COSTS OF BIODIESEL PRODUCTION

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Summary

- Biodiesel can be manufactured as a high quality fuel for compression ignition engines and is widely accepted, particularly when blended into conventional diesel fuel, when produced to specifications already established in Europe and North America. It has a lower energy content than conventional diesel and a volumetric fuel consumption increase of about 6% with biodiesel is typical of reported data.

- Biodiesel consists of the methyl esters of the fatty acid components of the triglycerides that make up most animal fats and vegetable oils. It is produced by transesterification, in which the fats/oils are reacted with methanol to form the biodiesel methyl esters and glycerol, the latter being sold as a byproduct.

- Commercial biodiesel production technology is available with plants of up to 100,000 tonnes per year having being constructed. The process technology is well understood although there are some variants on the technologies used. Although this technology continues to evolve, yields of biodiesel are already near theoretical limits. Technology for the pre-treatment of fats and oils and the purification of the methyl esters and glycerol is well established and commonly used outside the biodiesel industry.

- It is possible to use either tallow or vegetable oil in some commercial plant but not in others, the principal limitation being the different pre-treatment requirements of tallow and oil. The central transesterification process is unlikely to be a constraint in interchangeability with modern two stage plants, particularly when converting vegetable oils in a plant designed to process tallow.

- The full capital cost of a feedstock capacity of 70,000 tonne per year is likely to cost $20-30 million. About 120,000 tonnes of tallow are exported from New Zealand annually and could be used as feedstock. The unit capital cost of smaller plants, with capacities less than 10,000 tonnes per year, and the capability to be associated with sources of tallow or oil production, are likely to be 2 to 4 times higher.

- Prices of the principal biodiesel feedstocks, tallow and methanol, fluctuate significantly, as does that of byproduct glycerol and the conventional diesel fuel, which will be the reference price for biodiesel produced. These market price fluctuations are generally not inter-related, although there may be some weak link between those of tallow and glycerol, and have a major influence of the likely profitability of a biodiesel plant. Glycerol prices can be impacted by the production of biodiesel as the volumes involved a high in relation to the existing market.

- Capital costs are not sufficiently well defined to establish a link between costs and product quality/price, although costs of pre-treatment/purification is less than the

uncertainty in capital costs expressed above. Upgrading of glycerol to obtain higher prices is commonplace, although not always economic, particularly with smaller plants and low prevailing glycerol prices.

- Tallow comprises about 80% of the gross cost of production of biodiesel (excluding glycerol byproduct sales). The variation in the tallow cost component during the 1990's was greater than the more predictable capital and operating costs, which comprised less than 15% of the gross cost of production.

- During the period 1992 to 2000 the net cost of biodiesel production from tallow in a large plant, including income from glycerol, would have been significantly more than the price of conventional diesel in each year, except only in 2000, and would have averaged about 52 cents per litre. The high cost of vegetable oils likely would push the biodiesel cost to over $1.00 per litre. Costs in a small plant would be about 10 cents per litre higher than the tallow cost, although, when using waste cooking oil, this additional cost would be largely offset by the cheaper feedstock.

- Biodiesel is generally reported as being more costly than conventional diesel fuel, although it is not infrequently quoted as being competitive, as it will be if prevailing fluctuations in feedstock/product prices are favourable. Using the distribution of these prices over the last twenty years, less than 5% of costs benefit analyses based on fixed prices over the project life will show a positive result in producing biodiesel. If the feedstock/product prices are varied each year, as will be the case in reality, biodiesel production will always be more expensive than conventional diesel. This differential is about 25 cents per litre or 27 cents per litre if the additional 6% fuel consumption with biodiesel is included in the calculation.

- Future advances in production technology, yields and capital costs will have a limited impact on closing the differential as yields are already high and capital costs comprise only a small part of the total costs of biodiesel production.

- The impending carbon tax credit of $25 per tonne of carbon dioxide will contribute about 6 cents per litre to this differential. Similarly, a further 12 cents per litre could be taken from the differential if the estimated reduction of pollution costs arising from biodiesel use were to be factored into fuel prices. Virtually all of the taxation on diesel vehicle use is raised through Road User Charges, which may be impractical to adjust to favour biodiesel, particularly when used in a blend with conventional diesel.

- To be competitive with conventional diesel, biodiesel will require more than the combined assistance of carbon tax credits and the cost savings resulting from reduced diesel emissions to make it competitive with conventional diesel, unless the price of crude oil is maintained at prices significantly higher than historical averages.

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Glossary

C	Carbon
CFPP	Cold Filter Plugging Point (measure of low temperature waxing in diesel)
CO_2	Carbon dioxide
^0C	Temperature Degrees Centigrade
EECA	Energy Efficiency and Conservation Authority
FFA	Free Fatty Acids
H	Hydrogen
LFTB	Liquid Fuels Trust Board, New Zealand
ME	Methyl Ester
MED	Ministry of Economic Development, New Zealand
MTBE	Methyl Tertiary Butyl Ether
MW	Molecular Weight
O	Oxygen
OPEC	Organisation of Petroleum Exporting Countries
R R' R''	Hydrocarbon Components of Fatty Acids
PM	Particulate Matter
PPI	Producers Price Index
USA/US	United States of America
US EPA	Environmental Protection Agency, USA
US$	United States dollar

1 Product Chemistry

1.1 Tallow and Vegetable Oils

The common animal fats and oils and many of those from vegetable sources are esters of saturated and unsaturated monocarboxylic acids with the trihydric alcohol glyceride. Such esters are termed triglycerides and have the following general chemical formula:

Triglyceride	**Fatty (Monocarboxylic) Acids**
CH_2-O-CO-R	H-O-CO-R
|	
CH- O-CO-R’	H-O-CO-R’
|	
CH_2-O-CO-R’’	H-O-CO-R’’

Glyceride Component Fatty Acid Component

R, R’ and R’’ are the hydrocarbon groups from the monocarboxylic acids (commonly referred to as long chain fatty acids) and are of the form CH_3-$(CH_2)_n$- for saturated groups (those without double bonds). Nearly all the fatty acids in the glycerides are unbranched and have an even number of carbon atoms although branched chain acids are present in small amounts. Saturated acids (those without double bonds in the hydrocarbon chain) with 4 to 26 carbon atoms have been found in fats and oils but those occurring in greatest quantity are lauric acid (12 carbon atoms), mystiric acid (14 carbon atoms), palmitic (16 carbon atoms) and stearic acid (18 carbon atoms). Unsaturated acids range from 10 to 24 carbon atoms with the most important being oleic acid, linoleic acid and linolenic acid, all with 18 carbon atoms and having respectively one, two and three double bonds in the hydrocarbon chains.

Tallow consists mainly of triglycerides containing fatty acids with 16 or 18 carbon atoms, the principal components being approximately: mystiric (3%), palmitic (22%), stearic (26%), oleic (40%), linoleic (1%) and linolenic (1%) acids, with the remainder being made up of a complex range of isomers. Vegetable seed oils contain relatively larger amounts of the unsaturated components, in the order of 70% to 90%, depending on the plant variety (1).

As a general principle, triglycerides containing more saturated acid components have a higher melting point than those with similar chain lengths and more unsaturated components. Thus the melting point of tallow (45 to 55^oC) is higher than most seed oils. Tallow’s viscosity and melting point also is much higher than diesel fuel (cloud point below 0^oC) as its molecular weight of about 890 is much greater than that of diesel (about 270).

Raw tallow consists of over 95% trigycerides, the remainder being made up predominantly of free fatty acids with lesser amounts of water and unsaponifiable and insoluble components. The free fatty acids are largely removed prior to the processing of tallow to biodiesel. Vegetable oils must be pretreated to remove gummy materials, which are more likely to form in oils because of their more highly unsaturated nature.

1.2 Chemistry of Biodiesel

Biodiesel consists of the methyl esters of the fatty acids contained in the tallow or vegetable oil triglycerides. It has a high cetane number, good lubricity properties, an energy content comparable to conventional mineral diesel fuels and is easily mixed with its conventional counterpart. The molecular weights of the methyl esters are similar to diesel fuels, making their transport properties and melting points superior to the fats and oils from which they were derived. Technically, biodiesel can be considered a good quality component for mixing into diesel fuel, usually at concentrations of up to 20%, provided it is produced to adequate quality specifications.

The most common means of manufacturing biodiesel is the process of transesterification whereby the tallow or vegetable oil triglyceride is reacted with methanol in the presence of a catalyst to form the fatty acid methyl esters:

CH_2-O-CO-R				CH_2-OH		CH_3-O-CO-R
|				|		
CH-O-CO-R’	+	3 CH_3-OH	=	CH-OH	+	CH_3-O-CO-R’
|				|		
CH_2-O-CO-R’’				CH_2-OH		CH_3-O-CO-R’’
						Biodiesel
Triglyceride		**Methanol**		**Glycerol**		**Fatty Acid Methyl Esters**
MW: 890		MW: 96		MW: 92		MW: 894
						Average: 298 per molecule

For simplicity, the molecular weights shown above have been calculated for stearic acid esters only and illustrate that, under ideal circumstances, virtually the same weight of methyl esters will be produced from the triglyceride feedstock. Glycerol (alternatively known as glycerine) is a byproduct produced in significant quantities from the transesterification process.

However, the reaction is an equilibrium reaction, in that it will not proceed to completion, leaving traces of the feed triglyceride and methanol in the product. However, conversion of triglycerides to methyl esters can be increased by increasing the concentration of methanol and decreasing that ot glycerol in the reaction mix. Also mono- and di-glycerides in the form

CH_2-OH
|
CH-OH
|
CH_2-O-CO-R''

Monoglyceride

CH_2-OH
|
CH-O-CO-R'
|
CH_2-O-CO-R''

Diglyceride

can be produced due to partial reaction of the triglycerides and methanol. These factors are significant in the production process design and in the quality and necessary purification of the final products.

2 Production of Biodiesel

The transesterification process consists of four principal steps:

- Pretreatment of the tallow or oil feedstock to remove components that will be detrimental to subsequent processing steps. These are somewhat different for tallow and vegetable oils, the former removing free fatty acids and the latter gummy materials.
- Transesterification, where the pretreated triglycerides are reacted with methanol to form the raw methyl esters and glycerol. There are two basic steps: the reaction process followed by separation of the methyl ester and glycerol streams. In most technologies, these two steps are undertaken twice to push the transesterification closer to completion by reducing the concentration of glycerol in the second stage. The reaction is also pushed closer to completion by using an excess of methanol. Processes are generally designed to a high level of conversion, and methyl ester purity (>98%), as lower conversion rates result in increased levels of mono- and di-glycerides, causing processing problems with emulsion formation and low temperature hazing problems with the biodiesel itself as these compounds have higher melting points (and viscosity) than the methyl ester (2,3).
- Methyl ester purification, which removes the excess methanol, catalyst and glycerol carried from the transesterification process. Methanol removed is recycled to the transesterification process.
- Glycerol purification, removing methanol for recycling to the transesterification process. Further impurities, such as catalyst, tallow and methyl ester, are carried in the glycerol and may be removed to produce a higher grade of glycerol if economics dictate.

The catalyst used in the transesterification process is usually either sodium hydroxide or potassium hydroxide and is mixed with part of the methanol feed into the reaction vessel. After reaction and separation is complete, the catalyst is carried in the glycerol stream and, as part of the glycerol treatment, is neutralised by an acid. Typically hydrochloric or sulphuric acids are used, producing salts such as sodium chloride or potassium sulphate, the latter can be sold as a fertiliser.

The transesterification process can be undertaken using simple equipment and biodiesel is manufactured on a small scale by enthusiasts for the fuel, using buckets amongst other paraphernalia. However, to produce the fuel on a commercial basis, more sophisticated conditions are required to meet consistent quality requirements for the large volumes involved and to improve yields and rates of reaction. A number of process configurations are used with the principal alternatives being batch and continuous processes and high and low pressure systems. Generally, the more modern systems favour lower pressures because of the attendant lower plant costs and continuous processes are used in the larger and newer plant although some companies prefer batch systems (4). Plants have been built with capacities up to 100,000 tonnes per annum.

As the transesterification process is common for both tallow and vegetable oils, it is possible to interchange the feedstock in most types of plant, provided that account is made for the higher melting point of tallow. However, a single stage process designed for vegetable oils may not be able to produce a biodiesel with sufficiently low CFPP as the mono- and di-glycerides produced from tallow usually will have higher melting points than their vegetable oil counterparts. Two-stage transesterification, which appears to be the norm in most modern plant, will generally reduce the tallow mono- and di-glycerides to acceptable levels (3).

The requirements for pre-treating tallow and vegetable oils for subsequent transesterification are different. The emphasis of the former is on the removal of free fatty acids and the latter on the degumming of the oil because of its relatively high content of unsaturated material and resultant lower oxidation stability. Processes used for each of these treatments are different and plant designed for one feedstock may not be able to satisfactorily treat the other. For example, the plant built by Oelmuehle Leer Connemann GmbH in Germany is designed specifically for vegetable oils and cannot process untreated tallow, whereas the plant built by Energea of Austria is designed for both types of feedstock. The pre-treatment technologies are well understood. Similarly, the processes used for the purification of the methyl esters and the glycerol products are well known outside the fuel processing industry. Upgrading of glycerol is commonplace to achieve higher quality levels and enhanced prices.

Used cooking oil can be used as a biodiesel feedstock but the pretreatment requirements will be more onerous than raw oil because of the high incidence of oxidation and polymerisation products. Again, there is established technology to pretreat this type of feedstock.

With the establishment of specifications for biodiesel in Europe and North America, product quality is not necessarily an issue as new plant being built can be designed to meet these specifications, based on experience in the design and operation of commercial plant, particularly in Europe.

Ethanol (C_2H_5OH) can be used in place of methanol as a feedstock but is not used commercially as it is generally more expensive. The biodiesel esters produced from ethanol will be ethyl esters rather than methyl esters and will have somewhat different physical properties as the molecular weights are about 5% higher, for example viscosities areabout 7% higher than their methyl analogues. Generally, the dissimilarities between processing with methanol and ethanol are relatively minor, the major difference being in the alcohol recovery step where ethanol will form an azeotrope with free water. Overall the quality of ethyl esters will be lower than methyl esters as the reaction rate is slower with ethanol resulting in a somewhat lower level of conversion and higher levels of mono- and di- glycerides and also glycerol in the final product (5).

3 Costs of Production

The primary influences on the cost of manufacture of biodiesel are as follows:

- Capital and operating costs of the plant, including the processing plant, services, catalyst, feedstock and product storage, and buildings.
- Feedstock used in the process: tallow, vegetable or waste oil, and alcohol, most typically methanol.
- The glycerol byproduct, which provides a secondary revenue stream to the biodiesel produced or acts as an offset against the unit cost of biodiesel production.
- The yields and quality of the biodiesel and glycerol produced from the tallow/oil and methanol inputs.

Although the price of conventional diesel fuel is not a direct component of the cost of biodiesel production, it provides the baseline against which the cost of biodiesel production must be compared. From the perspective of the biodiesel producer, the price received for its biodiesel output will most likely bear a close relationship, if not equivalence to the price of diesel and therefore will be a direct influence on the profitability of the producer's operation.

When reviewing the cost of biodiesel production, it quickly becomes apparent that it is difficult to typify this cost as its components, notably the principal feedstocks and the byproduct glycerol, are subject to considerable and unrelated market price fluctuations. Also, the cost of conventional diesel fuel, which is directly related to the price of crude oil, is subject to similar fluctuations, creating uncertainty in targets for biodiesel production costs. For this reason, the cost study undertaken in this study concentrates on risk analysis and the price fluctuations inherent in the feedstock and product markets.

3.1 Capital Costs

The only published estimates of detailed biodiesel production costs in New Zealand were produced by the Liquid Fuels Trust Board in 1983. These were adjusted by Barry Judd (6), in his report for EECA on the production of biodiesel from tallow, using time based cost indices provided by the New Zealand statistics services. Most estimates of unit costs of production of biodiesel available in the literature include unspecified costs of feedstock and therefore give little or no insight into the capital and operating costs of the plant itself.

Energea, the Austrian company building the biodiesel from tallow plant in Western Australia, have provided cost data (7). However, this company supplies the processing plant only, which is provided in modular form, and leaves the provision of tankage, services, infrastructure and buildings to its clients.

Table 1

Energea: Capital Costs of Modular Processing Plant

Capacity tonnes/year	Euro million
20,000	3.8
40,000	4.3
60,000	5.1

In Table 2 these costs have been converted to New Zealand dollars and adjusted to a 70,000 tonne per annum plant capacity, using the scaling factor implicit in the Energea data, for comparison with the LFTB data updated from 1983 to a 2002 basis. Because the Energea equipment is supplied in modular form, the associated costs for installation, pipework and instrumentation used in the LFTB calculations have been scaled back as have the engineering and unallocated costs because of the greater degree of certainty in design.

Table 2

Full Plant Costs: LFTB and Energea

	LFTB 1983	LFTB 2002	Energea
Process Plant	3.4	7.2	10.9
Plant installation, piping, instrumentation	2.4	5.2	1.6
Plant buildings	0.2	0.5	0.5
Storage	1.6	3.4	3.4
Services	1.3	2.9	1.7
Civil Works	1.1	2.4	2.4
Spares	0.3	0.6	0.6
Unallocated	1.5	3.2	1.5
Contingency	1.0	2.2	2.2
Engineering	4.5	9.7	5.0
	17.5	**37.2**	**29.7**

The index used to scale the LFTB costs from 1983 to 2002 is the Capital Goods Index, all groups, between 1990 and 2002 and the Capital Expenditure Index, food and drinks processing group between 1983 and 1990. These comparisons and the assumptions contained in them are somewhat arbitrary but they do illustrate that the process plant alone is likely to be less than 50% of the whole plant capital cost.

Other points of reference for capital expenses are a cost of NZ$ 3 to 4 million for a plant of a capacity of 30 tonnes per day cited by Biofuel Systems (4), which is in the same order but somewhat lower than the Energea costs for the processing plant and a US cost of US$0.403 per US gallon for a 30 million gallon (100,000 tonnes per annum) for full plant costs in 1994 (8). The latter equates to a present day cost in the order of $20 million for a 70,000 tonnes per annum plant.

Whilst there is not a great deal of ready information available on the full costs of biodiesel plant, the cost of a 70,000 tonne per year plant is likely to be in the order of $20 to $30 million. This variation is considerably greater than the difference in costs for the pre-treatment of tallows and oil, the present day installed cost of the LFTB pre-treatment plant being $2.5 million, based on established technology.

Small scale biodiesel plants capable of being allied to a source of tallow or oil such as a freezing works or seed oil processing plant may provide logistics advantages in that the feedstock can be used at source, reducing transport costs to a centralised processing plant. The biodiesel produced from such plants could be blended locally into the conventional diesel supply chain. Typically, such plants are likely to have a capacity of less than 10,000 tonnes per annum. Their principal drawback is a relatively high capital cost compared to large capacity plants, unit capital costs in the United States being $0.500 per litre produced for a 10,000 tonne per year plant and $0.202 per litre for a plant with ten times the capacity (8). This is reflected in the original LFTB data (expressed in 2002 dollars) of $0.964/litre for a 4,300 tonne per annum plant and $0.222/litre for 70,000 tonnes capacity (2) and Energea's cost for the processing plant only of $.334/litre for a 20,000 tonne plant and $0.150 for 60,000 tonnes. Product yields are affected only to a minor degree with smaller plants, although there may be higher requirements for services per tonne of methyl ester produced (2).

3.2 Feedstock Requirements and Product Yields

The yield of methyl esters from tallow and oils will be close to the theoretical stoichiometric limits as is illustrated in Table 3 for the Energea technology and older technology considered by the LFTB. The Energea data shows the impact of a high free fatty acid content in tallow on the plant, reducing the glycerol yield and increasing the need for neutralising acid. The Oelmuehle Leer Connemann plant can tolerate a maximum limit of 2% FFA (9), although New Zealand tallow feedstock can be expected to have a free fatty acid content below this level (3).

Table 3

Feedstock and Yields

kg/kg biodiesel produced

		Energea		
	Stoichiometric	**<4.5% FFA**	**>4.5% FFA**	**LFTB**
Oil/Fat	0.995	1.000	1.000	1.067
Methanol	0.119	0.114	0.114	0.121
Acid	0.000	0.028	0.035	0.017
Catalyst	0.000	0.030	0.013	0.012
Glycerol	0.114	0.100	0.090	0.097
K_2SO_4		0.031	0.023	

Tallow
About 80% of New Zealand's tallow production of 150,000 tonnes is exported, competing with tallow exports from other countries such as the USA and Australia and with palm stearins produced in tropical countries. It is used in margarine, animal feedstocks and for soap manufacture. Like many export commodities, its price can vary considerably, depending on agricultural market supply and demand issues in importing and exporting countries, and generally follows the price of palm oils. Recent prices for exported New Zealand tallow have fluctuated from about $300 per tonne two years ago, up to $750 at the beginning of this year and now sit at $500 (10). The principal grade in New Zealand has a maximum FFA level of 4%. Published data from Aginfo Pty Ltd in Australia, show a similar fluctuation for a higher grade of tallow (<1 %FFA), with a time series shown in Figure 1. The Australian prices, although slightly higher and influenced to a greater extent by the domestic market, do follow the same general market trends as their New Zealand counterparts and can be used as a proxy to describe the fluctuations in this country's export prices.

Methanol
Methanol is one of the major commodity chemicals traded internationally and is used widely as a chemical intermediary and solvent. New Zealand has been a major regional exporter from Methanex's plants in Taranaki but the future of these plants is uncertain with the decline of production from the Maui gas field, the principal feedstock for the plants. Methanol can be produced from gas, oil or coal and, with the cost of production being the principal driver of profitability, plants based on cheap sources of natural gas are likely to be the most competitive. Like other commodity chemicals, prices of methanol fluctuate considerably, ranging between about US$150 and 250 per tonne supplied into Japan, although a spike in excess of US$500 per tonne has been experienced in the past ten years (11). With the phasing out of MTBE (which uses methanol as a feedstock) from reformulated gasoline in the USA from the end of 2002, there may be some

downward pressure on methanol prices in the short term. The current price of methanol is in the order of US$270/tonne in US and European ports (12). Judd (6) derived methanol prices over an extended period of time from a Methanex report, which are consistent with the data above and reproduced in Figure 1.

Glycerol

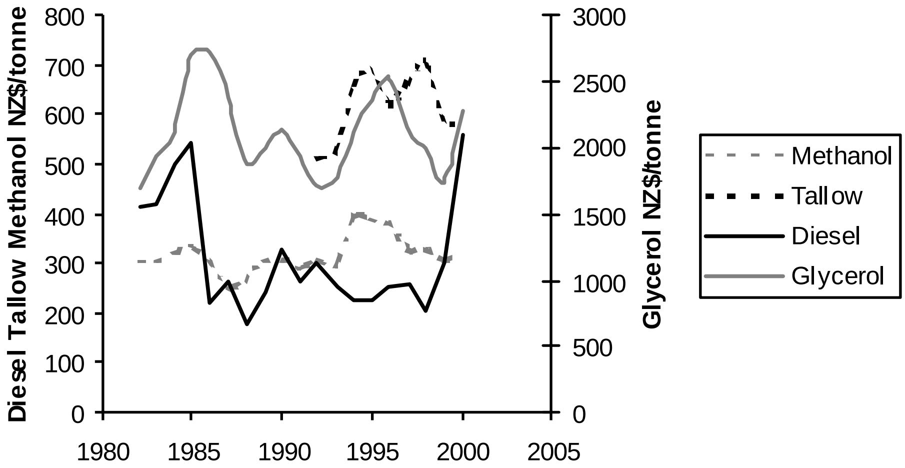
Glycerol is produced from a number of sources: the oleochemical processing industry, which produces glycerol as a co-product in the manufacture of esters, higher alchohols, fatty acids and amines from fats and oils; the byproduct of soapmaking; and from synthetic manufacture. It is used in a variety of grades to a wide range of applications, including resins, polyols, food, cosmetics, drugs, explosives, tobacco, paper making, adhesives and textiles. It is therefore a complex market with many countries having some level of manufacturing capability although overall world levels of production are not great in the context of the international chemical industry, being less than one million tonnes annually. Prices have fluctuated over US$1,000 per tonne in the last two years (13) and have been significantly affected by the production of biodiesel driven by low vegetable oil prices (14) in Europe, the resultant oversupply of glycerol caused a sharp reduction in its price. This indicates that prices are sensitive to supply, a factor of particular relevance for biodiesel production as the volumes of byproduct glycerol are high relative to most other production sources. Volumes so produced in New Zealand are unlikely to have any significant impact on international prices. A set of time based glycerol prices are included in Figure 1 (15).

Conventional Diesel Fuel

The price of conventional diesel fuel can be directly correlated to crude oil, although the price spread can vary somewhat with prevailing conditions. Crude oil prices are subject to a complex range of supply and demand issues, short term availability, and international political intervention affecting oil supply and market uncertainty. New Zealand imports about 10% of its domestic diesel consumption and the majority of its crude oil requirements, so domestic prices will closely follow regional prices, most particularly those in Singapore, the largest regional oil trading centre. A time series of diesel prices applicable in New Zealand based on Singapore export prices is included in Figure 1 for comparison with the other feedstock and byproduct prices involved in the manufacture of biodiesel (16).

Figure 1

Feedstock and Product Prices



3.3 Cost of Operations

Costs of operations include: maintenance, services, labour, miscellaneous chemicals such as the catalyst and neutralising acid and working capital. These will vary with the type of processing plant used and the size of the plant. Individually, each is a minor part of the costs of production as will be shown in Figure 2, so some simplifying assumptions have been made:

- Miscellaneous chemicals and services are assumed to increase from the LFTB 1983 basis to 2002 in accordance with the Producers Price Index. The multiplier is slightly over 2, which is consistent with increases over the same period in industrial gas prices, steam prices, electricity and the catalyst sodium hydroxide, which are the principal contributors to this cost category.
- Labour costs are increased by movements in the Labour Cost Index, which also has slightly more than doubled since 1983.
- Other items such as maintenance are increased in accordance with the Producers Price Index. Generally, details of maintenance costs are not specified (2) or are set at a proportion of capital costs (8), so use of PPI or the Capital Cost Index is appropriate in this context. Both indices are slightly over 2, compared to a 1983 basis.

3.4 Product Quality

Modern processing technology is designed to produce biodiesel fuels capable of meeting or exceeding national specifications in North America and Europe. In this respect, biodiesel presents no product quality concerns, provided that suitable processing plant is used. It does have some favourable properties compared to conventional diesel, notably a relatively high cetane index and a high degree of lubricity. The former may lead to the potential to blend biodiesel with a lower quality conventional diesel, although this requires further evaluation (6). Enhanced lubricity is a marketing advantage but its economic value is probably relatively small as a small dosage of fuel additive can provide adequate lubricity to diesel fuel (17).

The reported heat content of biodiesel varies between about 4% and 10% (5, 6, 18, 19) less than conventional diesel. It is generally accepted that this will result in a proportionately higher volumetric fuel consumption, although the US EPA is reported as suggesting a 20% blend of biodiesel will reduce fuel economy by 1 to 2%, rather than the proportionate 2% expected for a biodiesel with 10% less heat content than conventional diesel (5). A fuel economy of biodiesel of about 6% less than that of conventional diesel on a per litre basis would appear to be typical of the above data.

Some benefits may be obtained by upgrading the byproducts from biodiesel production, particularly glycerol which can have significantly higher values in its more highly refined forms. However, the benefits are not necessarily easy to define due to the economies of scale, the widely fluctuating prices of glycerol and the sensitivity of glycerol prices to its availability. Glycerol refining plants associated with biodiesel plants have been closed down in Austria as glycerol prices deteriorated and the economics of glycerol refining generally become less favourable with smaller biodiesel plants (2,20).

3.5 Unit Costs of Biodiesel Production

Using the feedstock costs in Figure 1 and a capital cost of $30 million in 2002 dollars, the derived unit costs of biodiesel produced from tallow are shown in Figure 2[1]. These have been determined for the feedstock and byproduct prices applying in each year the calculation has been made. Capital and operating costs have been adjusted by the appropriate capital cost, labour cost and producer price indices.

The cost of tallow comprises about 80% the overall cost of biodiesel production, with the overall fluctuation in the tallow cost over this period being greater than the other cost components combined. Whilst there are significant variations in the methanol price, its overall impact on biodiesel cost is relatively minor because of the smaller quantities and lower prices involved. Similarly, the impact of variations in the net catalyst and neutralising acid costs will be virtually insignificant compared with the tallow costs. The "fixed" operating and capital costs comprise about 15% of the total cost.

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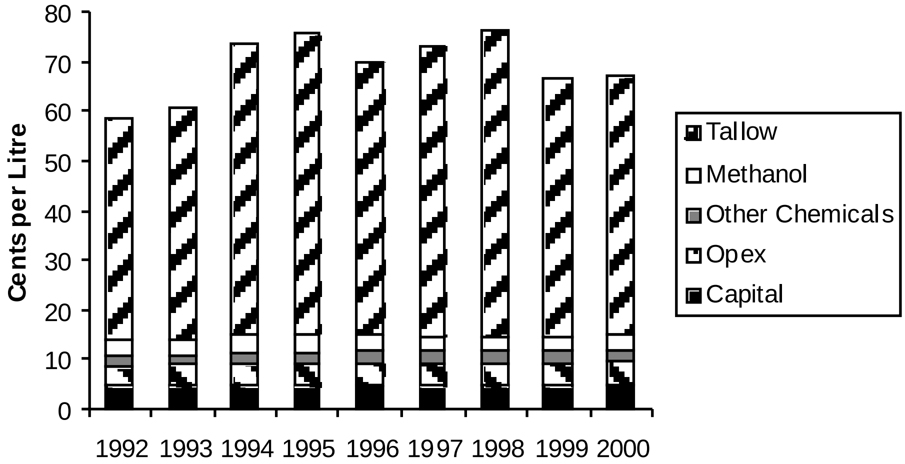
[1] All unit costs are based on a project life of 15 years and a 10% discount rate. All currency is in New Zealand dollars and cents unless otherwise specified.

Figure 2

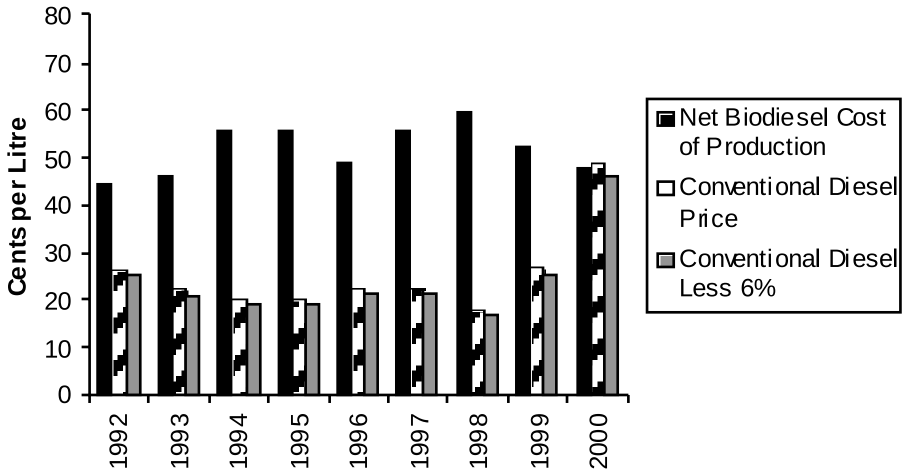
Gross Unit Costs of Biodiesel Production from Tallow



To assess the competitiveness of biodiesel production with conventional diesel, the biodiesel producer's revenue from sales of the glycerol byproduct must be deducted from the overall cost of production. This is done in Figure 3, where the net cost of production, after deduction of the glycerol credit from the overall cost of production, is compared to the average price of diesel imported from Singapore prevailing in the year of calculation.

Figure 3

Biodiesel Net Cost of Production Compared to Cost of Conventional Diesel



From 1992 to 1999, biodiesel was significantly more expensive to produce than conventional diesel, primarily because of the low price of crude oil and hence conventional diesel over the same period. It was only in 2000 when the average price of diesel and glycerol were at higher levels that the cost of biodiesel became competitive with conventional diesel and a prospective investor in a biodiesel plant, using feedstock and product prices applying in that year, would find that the project was economically viable. Similarly, the cash flow of an existing plant would turn positive.

It has been noted that an increase in fuel consumption of about 6% can be expected when using biodiesel because of its lower energy content. If the biodiesel were to be sold on an energy equivalence basis with conventional diesel rather than on an equivalent volumetric basis, the value of biodiesel would be reduced proportionately. The effect of valuing biodiesel this way is shown also in Figure 3.

These unit cost calculations have been done for plant with capacities in the order of 70,000 tonnes per year. Unit capital costs for plant with capacities less than 10,000 tones are about 2.5 times greater and services about twice as much, resulting in unit costs of biodiesel production about 10 cents per litre higher than those shown in Figures 2 and 3, with over 70% of the increase attributable to unit capital costs. This has implications for situating the biodiesel plants adjacent to tallow of oil sources rather than having a larger centralised plant in that the increased cost of production should be more than offset by savings in transporting the feedstock to a larger central plant.

A producer of biodiesel from waste cooking oil would most likely face these higher production costs because of the small volumes of waste oil available (6). The cost of waste cooking oil is in the order of $480 to 520/tonne (4,6), which would result in a typical net cost of production of about 69 cents/litre, about the same on average as those for the larger tallow plant shown in Figures 2 and 3 because of the lower cost of feedstock. Vegetable oil is significantly more expensive than both waste oil and tallow, ranging in the order of $900 to $1680 per tonne (4,6), pushing the cost of biodiesel production over $1.00 per litre if a feedstock cost of $1000 per tonne is assumed.

This comparison between biodiesel and conventional diesel assumes that no incentives are provided to biodiesel producers as they are in some European countries, where fuel tax exemptions on agriculturally based diesel fuels are applied, effectively closing the gap between renewable and conventional diesels.

The fluctuating relativity over time between biodiesel costs and conventional diesel prices explains the varying commentary on the cost competitiveness of biodiesel and the burgeoning interest in biodiesel when tallow prices are low or diesel prices high. Whilst either of the extreme comments on the competitiveness of biodiesel can be valid, depending on the market circumstances at the time, neither takes into account the future variability of prices. This is investigated in the risk analysis that follows.

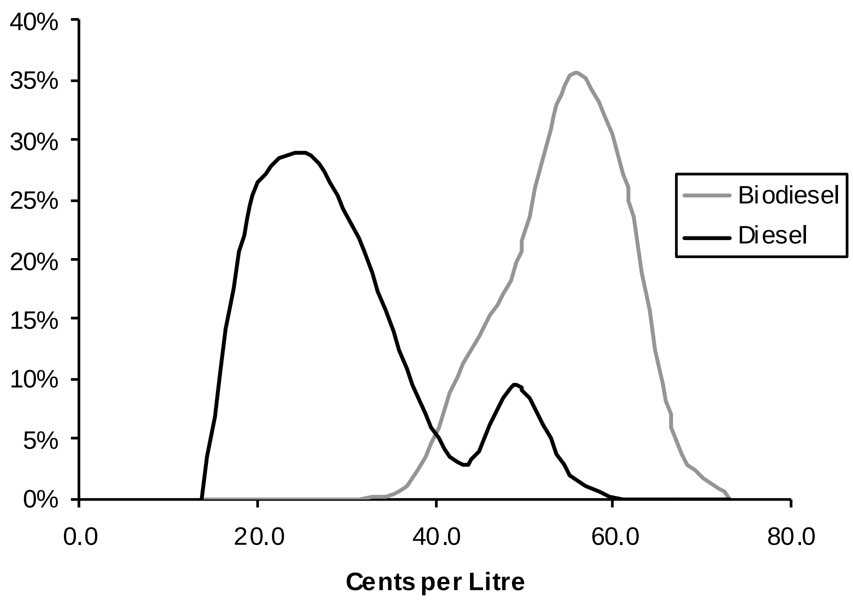
3.6 Risk Analysis

A simple risk analysis model is used to investigate the impact of feedstock and product price variability on the viability of producing biodiesel from tallow. Distribution functions were developed for the prices of tallow, methanol, glycerol and diesel using the time series data contained in Figure 1 and a range of biodiesel production costs developed. The analysis was undertaken in two ways:

- To demonstrate how frequently a positive cost benefit analysis will occur for the production of biodiesel. Most analyses of of biodiesel production costs assume fixed prices (or simply inflated with PPI or similar) for feedstock and products. Figure 4 shows the distribution of biodiesel costs of production and diesel prices based on the distribution of tallow, methanol, glycerol and diesel prices from 1982 to 2000 assuming fixed prices over the life of the project in the cost benefit analyses.

Figure 4

Distribution of Net Biodiesel Costs of Production Assuming Constant Feedstock/Product Prices over the Plant Life

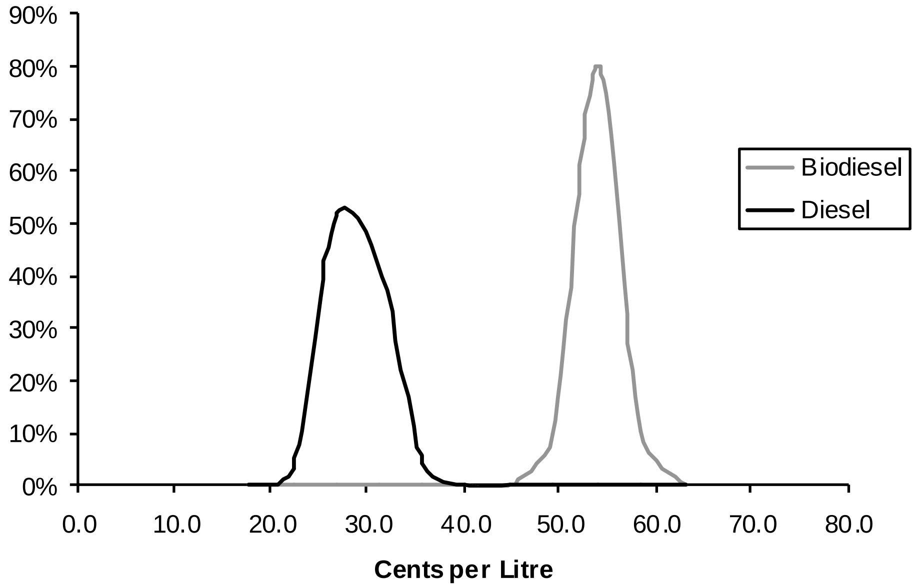


The intersection of two lines indicates the incidence of occasions the calculated costs of production will be less than the price received, or a positive net present value is obtained from the project investment. Using the distribution of prices over this period, the calculated cost of production will be less than the price received in less than 5% of cases.

- To demonstrate the frequency of costs of production under simulated operating conditions. The biodiesel producer will face price fluctuations for feedstock and product on an ongoing basis. Figure 5 shows the distribution of costs of production when the price of each feedstock/product is varied according to its distribution pattern in each year of the cash flow analysis, along with the equivalent value of conventional diesel fuel.

Figure 5

Distribution of Net Biodiesel Costs of Production With Varying Feedstock/Product Prices over the Plant Life



As the price for each feedstock/product varies each year the biodiesel plant is in operation, the average price received for each over the project life will be nearer to their distributed averages and the spread of costs of production and diesel prices narrower than in Figure 4. Hence there is no intersection of the lines representing biodiesel costs of production and the conventional diesel price. This indicates that in a "real" situation, where prices fluctuate continuously, a biodiesel producer's revenues will not match costs over the project life and a positive net present value will not be achieved on his investment as each good year of operational cash flow will be more than offset by bad years.

In these examples the feedstock and product prices fluctuate independently of eachother. The price data suggests there may be a weak link between tallow and glycerol prices, although if these are correlated there is little subsequent impact on the distribution curves produced.

The risk analysis demonstrates that, with the range of feedstock and product prices prevailing over the last twenty years, the lifetime cost of biodiesel production will be higher than that of diesel and the producer will not achieve a positive net present value on the investment in the biodiesel plant. However, the analysis does suggest that, when a cost benefit analysis is being undertaken, based on fixed feedstock/product prices, costs of production will be less than diesel from time to time but only in a relatively small number of occasions.

For both of the cases examined, the mean cost of biodiesel production from tallow was 52 cents per litre, which compares with an average cost of diesel of 27 cents per litre over the same period. Clearly, biodiesel production is uneconomic when compared directly to the cost of conventional diesel. The difference in average costs of 25 cents per litre is about twice that of the combined capital and operating costs, excluding the tallow and methanol feedstocks, of producing biodiesel. By including the 6% increased fuel consumption with biodiesel, this spread will widen to 27 cents per litre, if biodiesel is valued on its equivalence with conventional diesel. With already high product yields and low capital costs, improvements in capital costs and process technology will have only a minimal effect of biodiesel's competitiveness, the parameters having the greatest impact being:

- A sustained increase in the price of crude oil and hence diesel fuel
- A reduction in the cost of tallow or oil feedstock
- A change in the relative level of fuel taxation or charges applied to diesel powered vehicles.

The first two parameters largely are out of the control of policy makers, although in some European countries, subsidies are available on the production of vegetable oils through land use policies. Incentives for biodiesel use based on differentiated fuel taxes are common in Europe to meet the European Union's targets for renewable transport fuels utilisation.

Under today's circumstances, a diesel price of 27 cents per litre implies a crude oil price of about US$19 per barrel. An oil price of US$25 per barrel, about the midpoint of the OPEC target price range, results in a diesel price of some 37 cents per litre, which, if sustained over the life of a biodiesel plant, would reduce the margin between diesel price and costs of biodiesel to 15 to 27 cents per litre. However, the current political situation in the Middle East has created a great deal of uncertainty over near/medium term oil prices, with high and low price futures equally easy to rationalise.

4 Fuel Taxation

4.1 Fuel Carbon Content

Biodiesel has a lower carbon content than conventional diesel, due to its oxygen content. Consequently carbon dioxide emissions from biodiesel, measured as a ratio of fuel mass or volume, are lower than from diesel. However, as the energy content of biodiesel is less than diesel, likely carbon dioxide tailpipe emissions from vehicles will be similar for both fuels.

Table 4

Carbon Dioxide Emissions from Biodiesel

	kg CO_2 produced per			
	kg fuel	litre fuel	MJ	litre diesel displaced**
Diesel	3.18	2.70	0.0749	2.70
Animal ME*	2.79	2.46	0.0762	2.60
Vegetable ME*	2.85	2.51	0.0756	2.66

** Animal ME: Tallow/animal fat methyl ester, Vegetable ME: Vegetable Oil methyl ester*

*** assuming volumetric fuel consumption increases 6% with biodiesel*

If vehicle fuel consumption is assumed to be proportional to fuel energy content, tailpipe carbon dioxide emissions will be slightly higher (<2%) with biodiesel than conventional diesel. However, if consumption is assumed to increase only 6%, the energy content of animal and vegetable methyl esters being 11.9% and 8.6% less than conventional diesel (21), there will be a slight reduction in carbon dioxide emissions with biodiesel.

4.2 Potential Tax Benefits for Biodiesel

Direct taxes in New Zealand on automotive diesel fuel are less than 0.4 cents per litre, consisting principally of the Local Authority Tax. Revenue raising from diesel vehicles is achieved through the Road User Charges, applied to all diesel vehicles according to their weight and wheel configuration. These charges do not differentiate between biodiesel and conventional diesel fuels and it is probably impractical to adjust them in favour of biodiesel, particularly when used in a blend with conventional diesel. However, there are several potential avenues for closing the gap between biofuels production costs and the cost of conventional diesel:

- ***Carbon Tax Credit.*** It is anticipated that biodiesel will be eligible for the credit to be applied in advance of the impending carbon tax on fuels and subsequently be exempt from the carbon tax. This tax and the preceding credit will be capped at the rate of $25 per tonne of carbon dioxide produced from the fuel. The anticipated value to biodiesel of this credit is shown in Table 5.

Table 5

Value of Carbon Tax Credit on Biodiesel

	Carbon Credit * cent per		
	kg fuel	litre fuel	litre diesel displaced**
Diesel	7.95	6.76	
Animal ME	6.98	6.14	6.51
Vegetable ME	7.13	6.28	6.65

** assuming a $25 per tonne credit on carbon dioxide produced*

*** assuming volumetric fuel consumption increases 6% with biodiesel*

The effective value to a biodiesel producer of the carbon credit is about 6 to 7 cents per litre, well short of the difference of 15 to 27 cents per litre identified as the underlying difference in cost between biodiesel and conventional diesel. A $15 per tonne of carbon dioxide credit is worth some 4 cents per litre and to cover the full 25 cents per litre cost differential, a credit of about $100 per tonne of carbon dioxide would be required.

- ***Environmental Value of Biodiesel through Reduction of Emissions***. Use of biodiesel, either as a neat fuel or blended with conventional diesel, will result in significant reductions in vehicle emissions of particulate matter, carbon monoxide and hydrocarbons and a slight increase in oxides of nitrogen. In New Zealand particulate matter has the greatest impact on health human health, estimated at an order of magnitude greater than the other vehicle emission species and possibly impacting the same at risk groups, so an estimate of environmental impact can reasonably be made on particulate matter only (22). For neat animal derived biodiesel, the reduction in particulate matter emissions is 49% and is 33% for vegetable based product, with a more or less linear relationship between biodiesel concentration and reduction in emissions for blends (21).

  An initial assessment of the cost of particulate emissions from vehicles in New Zealand is $536 million, due largely to human mortality and morbidity, and $310 million in the Auckland Regional Authority area alone (23). The impact can be considered proportional to the level of particulate emissions (22).

  On this basis, if 120,000 tonnes of biodiesel were blended into all diesel consumed in New Zealand, the overall concentration of biodiesel would be 6%, resulting in a 3% reduction in particulate emissions. If this reduction is applied proportionately to the total impact cost of particulates in New Zealand, the reduction in pollution costs would be in the order of $16.7 million or 12 cents per litre of biodiesel. By concentrating all the biodiesel in the Auckland region, where pollution costs are disproportionately high, the pollution costs savings could be increased by about 5 cents per litre although this will be offset to some extent by the additional cost of transporting the tallow or biodiesel into the Auckland region.

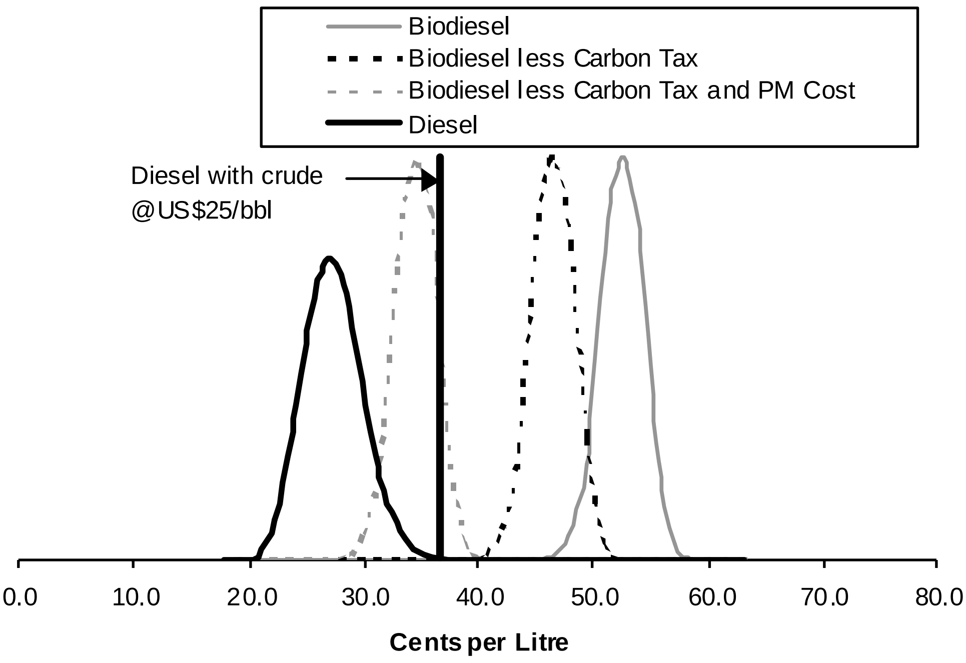
This simple analysis indicates there is likely to be some benefit from biodiesel if external costs such as pollution are included in the tax structure for transport fuels. However the data derived must be treated with circumspection as the pollution costs are preliminary only and a limited range of vehicles were used in the assessment of emissions from biodiesel (21). The Ministry for the Environment is currently undertaking a more detailed analysis of pollution costs from transport which will published later in 2003.

- ***Direct Incentives for Biodiesel***. Countries with transport biofuels industries use a mix of compulsion, subsidies for producers and/or relaxation of fuel taxes to sustain the production and marketing of the fuels. The latter two measures are being applied increasingly in the European Union for both biodiesel and ethanol to meet its renewable fuels standard. These options are available to New Zealand to meet its 2 PJ target for renewable transport fuels but will have to be assessed in the context of New Zealand's wider energy and transport policies and experience with such measures during the early 1980's.

To illustrate the potential impact of the carbon credit and environmental cost, they are included in the relative costs of diesel and biodiesel costs and shown in Figure 6.

Figure 6

Impact of Carbon Tax Credit and Particulate Costs on Net Biodiesel Costs of Production and Diesel Costs



Deducting both the carbon tax credit and the cost of particulate emissions from that of producing biodiesel will not close the gap of 27 cents/litre between historical diesel and biodiesel costs. Using the historical distribution of costs, the costs of diesel would be higher than biodiesel in less than 2% of cases and there would be insignificant convergence if only one of the two instruments were to be applied.

If the price of oil were to be sustained at over US$25 per barrel, convergence would be increased to over 97% with both instruments but reduced to 5% with the particulate emission costs applied only. With the carbon tax credit only there will be no convergence.

This analysis suggests that to be competitive with conventional diesel, biodiesel will require more than the combined assistance of carbon tax credits and the cost savings resulting from reduced diesel emissions to make it competitive with conventional diesel, unless the price of crude oil is maintained at prices significantly higher than historical averages.

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