biodiesel was recognised in the last budget (April 2002) when the chancellor announced a reduction in fuel duty for biodiesel to “allow the UK to benefit from the reduced gas emissions that biodiesel can offer”.

It is possible to produce biodiesel from Used Frying Oil (UFO). This report will show that current disposal routes for UFO are coming under increasing regulatory pressure. As a result UFO disposal is becoming increasingly costly for producers, many of which are small to medium sized enterprises. Biodiesel has the potential to provide a disposal route for UFO, which is more cost effective and environmentally sustainable than current disposal routes.

The most appropriate use for UFO biodiesel has been identified as a fuel for static diesel engines. Such engines are commonly used as standby electricity generators by a range of organisations such as water utility providers and hospitals.

It is estimated that around 8,000 tonnes of UFO are produced in Scotland in each year. Further work will be required to establish the exact quantities and composition of UFO available for biodiesel production. Preliminary economic appraisal of the production of biodiesel has shown it possible to produce biodiesel at a similar cost to mineral diesel. It should be noted that these calculations include no allowance for the sale of potentially valuable bi-products of biodiesel production, most notably glycerine.

Further investigation into the viability of small-scale production of UFO biodiesel in Scotland is required. This could be carried out by establishing a pilot plant which would use local supplies of UFO to produce the biodiesel. Such a scheme could include using the biodiesel produced in a test stand-by generator. This project could benefit from both capital grants and the fuel produced being exempt from fuel duty.

Contents Page

| | |
|--|-----------|
| EXECUTIVE SUMMARY | 3 |
| Aims & Objectives | 6 |
| 1.0 INTRODUCTION | 7 |
| 1.1 Waste Management in Scotland | 7 |
| 1.2 Used Frying Oil (UFO)..... | 8 |
| 1.3 Biodiesel from UFO..... | 10 |
| 1.4 Current use of Biodiesel..... | 11 |
| 1.5 Use of Biodiesel in Static Engines | 12 |
| 1.6 Biodiesel and Energy Policy | 12 |
| 1.7 Scottish Water and UFO | 13 |
| 2.0 THE SUPPLY OF UFO IN SCOTLAND | 15 |
| 2.1 Production of UFO in Scotland | 15 |
| 2.2 Collection of UFO in Scotland..... | 15 |
| 3.0 THE PRODUCTION PROCESS..... | 16 |
| 3.1 Introduction | 16 |
| 3.2 Conventional Feedstocks..... | 16 |
| 3.3 Crushing | 16 |
| 3.4 Refining..... | 17 |
| 3.5 Esterification | 18 |
| 3.6 Unconventional process routes..... | 18 |
| 3.7 EU Specification for Biodiesel | 18 |
| 4.0 UTILISATION OF BIODIESEL | 21 |
| 4.1 Introduction | 21 |

4.2 Fuel characteristics21

4.3 Emissions21

4.4 Spillage and Safety factors22

4.5 Warranties.....23

5.0 PRELIMINARY ECONOMIC APPRAISAL OF UFO BIODIESEL24

5.1 Introduction24

5.2 Legislative Background.....24

5.3 Biodiesel production cost25

6.0 POTENTIAL MARKETS AND USES27

6.1 Use by Utilities27

6.2 Use in environmentally sensitive areas27

7.0 THE WAY FORWARD29

AIMS & OBJECTIVES

Overall Aims

In November 2001 the following organisations formed a project group with the aim of investigating the potential for producing and using biodiesel derived from Used Frying Oil (UFO) in Scotland.

Forward Scotland: Forward Scotland was launched in 1996 as an independent company with charitable status. Its mission is “*To promote sustainable development in Scotland through innovative practical projects and influencing policy*”.

Scottish Water: Scottish Water is the new organisation that provides water and wastewater services to household and business customers across Scotland. It was created on 1 April 2002 from the three former water authorities - East, North and West of Scotland Water. Scottish Water is a public body and is answerable to the Scottish Parliament and to its customers, the people of Scotland.

Scottish Institute of Sustainable Technology (SISTech): The Scottish Institute of Sustainable Technology (SISTech) has been established by Heriot-Watt University and Scottish Enterprise to create an international centre of excellence in the practical delivery of sustainability through research, education and business development. The company is not-for-profit and has locations at the Tweed Horizons Centre (Melrose) and Heriot-Watt University (Edinburgh).

This report is a pre-feasibility study and its overall aims are to:

- define the potential uses of UFO derived biodiesel in Scotland.
- identify barriers to project development.
- outline the requirements of a full feasibility study.

Objectives

In order to achieve these aims, a range of objectives were identified. These are outlined below.

- Outline the present constraints associated with UFO disposal.
- Review the current usage of biodiesel and in comparison to mineral diesel.
- Describe the current patterns of UFO production and distribution in the UK.
- Provide an overview of the UFO biodiesel production process.
- Provide an initial economic appraisal of the use of UFO biodiesel
- Outline some of the potential markets for biodiesel in Scotland.
- Outline the scope, methods, timescale, resource requirements and potential funding sources for a full feasibility study.

1.0 INTRODUCTION

1.1 Waste Management in Scotland

Everybody produces waste through day-to-day activities. The overwhelming majority of the waste produced in Scotland is disposed of in landfill sites. The Scottish Environmental Protection Agency (SEPA) estimated that in 1999, 12 million tonnes was disposed of in this manner in Scotland (SEPA, 1999). Burying waste in the ground is now frequently referred to as being “unsustainable”. The level of waste produced can be minimised through re-use or recycling and value can be recovered from some waste materials through composting and energy recovery techniques. In addition, landfilling waste has adverse environmental impacts, for example through the generation of leachate which can contaminate groundwater and through the emission of methane, a particularly damaging greenhouse gas.

The sustainable management of waste can be summarised by the waste hierarchy (Figure 1.1). This provides a framework within which the most desirable waste management options are set out.

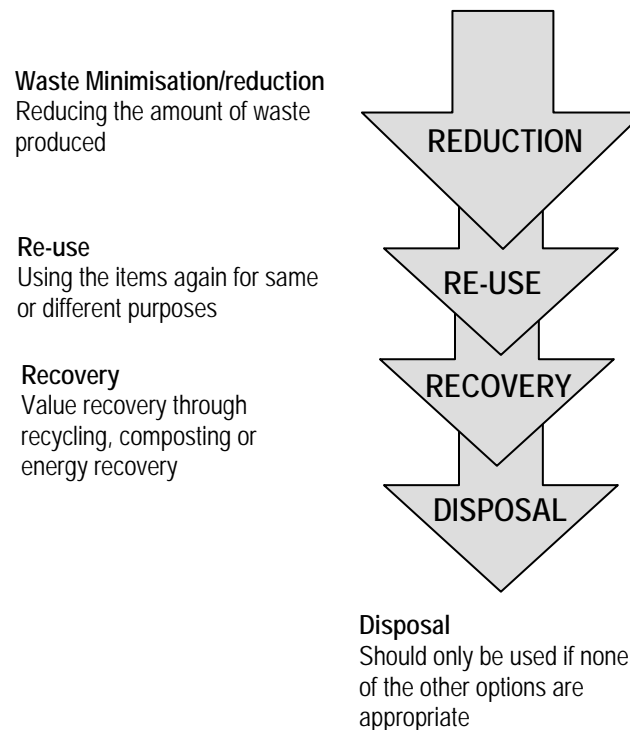


Figure 1.1 The Waste Hierarchy

Different types of waste are often referred to as ‘waste streams’. Careful consideration needs to be given to the choice of waste management options for a particular waste stream. This requires the use of decision making tools such as Best Practicable Environmental Option (BPEO). BPEO is a method of selecting a waste management option through the consideration of technical feasibility along with environmental, economic and social impacts. The proximity principle

should also be taken into consideration when deciding on a waste management strategy. This involves dealing with waste as close as possible to the point at which it is produced in order to improve social equity and reduce the effects of waste transportation.

The management of waste in line with the waste hierarchy is promoted in Scotland through the *National Waste Strategy* (SEPA 1999). This sets a framework for the reduction of the amount of waste produced in Scotland and the management of waste which has been produced in more sustainable ways.

1.2 Used Frying Oil (UFO)

Frying oil is frequently used in the preparation and cooking of many different types of food. Its use varies in scale from householders, to restaurants and take-aways, through to large food processing factories. In the case of commercial operations, significant quantities of waste oil are produced and there are legal obligations for correct disposal. Frying oil will be derived either from vegetable oils or animal fats. Vegetable oils are pressed or extracted from a variety of plant seed or fruits. The most common sources are sunflower, rapeseed, olives, coconut, soybeans, sesame, peanuts, corn germ, cottonseed and various palm oils. Animal fats are primarily lard, tallow and fat. Although fats and oils have the same general structure and chemical properties they have different physical properties. The most important for this project being that fats are often solid at room temperature. (Ensminger *et al.* 1994). Most UFO produced in the UK will originate from vegetable oils. However, it should be noted that vegetable oil becomes contaminated during cooking and will contain variable quantities of animal fat, water and solids.

The options for disposal of UFO within the waste hierarchy are limited. Most UFO is either used as base ingredient for Animal Feed or disposed of to landfill. The current methods of disposal are summarised in Figure 1.2:

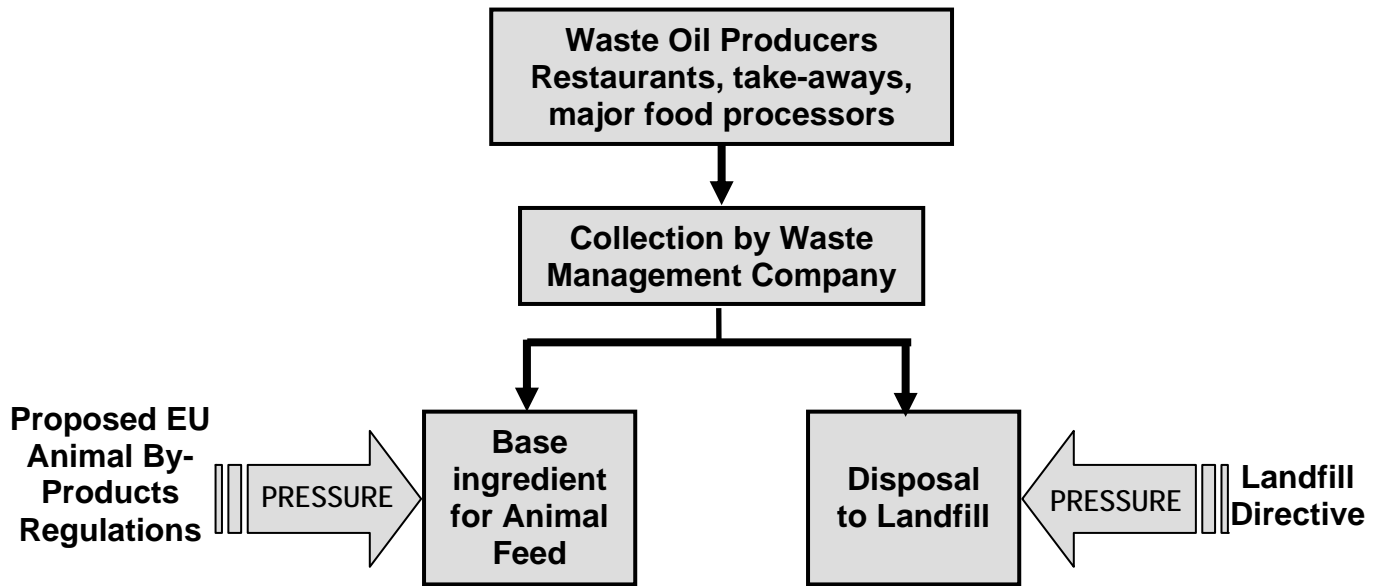


Figure 1.2 Current Disposal Routes for UFO

There are several issues associated with disposal by the above routes:

- **New Legislation on Animal Feed:** The draft EU Animal By-Products Regulation- Used Cooking Oils (European Commission 2001a)- proposes a ban on the use of used cooking oils in animal feed. If adopted, this ban could be in force as early as the end of 2002, thus closing off one of the disposal routes for UFO.
- **The Landfill Directive:** The EU Landfill Directive (European Commission 1999) puts in place targets for member states on the amount of waste that can be disposed of to landfill. This includes a substantial reduction in the amount of 'bio-degradable' material that can be disposed of and also a complete ban on the disposal of liquids. There is still uncertainty regarding whether or not UFO will be classified as a 'liquid'. However, it is certain that both of these measures will make disposal to landfill increasingly difficult and expensive in the future.
- **Costs to Businesses:** If the ban on UFO in animal feed is implemented the only disposal route available would be to landfill. As shown in Table 1.1 the increase in cost to businesses producing UFO is significant. There is a danger that this could lead to increase in the illegal disposal of UFO into public sewerage systems. Such action may initially save a company some costs but may lead to prosecution by SEPA or Scottish Water. Under the Sewerage (Scotland) Act 1968 the illegal discharge of oil to sewer can lead to a maximum fine of £20,000. In 1992, a food processing company in Scotland

successfully prosecuted was fined £10,000 for discharge of excessive levels of waste oil to sewer.

Table 1.1 Costs associated with UFO Disposal

| Disposal Route | Typical Costs |
|---------------------------|--|
| Ingredient in Animal Feed | Resale Value - £130 Collection and Processing Costs - £30-80 Cost to UFO Producer: £40-50 |
| Landfill | Resale Value - £0.00 Landfill Charges – £40-50 Collection Costs- £30 Cost to UFO Producer: £150-£200 |

Any person or business disposing of waste has a Duty of Care (Section 34 of the Environmental Protection Act 1990). Duty of Care places a legal responsibility on anyone disposing of waste to ensure that it is disposed of in a manner which does not cause pollution or harm. There is evidence that some organisations ignore the duty of care with regard to UFO and choose to dispose of it into the public sewerage system. The introduction of UFO into systems designed to deal with wastewater can cause serious problems, with congealed oil blocking drains and fouling equipment. This leads to increased infrastructure and plant maintenance costs. It seems likely that such problems will increase as current disposal routes become more restricted and expensive.

The current disposal routes for UFO are coming under increasing regulatory pressure. They are expensive and a waste of an energy-rich material. There is a clear need for alternative disposal routes for UFO to be identified and assessed.

1.3 Biodiesel from UFO

One potential use of UFO is in the production of biodiesel. UFO can be put through an esterification process that produces biodiesel and glycerol. The biodiesel can then be used pure in modern engines or blended with mineral diesel. The use of biodiesel as a substitute for mineral diesel has several environmental benefits as detailed below. With the correct collection and processing infrastructure in place, this disposal route could represent the Best Practical Environmental Option for UFO.

Summary of the Environmental Benefits of Utilising Biodiesel

- Reduction in emissions of pollutants such as carbon monoxide, sulphates and particulates.
- The CO₂ produced during combustion is to a large extent, offset by the CO₂ absorbed during the growth of crops used to produce the oil.
- Biodiesel has a very low toxicity and quickly biodegrades in the natural environment. This is in comparison to mineral diesel which is highly toxic and will remain in the environment for a long time before fully breaking down.

Biodiesel is classed as a form of renewable energy. This, combined with the environmental benefits outlined above can make its use very attractive to organisations currently utilising mineral diesel for their operations. This is demonstrated later in this section.

1.4 Current use of Biodiesel

Since the oil crisis in 1973, greater attention has been given to the use of biodiesel in many parts of the world. In the USA the use of biodiesel has grown quickly in the last few years. Amendments to energy legislation in 1998 include biodiesel fuel use as a way for federal, state and public utility fleets to meet the regulatory requirements for using alternative fuels. This amendment has led to a sharp increase in biodiesel users, which include the U.S. Postal Service and the U.S. Departments of Energy and Agriculture. A number of school districts, transit authorities, national parks, public utility companies and waste management companies also use the fuel (U.S. Office of Transportation Technologies, 2001). Recent energy shortages in southern USA have served to further increase the use of alternative fuels such as biodiesel. Last summer a hospital in Long Beach, California, switched to biodiesel to run on-site generators and boilers (Green Energy News, 2001).

Biodiesel is widely used in some European countries. In Austria's alpine region, mineral diesel has been replaced by biodiesel at garage forecourts. In France, biodiesel is blended into diesel fuel by an oil company on a general basis (European Commission 2001b). The EU is considering introducing regulations that will require member states to have biofuels (including biodiesel) make up at least 2% of transport fuels by 2005 and 5.75% by 2010 (European Commission 2001b). Targets for biodiesel production have been set for total EU at 2.7m tonnes per annum (tpa) by 2003 and 8.3 tpa by 2010. Current total EU production is around 0.7m tpa. Biodiesel is currently produced in significant quantities in only six member states (see Table 1.2 below).

Table 1.2: Production of Biodiesel in the EU European Commission 2001b

| Country | Biodiesel Production (kT) |
|----------------|----------------------------------|
| Germany | 100 (1998); 130 (1999) |
| France | 319 (1998); 344 (1999) |
| Italy | 96 (1998); 96 (1999) |
| Sweden | 50 (2000) |
| Austria | 16 (1998); 30 (2000) |
| Spain | 50 (2000) |
| UK | 0 (1998); 0(1999) |

A significant proportion of this fuel in Europe is derived from rapeseed oil, which is sometimes blended with UFO. Biodiesel production in the UK is presently limited to small scale operations such as the UFO collection and processing scheme run by *e-diesel* in Cheshire (<http://www.e-dieselfuel.co.uk/>).

1.5 Use of Biodiesel in Static Engines

Much of the biodiesel currently produced in Europe is aimed directly at the motor vehicle market. Provided the fuel is of the correct specification (British Association of Biofuels and Oils 2001), modern vehicle engines can burn biodiesel without modification. As rapeseed can provide oil of a consistent quality, it makes it an attractive feedstock for use in processing plants that are required to produce fuel of a consistent and exact specification. Although it would be a low cost feedstock, variation in composition would make the use of UFO on its own a less suitable feedstock for biodiesel intended for vehicle engines. In addition, in comparison to rapeseed oil, the potential feedstock available is limited. To date, on the continent UFO has been combined with rapeseed oil at the production phase. A proposed EU standard for biodiesel has been produced (Section 3.7). This specification appears to have been built around the properties of biodiesel derived from rapeseed.

There are advantages to using UFO biodiesel in static diesel engines:

1. These engines are more robust than vehicle diesel engines and can use biodiesel of a lower specification.
2. Many of these engines operate on an intermittent basis, for example standby generators and this is suitable to limited availability of UFO.

1.6 Biodiesel and Energy Policy

The Government's central policy objective in relation to energy is to ensure secure, diverse and sustainable supplies of energy at competitive prices. Its environmental priorities are influenced by global and international factors, including international agreements and EU policies to which the UK is committed. These include targets for the reduction of greenhouse gases, and in particular carbon dioxide emissions. Central to this policy is the drive towards the use of more alternative energy technologies such as Combined Heat and Power and the greater use of renewable energy. The government has set a target of generating 10% of the UK's electricity from renewable sources by 2010.

The Government has also attempted to stimulate interest in more environmentally friendly fuels and launched the 'Green Fuels Challenge'. This encouraged people to submit proposals arguing the case for reducing the duties on alternative fuels in the 2001 budget.

Traditionally, electricity has been generated in the UK by large power stations connected to the National Grid. However, it is intended that Renewable Energy and CHP plant be small and connect to local distribution networks (The Royal Commission on Environmental Pollution, 2000). This process is termed embedded generation and is considered to be a major growth area if the Government is to meet its targets (European Commission, 2001b; Inter-departmental Analysts Group, 2002). In many circumstances, businesses will be able to use on-site generators to provide their own power needs as well as selling 'excess' electricity to the national grid.

The fueling of static diesel generators for embedded generation is one potentially important market for UFO biodiesel.

The Government has two main policy instruments to promote the take up of renewable energy:

- **The Climate Change Levy:** Introduced in April 2001, this is effectively a tax placed on the business use of energy. Energy generated from CHP and renewable sources is exempt from the levy.
- **Renewables Obligation:** The main policy instrument proposed for achieving the Government's 10% target for renewable energy is the Renewables Obligation Order 2002 (covering England and Wales) and the corresponding Renewable Obligation Scotland. The Renewables Obligation creates a new market in Renewable Obligation Certificates (ROCs). These will have to be produced by every energy supplier to prove that they have sourced a set percentage of their electricity from renewables. (Smith & Watson 2002) Suppliers will be able to meet their obligation in three ways;-

1. By producing ROCs to show that they have generated or bought electricity from recognised renewable energy generators.
2. By buying ROCs on the open market from other suppliers with a surplus.
3. By paying the 'buyout price' of 3p per unit (kWh) to make up the shortfall between their stock of ROCs and their statutory target.

The new policy should allow renewable energy generators to earn revenue from both the sale of electricity and ROCs. The assumption is that this should give renewables an extra revenue boost by adding a subsidy of up to 3p/kWh to the wholesale price of electricity. ROCs will be issued to accredited renewable electricity generators and the Government intends to introduce this legislation in April 2002.

Generation of electricity from biodiesel (either UFO or rapeseed derived) would be exempt from the Climate Change Levy. This may serve as one incentive for organisations to switch to biodiesel for use in their own generators. Electricity produced from generators fueled by biodiesel could be sold to the national grid with an additional premium of 3p/Kwh.

1.7 Scottish Water and UFO

The illegal disposal of UFO to public sewers significantly increases Scottish Water's infrastructure and plant maintenance costs. It has been estimated that clearing sewer blockages within one of Scottish Water's operational areas costs around £1.6M per annum, a significant proportion of which is believed to be related to UFO disposal. The commercial production of biodiesel from UFO could reduce disposal costs for producers and reduce costs for Scottish Water. The production of biodiesel from UFO could be seen by Scottish Water as a

means of promoting the correct disposal of UFO. However, if Scottish Water utilised the biodiesel in its own operations then there are several other advantages.

Water Utility companies are the third biggest energy users in the UK. It is vital for Scottish Water that there is always a secure power supply available to enable its strategic water and wastewater treatment sites to operate correctly. Stand-by electrical generators are employed at all of its strategic sites, which can provide sufficient power in the event of an interruption to the mains supply.

The use of biodiesel in Scottish Water's standby generators could potentially have both environmental and economic benefits.

Environmental: As biodiesel has a low toxicity and quickly biodegrades it is an ideal fuel for storage and use in environmentally sensitive areas such as water treatment works. Pollution incidents involving mineral diesel have occurred at Water Treatment works with significant environmental and financial costs.

Economic: Operating generators with biodiesel has the potential to save costs through the following mechanisms:

- Reduction in Climate Change Levy.
- Offsetting costs of supplied energy. The generators could be used to provide electricity during high tariff periods. This is termed as "peak lopping".
- Gaining a ROC and exporting energy back to the national grid.

2.0 THE SUPPLY OF UFO IN SCOTLAND

2.1 Production of UFO in Scotland

Around 40,000 tonnes of fats and oils are sold in Scotland each year¹. At present minimal information is collected on the amounts of UFO produced in Scotland. The British Association for Bio Fuels and Oils (2001) has estimated that around 75,000 tonnes per annum (tpa) of UFO may be collectable in the UK. The Affiliated Cooking Oil Reclaimers Nationwide (ACORN) recently estimated the amount available to be around 85,000 tpa. If these figures are correct, and the volume of UFO produced is approximately proportional to population, then around 8000 tpa could be available in Scotland. Although minimal information is currently collected on the UFO production in Scotland waste oils, both mineral oils and cooking oils, are going to form part of the SEPA Waste Strategy in the future.

2.2 Collection of UFO in Scotland

There are around 200 companies throughout the UK that collect UFO. The umbrella organisation ACORN represents 14 of these companies, which collect an estimated 46% of the total collectable UFO. Most of the UFO produced is used in animal feed and it is uncertain what will happen to these collection schemes if this route is closed. In light of the potential banning of UFO in animal feed, alternative markets such as biodiesel are likely to be welcomed by organisations like ACORN.

The distribution of UFO across Scotland is unlikely to be uniform. It will be concentrated in urban areas and in areas with significant catering and food manufacturing facilities. The additional costs involved in collecting UFO in places with small dispersed volumes may make collection uneconomic. There is therefore likely to be a shortfall between the total volume of UFO available and the volume of UFO that is cost-effective to collect. However the wider costs of not collecting UFO should be borne in mind when calculating the cost-effectiveness of collection.

¹ Based on a consumption of 165g fat/capita/week

3.0 THE PRODUCTION PROCESS

3.1 Introduction

Vegetable oils were the original fuels for which the diesel engine was designed. At the World Exhibition in Paris in 1900, Rudolf Diesel ran his diesel engine on peanut oil. At that time, vegetable oils were cheaper than mineral oils but the development of the mineral oil industry quickly resulted in the reverse. Interest revived in vegetable oils in the 1970's with the oil crisis, illustrating the vulnerability of an industrial society dependent upon non-renewable and finite fossil reserves.

3.2 Conventional Feedstock's

Most vegetable oils or their derivatives can be used in diesel engines including rapeseed oil, maize oil, cotton oil and soybean oil. Some vegetable oils are unsuitable due to their extreme viscosity (e.g. castor oil) or drying properties (e.g. linseed). Rapeseed oil has been targeted for fuel use because the crop grows well in northern Europe and it produces oil, which can be converted into a form well suited to diesel engines. Rapeseed oil can be used in diesel engines in four ways.

1. as pure rapeseed oil
2. in mixtures of rapeseed oil with diesel
3. as rape methyl ester (RME)
4. in mixtures of RME with diesel

Pure rape oil (or many other vegetable oils) can be used in indirect injection compression ignition engines without modification but not in modern day direct injection diesel engines which dominate the market. The problem relates to gum being deposited on the cylinder head during inefficient combustion. Mixing with mineral diesel can partly overcome these problems. Conversion to the ester removes the glycerol, which is responsible for the gumming problems so allowing clean efficient combustion. RME can be used either alone or in mixtures with diesel. In Austria the former is the preferred route allowing targeting of the environmental benefits to these areas most likely to benefit. In France the latter is the preferred route so avoiding the cost of separate handling and distribution networks.

3.3 Crushing

The RME production process is presented diagrammatically in Figure 3.1. Rapeseed is crushed to extract the oil leaving behind a high protein meal. The amount of oil extracted varies with the system and the scale of operation. Small scale mechanical screw press systems can take the oil down from 40-44% (the approximate range of oil contents in oilseed rape) to about 10%. The high volume UK crushers (e.g. 1000 + tonnes/day) follow this up with chemical extraction using hexane leaving the meal with as little as 1-2% oil. The meal that is left is used as a high protein feed supplement for inclusion in animal feed rations.

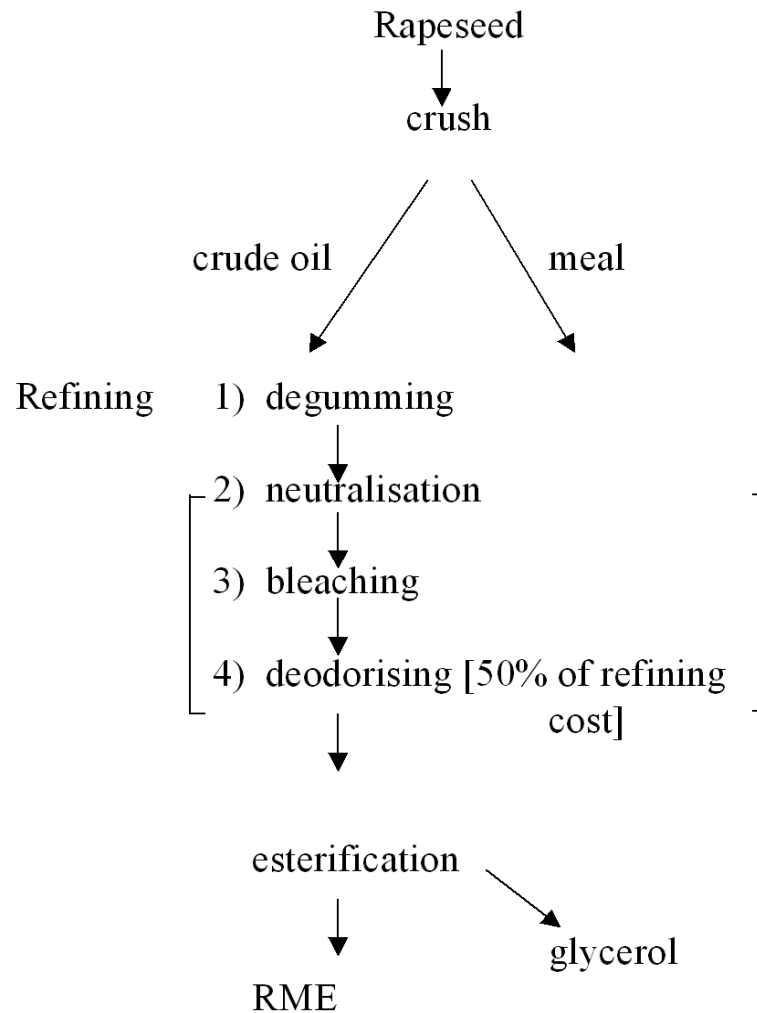


Figure 3.1 The Conventional Production Process

3.4 Refining

After crushing, the crude oil is refined. Refining for food consumption is a four-stage process involving

- degumming - for removal of phosphorous based gums and pigments
- neutralisation - for removal of free fatty acids
- bleaching - for removal of coloured impurities e.g. chlorophyll
- deodorisation - for removal of volatiles which cause unpleasant odours

This last process normally accounts for approximately half of the refining cost. Because the biodiesel specification has no parameters for colour or smell, the latter two refining stages are not required for biodiesel production so only limited refining capability is required.

3.5 Esterification

Plantoil methyl esters are obtained in a reaction called alcoholysis or transesterification by adding a monovalent alcohol such as methanol to triglycerides which are the main component of natural oils and fats. The triglycerides are transformed into fatty acid monoesters and glycerine. The reaction is facilitated by a catalyst (usually potassium hydroxide) dissolved in the alcohol. High throughput oil for esterification can justify continuous process esterifiers rather than batch processors.

Because glycerine has a greater density than biodiesel, it can easily be separated and after this basic reaction, cleaning steps are required for both products. For example, the biodiesel can contain some traces of soaps which can be removed by centrifuge and excess methanol is then removed by distillation and is recycled for further use.

3.6 Unconventional process routes

Figure 3.2 indicates unconventional biodiesel production routes that may be pursued either alone or in combination. UFO may enter the process at the refining stage. Much would depend on the quality of the UFO collected by the waste oil collecting agent and the cleaning process the agent practices, but theoretically UFO should not require degumming (as this will have occurred during virgin oil refining) and so only neutralisation would be required.

Problems of reaching specification can be overcome by dilution with high quality virgin rapeseed methyl ester. This can be added from the process already described or alternatively (if scale of operation does not justify crushing plant etc) then crude oil could be purchased on contract from existing crushing plants. Alternatively partially refined oil (stages 1 and 2) could be purchased. This could be of interest to the refiner as he could off-load batches of rapeseed known to be likely to incur high refining costs in stages 3 and 4 e.g. high chlorophyll rapeseed. However scale of operation would again dictate whether such feedstock selection was worthwhile to the refiner.

3.7 EU Specification for Biodiesel

The proposed EU standard for biodiesel is presented in Table 3.1. This proposal (pr EN 14214) is expected to be ratified by member states shortly. The specification appears to be built around the properties of rape methyl ester. For example, both sunflower and soybean methyl ester fail through having an iodine number in excess of 130. Any proposed biodiesel plant to be based in Scotland will require detailed information on the quality characteristics of the oil likely to be delivered for biodiesel production.

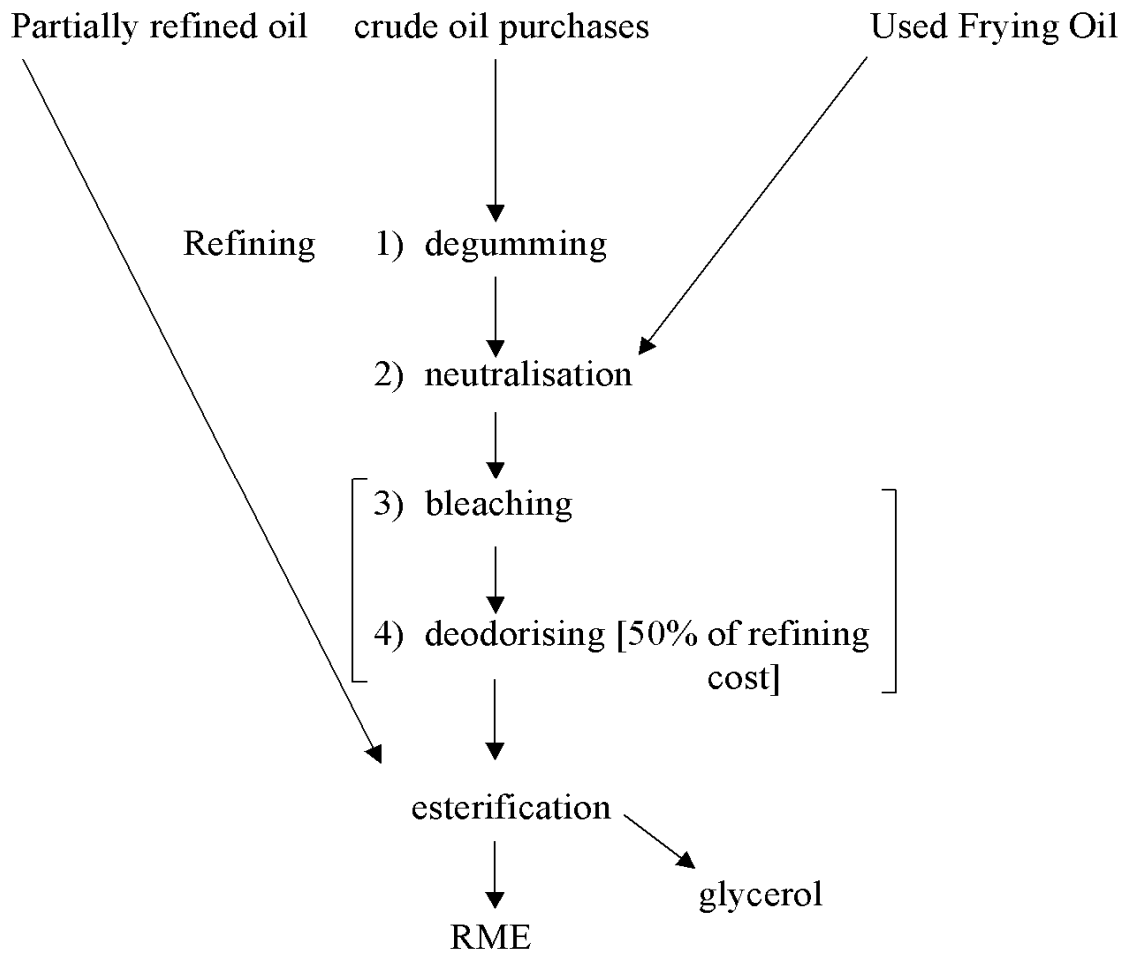


Figure 3.2 The Unconventional Production Process Routes

Table 3.1: Proposed EU Biodiesel specification (EN 14214)

| Property | Unit | Limits | | Test method* |
|--|--------------------|-------------------|---------|---------------------------------------|
| | | minimum | maximum | |
| Ester content | % (m/m) | 96.5 ^q | | prEN 14103 ^d |
| Density at 15% C ^b | kg/m ³ | 860 | 900 | EN ISO 3676 EN ISO 12185 |
| Viscosity at 40°C ^c | mm ² /s | 3,5 | 5,0 | EN ISO 3104 |
| Flash point | °C | above 101 | - | ISO/CD 3679 ^e |
| Sulfur content ^f | mg/kg | - | 10 | |
| Carbon residue (on 10% distillation residue) ^g | % (m/m) | - | 0,3 | EN ISO 10370 |
| Cetane number | | 51,0 | | EN ISO 5165 |
| Sulfated ash content | % (m/m) | - | 0,02 | ISO 3987 |
| Water content | mg/kg | - | 500 | EN ISO 12937 |
| Total contamination ^h | mg/kg | - | 24 | EN 12662 |
| Copper strip corrosion (3 h at 50° C) | rating | class 1 | | EN ISO 2160 |
| Thermal stability ⁱ | | | | |
| Oxidation stability, 110°C | hours | 6 | - | prEN 14112 ^k |
| Acid value | mg KOH/g | | 0,5 | prEN 14104 |
| Iodine value | | | 120 | prEN 14111 |
| Linolenic acid methyl ester | % (m/m) | | 12 | prEN 14103 ^d |
| Polyunsaturated (>=4 double bonds) methyl esters ^l | % (m/m) | | 1 | |
| Methanol content | % (m/m) | | 0,2 | prEN 14110 ¹ |
| Monoglyceride content | % (m/m) | | 0,8 | prEN 14105 ^m |
| Diglyceride content | % (m/m) | | 0,2 | prEN 14105 ^m |
| Triglyceride content | % (m/m) | | 0,2 | prEN 14105 ^m |
| Free glycerol ^b | % (m/m) | | 0,02 | prEN 14105 ^m prEN 14106 |
| Total glycerol | % (m/m) | | 0,25 | prEN 14105 ^m |
| Alkaline metal (Na+K) ⁿ | mg/kg | | 5 | prEN 14108 prEN 14109 |
| Phosphorus content | mg/kg | | 10 | prEN 14107 ^p |

^a See also 5.5.1

^b See also 5.5.2

^c If CFPP is -20°C or lower, the viscosity measured at -20°C shall not exceed 48 mm²/s. In this case EN ISO 3104 is applicable without the precision data

^d CEN/TC 307 publication of NF T 60-703:1997

^e Apparatus equipped with a thermal detection device shall be used

^f Suitable test methods to be proposed by CEN/TC 19

^g ASTM D 1160 shall be used to obtain the 10% distillation residue

^h Pending development of a suitable method by CEN/TC 19, EN 12662 shall be used. The precision of EN 12662 is however poor for FAME products

ⁱ Suitable test method and limit to be proposed by CEN/TC 19

^k CEN/TC 307 publication of ISO 6886 modified

^l CEN/TC 307 publication of NF T 60-701 (procedure A) and DIN 51608 (procedure B)

^m CEN/TC 307 publication of NF T 60-704: 1997

ⁿ Extension of this limit to cover additional elements, e.g. Ca and Mg to be considered

^p CEN/TC 307 publication of NF T 60-705 1997

^q Attention is drawn to 5.2

^r Suitable test method to be developed

4.0 UTILISATION OF BIODIESEL

4.1 Introduction

The success of biodiesel depends upon the fuel being of consistent quality and providing a performance similar to conventional mineral diesel but with significant environmental benefits where used.

4.2 Fuel characteristics

When compared with mineral diesel, biodiesel is found to have a 13% lower energy value in terms of MJ/kg and a 7% lower level in MJ/dm³ (as the density is higher). See Table 4.1.

Table 4.1 Calorific value and fuel efficiency

| <i>Fuel</i> | <i>Density g/cm³</i> | <i>Energy value</i> | | <i>Efficiency degree</i> |
|--------------------------|-------------------------------------|---------------------|--------------------------|--------------------------|
| | | <i>MJ/Kg</i> | <i>MJ/dm³</i> | <i>in % at 1200 rpm</i> |
| Diesel | 0.83 | 42.9 | 35.6 | 38.2 |
| Biodiesel | 0.88 | 37.2 | 32.9 | 40.7 |
| Variation from diesel | | -13.3% | -7.6% | +6.5% |

Source Walter 1992

On an analytical basis biodiesel differs most markedly from mineral diesel in having virtually no sulphur present. Diesel however contains no oxygen compared with 10-11% in biodiesel. It is the presence of oxygen that is claimed to explain the improved combustion in terms of energy efficiency and reduced emissions as indicated in Table 4.1. There have been many studies conducted across the world comparing the efficiency of biodiesel with diesel and different results are produced according to the engine test cycle, the engine design and quality of the biodiesel. On balance there appears to be little difference in potential power output but an increased fuel consumption of approximately 5% within the range of -5% to +14% (Schafer, 1991; Sams and Schindlbauer, 1992; Walter, 1992). Other factors of note are dilution of sump oil ranging from +1% to +10%. Specific biodiesel engine lubricating oils have been developed e.g. BP Vanellus – FE, Castrol Powermax etc. The move to low sulphur diesel fuels results in poorer lubricity of the fuel causing adverse scoring and wear of the cylinder and piston. Here biodiesel offers significant advantages and the addition of biodiesel to mineral diesel has significant benefits in this respect.

4.3 Emissions

In the same way that engine efficiency studies vary according to test cycle, engine, fuel used etc., so emissions comparisons between biodiesel and mineral diesel vary. See Table 4.2.

Table 4.2 Exhaust emissions* from direct injection engines of biodiesel compared to mineral derived diesel

| Reference | SO ₂ | CO | HC | PAH | NO _x | Particulate | Smoke |
|-----------|-----------------|--------------------|--------------|---------------|--------------------|-------------|--------------|
| Long | | > 10% lower | | 60% lower | > 10% lower | | 50% lower |
| Patcher | almost zero | lower or higher | 50% lower | | slightly higher | | |
| Austria | | | lower | much lower | slightly higher | | |
| FOP | | 65% lower | 12% lower | | 16% lower | | 57% lower |
| Koch | 90% lower | | lower | lower | | lower | lower |
| Wade | 90% lower | 10% lower | 40% lower | higher | 10-12% lower | | |

*HC = unburnt hydrocarbons; PAH = polycyclic aromatic hydrocarbons;
 NO_x = nitrogen oxides; part = particulates. Smoke levels are measured
 on the Bosch Index

Source Culshaw and Butler 1992

Generally speaking, results tend to indicate most emissions are down except for NO_x which are generally up by around 3-5%. As NO_x is a greenhouse gas that is particularly damaging, more detailed studies have shown how engine timing adjustments specifically for biodiesel use can improve the NO_x figure (see Table 4.3).

Table 4.3 Emission from Austrian bus trials, Biodiesel relative to low sulphur fossil diesel.

| Emission | SO _x | CO | NO _x | NO _x * | PM | VOC | BS |
|-------------------------------|-----------------|-----|-----------------|-------------------|-----|-----|-----|
| % reduction with biodiesel | -99 | -20 | +1 | -23 | -39 | -32 | -50 |

*NO_x result for an engine adjusted for biodiesel use.

Source Sams 1996

4.4 Spillage and Safety factors

Biodiesel represents a far lower hazard on spillage than does fossil diesel. It has excellent biodegradability in soil and ground water and is even used to help clean up mineral oil slicks. It breaks down four to five times quicker than mineral diesel. In addition, the heavier oils left by mineral diesel after initial degradation are particularly slow to disappear.

Studies by Birchall et al (1996) showed biodiesel on spillage onto watercourses was considerably less toxic to trout, daphne, cress, green algae and bacteria. Biodiesel has lower dermal toxicity than soap and lower oral toxicity than salt. It is particularly well suited for environmentally sensitive areas. The only combination of circumstances where its biodegradability could be a disadvantage would be where a large quantity of biodiesel were filled into a small volume of fresh water, e.g. a pond. The rapid breakdown of the biodiesel would result in a high Biological Oxygen Demand with consequent removal of oxygen from the water course. However, mineral diesel spillage in a similar situation would be much more serious as it would take longer for the ecosystem to recover.

4.5 Warranties

Existing warranties are available for engines used by Audi, BMW, Mercedes Benz, Seat, Skoda, Volkswagen and Volvo. In addition warranties cover engines produced by Case, Claas, Faryman, Fiatagri, Ford, Holder, Iseki, John Deere, KHD, Kubota, Lamborghini, Same, Steyr and Valmet. The list of warranties is continually extending and so it is worth contacting the manufacturer direct to obtain the latest position on companies not mentioned.

5.0 PRELIMINARY ECONOMIC APPRAISAL OF UFO BIODIESEL

5.1 Introduction

Biodiesel production benefits from the economies of scale. However it is possible for small scale plants to operate successfully. This is especially the case where:

- redundant chemical plant is adapted thereby reducing capital cost of investment;
- transport costs can be avoided by localised production and transportation;
- a plant with new technology development could be viewed as a pilot project and therefore qualify for capital grants and exception from fuel duty; and
- environmental or risk avoidance is a prime concern and can be taken into account in economic calculations.

5.2 Legislative Background

The EU draft directives issued in late 2001 propose that 2% of road transport should be provided by biofuel by 2005 and at least 5.75% by 2008. There is also the proposal that duty rebate may be put at 50% of relevant national rates. The UK has not been supportive of the 50% rebate as it views this as too high. In contrast, Germany has not been supportive either as the country enjoys 100% duty relief and has built up its biodiesel industry on this basis. A summary of the duty payable on various fuels is provided in Table 5.1.

Table 5.1: Exercise Payable on Various Fuels

| Fuel | Pence/ litre |
|--------------------|---------------------|
| Diesel | 51.82 |
| ULSD | 45.82 |
| Unleaded petrol | 46.82 |
| Reduced Tax Diesel | 4.58 |
| Gas for road fuel | 9 (per kilogram) |

As announced in the budget in 2001, the 2002 budget confirms a new excise duty for biodiesel of 20 pence per litre below the Ultra Low Sulphur Diesel (ULSD) rate. This is equivalent to 43.6% of the duty payable on ULSD and will come into immediate effect. The proposed duty reduction would apply to biodiesel but not to Reduced Tax diesel which already receives an excise duty reduction much greater than this. In addition, it seems likely that the UK will have just two standards for biodiesel – 5% blend and 100% straight. This equates to 1p/litre for the former and 20p/litre for the latter. Information from Department of Transport and Local Regions (DTLR) suggests that only fuels reaching the pr EN14214 standard will be eligible for rebate.

To aid comparison with potential costs of biodiesel production the price structure for mineral diesel is given in Table 5.2.

Table 5.2: Price Structure of Diesel

| Mineral Diesel (ULSD) | |
|------------------------------|--------------------|
| | Pence/litre |
| Production | 10 |
| Distribution | 7 |
| Excise | 45.82 |
| | |
| Sub-total | 62.82 |
| Plus VAT@ 17.5 % | 11 |
| | |
| Sub-total | 73.82 |
| Retail Margin + VAT @ 17.5% | 5 |
| | |
| Total | 78.82 |
| Reduced Tax Diesel | |
| Production | 10 |
| Distribution | 7 |
| Excise | 4.58 |
| | |
| Sub-total | 21.58 |
| Plus VAT@ 17.5 % | 3.77 |
| | |
| Sub-total | 25.35 |
| Retail Margin + VAT | 3 |
| | |
| Total | 28.35 |

5.3 Biodiesel production cost

Costings for large throughput biodiesel plants crushing, 60,000 tonnes of rapeseed per year and producing 19,620 tonnes RME (22 million litres) suggest a cost of production of between 30 and 32p/litre. This takes into account the sale of 39,600 tonnes of meal and 2,520t of glycerine and includes NO profit element.

Where the same facilities are used to crush rapeseed but 3,000t used frying oil substitutes for some of the rapeseed to produce similar quantities of RME (just under 22 million litres) then the net cost of biodiesel falls to 29 from 31p/litre. This uses the same assumptions as for the previous scenario and with a UFO price of 15p/litre. In this second example, the lower price for oil is offset by the higher cost of the technology to convert it to RME coupled with the density differences between oil and biodiesel.

The balance of 33,000 tonnes crude oil to 3000+ used vegetable oil is optimum for confident achievement of the biodiesel specification.

Small scale production is unattractive where off-the-shelf equipment is purchased. A batch process handling 4,500 t/yr. rapeseed and producing 1500t refined oil (and high oil content meal) has a production cost of over 40p/litre BEFORE esterification.

Table 5.3: Potential Pricing Structure for Biodiesel

| | Pence/litre |
|-----------------------------|--------------------|
| Production | 30.00 |
| Distribution | 26.00 |
| Distribution and Marketing | 7 |
| | |
| Sub-total | 63 |
| Plus VAT@ 17.5 % | 11.03 |
| | |
| Sub-total | 74.03 |
| Retail Margin + VAT @ 17.5% | 6 |
| | |
| Total | 80.03 |
| | |

The above figures allow a retail margin but no element of profit from the crushing or biodiesel production process.

It is thought that biodiesel used for electricity production from static generators will be eligible for the 3p/Kwh renewables obligation levy. Consequently, on the assumption that energy conversion is 6Kwh/litre biodiesel then net cost should be reduced from 80p/l to 62p/litre. This compares very favourably with the mineral diesel forecourt price of 79p/l but is still much more expensive than the 28p/litre payable for reduced tax diesel. Further information on the reduced risk of water pollution, the value placed on this reduced risk and the other environmental benefits associated with biodiesel would be required to give a fuller picture of the comparison between reduced tax diesel and biodiesel.

6.0 POTENTIAL MARKETS AND USES

The reasons for focusing this report on the use of biodiesel in static diesel engines has been discussed in Section 1. However, biodiesel like mineral diesel has a wide variety of applications. Therefore, this section provides an overview of other potential markets for biodiesel.

A summary of a number of potential sectors for biodiesel is provided below in Table 6.1. This table also indicates specific advantages for each sector.

Table 6.1 Potential Sectors for biodiesel

| Biodiesel usage | Potential Advantages |
|--|---|
| By water authorities where there is a significant risk of a diesel spillage contaminating the public water supply. | <ul style="list-style-type: none"> ▪ Lowers the risk of contamination. ▪ Allows the adoption of less stringent risk management procedures. |
| Limit the fuel sold in environmentally sensitive areas to biodiesel. | <ul style="list-style-type: none"> ▪ Lower environmental impact in the event of spillage during transport and storage. |
| In backup generators. | <ul style="list-style-type: none"> ▪ Biodiesel is a renewable energy source and as such is exempt from the climate change levy. The robustness of generators would enable them to use biodiesel without engine modification. |
| In supermarket road freight distribution. | <ul style="list-style-type: none"> ▪ Provides a green marketing opportunity. |
| In urban public transport. | <ul style="list-style-type: none"> ▪ Reduces the concentration of air pollutants in urban areas. |

6.1 Use by Utilities

Biodiesel could be used by Utilities e.g. in generators or excavators, where there is risk of a spillage contaminating the public water supply. Spillage of mineral diesel can have serious environmental and financial impacts. In addition to the initial cost of cleaning up a spillage, the increased stringency of risk management practices resulting from a spillage can lead to long term increases in costs. The use of biodiesel, with its low dermal and oral toxicity and rapid rate of biodegradation, has the potential to lessen the initial impact of a spillage and would require lower levels of risk management.

6.2 Use in environmentally sensitive areas

In Scotland, biodiesel could be used by those working in proximity to sensitive areas such as Special Areas of Conservation and Special Protection Areas, and in other areas where spillage could present a serious threat to the environment. Potential users could include, among others, the following: the Forestry Commission, Scottish Natural Heritage, Scottish Water, power companies, ski resorts, hotels and golf courses. It should be noted that the appeal of biodiesel to agriculture, and to other groups using reduced tax diesel such as water authorities, is likely to be less attractive than to those using diesel taxed at the normal rate.

In 1995 the Home Grown Cereals Association (1995) carried out a study into the potential market for biodiesel. It identified a number of niche markets where the environmental benefits of biodiesel would be important. Table 6.2 gives a summary of the markets identified.

Table 6.2 Summary of Potential Markets for Biodiesel (adapted from Home Grown Cereals Association, 1995)

| Market | Current use of diesel | Annual Consumption of Diesel |
|-----------------------------|--|---|
| Boats | Engines and heating system | Coastal and inland boat consumption 348, 883t of diesel (1994). |
| Timber, paper and pulp | Timber harvesters, forwarders, forklift trucks | 55 Mt of gas oil /year. |
| Construction and Tunnelling | Range of applications for mobile and static plant, generators and heaters. | NA |
| Mining | Vehicles which transport men, equipment and consumables to and from faces and headings | NA |
| Golf Courses | Gas oil used for most machinery | NA |
| Agriculture | Vehicles and machinery | 6.4 Mt of gas oil (1994) |
| Armed Forces | Plant and vehicles | 109, 058 t of gas oil (1995) |
| Fire Brigade | Training for fighting diesel fires | 8 tonnes per year |
| Ski Resorts | Generators, ski lifts, piste maintenance vehicles. | NA |

The Home Grown Cereals Association report drew the following conclusions:

- In most instances biodiesel would have to compete with gas oil, a fuel that is subject to very low taxation.
- In some markets where fuel represents a small proportion of total operating costs, biodiesel may be attractive. For example, in sailing boats, the construction industry and mining operations.
- Although environmental factors are important for most of the markets assessed many industries already have regulations in place with respect to the handling and use of diesel. It is unlikely therefore that industry will pay a large premium for biodiesel, a fuel that is providing a solution to a problem that industry feels is already taken care of.
- It is possible some companies may use biodiesel to improve their environmental image.

7.0 THE WAY FORWARD

The concept of producing biodiesel from UFO is attractive as:

- it deals with a problematic waste stream in a manner which is more cost effective and environmental sustainable than current disposal options;
- the use of biodiesel as a fuel has several important environmental advantages over mineral diesel;
- the establishment of a market in UFO biodiesel would help local businesses save costs in UFO disposal.

The report has shown that biodiesel is widely used in both Europe and around the world. The European Commission now views biodiesel as an important alternative to mineral oil as it can be used in many existing diesel engines. In addition, the potential exists to manufacture biodiesel at a similar cost to mineral diesel. The importance of biodiesel in the UK was recognised in the last budget (April 2002) when the chancellor announced the reduction in fuel duty for biodiesel to “allow the UK to benefit from the reduced gas emissions that biodiesel can offer”.

To reduce transportation and distribution costs it may be appropriate to base UFO biodiesel production around small scale esterification plants handling local supplies of UFO.

To enable this project to move on from this initial study will require the following future work:

1. Investigation into the potential volume and sources of UFO available in Scotland
2. Investigation into the chemical and physical properties of UFO produced in Scotland
3. Design pilot plant, which will use local supplies of UFO to produce biodiesel. This scheme will include using the biodiesel produced in a test stand-by generator.
4. Investigate funding for this pilot plant through the green fuels challenge and other capital grant schemes.
5. Benchmark the biodiesel produced with that produced in other countries in Europe.

Points 1 & 2 would require short term research projects. Such projects could attract funding from government sponsored research programmes, the Landfill Tax Credit Scheme and charitable trusts.

Funding for a pilot plant could arise from capital grants schemes specifically given over to new and renewable energies. For example, the Scottish Clean Energy Demonstration Scheme. In addition, fuel produced from a pilot plant would be exempt from excise duty. To ensure the success of future projects the funding package will likely have to come from a range of sources. Projects of this

nature usually benefit from partnerships between private companies, environmental organisations and researchers.

8. References

Birchall C., Newman J.R. and Greaves MP (1996). Degradation and phytotoxicity of diesel oil. Contract Ref. CSA 2614. Centre for Aquatic Plant Management. IACR Long Ashton Research Station, Bristol.

British Association for Bio Fuels and Oils (2001) *Green Fuels Challenge - Submission for Biodiesel and Bioethanol (Budget 2001)*.

Culshaw and Butler (1992). A review of the potential for biodiesel as a transport fuel. ETSU-R-71 publication HMSO, London.

Darlow , T.J. (2000). *Waste Stabilisation Ponds: A feasibility study of their use in the UK*. Thesis Submission for Master of Research in the Built Environment, University of Leeds.

DETR (2000). National Air Quality Strategy for England, Scotland, Wales and Northern Ireland. HMSO.

Ensminger A.H. *et al.* (1994). *Foods & Nutrition Encyclopedia: 2nd Edition*, Boca Raton, USA, CRC Press.

European Commission (1999). *The Landfill Directive*. (99/31/EC)

European Commission (2001a) *Proposed Animal By-Products Regulation*. (IP/01/1616)

European Commission (2001b) *Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions on Alternative Fuels for Road Transportation and on a Set of Measures to Promote the Use of Biofuels* COM (2001) 547

Fraser, R. (1998). *The Burncrooks Inquiry: Report on the disruption to public water supplies in the area served by Burncrooks Waterworks, December 1997*. HMSO.

Fröhlich/Teagasc (1995). IEA Bioenergy Liquid Biofuels Activity IEA/BA Task XII Activity 3.1 November 1995, Vienna, Austria

Green Energy News (2001). California Hospital Uses Soy-Based Fuel to Face Energy Crises. Sourced from Internet [<http://nrglink.com/pressreleases/pr062201nbb.html>], accessed 7th May 2002.

Home Grown Cereals Association (1995). *Fuel Markets for Biodiesel*

Inter-departmental Analysts Group (IAG) (2002). Long-Term Reductions in Greenhouse Gas Emissions in the UK. HMSO

The Royal Commission on Environmental Pollution (2000). *22nd REPORT: Energy - The Changing Climate*. HMSO.

Sams, T and Schindlbauer (1992). Investigations on running a diesel engine with RME. Proceedings of the symposium "RME Draftstoff und Rohstoff, 49-66 RICHTE/Technical University, Vienna, Getreidemarkt 9, A1060 Vienna, Austria.

Sams, T (1996). Use of Biofuels under Real World Engine Operation 2nd European Biofuels Forum. 225-233.

Schafer (1991). Pflanzenölfeltsäure-Methyl-Ester als Dieselkraftstoffe/Mercedes Benz. (fuels from vegetable oils for Diesel engines – June 1991 and 1992. Technische Akademie Esslingen POB 1265, D-7302 Ostfildern, Germany.

SEPA (1999). *National Waste Strategy: Scotland*.

Smith, A & Watson (2002). The Renewables Obligation. Can it Deliver?. Sourced from Internet [http://www.tyndall.ac.uk/publications/briefing_notes/note04.shtml], accessed 15th April 2002. Tyndall Centre for Climate Change Research.

U.S. Office of Transportation Technologies (2001). Alternative Fuels Data Centre: Biodiesel. Sourced from Internet [http://www.afdc.nrel.gov/altfuel/bio_general.html], accessed 7th May 2002.

Walter (1992). Investigations on emissions of lorry engines in a bench test using RME. Swiss Research Institute, Dübendorf. Proceedings of the symposium. "RME – Draftstoff und Rohstoff, 49-66, FICHTE/Technical University Vienna, Getreidemarkt 9, A-1060 Vienna, Austria