SOPAC

LIQUID BIOFUELS IN PACIFIC ISLAND COUNTRIES

April 2007 *SOPAC Miscellaneous Report 628*

Jan Cloin

with contributions from

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Cover page photo: “Island Fuel” bowser in Vila, Vanuatu belonging to Tony Deamer who retails filtered Coconut Oil Fuel blends to motorists *(Source: SOPAC)*

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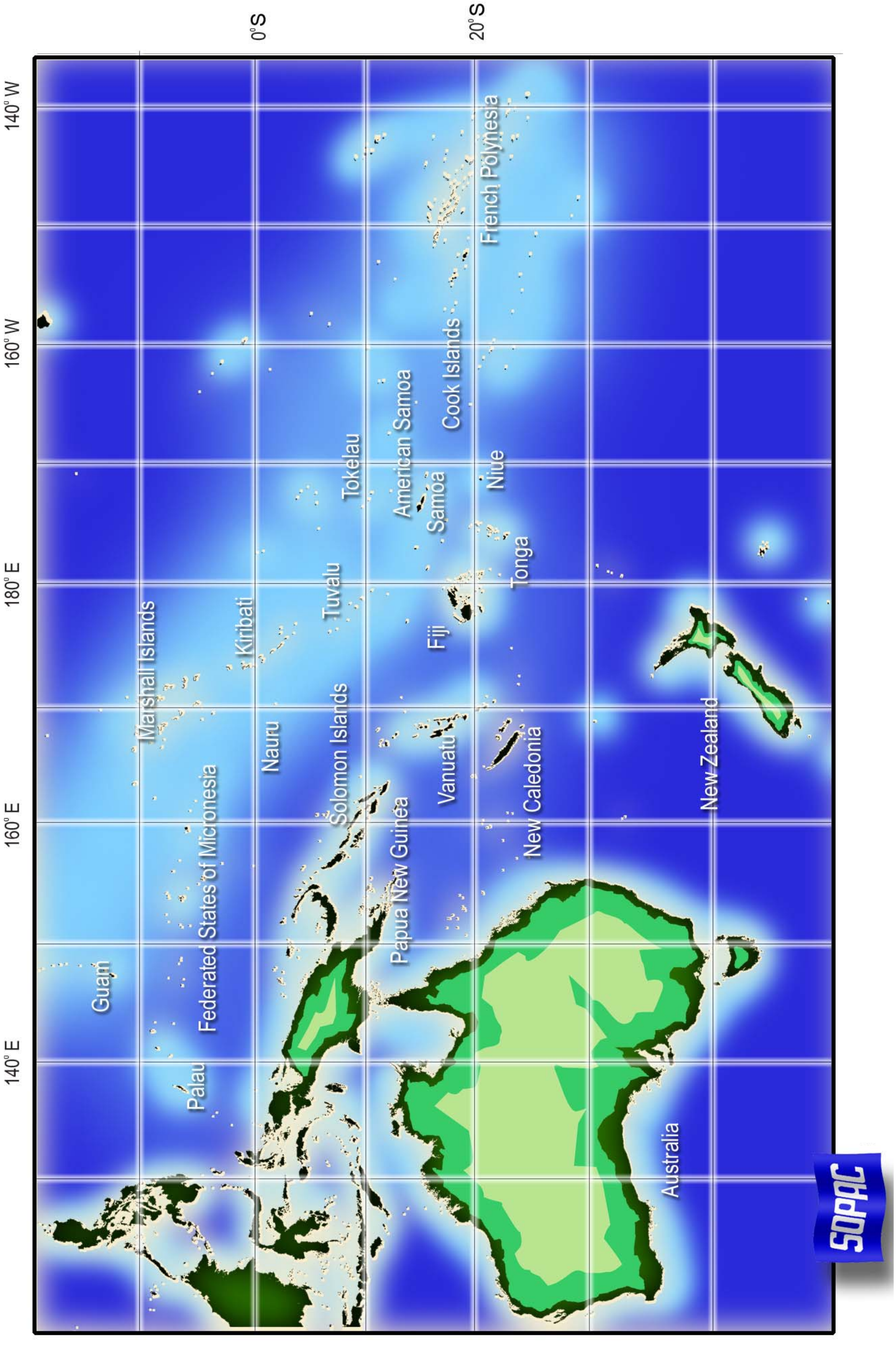
ACRONYMS

ACP	EU member states in Africa, Caribbean and Pacific
ADB	Asian Development Bank
ASTM	American Standards and Measurements Bureau
APCC	Asian Pacific Coconut Community
B20	Blend of 80% diesel and 20% biodiesel
C10	Blend of 90% diesel and 10% filtered coconut oil
CDM	Clean Development Mechanism
CIDA	Coconut Industry Development Authority, Fiji
CIRAD	Centre de co-opération internationale en recherche agronomique de développement
CNO	Coconut oil
COPS	Copra Oil Production Samoa
CO_2	Carbon Dioxide
EPC	Electric Power Corporation, Samoa
DME	Direct Micro Expelling, a method to produce virgin coconut oil
DIN	Deutsche Industrie Norm, German Industrial Norm
DI	Direct Injection, a fuel system for compression ignition engines
E10	Blend of 10% ethanol and 90% petrol
EMA	Engine Manufacturers Association
EN	European Norm
EU	European Union
FFA	Free Fatty Acids
FSC	Fiji Sugar Corporation
F$	Fiji Dollar
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GHG	Greenhouse Gas
IDI	Indirect Injection, a fuel system for compression ignition engines
IEA	International Energy Agency
IMF	International Monetary Fund
LTA	Land Transport Authority, Fiji Islands
KCMC	Kiribati Copra Milling Company
KOIL	Kiribati Oil Company Limited
kVA	Kilo Volt Ampere, a measure of apparent power
kW	Kilo Watt, a measure of real power
MJ	Mega Joule
NO_x	Nitrous Oxides
PIC	Pacific Island Country
PIEPSAP	Pacific Island Energy Policy and Strategic Action Planning
PIFS	Pacific Islands Forum Secretariat
PIREP	Pacific Island Renewable Energy Project
PNS	Philippine National Standard
PNG	Papua New Guinea
PNG SDP	Papua New Guinea Sustainable Development Programme
PPIACO	Producer Price Index All Commodities

PROALCOOL	Brazilian Government national Ethanol fuel programme
RESCO	Rural Energy Service Company
RON	Research Octane Number
SNPL	Samoa Niu Products Limited
SOPAC	Secretariat of the Pacific Islands Applied Geoscience Commission
SO_x	Sulphur Oxides
SPC	Secretariat of the Pacific Community
SPD	South Pacific Distilleries, Fiji Islands
SPS	Special Preferential Sugar agreement between ACP and EU under the Sugar Protocol
STP	Solomon Tropical Products, Solomon Islands
SVO	Straight Vegetable Oil
TORBA	Province of Torres and Banks Islands, Vanuatu
UK	United Kingdom
UNCTAD	United Nations Conference on Trade And Development
UNDP	United Nations Development Programme
UN	United Nations
UNELCO	Vanuatu's Power Utility
USP	University of the South Pacific
US	United States
US$	United States Dollar
VAT	Value Added Tax
WB	World Bank

BIOFUEL CONVERSION FACTORS

Energy Content		
Product	Value	
Ethanol	21.1 MJ/litre	
Petrol	31.6 MJ/litre	
Coconut Oil	35.0 MJ/litre	
Biodiesel	34.0 MJ/litre	
Diesel	41.0 MJ/litre	
Density / Extraction Rates		
Density of Petrol	0.73 kg/litre	
Density of Diesel	0.84 kg/litre	
Density of copra oil [kg/l]	0.915	
Extraction rate of copra oil mill [%]	57-62%	
Extraction rate of copra minimill [%]	50-55%	
Coconut Conversion Factors (1,000 Coconuts) – Metric		
Coconut Product	Weight [tonnes]	
Coconut	1.2	
Husks	0.39	
Shells	0.17	
Cocowater	0.24	
Green Copra	0.37	
Dry Copra	0.2	
Copra Meal	0.08	
Copra Oil	0.12	
1 m^3 copra	0.53	
1m^3 copra meal	0.47	
Coconut Conversion Factors (1,000 Coconuts) – Imperial		
Coconut Product	Weight [lbs]	[tons]
Coconut	2646	1.323
Husks	860	0.430
Shells	375	0.187
Cocowater	529	0.265
Green Copra	816	0.408
Dry Copra	441	0.221
Copra Meal	176	0.088
Copra Oil	265	0.132
1 m^3 copra	1169	0.584
1m^3 copra meal	1036	0.518
Metric to Imperial		
Weight	1.10 2 short tons / metric tonne	907.4 kg / ton
Weight	2.21 lb / kg	0.454 kg / lb
Volume	0.264 litre / gallon	3.78 litres / gallon


140° W
160° W
180° E
160° E
140° E
0° S
20° S
French Polynesia
Cook Islands
American Samoa
Tokelau
Niue
Samoa
Tonga
Tuvalu
Fiji
Kiribati
Marshall Islands
Nauru
Solomon Islands
Vanuatu
New Caledonia
New Zealand
Federated States of Micronesia
Papua New Guinea
Guam
Palau
Australia
SOPAC

EXECUTIVE SUMMARY

The volatile world market prices for fossil fuels in the past years have significantly increased interest in the development of indigenous sources of energy in the Pacific islands. As part of their resources governance strategy, many Pacific island Governments are looking into the use of local biomass resources to replace traditionally imported fuels such as petrol and diesel with biofuels. This report gives an overview of biofuel technology, activities, experiences and key achievements in the Pacific region with regard to efforts to develop alternative fuel.

Experiences in the region show a niche for vegetable oil, especially coconut oil, fuel blends with diesel or kerosene, in certain cases, but will lead to additional maintenance and repair cost. Vegetable oil fuel that respects quality standards such as DIN 51 605 can be used in blends in indirect injection engines only. For use of vegetable oil blends in direct injection engines, modifications to the engine must be implemented and special operating load characteristics need to be followed. Modification of engines can lead to high up-front cost for a car or generator, however the additional repair cost of not following standards, suitable types of engines and operational characteristics are significantly higher over the life cycle of the engine.

If vegetable oil is converted into biodiesel by esterification, following standards such as PNS 2020 or equivalent, it can be used in virtually any engine with no adaptation. The cost of small-scale esterification of vegetable oil is estimated at US$ 0.3 – 0.6 per litre depending on the size of operation and requires importing methanol, required for the esterification reaction. Small-scale biodiesel can supply fuel for ships and trucks on remote islands where fuel prices are high, provided there is sufficient management capacity to run a biodiesel conversion plant.

Ethanol produced from sugar cane and starchy crops can partly replace petrol as a fuel. The production of ethanol following the proposed ANZ Standard (or equivalent) can replace petrol in vehicles up to 10% with no modification and up to 22% with some modifications according to the model and year of production.

There are no quality standards for biofuels in any of the Pacific Island Countries whereas it is widely acknowledged that this would greatly facilitate market acceptance. In order to achieve sustainable indigenous biofuel industries, it is imperative to enhance regional co-operation and information sharing and to establish quality standards on a national level. It is also imperative that guidelines for appropriate production methods are agreed upon, taking into account the total environmental impacts of biofuel production, use and the creation of side products.

Biodiesel from coconut oil and the production of fuel ethanol will not take off unless governments assist with these developments at prices below US$ 100 per barrel of oil. Government support in the form of tax incentives, partial duty concessions, investment promotion and public-private partnerships can significantly advance a biofuel industry.

Most countries in the Pacific region have the resources to produce large amounts of coconut oil-based fuels, while the larger countries also have a vast potential for the production of ethanol. 30% of all regional transport fuels could be replaced by biofuels in 2015, if plantations are revived and industries restructured.

Economic advantages of indigenous biofuels include reduction of energy import dependence, increasing economic resilience, an improvement of the balance of trade and support to local farmer prices. It is suggested that not all fossil fuel duties are waived for biofuels as the overall impact on the country’s finances might be negative, if subsequent losses of agricultural exports are also taken into account.

Biofuels are part of the solution to make the Pacific countries’ energy supply more renewable and will pave the way for a cleaner environment, creation of jobs and a more resilient economy.

1. INTRODUCTION AND BACKGROUND

In the past few years, there has been an increasing interest in biofuels to replace imports of fossil fuel to Pacific Islands Countries. In the European Union and Japan biofuel industries have mainly emerged because of environmental concerns and commitments to the Kyoto Protocol. In the United States and Brazil biofuel has become mainstream for reasons of energy security and reduction of dependence on oil imports. Finally, in countries like Australia and Russia, biofuels have developed to support prices that farmers receive. Currently it is countries like India, the Philippines, Malaysia and Indonesia that are fast-tracking biofuel industry developments through a combination of concerns for energy security, assistance to farmers and environmental concerns.

The significant targets that all these countries have set are having impacts on both the vegetable oil and sugar world market prices, as well as having a tempering effect on crude oil prices [43]. At the same time environmental concerns with regard to the impact of large-scale palm plantations that are taking the place of indigenous forests have become part of the mainstream biofuel policy discussions [33]. These global developments have their impact on markets and initiatives in the Pacific islands.

The call for the use of locally produced biofuels in the Pacific has been motivated largely by the desire to reduce dependence on imported fossil fuels. However, as can be read in Chapter 3 of this report, about the impact of biofuel import substitution on the balance of payments of a country finds that the impact biofuels can have is rather limited. The once thriving coconut oil sector during colonial times is an important product for exports. Using it to replace imports of fossil fuels will also cause total exports to drop. In addition, if duties and excises are waived so as to promote the use of biofuels, the impact on Government finance might even be negative.

With petrol substitution by ethanol in Fiji or Papua New Guinea, very often it is argued that the size of the Pacific islands is not sufficient to produce these fuels in large volumes to achieve economies of scale. Similarly, diesel substitution by biodiesel requires the importing of high quantities of methanol, while many coconut oil products, with for example organic certification and Direct Micro Expelling (DME) could target much higher value-added markets than is possible with biofuels. These high value-added markets are however typically characterised by limited volumes due to small demand from niche markets.

The emerging demand for cleaner and cheaper fuels in the region will have to create a market for biofuels that currently does not exist. It will be up to Governments to create the framework of this niche, as has been the case in other parts of the world.

Recent Regional Developments on Biofuel

Through a combination of international turmoil and supply side constraints, coupled with consistent high demand, average world oil market prices have been rising consistently since 1999 (Figure 1). This is a historic break from a period of relatively low oil prices from 1987 – 1999. Simultaneously, Coconut oil as an export commodity has been very volatile on the world market. The significant price reduction after the relative peak of 1999 has led to disarray in the copra sector in many Pacific Islands Countries.

The international development of prices led to a number of studies on the use of coconut oil as a fuel in power generation [44]. For use of coconut oil or palm oil as a biofuel in the transportation sector, conversion to biodiesel through transesterification is required. The estimated cost of US$ 0.3 – 0.6 per litre of this conversion is currently perceived to be too high to make it viable to use coconut oil as a feedstock.

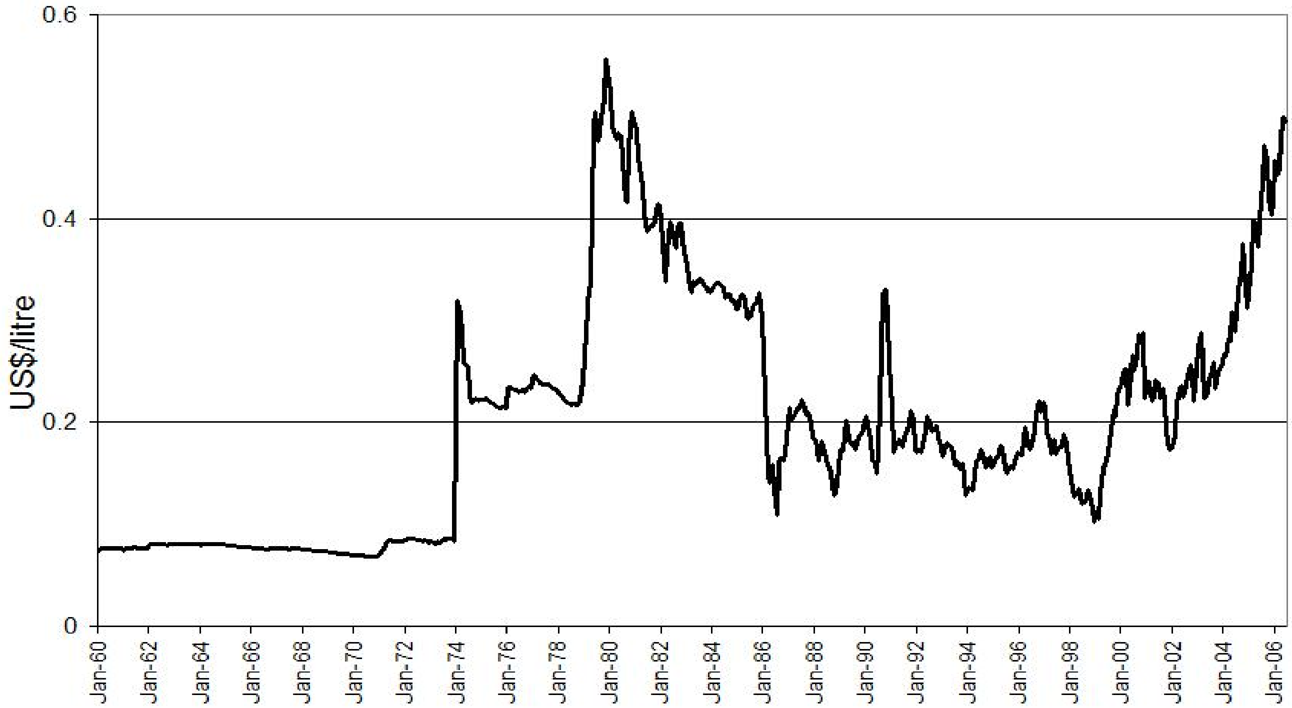


Figure 1: Average Diesel prices landed in the Pacific 1960-2006 at constant prices (Sources: UNCTAD database, PIFS Fuel Price Monitor [6], Federal Bank of St. Louis PPIACO all commodities price index)

It is however viable to produce biodiesel from other sources of (waste) oil such as waste cooking oil. It depends largely on the amount of feedstock available that can be collected at an acceptable cost whether this can be a viable business opportunity. In many Pacific Islands Countries it has been found that cooking oil gets all used up and that the only sources of waste cooking oil are restaurants that generally deep-fry their food, such as fast-food. A certain minimum amount of oil is needed to make an operation based on waste-oil viable, as is for example the case in O'ahu, Hawai'i.

Many options exist to utilise biofuels in various blends. The biggest question is however not which technology will get us to use most biofuels, but where we will get the feedstock to supply the biofuels. The regional potential has been estimated at about 30% of transport fuels[1], assuming major replanting and restructuring of the industries. On a worldwide scale, scenarios suggest major difficulties over 10% supply of transportation fuels due to limited arable land and competition with food markets.

This leads us to the notion that biofuels can and will be part of a sustainable solution to the Pacific island energy challenges, but will in no way be able to completely replace petroleum products. Other solutions like hydro power, wind, solar and perhaps in the medium term ocean energy will also have to play a major role.

Although the term 'biofuel' refers to various technologies, in this report we will define biofuels as liquid energy carriers derived from biomass that can be used in a standard or adapted combustion engine.

This report will take a look at the underlying technologies first, after which the economic and environmental impacts of biofuels production and utilisation will be discussed. Finally, some examples of current biofuel utilisation in Pacific Islands Countries are given and conclusions and recommendations made on which technology to use and what policy ensures the highest economic benefits to Pacific Islands Countries.

[1] SOPAC inventory at Sub-regional Biofuel workshop Vanuatu, 2005

2. VEGETABLE OIL AS A DIESEL SUBSTITUTE

Liquid biofuels are derived from biomass (trees, grasses, agricultural crops) and have been prepared to fulfil a specific purpose. Vegetable oils are used to replace fossil diesel fuel, while ethanol is typically replace petrol (Chapter 3). Other gaseous forms of biofuels such as methane can be a replacement for natural gas. Also, solid forms of biomass such as wood, wood-products or agricultural waste product pellets can replace coal in many applications. This report will however focus on liquid biofuels and its applications in Pacific Islands Countries.

2.1 Vegetable Oil Fuel Technology

The use of vegetables oils as a biofuel finds its application in compression ignition engines. Another well-known biofuel, ethanol, is a petrol replacement and is applied in spark ignition engines and will be discussed in Paragraph 2.2.

Compression ignition engines, normally run on diesel, are applied in power generation and transportation. Vegetable oil was first demonstrated at the world trade fair in Paris in 1900 when an Otto Engine ran on peanut oil. It was thought then that vegetable oil would be the main source of fuel. However, large-scale exploration of oil along with its low price in comparison to vegetable oil, has now made diesel the fuel of choice for more than a century. It is only in periods of history when there has been a supply shortage of diesel fuel that alternatives were seriously considered and used. However, after restoration of supply (i.e. after a war or fuel crisis) diesel once again re-established itself as the fuel of choice through its low price and high availability (See Box 1).

For the initial use of vegetable oil in the diesel engine, a number of obstacles had to be overcome. Plant oils typically show viscosities ten to twenty times higher than the viscosity of fossil diesel fuel [29]. This leads to poor fuel atomisation and results in incomplete combustion, which was attested in 1921.

The extremely high flashpoints of vegetable oils and their tendency for thermal or oxidative polymerisation aggravate the situation, leading to the formation of deposits on the injector nozzles, a gradual dilution and degrading of the lubricating oil and the sticking of piston rings. As a consequence, long-term operation of most pure plant or mixtures of pure plant oils with diesel eventually leads to engine breakdown. Either adapting the engine or the fuel can solve these problems.

Box 1: History of Vegetable Oil used as a fuel

The first known use of vegetable oil as fuel for a diesel engine was a demonstration of an engine built by the Otto company and designed to burn mineral oil, which was run off of pure peanut oil at the 1900 World Trade Fair. While there is no record of Rudolph Diesel, himself, ever experimenting with the use of vegetable oil as a fuel for his engines, he was certainly aware of the possibility. In a 1912 presentation to the British Institute of Mechanical Engineers, he cited a number of efforts in this area and remarked, "The fact that fat oils from vegetable sources can be used may seem insignificant today, but such oils may perhaps become in the course of time be of the same importance as some natural mineral oils and the tar products are now."

Periodic petroleum shortages spurred research into vegetable oil as a diesel substitute during the 1930s and 1940s, and again in the 1970s and early 1980s when straight vegetable oil enjoyed its highest level of scientific interest. The 1970s also saw the formation of the first commercial enterprise to allow consumers to run straight vegetable oil in their automobiles, Elsbett of Germany.

Academic research into straight vegetable oil fell off sharply in the 1980s with falling petroleum prices and greater interest in biodiesel as an option that did not require extensive vehicle modifications.

Source: Wikipedia: http://en.wikipedia.org/wiki/Vegetable_oil_used_as_fuel

This chapter will describe both the adaptation of the fuel (biodiesel) and the adaptation of the engine (modified engine). Paragraph 2.2 will also discuss the option of running certain types of unadapted engines on pure coconut oil or mixtures of coconut oil with diesel.

Operation of a compression ignition engine

A compression ignition engine operates on the principle of a piston moving in a cylinder. As the piston moves upwards, it compresses the air and consequently increases the temperature of the air. The diesel engine has no spark plug (unlike a petrol engine), and injects the fuel directly into the combustion chamber (direct injection), or injects the fuel in a pre-combustion or swirl chamber (indirect injection). It is the heat of the compressed air that lights the fuel in a diesel engine.

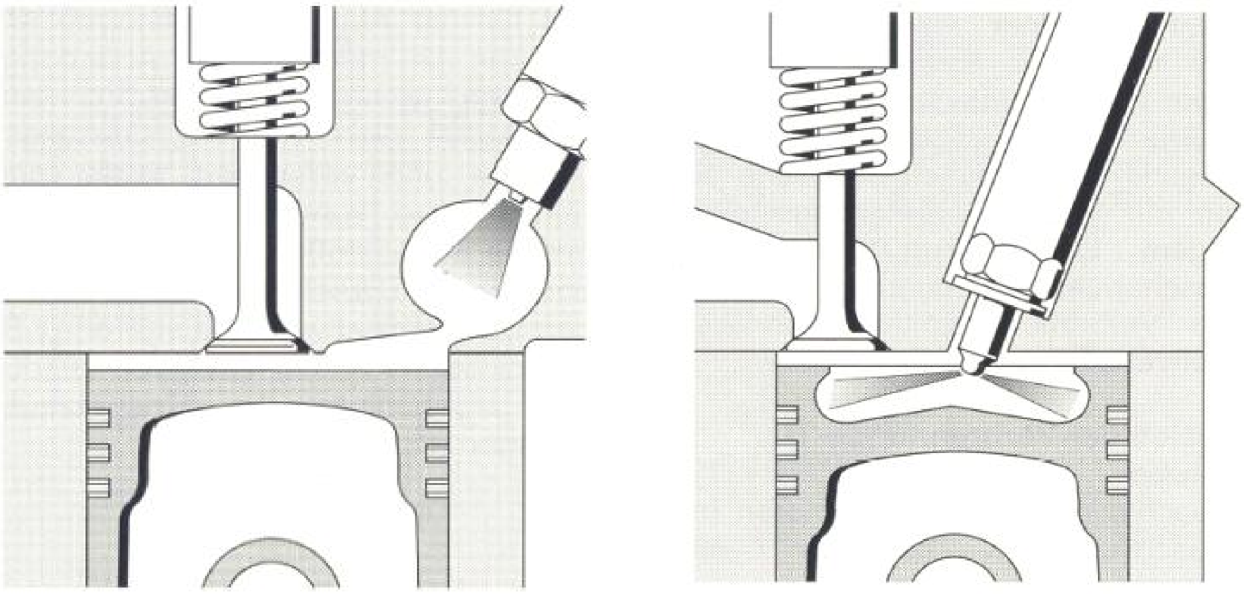


Figure 2: Operation of an indirect injection (left) and direct injection (right) (Source: [22]).

The injector on a diesel engine is its most complex component and has been the subject of a great deal of experimentation, in any particular engine it may be located in a variety of places. The injector has to be able to withstand the temperature and pressure inside the cylinder and still deliver the fuel in a fine mist. Getting the mist circulated in the cylinder so that it is evenly distributed is also a problem, so some diesel engines employ special induction valves, pre-combustion chambers or other devices to swirl the air in the combustion chamber or otherwise improve the ignition and combustion process [19].

2.2 Pure vegetable oils in unmodified engines

Many studies involving the use of pure vegetable oils (including coconut oil) were conducted in the early 1980s. Short-term engine testing indicates that vegetable oils can be readily used as a fuel or in a range of blends with diesel fuel. Long-term engine research however shows that engine durability is questionable when fuel blends containing more than 20% vegetable oil are used [1, 7, 26, 27].

The lower iodine value of coconut oil, compared to other vegetable oils, works favourably and reduces carbon deposits. Nevertheless, positive experiences using coconut oil have only been found in indirect injection engines, or direct injection engines that operate only on a high load. If this was not the case, deposits on the pistons, valves, combustion chambers and injectors have shown to cause severe loss of output power, engine lubricant deterioration or even catastrophic failure of engines [53].

The theoretical explanation of why indirect injection engines are not subject to the deposit problems that occur in direct injection engines is related the average combustion chamber temperature. At idle speed or low loads, for example, the indirect injection combustion chamber is 400-500 ^{o}C, whereas in a direct injection engine, the combustion chamber may only be 100-200 ^{o}C. Droplets of fuel, especially if these contain vegetable oil, do not have sufficient time to evaporate in these conditions and can form deposits on all parts of the combustion chamber. If the temperature of the combustion chamber is sufficiently high, the droplets will evaporate and hence avoid deposits [34, 53].

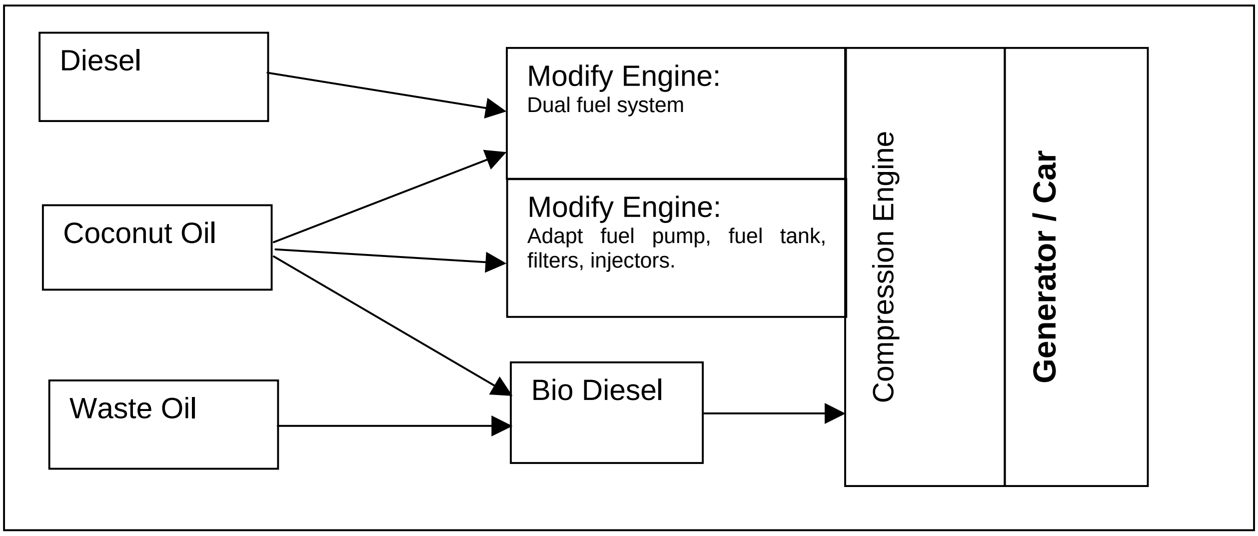


Figure 3: Overview of the biofuel choices for compression (diesel) engine.

The long-term use of raw coconut oil in unmodified diesel engines is such a specialised activity that it is not recommended without special technical supervision. Further research needs to be done to describe and define the key variables in order to minimise modification costs to engines. Current experiences in Vanuatu in the transport sector are promising and deserve follow-up activities in other Pacific Islands Countries.

2.3 Pure coconut oil in modified engines

There have been a number of successful modified diesel engines that have run on both mixtures of vegetable oil and diesel as well as 100% vegetable oil. There are mainly two types of engine modifications that have been attempted: firstly to add an extra fuel supply system to the existing diesel supply and secondly to adapt the fuel supply system and injectors.

Figure 4: Dual fuel system in Fiji, Welagi community generator (Source: SOPAC).

As coconut oil has up to 10 times higher viscosity than regular diesel at the same temperature, most engine modifications include a fuel heater. This device heats the fuel up to 70-80^{0}C before injection, using the engine coolant cross flow with the fuel in a heat exchanger. By heating up the coconut oil, the resulting oil viscosity can approximate the viscosity of diesel [29].

Dual Fuel Systems

Dual fuel systems start and stop on regular diesel. As soon as the engine is operating at rated temperature, the fuel supply is switched to vegetable oil and just before shutting down, the supply is switched back to diesel to ensure that the fuel system has diesel ready for a cold start and to avoid the possibility of any residues in the fuel system.

In some areas there is also an electrical heater incorporated into the fuel tank, to ensure that the fuel remains liquid, even at ambient temperatures below 25^{o}C. A technical challenge is to ensure that the return line of the alternative fuel does not cause contamination of the regular diesel. This can be done through using a third "day" tank that assembles the excess mixture fuel during switching, or to short-circuit the return line and using an extra pump during operation on vegetable oil.

A good example of a dual fuel system is used in the village electrification system in Welagi, Taveuni, Fiji Islands. Welangi uses diesel and copra oil in a dual-fuel system fed into a 45-kVA diesel generator [10, 11]. As part of a French-funded project, the village obtained a small copra oil press enabling the local small-scale oil production by means of dried copra. Technically this system has proven to operate with little problem.

This generator has however suffered from problems related to spare parts but these problems are not directly attributable to the use of copra oil. The challenge with the system has been to keep it running on copra oil, as first a cyclone deprived the community of coconuts for 6 months and the acquisition of coconut oil from other mills proved to be more expensive than regular diesel. The local production of coconut oil also proved to be a very laborious process that can only be maintained with a strong community commitment.

Because the generator has often only been used for a small portion of its design load (as low as 17%), excessive carbon deposits were found in the exhaust gaskets of the generator. This can cause engine failure in the long term and could be solved by connecting a useful extra load such as water pumping or street lighting, when the generator is running at low load.

In Europe and the United States, the use of dual fuel systems, mainly in automotive applications, is slowly developing, through promotion projects such as the Veggie Van in the US and the VegBurner in the United Kingdom (UK). These applications have gained wide publicity. Through a combination of very high taxation on fuels (particularly in Europe), low vegetable oil prices (particularly in the US) and growing environmental concerns, an increasing number of consumers have acquired an alternative fuel system built in their (diesel) vehicles. The emissions reductions measured as a result of the use of these fuels in regular cars have been mixed as compared with the baseline of regular diesel [30].

Figure 5: Vegetable Oil conversion kit (Source: Greasel.com).

Adapted Fuel System

Engines with adapted fuel systems can run on pure coconut oil and use no fossil fuels. Mostly, they feature adapted fuel injectors, special pumps and extra filters. Especially if the coconut oil is manufactured locally on a small scale, the quality is not always stable. Therefore regular quality control and a number of filtering stages are essential to ensuring a long life of this type of system. Often an electrical operated fuel heating system is incorporated for ambient temperatures below 25°C.

A good example of this is the pilot plant in Ouvéa implemented by the Secretariat of the Pacific Community (SPC) and Centre de coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) in the 1990's. The generator is currently not in use because of supply problems with locally produced oil. Further feasibility studies have shown a favourable opportunity for the Lory Co-operation on Espirito Santo in Vanuatu. This study also describes the incorporation of the use of raw copra oil in a small number of modified taxi engines [44].

It has been shown in a number of Pacific Islands Countries that some types of vehicles can run on coconut oil without major long-term impact (see also Chapter 6: Pacific Island Biofuel Experiences).

2.4 Other pure vegetable oils in diesel engines

As mentioned in 2.1, many experiments have been undertaken with other types of vegetable oil. Some promising results were obtained with using palm kernel oil, Jatropha oil, soybean oil, sunflower oil and rapeseed (canola) oil. Depending on their physical properties, these oils need to be cleaned and refined so that engines do not experience negative effects from the use of these oils.

Figure 6: Jathropha is a plant that is growing in many Pacific Islands Countries as a hedge or support for vanilla and is widely seen as a promising crop for vegetable oil fuel in the region (Source: www.jatrhopha.de).

Gums

Crude, unrefined oil contains 1-3% phospholipids (or 400 – 1200 ppm phosphorous[2]). These phospholipids are also referred to as gums. Gums lead to filters clogging and have the tendency to form deposits in the combustion chamber and empirical evidence suggests it is best to completely remove gums using a refinery stage.

Waxes

Some oils, like sunflower and corn contain waxes, which also can lead to deposits during combustion; waxes can be removed by winterisation[3] or in a refining process using chemicals.

[2] The rate of phospholipids is determined by measuring phosphorous content. Roughly 400 ppm phosphorous corresponds to 1% phospholipids.
[3] Winterisation is a process of removing components with high melting point (e.g. waxes) from vegetable oils.

Proteins

Unrefined oil contains a certain level of protein that will break down over time. When this happens, the oil becomes blurry and less viscous, or rancid. The breakdown process is sped up by higher temperature, exposure to light and the presence of oxygen. After oil has become rancid, it is less suitable for use as a fuel, having a higher likelihood to block filters and might also lead to corrosion due to higher acidity.

Free Fatty Acids

Vegetable oil is a series of chains of hydrocarbons which contains up to 10% Free Fatty Acids (FFA), depending on the production process and state of deterioration. FFAs can be removed by mixing the oil with caustic soda, turning the FFAs into soapy particles, which can then be filtered out using a centrifuge.

Temperature

It is important that the vegetable oil used as fuel stays liquid throughout all operational temperatures of the machine that it is used in. Therefore the solidification point or temperature where the oil becomes solid is an important parameter. In Pacific climates this is only sometimes a problem for palm oil and coconut oil, which have their solidification point at 35 ^{O}C and 25 ^{O}C respectively.

Iodine Value

An important indicator for the tendency to form engine deposits has been found to be the Iodine Value. The lower the iodine value, the less tendency the oil has to polymerise in the combustion chamber of the engine. Another consideration for the type of oil to be used is the typical yield when the oil is produced on a plantation.

Table 1: Melting points, Iodine Values and typical yields of selected Oils (Source: Journeytoforever.org).

Type of Oil	Melting point [^{O}C]	Iodine Value	Typical Yield [kg oil per ha]
Coconut	25	10	2260
Palm Kernel	24	37	460
Palm	35	45	3260
Castor	– 18	85	1188
Peanut	3	93	890
Jathropha	– 5	96	1590
Rapeseed (Canola)	– 0	98	1000
Cotton Seed	– 1	105	273
Sunflower	– 17	125	800
Soybean	– 16	130	375
Linseed	– 24	178	402

2.5 Quality standards for vegetable oil fuels

Based on decades of experiences in Europe with the use of Rapeseed oil in diesel engines, a vegetable oil fuel quality standard has been established. Annex 1 lists the parameters with suggested values for vegetable oil as defined in the German DIN 51 605 standard.

A number of coconut oil experiments in the region have failed because of quality problems with the oil used. The absolute minimum requirements in this German standard will ensure that problems caused by quality of oil will be kept to a minimum.

2.6 Additional costs of using vegetable oil in diesel engines

[This section is adapted from Daniel Fürstenwerth MSc. Thesis [19].]

As described above, the running of engines that have been designed for diesel fuel, on different vegetable oil-based fuels can lead to additional wear, maintenance and lubrication oil change. These additional requirements will also lead to additional operational cost.

SOPAC has been involved in research to establish the additional cost of using vegetable oil fuels with a case study in the Marshall Islands. The research identified four different cost components, with options for a more positive estimate, "lucky" and a more conservative estimate, "unlucky".

Cost of Initial Investment

This category includes additional investment costs necessary when using coconut oil instead of diesel. In some cases, this refers only to the adaptation of the engine. In other cases, this category also includes the establishment of an additional fuel supply or additional filtration system. To calculate cost of initial investment per year, initial investment cost is divided by the number of years that the engine is expected to be used ("straight-line-depreciation"). This time is assumed to be 6 years in all cases except in the case of a new power plant, where a lifetime of ten years is assumed.

Cost of Maintenance

Estimations of the maintenance intervals in the case of using diesel and coconut oil, together with the amount of running hours (or: kilometres) per year, allows the calculation of incidents in which a specific maintenance procedure is executed per year. For each type of maintenance procedure in each case, the cost incurred is estimated. Total costs for each maintenance procedure per year are calculated and summed up, for the "diesel" case as well as the "lucky" and "unlucky" coconut oil scenarios. The relevant value of "extra cost of maintenance" is calculated as the difference in maintenance costs per year between each of the "coconut" scenarios and the "diesel" case.

Cost of Repair in Case of Failures

This category includes the "statistical" costs for failures per year. All probabilities are transformed into "probability per year". Because only "extra" probabilities of failures are specified, no repair costs for the diesel case are considered. For each type of failure in each case, the cost incurred is estimated. Financial consequences are calculated by multiplying these costs with the corresponding "probability of failure per year". The summation for the different types of repair costs yields the overall value of "cost of repair" in the "lucky" and the "unlucky" scenario.

Cost of Additional Fuel Used

This category includes cost incurred due to increase in fuel consumption. Based on the estimation of the total amount of diesel used per year (if diesel would be used) and the increased fuel consumption when using coconut oil, the amount of additional fuel that is consumed per year is calculated for both the "lucky" and "unlucky" scenario. Only this additional quantity of fuel is multiplied with the assumed price of coconut oil that applies in the respective application.

With these cost categories, an example was calculated for biofuel use in a vehicle in Marshall Islands. Figure 7 shows the results with an estimated additional cost per litre for a range of applications in land transportation. "Individual land transportation" and "professional land transportation" both represent cases of using small vehicles in urban areas. Specifications of the cases considered and assumptions made can be found in [19].

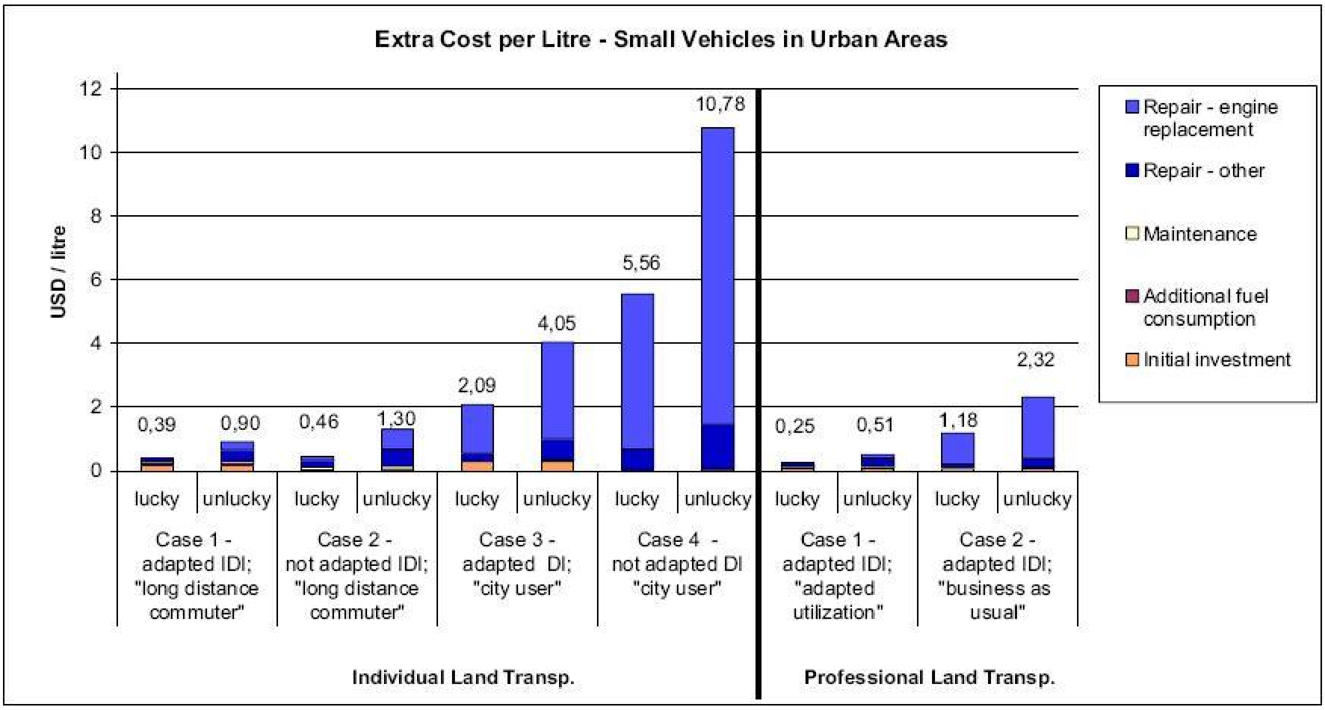


Figure 7: Additional cost per litre of vehicles running on coconut oil. (Source: [20])

The extra cost incurred in using coconut oil varies widely. Most striking are very high costs in the cases of the "city users" in "individual land transportation" (cases 3 and 4), where a "business as usual" utilization pattern is applied. In these cases, "cost of repair – engine replacement" is the dominant cost driver. Extra cost is estimated at 2.09 – 4.05 US$/litre in Case 3 while it is 5.56 - 10.78 US$/litre in Case 4. Hence the use of coconut oil in unadapted direct injection engines is not recommended, as it will lead to extremely high additional costs.

A comparative look at Case 2 and Case 4 of "individual land transportation" allows for a quantitative assessment of the consequences that a "plug and play" approach of using coconut oil in an unmodified car has. Users that fit in the category of Case 4 (car with a direct injection engine, used primarily in the city) will, on average, face substantially higher extra cost per litre than those that fit in the category of Case 2 (indirect injection engine, primarily used for long distances). The difference in financial consequences of this "best" and "worst" case of a "plug and play" approach is a factor of approximately 10.

High extra cost in Case 3 of "individual land transportation" emphasises that adaptation alone is not a guarantee for favourable financial consequences incurred in the use of coconut oil. High amount of low load operation and a lack of appropriate maintenance and caution lead to high risks of fatal engine failures (40% to 80% in five years) that make up for over 70% of the extra cost per litre.

In "professional land transportation", extra cost per litre are more than four times as high when using an adapted engine with a "business as usual" utilization pattern (Case 2; 1.18- 2.32 US$/litre) instead of an "adapted" utilization pattern (Case 1; 0.25-0.51 US$/litre). Cost of engine replacement is the main cost driver that makes up for the difference and accounts for approximately 80% of the cost in the “business as usual” case.

Cost of maintenance is 3 to 6 times higher where an “adapted” utilization pattern is applied (0.06-0.07 US$/litre as opposed to 0.01- 0.02 US$/litre), but is only a minor constituent of the total extra cost. Thus the calculated quantitative financial consequences of the use of coconut oil clearly highlight the importance of the utilization and maintenance pattern.

Summary of additional costs of using coconut oil

The findings of this study indicate that there may be significant costs associated with the use of coconut oil in unadapted engines. These costs might not materialise immediately but can result in having to replace the engine earlier than what otherwise would be the case. Even in the best case scenarios with adapted usage and adaptation of the engine, additional costs in the order of 0.25 – 0.50 US$ per litre can be expected. It is therefore important that users only use coconut oil when there is a significant price differential between coconut oil and diesel fuel. In addition, users are advised to take the differential cost of coconut oil and diesel to ‘save’ for unexpected extra maintenance that the use of coconut oil fuel can bring about.

Additional costs in medium- and large-scale power generation are significantly lower per litre as these machines are under continuous supervision and very often their load can also be controlled to a certain degree. Estimates on the additional costs in medium- to large-size power generation in the above study ranged from 4.8 – 9.9 US cents per litre.

2.7 Small-Scale rural coconut oil fuel production

In large urban centres, copra mills have been expelling copra into copra oil for more than a century around the Pacific. For coconut oil to be used as a fuel in rural areas cost effectively, it needs to be produced in the community. The copra that is often exported to a main island or urban centre is (partly) used to provide feedstock for copra production.

There are two types of oil expellers suitable for producing coconut oil. The first way is based on the copra process; the second is based on Direct Micro Expelled oil.

Copra Oil from a Mini-mill

After the endosperm of the coconut tree ripens, dries and falls from the tree, nuts are collected and cut in halves. They are then left to dry in the sun for a period of 2-3 days or dried on a wood fire, depending on the climate and local customs. The white flesh from the nut has now only a water content of less than 5%. This is called dry copra and should be processed as soon as possible to avoid growing of mould and absorbing moisture from the surroundings.

For processing into oil, chunks of copra are first processed in a Copra Cutter (see Figure 8). The cutter contains rotating knives that create little chunks of copra from nut halves.

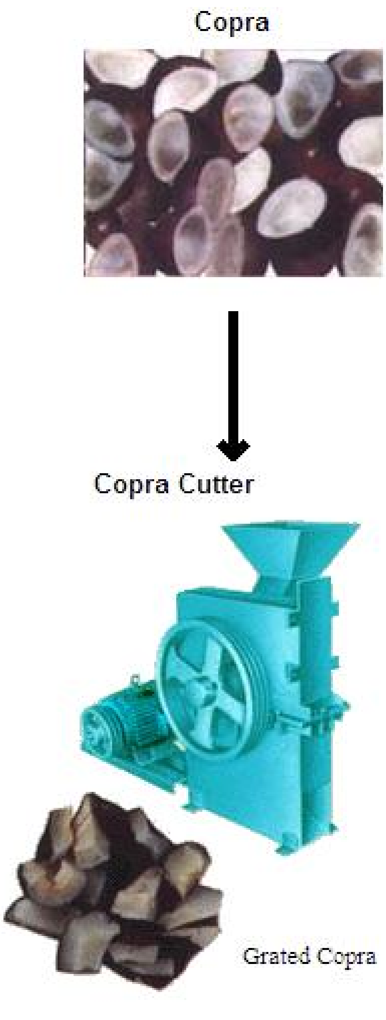


Figure 8: Copra Cutter (Source: Tinytech.com).

The grated copra then gets cooked (using steam) and is expelled using force in a screw press (Figure 9). The expeller produces copra cake that is a very good fertilizer and feedstock for animals. It also produces 50-55% oil from a unit of grated copra, depending on the pressure set by the screw press and the temperature of the grated copra.

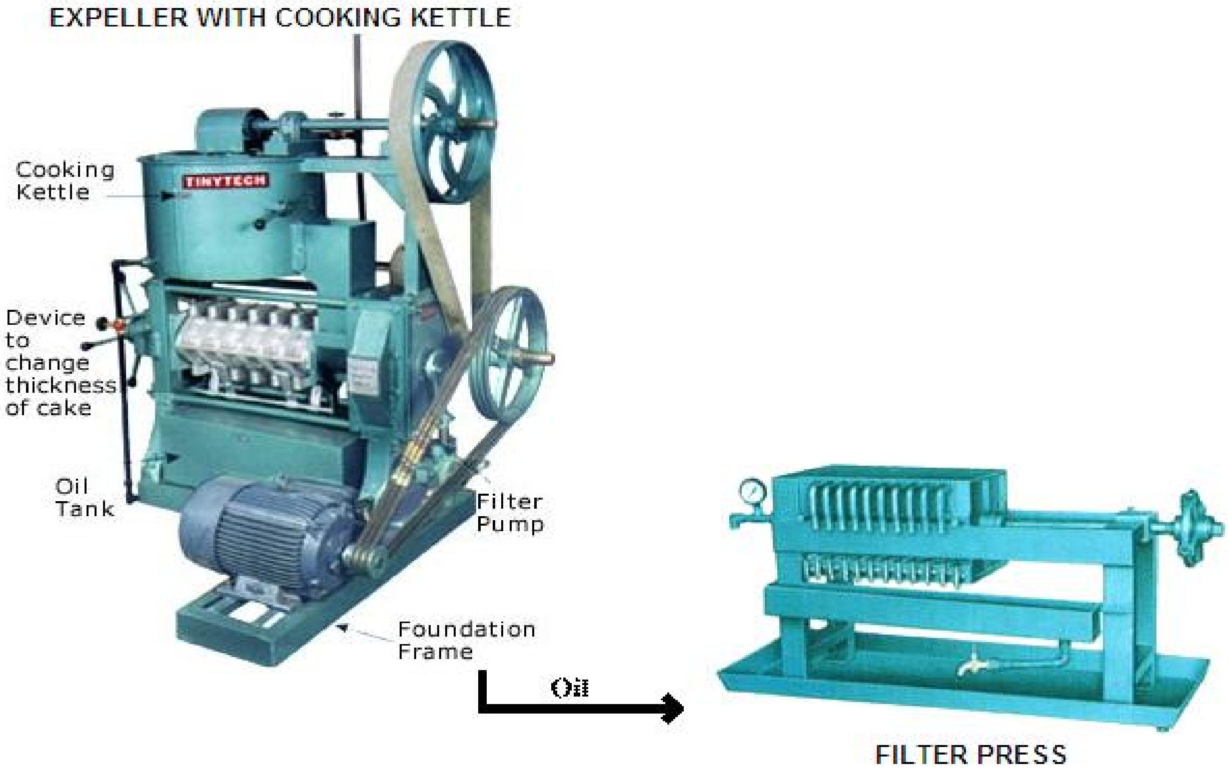


Figure 9: Expeller and filter press (Source: Tinytech.com).

After it is pressed, the oil contains up to 5% solids that need to be removed from the oil. First, the oil is kept in a range of settling tanks for a number of days, in which the solids sink to the bottom of the tank and are separated from the oil. Then, the oil is put through a filter press as depicted in Figure 9. Oil that is produced in this way contains up to 3% FFA's, up to 2% water and particles of up to 10 micron.

The copra mini mill is powered by a 5-kVA electric motor or a "Listeroid[4]" diesel engine and is capable of producing an average of 30 litres of oil per hour. The generator operates on coconut oil produced by the mill.

The amount of oil produced should be matched with the demand for electricity and the consumption of the generator. Copra oil can be stored for 6 months with no problems if there is no humidity and it is not exposed to sunlight.

Operating a mini mill requires technical knowledge and a professional set-up, including trained technicians able to undertake repair and maintenance. The mill requires at least two people to operate. A typical mill with tanks and a simple building costs about US$ 25,000.

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4 The term "Listeroid" refers to engines that are built along the design of a very robust one cylinder engine from UK manufacturer Lister. Listers are not in original production anymore but a number of manufacturers in India and China still produce engines along this design.

Coconut Oil from a DME plant

Figure 10: Grated coconut drying for DME processing (Source: SOPAC).

An alternative method for producing oil is the Direct Micro Expeller[5] (DME). Coconuts are collected and split in halves. The white flesh (wet copra) is removed with a mechanical grater, which takes fine strips of wet copra out of the shell.

The wet grated coconut flesh then gets dried on top of a hot plate until the temperature and moisture content are optimal for pressing (Figure 10). Under the hot plate, wood, coconut husks and shells feed a fire.

After the optimum state of the grated coconut has been reached, a stainless steel cylinder is filled with the grated coconut and put under a hand-operated press.

Figure 11 shows the oil that is produced from the DME press. It is referred to as cold pressed coconut oil, also known as virgin coconut oil. After settling of the DME oil and filtering, it can be readily used as a fuel.

On the world market, DME fetches a much higher price (1-3 US$/litre) than copra oil (0.5 US$/ litre through its superior composition and quality. It is therefore mainly used for body lotions and cooking. To use DME oil as a fuel could be called a waste of the oil, however if a community does not have access to world market through high transport costs, it is a good ‘second best’ option.

Figure 11: DME press with oil produced (Source: SOPAC).

Operating a DME is less complex then a mini mill. The DME plant is operated mechanically and only uses electricity for grating the nuts. Producing oil with a DME is very labour intensive and a team of four people could produce between 25-35 litres per day.

A DME plant would cost about US$ 10,000 to build, assuming electricity is already available.

Comparison between DME and Copra Mill

As with many things, there is no solution that fits all and therefore, DME plants are not better or worse than a copra mini-mill. While the DME process requires more labour than the Copra mini-mill, it is cheaper to build and no great technical know-how is required to operate the plant.

An added advantage to setting up a DME plant is the option for the community to produce excess oil to the preferential markets in the US and Europe. High quality DME oil has been sold recently to specialist markets, such as, organic applications. This brings in the option of bringing electricity to a community while also creating income

[5] For more information See: Kokonut Pacific http://www.kokonutpacific.com

opportunities. It needs to be assessed however, whether this suits the local demands and needs.

Therefore, both the Mini Mill and the DME plant could be used to produce coconut oil on a remote island. The mini mill is more efficient and less labour-intensive but requires more trained staff. DME oil only receives its premium price if the workers are committed to high standards of hygiene and are prepared to spend long hours in hot conditions, whereas copra is an established and traditional process that fits into the island style of life.

Box 2: Biofuel Electrification in Villages: The Fiji experience

In 2001, two biofuel projects were implemented by the Secretariat of the Pacific Community (SPC) and the Fiji Department of Energy. Both villages that produced significant amounts of copra received a generator that was a dual-fuel system, able to run on both diesel and copra oil (See also Figure 4). In 2006, Fiji Department of Energy requested Partners in Community Development Fiji (PCDF) and SOPAC to evaluate the socio-cultural aspects and the techno-economic aspects respectively.

The PCDF report concludes amongst others:

"The project could be regarded as unsuccessful because the generators are not operating as intended (with diesel and not coconut oil), in Lomaloma's case not operating at all; there was little interaction amongst stakeholders and communication breakdowns were experienced; the technology was complicated and not understood by the community, operators or technicians; and running the generators was labour intensive.

However, the advantages of the biofuel project to the communities so far out weighs these factors. These advantages include better social services, for example the division of labour and night time activities (studying, social functions), economic advantages (small businesses starting) and health (better light for studying). Also the generator uses coconut, a commodity that is a common local resource and has become valuable again in the eyes of the community, including some neighbouring islands where coconuts are the main source of income."

The SOPAC report concludes amongst others:

"The biofuel projects in Taveuni and Vanua Balavu have successfully demonstrated the technical possibility to use coconut oil as a fuel for rural electrification. They have however not resulted in the expected socio-economic development as anticipated. Provision of reliable and affordable electricity services to the remote communities of Taveuni and Vanua Balavu is a highly valued service to improve standard of living. Diesel has been found the most appropriate and lowest-cost fuel option for the provision of electricity at both sites….

Even though thorough feasibility studies on technology and socio-economics have been carried out before the implementation of the projects, the expectations of the villagers and the results of the projects have not been in line with each other. "

Even though the technology worked to some degree, the socio-economic embedding could have been further optimised to have both communities reap the full benefits of biofuel electrification. In one village, there was no mill included in the project as during the planning stages, an oil mill was still operating, but ceased shortly before the generator was installed. In the other village, after the generator was operating, the revenues from the dalo plantation belonging to the community were much higher than from copra production, leading to a shift of activities away from copra production. The copra milling with a small mill turned out to be very labour intensive. These factors led the villagers purchasing diesel from dalo revenue instead of using copra biofuel.

(Sources: [32, 39])

2.8 The Use of Biodiesel in Compression Ignition Engines

Biodiesel is a standardised fuel that consists of vegetable oil methyl ester. It is a product of pure vegetable oil that reacts with an alcohol and a catalyst, such as sodium hydroxide. This process generates two products: glycerine, which can be used in soap production, and vegetable oil methyl ester, also called biodiesel.

There are two fully developed standards of biodiesel, ASTM-D 6751 in the US and EN14214 in the EU. The Philippines have developed their own standards that fit better with esters from coconut and palm oil (PNS-2020:2003). Annex 2 states the Philippine standards.

Figure 12: 300-litre biodiesel processor *(Source: Biodieselgear.com).*

If these standards are followed, the validity of all manufacturer guarantees stand if used up to 5% [13], with most manufacturers guaranteeing up to 20%. Individual manufacturers have declared full support for certain models operated up to 100% biodiesel (Audi, Mercedes-Benz, Volkswagen, Volvo). Positive impacts on engines include increased lubricity and a reduction of visible particles in the exhaust. Some engines need replacement of rubber hoses and O-rings, as biodiesel can be slightly abrasive [6, 13].

The use of biodiesel is becoming a more mainstream practice in the US and the EU. Total production in the EU grew 35% in 2003 to 3.2 million tonnes and in the US to 83,270 t. It is mostly mixed with regular diesel in low blends. In Germany alone, there are already 800 biodiesel refuelling stations. In Hawaii, 1.2 million litres of biodiesel is produced annually from used vegetable oil and sold as B1 (1%) B20 (20%) or B100, 100 % biodiesel. In the winter time, blend ratios (biodiesel:diesel) have to be decreased as biodiesel has a higher cloud point than regular diesel.

The major disadvantage of biodiesel is that it has to be prepared in a chemical facility. The production cost is estimated to be US$ 0.3 to 0.6 per litre, depending on the size of operation. A Canadian study has indicated that biodiesel cost can be reduced if a market for the main by-product (glycerine) can be found [8]. With increasing biodiesel production worldwide, glycerine prices have been going down and alternative uses for the glycerine products are being sought.

If biodiesel is produced from waste vegetable oil or beef tallow in large volumes, the resulting price might be lower than the regular diesel. There are also options to produce biodiesel on a very small scale, which has been undertaken in the Philippines [6]. It does not however appear to be attractive for small island communities because of the use of potentially dangerous chemicals and the need for high hygiene working requirements [21].

The conversion of vegetable oils into biodiesel is currently the only realistic way for a country to replace part of their diesel imports on a national scale with biofuels in the transport sector. The risks of using pure vegetable oil, regardless of its purity, and regardless of which blend with diesel is used, will cause problems in a part of the vehicles (especially direct injection engines) in the long term. Therefore, biodiesel conversion is required for countries seeking to reduce their diesel imports through the compulsory blending of all diesel.

2.9 Conclusion

When vegetable oil is used as a fuel it needs to be of sufficient quality and preferably match or exceed the standards as laid out in DIN 51 605 (Annex 1).

There are three ways to utilise vegetable oil as a diesel replacement:

1. First, refined vegetable oil in a blend up to 50% can be used in an un-adapted indirect injection engine. The advantage of this option is simplicity, however it will come with additional maintenance costs and emissions can be more harmful than diesel. This is only recommended on a fleet of vehicles that are under strict supervision by skilled mechanics.

2. The second option is to use refined vegetable oil in adapted or custom designed engines with special fuel heaters, injectors, adapted pistons, injector pump and storage tank. The advantage of this option is that operation is more reliable than using vegetable in an unmodified engine, however there are significant up-front costs associated with adapted engines. This option is most applicable for medium- and large-scale power applications.

3. The third option is to convert vegetable oil into biodiesel by producing methyl esters. The resulting biodiesel should at least match or exceed the biodiesel standard as laid out in Annex 2. The advantage of this option is that standard diesel engines can be used, however it will come at a significant production cost of 0.3 – 0.6 US$ per litre. The processing of biodiesel is not fit for rural or remote application due to the use of hazardous chemicals in the production process and the resulting by-products. The production of biodiesel is currently the only reliable way to utilise vegetable oils on a national scale in transportation.

3. ETHANOL AS A PETROL SUBSTITUTE

In 2005, about 46,000 million litres (up from 41,000 million litres in 2004) of ethanol fuel[6] were produced around the world from a variety of crops, either as an additive to or a replacement for petrol in vehicles. The role of ethanol as a fuel is expected to double by 2012 due to strong financial incentives and a demand to reduce carbon emissions caused by fossil fuel use in the transport sector [25]. The climate of the Pacific is well suited for the production of sugary or starchy crops that can be used to produce ethanol as a fuel, if agricultural challenges can be resolved and cost-effective production frameworks can be put into place.

3.1 The production of Ethanol

Ethanol can be produced in different ways, using a variety of feedstock[7]. In Brazil, sugar cane (and increasingly a variety called "energy cane") is used as primary feedstock. In the US, more than 90% of ethanol is produced from corn. In Fiji, ethanol would most likely be produced sugar cane, whereas in the Solomon Islands and Papua New Guinea also has the climate suitable for large-scale starchy crops (such as cassava) cultivation.

Ethanol is produced by yeast fermentation of the sugar extracted from sugar cane or sugar beets. Production of ethanol from sugar cane requires a tropical climate, such as found in many Pacific Islands Countries, to grow productively [12].

Basic steps for dry mill production of ethanol from sugar cane are: refining into starch, liquefaction and saccharification (hydrolysis of starch into glucose), yeast fermentation, distillation, dehydration (required for blending with gasoline), and denaturing (optional). Ethanol is mostly made in large facilities to benefit from economies of scale in production (Figure 13).

Carbon dioxide, a potentially harmful greenhouse gas, is emitted during fermentation. However, the net effect is offset by the uptake of carbon gases by the plants grown to produce ethanol. When compared to petrol, ethanol releases less greenhouse gases.

For ethanol to be usable as a fuel, water must be removed. Most of the water is removed through distillation, but the purity is limited to 95% due to the formation of a low-boiling water-ethanol azeotrope. The resulting 95% ethanol 5% water mixture, known as hydrated ethanol, may be used as a fuel in specially adapted vehicles.

When ethanol is blended with gasoline, a purity of more than 99.5% is required, to avoid phase separation. Currently, the most widely used purification method is a physical absorption process using molecular sieves.

Figure 13: Ethanol Plant with distillation columns (Source: US Department of Energy, Chris Standlee).

[6] According to the American Renewable Fuels Association http://www.ethanolrfa.org/industry/statistics/#E)

[7] This section is adapted from : http://en.wikipedia.org/wiki/Ethanol_fuel

De-natured ethanol

After achieving 99.5% purity, ethanol is often immediately blended with a certain percentage of petrol, thereby converting it into de-natured ethanol. This is to avoid abuse of the ethanol in alcoholic drinks without paying the appropriate duty that is applicable in most countries.

Biotechnology may improve the energy gain of bioethanol by also using the cellulosic material of plants to be turned into starch first, and then into sugars by specially bred enzymes. This technology is currently being developed in a number of laboratories around the world, and by the year 2010 this technology is expected to be viable.

The long-term storage of ethanol is problematic because of its high absorption of water and therefore special tanks are required as compared with regular gasoline.

3.2 Sources for Ethanol Production

As mentioned in 3.1, there are many crops that can be used to grow feedstock for ethanol production. Brazil has built its ethanol industry around sugar cane, whereas the United States have built theirs around the use of maize and grain. Table 2 indicates typical yields of different crops in terms of eventual ethanol production per hectare.

Table 2: Yields of Ethanol per ha from different crops (Source: www.energyvalley.nl, US Department of Agriculture).

Crop	Litres per ha	Process
Energy Cane	8,000	Direct Sugar -> Ethanol
Sugar beet	5,700	Direct Sugar -> Ethanol
Potato	5,600	Starch -> Sugar -> Ethanol
Sugar Cane	5,000	Direct Sugar -> Ethanol
Sweet Sorghum	4,500	Direct Sugar and Starch -> Sugar
Corn	3,300	Starch -> Sugar -> Ethanol
Wheat	3,000	Starch -> Sugar -> Ethanol

Energy cane is especially bred for energy production as opposed to sugar cane with higher sugar content. It has the highest yield and is increasingly being utilised by producers in tropical countries. However energy cane also requires more irrigation and fertiliser than sugar cane. Sweet sorghum is also promising for tropical climates as it requires less attention and has similar yields to sugar cane.

3.3 Properties of Ethanol as a fuel

Table 3 presents selected physical properties of ethanol as a fuel. E 10 has similar properties to petrol, but has a higher degree of evaporation. This is caused by a combination of properties of ethanol and petrol constituents, leading to a lower vapour pressure. Evaporation of these hydrocarbons contributes to the global warming effect of the fuel and is therefore siphoned off during production, storage and retail sale into vehicles.

Table 3: Properties of Petrol and Ethanol (Source: Wikipedia).

Property	Petrol	Ethanol	E10 (10% Ethanol, 90% Petrol)
Lower Heating Value (MJ/litre)	31.6	21.2	30.6
Air Fuel Ratio (g air / g fuel)	14.6	8.9	14.0
Octane Number (RON)	91.0	106.0	93.0

The properties as listed in Table 3 such as the air to fuel ratio and the lower heating value (energy content) also indicate that engines are required to operate differently once the blending component of ethanol in petrol becomes larger.

3.4 The use of Ethanol blends in petrol vehicles

Around the world, vast experience has been gained with a number of ethanol blends. Even though there are many variations from 1% to 100% blends of ethanol with petrol, the most common are listed below.

E10

The blending of 10% de-hydrated ethanol in petrol results in a product often referred to as E10. Most countries in the world have taken an amount of up to 10% ethanol in their petrol standards and most car manufacturers also support the blend. As the energy content of ethanol is lower than petrol, an E10 blend slightly lowers the fuel energy content as compared to petrol, however at a 10% blend it reportedly has no noticeable effects on driving.

E22

A 22% blend of ethanol in petrol has long been used in Brazil with slightly modified cars. Most cars in the country can run on this blend without problems. Some models require engine components to be replaced so as to withstand the corrosive effects of ethanol and water. Since 1986, most car models around the world can run on this blend, however many car manufacturers will not extend a guarantee if cars are operated on blends above E10. Because of the large volume of ethanol fuel production in Brazil, car manufacturers were obliged to design cars that could run on ethanol blends of up to 22%, which was considered the maximum achievable blend without having to change carburettor design.

E85

Figure 14: Flex Fuel vehicle launched by Saab cars in 2005 (Source: Rocky Mountain Institute).

When anhydrous ethanol is blended with 15% petrol, the resulting fuel product is very different from petrol. This requires a specially adapted engine that can cater for this lower-energy fuel. The carburettor requires greater volumes of fuel to be transported and provisions need to be made for the higher degree of evaporation of the fuel. E85% has been developed especially for countries with a high local production of ethanol and is used in so-called flex-fuel vehicles (Figure 14).

Flex-fuel vehicles have the ability to run on any blend of petrol and ethanol (up to 85% ethanol) through a sensor that senses the composition of the blend and adjusts the motor management system accordingly. Since 2004, most car manufacturers have launched one or more models with flex-fuel capabilities.

3.5 The use of Ethanol blends in diesel vehicles

Trials have been carried out with hydrous ethanol (which contains some water) with 85% diesel. This blend must be mixed with an additive to avoid phase separation of the two fuels. Results have shown good short-term operation and acceptable power outputs with less emissions than diesel. However, the long-term effects of hydrated ethanol on diesel engines have been detrimental and many diesel car manufacturers do not extend warrantees if ethanol is added to diesel. This is because of increased wear to injectors, and pump failure due to lower lubricity, which occurs when hydrous ethanol is used.

Another major problem that E-diesel or “diesohol” poses has to do with storage. When ethanol is added to diesel it becomes much more flammable since the flashpoint of ethanol is only 13 ^{O}C. The limitations associated with ethanol blends, discussed above, make it unlikely that such blends will become mainstream in the near future.

3.6 The cost of Ethanol production

The cost of ethanol varies considerably depending on the type of crop used in production and the size of manufacturing operations. Literature suggests that prices range from US$ 0.37 per litre to 1.66 US$/litre.

Due to their small size, Pacific Islands Countries will be dependent on relatively small operations that suit their markets. They will therefore be unable to compete with large exporters such as Brazil, the U.S. and Australia, since they will not be able to take advantage of the same economies of scale in production. Solutions for the region can be found in smaller operations, up to 10 million litres per annum. Given this production capacity, it is likely that ethanol will only be able to compete when the price of oil is above US$ 100 per barrel. Without financial backing from a government through (partial) duty exemption, ethanol production will remain a risky investment proposition.

Government subsidies such as duty exemptions on ethanol blends can be justified on the basis that the environmental costs associated with the use of diesel fuel are avoided. These include negative environmental externalities such as greenhouse gas emissions, spillage hazards and contamination hazards.

3.7 Conclusion

Ethanol is a biofuel option for larger Pacific Islands Countries that can grow sufficient amounts of sugary or starchy crops. Ethanol, if compliant with the quality standards laid out in Annex 3 can be used in different blends in cars to replace petrol. Advantages include a reduction in overall emissions, reduced dependence on foreign imports of petrol and support for sugar or starchy crop prices. In addition, ethanol production will provide an increased independence of fuel imports, thus resulting in increased economic resilience.

When ethanol blends above 10% are used, cars must be monitored and when blends exceed 22%, car engines must be modified. When ethanol accounts for less than 10% of fuel demand in Pacific island economies, it is likely that it will be more expensive than petrol when world oil prices are below US$100 per barrel.

4. ECONOMIC IMPACTS OF BIOFUEL

The major rationale behind the introduction of biofuels in the Pacific is often to decrease the cost of imported fuels. While this may be true, there are certain effects, such as foregone duty on fuel imports, which would result in a decline in government revenues and the diversion of valuable export products for local biofuel production. Therefore, the economic effects of biofuels will be looked at in greater detail[8].

4.1 Introduction – Pacific Island Country balance of payments situation

Given the heavy dependence of PICs on imports and the narrow export base of many PICs, it is not surprising that many countries in the Region have faced significant balance of payments problems, where imports greatly exceed exports as illustrated in Table 4.

Table 4: Pacific Island Country Trade Balance *(Source: IMF and ADB).*

Country	Trade Balance [Million US$]	Year
Papua New Guinea	+ 353	2002
Fiji	– 769	2004
Solomon Islands	+ 7	2003
Samoa	– 135	2003
Vanuatu	– 60	2003
FSM	– 114	2004
Tonga	– 63	2000
Kiribati	– 48	2002
Marshall Islands	– 456	2000
Cook Islands	– 7	2004
Palau	– 82	2002

For example, since the mid-1980s, countries such as Kiribati and Tuvalu have had import levels, which are ten times greater than export levels [35]. Only PNG and the Solomon Islands have been able to maintain positive trade balances, mainly through high volumes of natural resource exports.

This chapter focuses on the benefits of fuel import-substitution. The development of local biofuel resources in the Pacific can be seen as a way to:

1. reduce the outflow of funds from Pacific Island Countries' (PIC) economies for imported petroleum products, thereby improving countries' balance of payments and conserving foreign exchange; and
2. reduce the vulnerability of PIC economies to world commodity price shocks by partially substituting imported petroleum products with domestically-produced biofuels.

All PICs are highly dependent on imports, which account for a substantial portion of their GDP. On average, imports account for approximately 40% of GDP, but the figure is significantly higher in countries such as Kiribati and Palau [35]. Furthermore, with the exception of Papua New Guinea (PNG), Pacific Islands have few indigenous sources of fossil fuel [58]. As a result, imported oil is the primary energy source in all countries, which accounts for between 8-37% of total imports, seeTable 5.

8 This section is provided by Allison Woodruff, SOPAC Resource Economist

Table 5 shows that the export structure of many PICs is such that it is insufficient to even cover countries' oil imports, which may not be sustainable in the long run[9]. If the current trend of rising oil prices continues, this will continue to exert growing pressure on the balance of payments of many PICs, as their trade deficits grow.

Table 5: Pacific Island Petroleum Imports (Source: IMF and ADB).

Country	Import Value (M US$)	% of Total Imports	% of Total Exports
Papua New Guinea	358.7	25.1	16.2
Fiji	340.2	23.5	50.0
Solomon Islands	11.7	27.4	15.8
Samoa	22.6	15.1	160.3
Vanuatu	12.8	14.3	64.3
F.S. of Micronesia	17.3	13.0	88.3
Tonga	17.6	25.5	293.3
Kiribati	5.7	10.0	172.7
Marshall Islands	20.4	37.3	224.2
Cook Islands	6.2	8.4	86.1
Palau	12.4	13.0	104.5

Given their small size, geographical isolation and resource endowments, it is likely that trade balance deficits will remain a permanent feature of many PIC economies. The size and structure of PIC economies and their heavy dependence on fuel imports also makes them vulnerable to oil price shocks, which can compromise macro-stability, and affect variables such as the exchange rate, inflation and debt levels. For example, oil price increases can exert a large amount of inflationary pressure on PIC economies, if the value of oil imports accounts for a significant portion of GDP (see Box 2). Therefore, it is important to look at ways in which these chronic balance of payments problems can be eased, especially through the development of indigenous energy resources.

Box 2: Macro-economic Impact of High Oil Prices

In oil importing countries, high petroleum prices can affect output, inflation and the balance of payments in several ways. First, high oil prices can exert downward pressure on income and demand, since for a given exchange rate, more income is needed to pay for the same volume of oil imports. Furthermore, if the exchange rate depreciates to address balance of payments deficits, this leads to further increases in the domestic price of oil, which can trigger inflation, as seen during the 1973 and 1979 oil crises.

In addition, higher oil prices can affect aggregate supply. As input costs increase, output may fall, or as profits decline, investment spending may be reduced. If the costs of higher oil prices are passed on to consumers, this may result in higher wage costs, which may exert further inflationary pressures on the economy.

Finally, if fuel prices are subsidized, as oil prices rise, government expenditures on subsidies will grow, thereby potentially compromising the sustainability of a government's fiscal position.

Source: [4]

9 Such a situation is sustainable as long as PICs are able to finance their current account deficits through foreign exchange reserves and/or net inflows from abroad.

4.2 Potential for Coconut (Oil) Production in the Pacific

Once a major agricultural crop, there has been a decline in copra's contribution to Pacific island economies. Coconut oil production has almost ceased in countries such as Samoa, Tonga, and Fiji, due to low returns on labour. However, in Vanuatu, where the opportunity cost of labour in copra production is still relatively low, copra still accounts for between 30-85% percent of export earnings [35].

Not only do the low returns to labour discourage copra and coconut oil production in PICs, but volatility in the world prices (Figure 15) of these commodities also discourages their production due to uncertainty over export revenues. Given their small size, PIC copra producers are 'price takers' rather than 'price makers', and therefore subject to the uncertainly of international price movements. Also, coconut oil has increasingly been losing its share of the world market to other vegetable oils such as palm and soybean oil, which are increasingly being produced by low-cost producers in Asia [52][10].

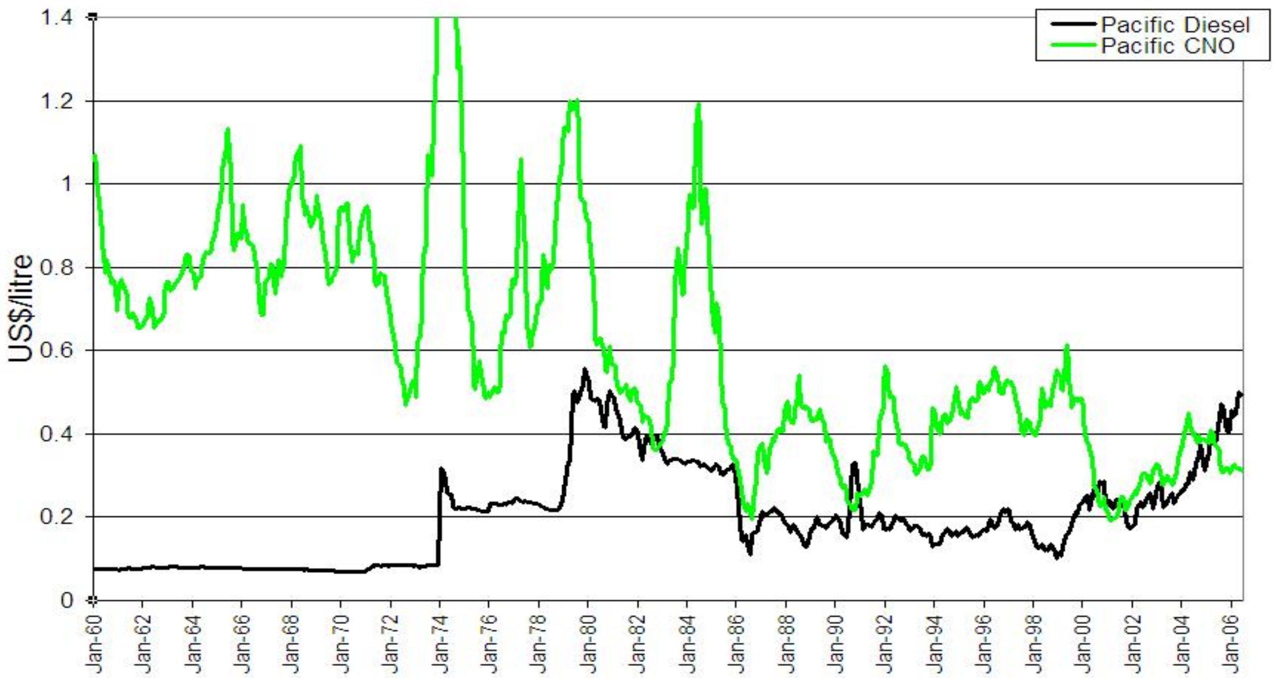

Figure 15: Average coconut oil and diesel prices in the Pacific 1960 – 2006 (Sources: UNCTAD database, PIFS Fuel Price Monitor [41], Federal Bank of St. Louis PPIACO all commodities price index).

Thus, in many PICs, there exists a potentially large, but untapped source of renewable energy. SOPAC has estimated potential domestic coconut oil supplies in several PICs, based on peak production levels over the past five years, which are presented in Table 6. This table shows that a substantial portion of PIC energy needs could be met with domestically produced coconut oil, if producers were provided with the right incentives.

[10] All data has been indexed with an all commodity price index PPIACO to constant year 1992 US$. Individual Pacific island country prices will differ: Average Pacific diesel price calculated from world oil market price UNCTAD Database [52] and PIFS Fuel price monitor [41] average ADO price; Price of Coconut Oil calculated on the basis of UNCTAD database price of Rotterdam CIF prices minus US$100 per tonne for transport and US$0.10 per litre filtering/refining costs, factoring in 8% per litre less energy content than diesel. The indexed price of coconut oil peaked in 1974 to US$2.15 per litre.

Table 6: Coconut Oil production potential and exports (Source: SOPAC sub-regional workshop).

Country	Coconut Oil [Million litres]
Fiji Islands	17.47
Kiribati	3.06
Marshall Islands	3.44
Papua New Guinea	53.91
Samoa	10.92
Solomon Islands	7.10
Tonga	0.00
Tuvalu	0.29
Vanuatu	30.51

For example, in Samoa, coconut product exports, once the mainstay of the economy, fell to almost zero in 2000. According to the CocoGen study carried out by a research team under SOPAC, Samoa has the potential to harvest 126 million coconuts per year, sufficient for the production of over 10 million litres of coconut oil [9].

If domestic demand was sufficient, the domestic price of coconut oil could rise above its world price, thereby providing greater incentives for its production[11]. Furthermore, given the volatility of world coconut oil prices, stable domestic demand might lend some stability to prices. There is also a potential role for governments, in setting a price floor for coconut oil, in order to ensure that there are adequate returns from production, and to protect producers from price swings.

4.3 The case for import substitution

In the past, countries have adopted import substitution policies as a means of reducing dependence on imports, addressing trade imbalances and conserving foreign exchange reserves, by replacing imports with domestically-produced goods (see Box 3).

In the Pacific, a large potential supply of coconut oil exists, which can be used as a diesel substitute. It is technologically possible for coconut oil to completely replace diesel, however engine adaptations are needed for diesel blends, which contain more than 10% coconut oil. Reduced dependence on imported petroleum products can cushion PIC economies against world oil price shocks. Given the expected continuing rise in fuel prices and the increasing demand for energy supplies, without any indigenous fuel substitutes, PIC balance of payments can be expected to further deteriorate.

Box 3: Import-Substitution of Fuel in Brazil

During the oil crises of the 1970s, in order to reduce the country's dependence on oil imports and to address growing balance of payments deficits, the Brazilian Government established the National Fuel Alcohol Programme (PROALCOOL). This programme was designed to promote domestic use and production of ethanol, made from sugarcane, to use as a substitute for gasoline. The programme induced a strong response and gasoline sales dropped sharply until 1990. Alcohol production rose from 0.5 million cubic meters/year in the late 1970s to 15 million cubic meters/year in 1987. However, this programme was less successful in the 1990s, due to [temporary] ethanol shortages and low fossil fuel prices.

Under PROALCOOL, US$20 billion in oil imports have been avoided. Also, since gas and alcohol prices were deregulated, alcohol pump prices have fallen to levels which are 25-50% lower than the equivalent volume of gasoline. In Brazil, ethanol is now competitive with gasoline, as long as the international price of oil remains above US$ 20 a barrel.

Source: [12]

As part of an Asian Development Bank (ADB) study on the impact of fuel price increases on net-imports of countries in the Pacific region, the impact of a seventy-five percent oil price increase on PIC net import bills was estimated[12], which is presented in Table 7. As these figures demonstrate, with the exception of Papua New Guinea, the negative impact on PIC trade balances is significant. Therefore, if PICs had the option of partially substituting imported diesel with locally-produced biofuel; this could help ease the negative impact of oil price hikes on these countries' economies.

Table 7: Impact of Oil Price Increase on Pacific island economies (Source: [3]).

Country	% loss in GDP growth after 75% oil price increase
Fiji Islands	– 6.20
Kiribati	– 5.70
PNG[13]	3.47
Samoa	– 5.55
Solomon Islands	– 6.68
Tonga	– 7.35
Vanuatu	– 3.42

Using data on PIC current imports, energy consumption levels and fuel prices, the impact of substituting 10 percent, 20 percent and 50 percent of diesel imports with equivalent volumes of coconut oil was estimated. The results are presented in Table 8.

Table 8 shows that for some countries such as the Solomon Islands and Palau, even relatively low levels of fuel substitution can impact the overall value of imports, thereby improving countries' trade balances. At levels of 50%, the average percentage change in imports is approximately 10%. However, in reality, few countries have the potential to produce the needed volumes of coconut oil to attain this level of diesel substitution, which would also require widespread engine adaptations.

Table 8: Impact on Pacific Island Countries imports by replacing Diesel with Coconut Oil (Sources: [3, 14, 41, 48]).[14]

	Percentage change in total imports		
Country	10%	20%	50%
Cook Islands	0.4	0.7	1.8
Fiji Islands	0.6	1.2	3.0
Federated States of Micronesia	2.6	5.1	12.8
Kiribati	0.8	1.7	4.1
Palau	4.8	9.6	24.0
Papua New Guinea	0.7	1.5	3.6
Samoa	1.2	2.5	6.1
Solomon Islands	5.4	10.9	27.2
Tonga	1.9	3.8	9.6
Vanuatu	2.5	5.1	12.7
Average	*2.0*	*4.0*	*9.9*

[12] A 75% increase in the price of oil was chosen since this represents the increase in oil prices between the beginning of 2005 and the end of August 2005.

[13] Papua New Guinea would actually gain as it is an exporter of oil and gas.

[14] Petroleum consumption estimates taken from PIREP 2004 Pacific Regional Energy Assessment; Fuel price estimates taken from July/Aug 2005 Pacific Fuel Price Monitor; Percentage of diesel consumption taken from 2002 EIA country energy data reports; Data on imports from most recent IMF country reports and 2005 ADB economic outlook reports.

Other factors to consider:

- **Reduction in export earnings:** By diverting copra and coconut oil exports towards domestic fuel production, countries may suffer declines in export earnings. In the case of Vanuatu, where coconut oil exports account for a significant percentage of total exports, the negative impact on the balance of payments from diverting coconut oil from the export market, to the domestic market, must be considered. However, as long as the value of substituted diesel imports is greater than the value of diverted copra product exports, the net effect on the trade balance will be positive.

- **Reduction in customs revenue:** In addition, it is important to consider the impact of reduced petroleum imports on government revenues, since for most PICs, a substantial portion of public revenues are derived from import duties. For example. In Fiji, the value-added and excise taxes account for 29% of the total price of diesel (Figure 16). Given the fact that oil imports account for a substantial portion of the total value of imports, revenue loss could be substantial.

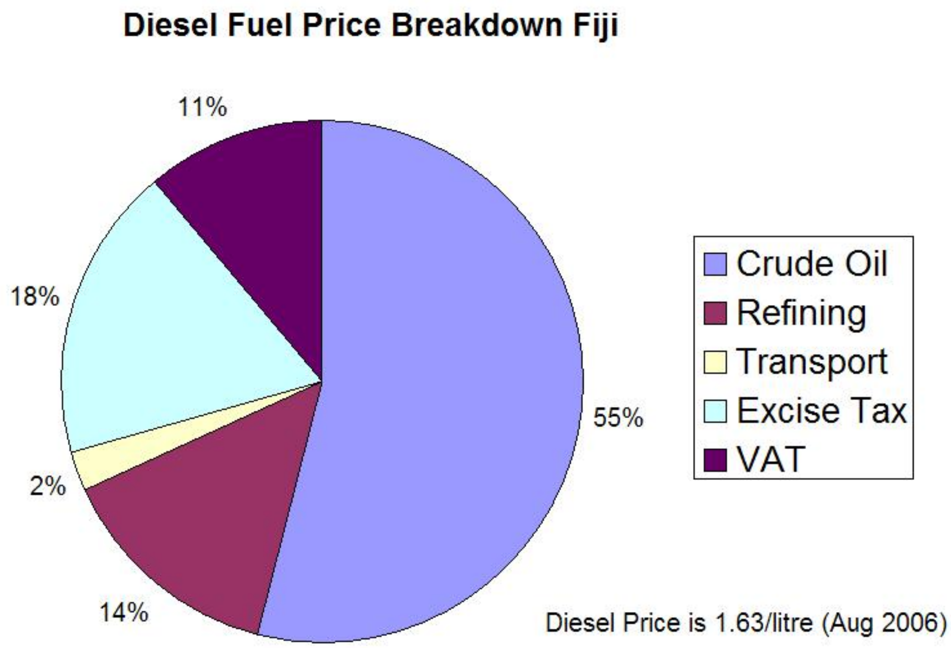

Figure 16: Diesel Fuel Price Breakdown for the Fiji Islands (Source: SOPAC Survey).

4.4 Case Study: Fiji's Potential for Import-Substitution of Fuel

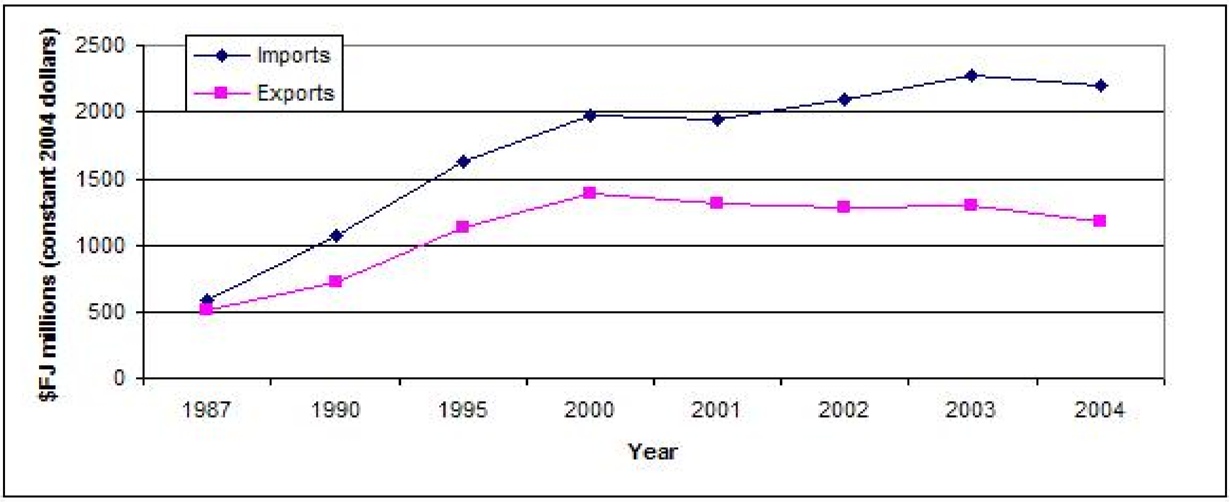

Figure 17: Fiji trade deficit 1987 – 2004 (Source:[3]).

Like other Pacific Islands Countries, Fiji is heavily reliant on imported petroleum. Fiji has a relatively narrow export base, largely comprising of sugar and textiles. Two factors are expected to have a negative impact on Fiji's sugar exports. First, the expiration of land leases in Fiji will lead to reduced sugar cane production. Second, reform of the EU sugar market threatens both Fiji's guaranteed share of the market and the high prices it receives for its sugar exports. Since 1987, Fiji's trade deficit has been steadily growing, as import growth continues to outpace export growth, as shown in Figure 17.

In order to address these problems, Fiji will have to find a means of reducing its reliance on imported oil production and finding new demand for its sugar output.

In 2004, Fiji imported 517 million litres (350 million of which was for domestic consumption) of petroleum fuel at a cost of F$276 million. Estimated annual growth in demand for petroleum products is listed in Table 9. Currently, petroleum imports account for an annual average of approximately 15% of total imports. As fuel consumption increases over time with economic development, fuel imports can be expected to account for an increasing share of imports[15].

Table 9: Fiji Projected petroleum consumption up to 2025 (Source: Binger et.al).

Fuel Type	% of total	2004	2010	2015	2020	2025
Petrol	17	61	81	104	132	169
Kerosene	5	17	23	29	37	48
Automotive Diesel	24	83	112	143	183	234
Industrial Diesel	30	105	141	180	229	293
LPG	6	20	27	34	44	56
Total	*100%*	*350*	*384*	*490*	*625*	*798*

[15] It is assumed that demand for imported fuel is highly income elastic, also. it is likely that increases in energy efficiency will not be sufficient to offset increased consumption of fossil fuels.

Bio-diesel from coconut oil

Given Fiji's growing trade deficit, substituting imported diesel for domestically-produced coconut oil, could partially address this imbalance. In 2004, Fiji produced approximately 9 million litres of coconut oil [17]. In addition, the Fiji Coconut Industry Development Authority (CIDA) has plans to replant and revive 6 million coconut trees. By 2025, Fiji could have the potential to produce 27.3 million litres of coconut oil (assuming 80% of total output was used for fuel), thereby replacing 23.7 million litres of imported diesel [5]. Also, the diversion of coconut oil from the export to the domestic market would have relatively little impact on Fiji's export revenues since coconut oil accounts for less than 1% of the total value of exports.

Ethanol from sugar cane

In Fiji, sugar accounts for 23-25% of the total value of exports, the bulk of which are exported to the European Union (EU). However, given the likely erosion of African, Caribbean and Pacific (ACP) countries' current preferential access to the EU market; it may be economically attractive to divert the supply of sugar cane towards the domestic ethanol market in the near future. This is because ethanol could potentially be used as an additive in diesel or petrol [36]. Compared with biofuel from coconut oil, the potential supply of ethanol, in Fiji, is much larger.

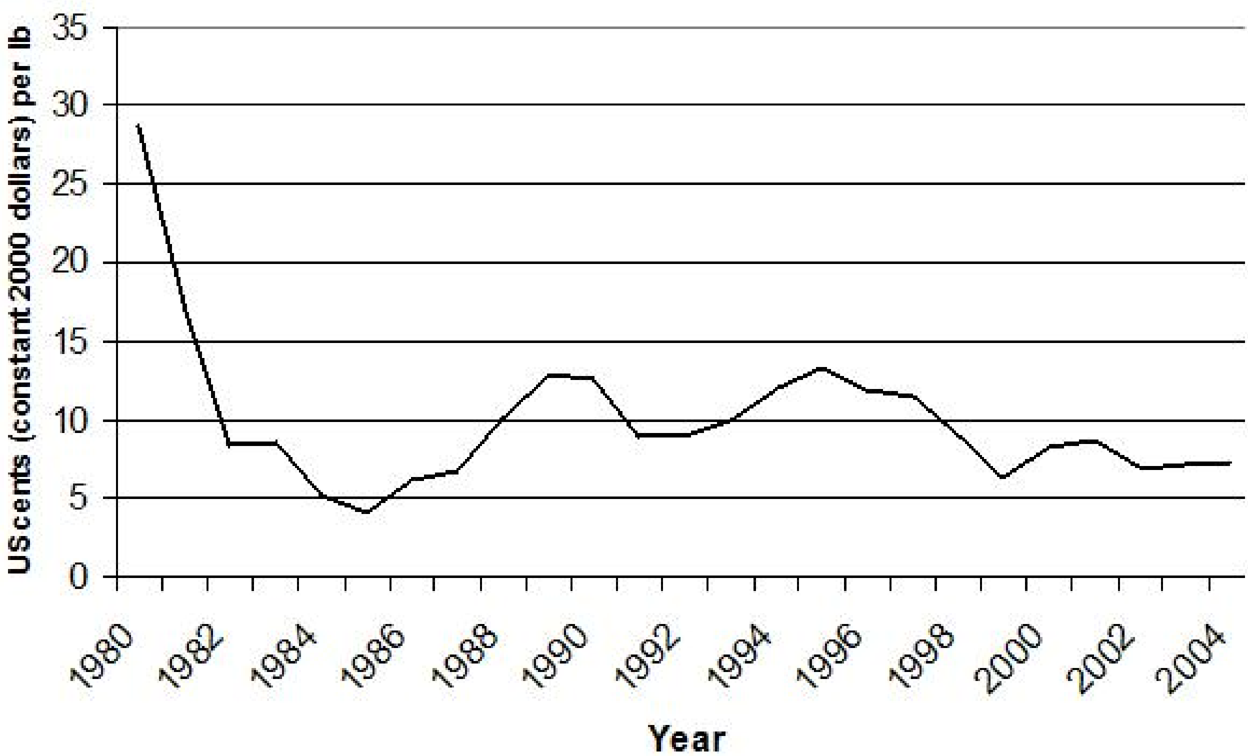

Figure 18: World Sugar prices 1980 – 2004 (Source: [52]).

As Figure 18 shows, the world price of sugar has followed a downward trend over time. This can in part be attributed to developed country export subsidies[16].

[16] If these subsidies were reduced or eliminated, the world price of sugar could be expected to rebound. [45] reviews the results of eleven quantitative analyses of the effect on the world price of sugar under various liberalization scenarios. The authors find that under the "major CAP reform" scenario, the world price of sugar increases by 31%, against a 25% decline in the internal EU price of sugar [45].

Potential for ethanol production

Fiji produces approximately 300,000 tons of sugar per year. Oxfam [36] estimates that Fiji has the potential to produce around 22 million litres of ethanol per year from molasses[17]; and if a third of Fiji's sugar cane output was diverted towards ethanol production, 80 million litres of ethanol could be produced annually.

Currently, Fiji imports 70 million litres of petrol per year. By substituting a portion of petrol imports with locally-produced ethanol, using five percent (E5), ten percent (E10), or twenty-five percent (E25) blended ethanol with petrol, could reduce its reliance on petroleum imports. However, the main barrier to achieving this is making ethanol price competitive with imported petrol. Through economies of scale and substantial government support, Brazil was able to eventually achieve this; however, given Fiji's size and the government's fiscal position, it is questionable whether Fiji could successfully implement such policies.

In addition, taxes and excise duties on imported petrol make up a substantial portion of Fiji's government revenues. For example, the fiscal duty on unleaded fuel in Fiji is F$0.44 per litre. Therefore, if Fiji imports 70 million litres of petrol, annually, duties contribute F$30,800,000 to government receipts. A reduction in petrol imports would thus, have an adverse affect on the government's fiscal position.

The impact on Fiji's import levels, of partially substituting petrol with ethanol, would not be significant, unless there was a substantial increase in the price of petrol (See Table 10).

Box 4: Fiji's Sugar Industry and the Sugar Protocol

Fiji's sugar industry has become almost entirely reliant on access to the EU market. The Sugar Protocol (SP), embodied in the Lomé Convention and carried over practically unchanged into the Cotonou Agreement, gives ACP sugar producers preferential access to the EU sugar market, which, for the most part, remains closed to imports. Sugar supplied to the EU under the Protocol is not subject to import duties and receives a guaranteed price, which is 2-3 times the world price

Fiji's annual allocation, which is the second largest among ACP sugar-producing countries, is 165,348 tons (12.75% of the total). In addition, under the Agreement on Special Preferential Sugar (SPS), Fiji has exported an extra 30,000 tons of sugar annually to the EU (allocations under the SPS are determined on an annual basis by the European Commission, based on predicted shortfalls in sugar supply).

There has been growing pressure on the EU to reform its sugar policies by lowering the internal price of sugar or even phasing out the Sugar Protocol. Proposed reductions in the internal EU price of sugar can be expected to have a large impact on the price paid for SP and SPS sugar imports.

Under the Cotonou Agreement, Fiji should not only expect to see an erosion in its market share as it competes with other developing country producers, but also a decline in the price it receives for its sugar exports. This will have serious repercussions for Fiji's sugar industry.

Although, the Sugar Protocol has provided an essential lifeline to Fiji's sugar industry, it has also resulted in inefficiencies and high cost structures, by providing a guaranteed market for Fiji's sugar exports. Fiji's sugar industry is currently in need of restructuring due to its faltering productivity in harvesting, transportation and processing. Given that in the near future, Fiji can be expected to face greater competition and lower prices for its sugar exports, domestic demand for sugar cane for ethanol production could prove to be essential for reviving the industry.

Source: [45]

[17] Assuming 25% molasses, and a conversion rate of 300 litre per ton of molasses

Table 10: Total Impact of replacing petrol with ethanol in Fiji (Source: SOPAC Survey).				
Petrol replaced	Volume replaced [Ml]	Value petrol imports reduction[18] [MUS$]	% change in net imports	Duty Loss [MUS$]
E5 (5%)	3.5	1.7	0.3%	0.87
E10 (10%)	7.0	3.4	0.6%	1.74
E25 (25%)	17.5	8.4	1.5%	4.35

However, the strongest rationale for promoting import-substitution of fuel in Fiji is the inevitable decline in export earnings due to the reform of EU sugar policies (see Box 4). Currently, Fiji enjoys sugar export revenues of FJ$178.4 million (which accounts for 20% of domestic export revenue) largely due to its preferential access to the EU market. However, were Fiji to sell its sugar on the world market at the going world price of sugar, these revenues would be approximately two and a half times lower.

Even though revenue from selling sugar for ethanol production would be lower than from sugar exports, the opportunity cost of sugar diversion would be much lower in a post-Sugar Protocol situation, falling from FJ$89 million, to FJ$35.7 million. The quantity of ethanol that could potentially be produced in Fiji would be more than sufficient to cover domestic demand, especially if E25 or lower fuel blends were used. Only if vehicles adapted to run on ethanol were widely adopted in Fiji, would domestic demand for ethanol be sufficient to absorb a significant portion of total sugar exports. This is unlikely to happen in the coming 10-15 years. Also, given larger and more efficient world ethanol exporters such as Brazil, exporting surplus ethanol from Fiji would not be feasible except to Fiji's immediate neighbours.

4.5 Conclusion

The majority of Pacific Island Countries are experiencing acute balance of payments deficits. This can be attributed not only to small country size, country endowments, level of economic development and geographic isolation, but also to heavy dependence on petroleum imports. Moreover, the value of petroleum imports has been increasing over time with increased demand and rising oil prices.

Most PICs have the potential to produce large amounts of coconut oil biofuel, and ethanol in the case of Fiji, which can serve to reduce dependence on energy imports and address balance of trade problems. Demand for coconut oil could also help to stabilize the price that domestic producers receive for their output, thereby avoiding the uncertainty created by volatile price movements in international primary commodity markets or drain Government Stabilisation Funds.

If ten percent of diesel imports were replaced with domestically-produced coconut oil, the average value of PIC imports could be reduced by two percent; and if fifty percent of diesel imports were replaced, the average import bill would fall by ten percent.

Countries should also consider the impact of such import-substitution policies on export earnings and government revenue from taxes and custom duties on imported fossil fuels. The figures in this study suggest that some duty on locally-grown biofuels will be required to offset this loss.

Import substitution can have a positive impact on government revenues if both impact on trade balance, duties and taxes are taken into account.

[18] At 2005 prices; the wholesale price of petrol is assumed to be US$0.48 per litre, excluding duty and taxes (Source: July/August 2005 Fuel Price Monitor Regional Wholesale Mogas Price for Fiji)

5. ENVIRONMENTAL IMPACTS OF BIOFUEL

There are a range of positive and negative impacts of producing and using biofuels on the environment. Given that the impact on exploration and use of fossil fuels on the environment is generally negative, biofuels present a good alternative to fossil fuels. The large-scale production of crops for ethanol or biodiesel was shown to have negative impacts on the environment, leading to questions on the overall lifecycle costs and energy balance of biofuels.

5.1 Greenhouse Gas Emissions

There is mounting evidence that global climate change associated with increased probabilities of extreme weather events, sea-level rise and possible radical changes in weather patterns, is caused by anthropogenic (human enhanced) greenhouse gas (GHG) emissions. Especially in the Pacific region, these are relevant threats that need to be avoided; however most are caused by the great GHG emitters of the developed world, not the Pacific Islands Countries themselves.

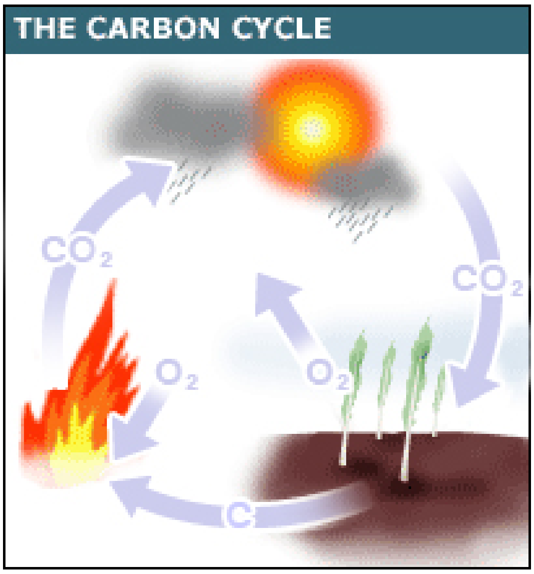

Figure 19: The stages of the carbon cycle (Source: BBC News).

There are a number of initiatives to reduce the emission of CO_2 and other greenhouse gases, the most famous being the Kyoto Protocol on climate change. Other non-binding 'carbon sequestration funds' from countries such as Australia and selected states in the U.S. also create markets for CO_2 "credits" for the avoidance of emissions of greenhouse gases as compared to a baseline scenario. One funding option under the Kyoto Protocol is known as the Clean Development Mechanism (CDM), which enables developed countries to buy 'emission credits' in less developed countries, provided that such interventions also promote sustainable development. Typical prices paid for a carbon credit amount to US$ 5 -20 per tonne of CO_2. This could provide for some support towards promoting biofuel industries in developing countries.

In agriculture, CO_2 gets captured as part of photosynthesis in biomass (crops, trees, grass) from the atmosphere. During combustion of biomass materials (i.e. biofuels) the CO_2 is again released in similar quantities to what would have been the case if the biomass was not used as fuel, but instead left to decompose (Figure 15). In fact, during decomposition under anaerobic (no oxygen) conditions, methane emissions would significantly contribute to the GHG effect.

During the production of biofuels and the growing of crops in agriculture, CO_2 emissions contribute to the total emissions of biofuels. The total emissions from fossil fuels are much larger, as they add carbon to the atmosphere that was previously stored in the earth's crust.

Table 11: Carbon Emissions of Ethanol production of different crops (Source: [2]).

Crop	Carbon [tonne per ha]
Sweet Sorghum	1.10
Sugar Beet	1.34
Sugar Cane	0.42
Corn	135.18
Wheat	1.96

According to calculations [15], ethanol production from sugar cane may prove to be an important alternative for producing energy from biomass, since it emits less carbon than any other energy crops. For example, intensive production of corn indicates high emissions per hectare as when compared to other crops.

If emissions during the production of ethanol from sugar cane were the only emissions associated with this fuel, the carbon intensity would be 0.22 kg CO_2 per litre, whereas a litre of petrol is responsible for 2.36 kg CO_2 per litre.

5.2 Energy Balance

The energy balance is defined as the ratio between energy input and energy output and is a measure of how much energy is actually gained by choosing a particular biofuel technology. In general, the major input into the energy balance will be solar energy, providing the energy for photosynthesis to take place. However, in most cases, energy is required for production. In some cases even, it was found that biofuel production requires more fossil fuel energy than the energy content of the actual biofuel product. Therefore it is important to have a critical look at the energy streams around biofuel production and use.

Biofuel production requires significant energy inputs such as fertiliser, transport, electricity for irrigation and crop treatment. Especially in the case of ethanol, it is often questioned whether there is really more energy produced than utilised in the ethanol production process. The scientific debate, for example in [38] shows that depending on the assumptions on the underlying energy input of agricultural practices, both a positive and a negative outcome on the energy balance could be found. Table 12 gives an overview of the breakdown of energy inputs and outputs from different crops.

Table 12: Energy Balance for Ethanol from different crops (Source: [2]).

Product	Wheat	Sugar Beet	Sugar Cane	Sweet Sorghum
Inputs	MJ/litre			
Agricultural	5.19	3.74	2.55	2.10
Transport	0.25	0.96	0.9	–
Production	17.05	12.67	1.09	2.22
Total Input	*22.49*	*17.37*	*4.55*	*4.32*
Outputs	MJ/litre			
Ethanol	21.26	21.26	21.26	21.26
By-products	1.73	1.25	2.73	–
Total Outputs	*22.99*	*22.51*	*23.99*	*21.26*
Energy Balance	*1.03*	*1.30*	*5.27*	*5.03*

The energy balances for vegetable oils (Table 13) are much less subject to debate as the agricultural practices are less intensive, requiring less energy and fertiliser, and the energy content of the resulting material is higher.

It can be seen that the use of Straight Vegetable Oils (SVOs) is more energy efficient than turning the oil into an ester, or biodiesel. With rapeseed oil, a factor of 24[19] times more energy can be obtained than it cost to produce it. With coconut oil it is even higher, provided not too much energy is put into the transport of the nuts. Agriculture of coconuts is very low-energy intensive.

[19] This assumes that local energy input is provided from renewable resources, i.e. the tractors run on Rapeseed Oil as well. If this is not included, the energy balance of Rapeseed oil gains a factor of 11.

Table 13: Energy Balance for Biodiesel and vegetable oil from different crops (Source: [15, Own survey]).				
Product	Rapeseed Oil	Coconut Oil [20]	CME Biodiesel	Biodiesel Palm
Inputs	MJ/litre			
Agricultural	0.60	0.15	0.05	0.037
Pressing	0.90	1.00	1.00	1.66
BD Production	–		3.15	3.15
Total Input	*1.50*	*1.05*	*4.20*	*4.86*
Outputs	MJ/litre			
Biofuel	36.34	35.00	34.00	34.06
By-products	1.00	1.00	10.38	1.80
Total Outputs	*37.34*	*36.00*	*44.38*	*35.86*
Energy Balance	*24.85*	*31.30*	*10.57*	*7.378*

Coconut Methyl Ester (CME) and Esters from palm oil have a less favourable energy balance as they require energy (heat, electricity, methanol) to process the oil into biodiesel. Still, the energy balances are higher than with ethanol. It is also clear that in case the fuel needs to be transported to the user over long distances (as is the case with EU importing palm oil from Malaysia and Indonesia), the energy balance deteriorates further.

5.3 Other Emissions

Vehicles and equipment being operated on biofuels shows a significant overall decrease in harmful emissions. It is the absence of components such as sulphur, soot and other constituents that may be harmful for human beings and the environment, that make the emissions cleaner. A notable exception to this is the slight increase of aldehydes through ethanol and the increase of NO_x using biodiesel. Otherwise, the percentage of blending generally indicates the percentage of decrease in emissions.

If unadapted vehicles are run on straight vegetable oil, it has been noted in some studies such as [30] that the emissions actually can increase, caused by the fact that fuel system equipment cannot handle the proper combustion of high viscous fuels.

5.4 Fuel Contamination

Fuel contamination in Pacific Islands Countries, especially in the outer island context, is a recurring problem. Biofuels have the advantage to be biodegradable many times faster than their fossil fuel counterparts.

Islands where drums of diesel are often offloaded from a small boat and swum to shore in case there is no jetty, there is a strong case to be made for the use of biodiesel. Also in ships that are being used in eco-tourism, the threat to the environment by the fuel used should be kept at a minimum. The spill of a litre of coconut oil is a much less problematic event than the spilling of a litre of diesel in a fragile reef environment.

5.5 Large Scale Plantations

With the call for large increases of biofuel into the European Union energy mix, with an aim to have 5.75% biofuel by 2010, a number of countries invested heavily in the provision of vegetable oil for biofuels. This is having a seriously negative impact on a large area of indigenous forests, mainly in Malaysia and Indonesia, with some species being driven to the verge of extinction.

[20] SOPAC estimates

This effect is felt less in the Pacific Islands Countries, however it should be noted that biofuels and plantations can come with a price in terms of environmental impact that always should be weighed against the benefits. Most countries in the region have a history of colonial plantations that form a good basis for production of biofuels through coconut and palm and are often operated on an organic basis.

5.6 Food versus Fuel

As was mentioned in Chapter 1, the use of agricultural crops for our energy needs is an emerging area, which has attracted a lot of attention from the world with a lot of finance behind it. Even though it is often referred to as a problem that will sort itself out by ‘the market’, there is a real threat that the demand for crops that can be used for biofuel production will lead to price rises that eventually will hit the poor in the world.

Recent price rises in oil have proven to have their influence on sugar, wheat and edible vegetable oil markets. There is no doubt that conversion technology improvement will further lead to the ‘binding’ of the two markets, which will lead to further volatility in a number of key food sectors as they will be linked up with oil price volatility.

A number of Pacific island country governments have therefore opted to have their staple foods such as cassava, taro and yam out of the fuel markets so that the rural people will not be confronted with strong food price rises should demand for the crop for fuel use increase. Because of the isolated character of most countries in the region this strategy will work to a certain degree. Globalisation will however affect all price levels in every country and so will the commodities that are connected with the production of biofuel.

It is not difficult to envisage a poor country being driven by high profits to grow crops for fuel and export them, as opposed to lower returns per hectare when producing food. This might lead to more arable land becoming available for fuel production, pushing out food production to more marginal lands.

The worldwide demand for fuel in the past decades, and the price consumers are prepared to pay appears to have no boundary and will easily affect the livelihoods of the most vulnerable people if biofuel production is left entirely to the market. Therefore the food versus fuel debate must be held comprehensively and regularly with both the global and the many local impacts in mind.

5.7 Biofuels and the future

The challenges of today’s energy use and the amounts of energy that are required by upcoming countries like India and China are enormous. For everyone to keep on driving, using electricity and travelling in planes is just impossible with the sources of energy that we now know. Therefore, the so-called ecological footprint (environmental impact of everything we do) must decrease.

First, at planetary level, if we must decrease our GHG emissions by at least 60% and we must look for new fuels. Availability or scarcity of petroleum products is not the problem, even though some claim fossil fuel oil has ‘peaked’. The Stone Age did not end because of a lack of stones; it ended because something better came up.

As 2/3 of GHG are emitted by the transport sector, an obvious option is to look for replacement of liquid fuels for engines. Annual global consumption for the transport sector is around 6.8 millions tonnes per day, with an average annual growth rate of 1.6 %. The total production of palm oil in the world is able to “run” our transport for 6 days per year.

These numbers have justified new research toward a second generation of biofuels coming from biomass. The two main ways are thermo chemical processes: BTL (Biomass to Liquid) and GTL (Gas to Liquid). Prospective yields per hectare are in the range of 15 000 litres to produce biodiesel and 50 000 litres to produce bio-methanol.

At the same time, at local level, rising oil prices create immediate financial interest to biofuels of the 1st generation essentially produced from vegetable oils and ethanol. So, when we talk about reducing GHG at the planet level, we are not at all in the PICs context. If to day the pressure is on 1st generation biofuels, because they are the only ones available, it can change tomorrow.

5.8 Conclusion

Biofuels have positive effects on the environment because they produce much lower CO_2 emissions in their lifecycle compared to fossil fuels. Biofuels, through their oxygen content, lead to cleaner combustion and therefore have lower overall emissions than their fossil counterparts. They are biodegradable which make them very suitable for use in fragile reef environments, often found in the Pacific island region.

The environmental benefits of biofuels, especially their lower carbon dioxide emissions can be turned into financial support through the Clean Development Mechanism.

Increasing demand for biofuels has also lead to a number of detrimental effects on the environment in their production and transport stages and is also leading to higher prices in agricultural commodities which might affect the poor.

6. PACIFIC ISLAND BIOFUEL EXPERIENCES

The use of biofuel in the Pacific Islands Countries is picking up quickly, below is an overview of the main experiences in seven Pacific Islands Countries.

6.1 Marshall Islands

The Marshall Islands are characterised by a relatively high volume of diesel usage per person for both power generation and transport. The Marshall Islands pays an above average amount for diesel compared to other Pacific Islands Countries. This combined with significant fuel taxes results in one of the higher diesel prices in the Pacific. As part of a highly subsided industry to keep income levels maintained on the outer islands, the country produces and exports about 3,000 tonnes of coconut oil per annum. With the increase of fuel prices, the Marshall Islands oil mill has started retailing various biofuel blends in the capital Majuro and investigations are on-going to utilise biofuels for power generation on some outer islands.

Biofuel retail in Majuro

The copra mill, run by Tobolar is retailing fuel based on coconut oil. It consists of coconut oil, which is de-watered and filtered to 5 micron. At the bowser, there is a 50/50 blend with diesel and a pure coconut oil product available. The coconut oil fuel is cheaper than diesel and this has led to a number of people trying the fuel in their cars and boats. Given the uncertainties around the increased maintenance costs of using coconut oil as compared to diesel, SOPAC, through its PIEPSAP project has supervised a MSc. Mechanical Engineering student to study this subject [18].

Review of the effects of using Coconut oil as a diesel replacement

In April 2006, an indirect injection 2.9 litre Mazda truck (Figure 20) running on pure coconut oil for a period of three years and 60,000 km was partly disassembled. It was found that no serious detrimental effects that could lead to premature engine failure were present. However, the study did report increased fuel filter changes, deposits on piston rings, deposits on injectors and a 10% decrease in power. The highest risk to future operation by the use of coconut oil were the deposits on the valve stems, which could lead to sticking valves, and hence loss of compression.

Figure 20: RMI truck that ran on coconut oil for three years showed signs of increased maintenance requirements (Source: Fürstenwerth).

The major finding of the MSc study was that coconut oil could be used in indirect injection engines with the right injector equipment, provided that vegetable oil fuel quality standards such as DIN 51 605 (Annex 1) are respected. Even then, additional maintenance costs as compared to operation on regular diesel fuel should be expected.

6.2 Vanuatu

Vanuatu has been a leader in the use of coconut oil as a fuel in the Pacific. It has been active in the area for years, driven by keen entrepreneurs and a high diesel fuel price. Vanuatu has the highest landed cost for diesel of the seven Pacific Islands Countries considered in this paper.

"Island Fuel 80", a blend of filtered 80% coconut oil and 20% kerosene is retailing in Vila for about US$ 0.30 per litre less than regular diesel. Nevertheless, it is still serving a niche market, as the customers require a pre-heater to be installed in their vehicles. The Government of Vanuatu is the only country in the Pacific that has a reduced excise tariff in place for biofuels (0.05US$ instead of 0.28 US$ per litre).

UNELCO coconut oil fuel trials

Vanuatu's power utility UNELCO has been experimenting with highly filtered coconut oil for about 1 year, with encouraging results. It has been running one of their 4MW MAN 9L32/40 generators on a blend of 5% coconut oil, utilising over 1,000 litres of locally-produced fuel per day (Figure 21). After an overhaul with MAN experts, no signs of detrimental effects were found and consequently the trial was broadened by involving another machine at 5% and increasing the first to a 10% coconut oil blend.

Figure 21: UNELCO Generators in Port Vila running on coconut oil fuel blend (Source: UNELCO).

The machine could best be called a 'dual fuel' engine as the coconut oil is added into the fuel lines at 50 ^{o}C just before the injection pump, during times that the load is higher than 60% of rated power.

The long-term aim of UNELCO is to 'industrialise' the use of coconut oil fuel by making it part of their aim of cost reduction, environmental awareness and assistance in improving the balance of payments.

TORBA biofuel electrification pre-feasibility study

At the request of the Vanuatu Government, SOPAC carried out a pre-feasibility study together with UNELCO on the use of coconut oil fuel on the remote island of Vanua Lava in TORBA province. The study found a great potential of copra that is currently being transported at great cost to Santo for milling. In addition, the current diesel-powered electricity grid is very inefficient because of low loading, however could be extended to include additional load and hence more efficient generation.

Given future load increases to be expected through the building of a hospital and an ice making facility, there is good potential to add an adapted generator that can run on coconut oil fuel. The villagers could use part of the copra produced to be milled and filtered for fuel as well as utilise oil for local value adding such as soap, body and cooking oil production. The greatest challenge has been identified to be the management of such a production unit and Renewable Energy Service Company (RESCO), with limited capacity on the island.

6.3 Samoa

Samoa slowly lost its copra oil exports in the last 6 years; trials to keep the copra sector alive through Government intervention, and later corporatisation, failed with Coconut Oil Production Samoa (COPS) going into receivership in 2006. The local price for copra was too low for farmers to go through the trouble of even picking up nuts and the subsequent volumes that COPS was able to produce were too small to keep the operation viable.

A similar situation has arisen for Samoa Niu Products Limited (SNPL), which mainly produced desiccated coconut. Indications are that with existing equipment it could produce a high quality coconut oil at a premium price of US$ 0.90 per litre. Even at this higher level, it would be competitive with retail diesel and bulk supply to power utility EPC. However, no concrete plans for SNPL to produce oil on a large scale currently exist.

Other small-scale initiatives involving organic certification and virgin oil production appear to be quite successful and will keep a small remainder of the coconut sector going through high added value niches.

EPC Truck running on Coco-Kero Blend

A new unmodified Toyota Hilux EPC service truck (Figure 22) has been running on a 80% coconut oil 20% kerosene[21] blend for the last year with no problems reported. It is a showcase to the people of Samoa that EPC takes biofuels as a serious option for the islands' energy challenges. The truck drives on the remaining COPS copra oil stocks.

Figure 22: EPC service truck running on coconut oil fuel blend (Source: EPC).

Cocogen Blending Trials continue

At the power station in Savai'i, a 250 kW generator[22] is currently running on a 20% blend of coconut oil with diesel. The coconut oil here used is also the remaining stock of COPS. Continued testing of the engine oil contamination by vegetable oil and close monitoring of the quality of the coconut oil fuel support the continued use of the 80-20 blend. During the recent overhaul of the engine, it was revealed that no adverse effects caused by the use of coconut oil could be found.

As part of UNDP-Samoa/SOPAC continued assistance to Samoa's Power utility EPC, *"CocoGen"*, an investment plan will be developed to build a coconut-based power unit as part of the new Savai'i power station. It will make use of an estimated 15 million coconuts per year, with copra milled for coconut oil fuel while the shells will be used in a gasifier for co-generation of heat and power [9]. Copra will be dried on site with the power plant excess heat and the combustion of coconut husks. Activities under the project include the identification of appropriate technology, calculation of the heat balance and a detailed Environmental Impact Assessment.

[21] This blend is based on the "Island Fuel" blend in Vanuatu
[22] 400 kW de-rated to 250 kW Cummins engine

6.4 Fiji Islands

The Fiji Islands have a remarkably large potential to utilise biofuels through the relatively strong coconut and sugar industries. Landed cost for diesel are the lowest of the seven countries considered. Fiji Islands has the potential to be a net-exporter of fuel ethanol even if all gasoline for transport on the islands were replaced. It could also potentially replace about 20% of its transport diesel consumption with coconut oil biodiesel. It was however established by the World Bank that even at the current oil prices, the production of both ethanol and biodiesel would not be viable. Therefore, the Fiji Government have requested the World Bank team to carry out a study on the exact cut-off points, where indigenous production of biofuels would become competitive, to assist on decisions in restructuring the sugar and coconut industries.

Biofuel Development Unit

During a UNDP-GEF PDF-A "Resilience Building" project implemented in 2005 through SOPAC to identify the biofuels potential, the Prime Minister of Fiji established the Biofuels Development Unit with the task to further biofuels production in Fiji. Since then, this unit has been working together with the industry, to establish standards, carry out blending trials in transport and power generation, promote dialogue over biofuel issues and investigating the feasibility of small-scale biodiesel production.

Small-scale Biodiesel production

At the request of the Fiji Government, SOPAC has been assisting CIDA on a feasibility study for small-scale production of biodiesel at the oil mill in Savusavu. It was found that biodiesel production cost would add an estimated US$0.5 to every litre of oil, making it only viable if tax and/or excise incentives are provided to the producer. There have been various expressions of interest from parties abroad to enter into a joint venture with CIDA for biofuel production, however none of these have come to an agreement yet. The main hurdles a biodiesel venture has to overcome are the relatively high prices for coconut oil and imported methanol and the limited size of production. The appropriate capacity for Fiji would be 5 to 10 million litres per year whereas most countries are currently building plants starting at 100 million litres per year.

Biodiesel production MSc. study

In collaboration with the USP Chemistry Department and Fiji Biodiesel Ltd, SOPAC has co-funded with the PIEPSAP Project a study into the most appropriate way to produce biodiesel in Fiji. Special emphasis of the study is on the use of locally available oil feedstocks such as coconut oil and waste vegetable oils and the utilisation of locally available ethanol instead of imported methanol. The study has established properties of the locally available vegetable oils; the parameters for successful biodiesel production; and the implications of utilising ethanol. Current activities include quality control of biodiesel production and an investigation into the disposal of biodiesel by-products. Once the final research findings become available, it is expected this will further lay the foundation for locally produced biodiesel.

Ethanol production

The Fiji Sugar Corporation (FSC) first looked into the production of ethanol in the 1980s. After the oil price peak, it appeared not to be commercially viable. This has been revisited in 2006 with the South Pacific Distilleries (SPD) making 95% ethanol from molasses for the beverage industry claiming they can produce the required fuel grade ethanol of 99.9% with relatively modest investment, given the right incentives by the Fiji Government. The plant would be able to produce roughly 1 million litres per year, supplying the fuel market with E10 at a 15% share of the petrol market. FSC is also looking into the production of ethanol but is currently focussed on refurbishing sugar production facilities through assistance from the Indian Government. Fiji oil companies have shown a positive attitude towards introduction of an E10 fuel based on experience in Australia, provided quality standards are respected and the security of supply is ensured.

6.5 Solomon Islands

The relatively high landed costs of diesel and the high cost of exporting coconut oil from Solomon Islands paved the way for the establishment of a biofuel industry in Solomon Islands. While there are a number of buses running on Solomon Tropical Products (STP) “Cocoline” which is a blend of 80% coconut oil and 20% kerosene, there are investigations to venture into biodiesel production from palm and coconut oil. In addition, the local power utility SIEA is looking into the use of a coconut oil blend to be utilised in the main power generators of the capital Honiara.

Honiara Biofuel Production and Retail

STP has been endeavouring to produce of biofuels after the period of ethnic tension. Building on the “Island Fuel” experience in Vanuatu, it is now retailing this biofuel in Honiara. Copra oil is cold pressed and filtered in 3-micron aviation fuel filters, before being mixed with Aviation Kerosene and a proprietary additive. In addition, the company is preparing biodiesel production together with a foreign partner and the Solomon Islands Government as stakeholders. The feedstock for this biodiesel can be coconut oil or palm oil and the output could be used as a nation-wide blend with diesel for land and sea transport.

Coconut fuel for isolated areas

SOPAC is assisting with the supervision of a USP MSc student in his research for applications of remote area coconut oil milling and its residues for adding value into the production of biofuels and other related products. The research will undertake a) coconut production per village in selected communities; b) visit farmers for copra and residue production potential; c) take samples of CNO for analysis; d) design appropriate power generation systems and e) identify an appropriate biomass system to use coconut residues. The research will include a cost-benefit analysis a socio-economic and environmental impact analysis.

6.6 Kiribati

The Kiribati copra sector is currently highly subsidised through high transport cost to the outer islands, highly subsidised copra beach prices (US$ 0.46 per kg versus slightly subsidised US$ 0.29 per kg in Fiji, and un-subsidised US$ 0.18 per kg in Solomon Islands). In addition, there are high costs of exports through handling of the oil in containers with flexi bags as opposed to bulk transport. It was estimated the copra sector costs the Kiribati government up to 1.5 Million AU$ per year at an output volume of 3,500 tonnes. The social benefits of these expenses are income generation on the outer islands; in addition, coconut oil is the only significant export product on the island.

National Task Force on Biofuel

Kiribati has established a national task force on biofuels, consisting of the Ministry of Works and Energy, the copra mill KCMC and the national oil company KOIL, to lead the way in establishing a national biofuel industry.

KCMC experiments with biofuel

The country's sole copra milling company, Kiribati Copra Millers Company Ltd (KCMC) has embarked on utilising its own product as a fuel. In addition to a number of government vehicles, it has its own truck running at a 50-50 blend with diesel and is considering expanding these experiments. In addition, KCMC identified their production boiler is working well at a 60% coconut oil 40% kerosene blend and is using this mix as part of normal operations (Figure 23). In order to be able to utilise coconut oil, the product is treated and filtered in a separate section of the production plant to make the oil fuel-grade. Recent tests of KCMC filtered oil at USP has pointed out that the oil can be used as a fuel if all moisture is removed.

Figure 23: KCMC copra mill in Kiribati uses coconut oil blended with kerosene in their production boilers (Source: SOPAC).

6.7 Papua New Guinea

Country Overview

Papua New Guinea (PNG) is the region's largest exporter of coconut oil and in addition has a large potential for production of ethanol from starchy crops. Even though PNG produces crude oil and has a refinery, it is still partly dependent on petroleum product imports. Actors in the field of biofuel include various initiatives under the PNG Sustainable Development activities to start rural electrification with copra oil as a biofuel.

Figure 24: Boat powered with indirect injection engine from China run on coconut oil by National Fisheries College (Source: Carr, Walton, Rigby, National Fisheries College, Papua New Guinea).

Buka Coconut Diesel

An entrepreneur in Buka, East New Britain has established coconut oil fuel filtering for retail of a coconut-diesel blend. Mr Horn has a series of four tanks where the oil goes through a step-by-step process for use in engines. Apart from a fuel for diesel engines, the oil is also used for home-made lamps, chainsaw bar lubrication, cosmetic oils and high-grade cooking oil. The University of Papua New Guinea is assisting with oil analysis. In past years, the province of Bougainville was already using coconut oil fuel successfully during its period of political tensions when diesel deliveries had come to a standstill.

Coconut Fuel Trials at Unitech

The Technical University in Lae, has been a regional leader in establishing the efficiencies and operational characteristics of various derivatives of coconut oil [29]. The findings suggest the use of up to 40% coconut oil blends with diesel, above which the use of biodiesel is recommended.

Papua New Guinea Sustainable Development Programme (PNG SDP)

PNG SDP, in collaboration with Hydro Tasmania Consulting has been looking into the use of coconut oil for rural electrification, mainly for the western provinces. As part of these activities, a direct injection generator has been trial run with coconut oil at a varying load pattern, which led to early engine failure. The findings provide further evidence that a generator run on coconut oil fuel must be of the indirect injection engine type for long-term viable operation, or have a dual-fuel system to switch back to diesel at low loads.

National Fisheries College Coconut Oil Fuel experiments

The principal objective of the project is to undertake a detailed assessment of the feasibility of commercial production of coconut oil as an alternative fuel for diesel in both fisheries and community applications. This will be achieved through the establishment of an oil production base in the National Fisheries College engineering workshop. The facility will be equipped to produce up to 2,500 litres of fuel per day requiring up to 4,000 kilograms of dried copra. Production operational details will be recorded and analysed in regard to operational economics.

Coconut oil will be tested in both small and large vessels and compared with diesel in regard to cost and potential effects on engines. This will include a review of the newly available coconut oil powered outboards (see Figure 24).

The project also includes a study of village level oil production and applications. This will be undertaken by the deployment of a number of hand presses for oil production. Training will be provided to operators and production details recorded and analysed in regard to cost benefits. This will include analysis of the use of coconut oil for village lighting and the trial operation of community operated vehicles on coconut oil fuel.

6.8 Price levels of diesel and CNO blends in the region

Figure 25 shows the price levels of coconut oil, diesel landed cost, retail prices for diesel (including oil company margin and taxes) and, if applicable, the retail price of a coconut oil blend. In all countries except Samoa[23], coconut oil is less expensive than the landed cost of diesel. Taking into account the additional cost range that was established in section 2.6, utilising coconut oil blends in vehicles can be justified in only a few countries.

Nevertheless, in the Solomon Islands, Vanuatu, Papua New Guinea and the Marshall Islands, blends of filtered coconut oil and diesel are retailed at prices between the level of coconut oil and retail diesel. Only Vanuatu has a reduced duty tariff on coconut oil blends of 3.8 US cents per litre versus 23 US cents on diesel. All other countries have no duty on the coconut oil component of the blend.

The local cost of coconut oil, as discussed in Chapter 2, is dependent on world market developments, as is the price of diesel. Continuous monitoring of the price levels and a further assessment of the additional cost of using coconut oil in diesel engines are required to make an informed decision on which fuel to use.

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[23] There is currently no copra oil production in Samoa, this price refers to virgin coconut oil cost on an industrial scale.

6.9 Conclusion

Pacific Islands Countries have gained significant experience with the use of vegetable oils as a diesel replacement. In addition, the use of ethanol as a petrol replacement is considered in the larger countries.

Experiences indicate that there are technical and economically viable applications in small power applications in remote islands where diesel prices are high. Local production of coconut oil that is burnt in a special generator can cut expenditure on fuel, provide local jobs and have positive impact on the island environment.

Refined coconut oil in large-scale power applications is proven to be viable in machines that are fit to run on heavy fuel with minor adaptations. Biodiesel production for use in national-wide applications is being studied around the region and will only be viable if Governments support this for the years to come.

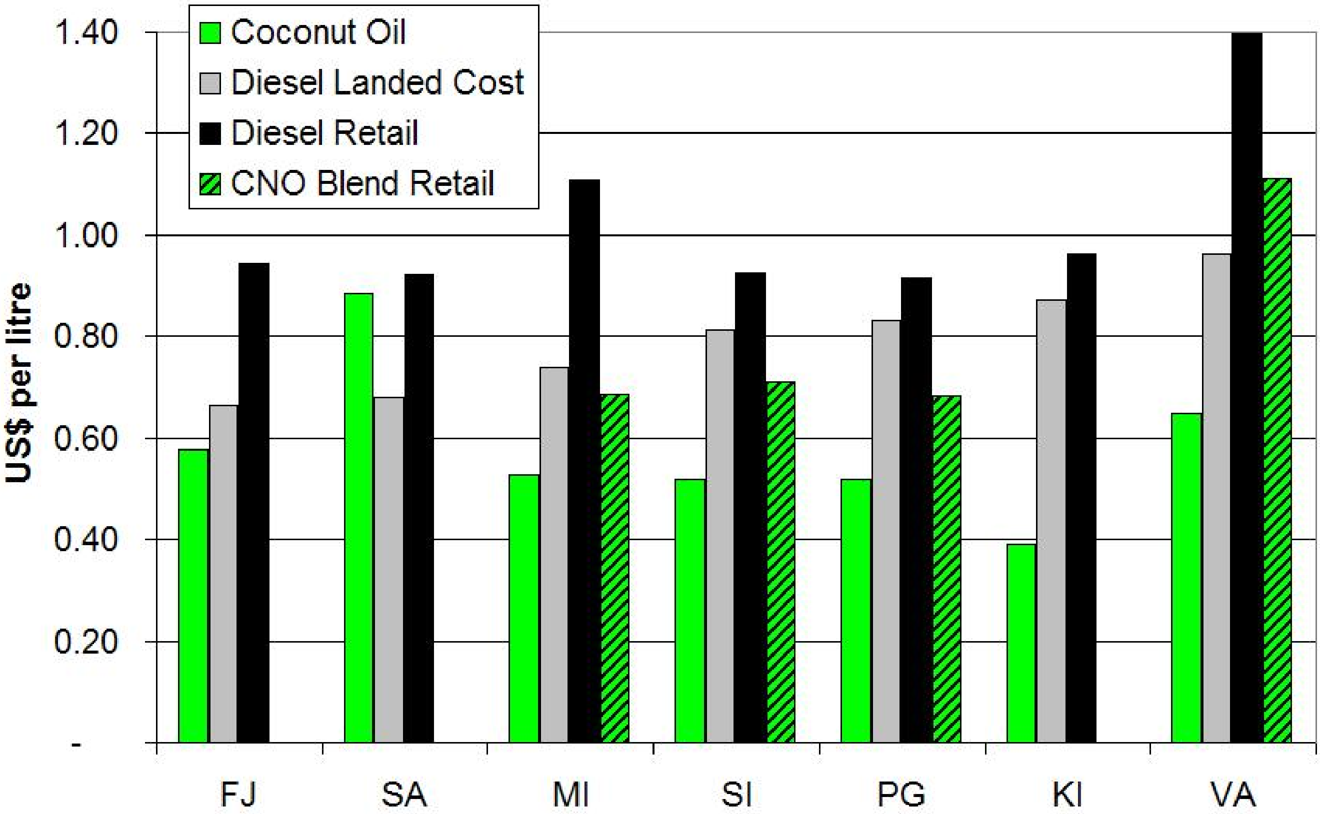

Figure 25: Selected regional prices (sorted by landed cost of diesel) of a) coconut oil net revenue; b) landed cost of diesel; c) diesel retail prices; and d) retail prices for filtered coconut oil blends with diesel as of August 2006. SA, FJ, KI have no biofuel retail. (Source: SOPAC Survey).

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

When vegetable oil is used as a fuel it needs to be of sufficient quality and preferably match or exceed the standards as laid out in DIN 51 605 (Annex 1).

There are three ways to utilise vegetable oil as a diesel replacement:

First, (a blend of) refined vegetable oil can be used in an un-adapted indirect injection engine. The advantage of this option is its simplicity, however it will come with additional maintenance costs and emissions can be more harmful than diesel. This is only recommended on a fleet of vehicles that are under strict supervision by skilled mechanics.

The second option is the use of refined vegetable oil in adapted or custom designed engines with special fuel heaters, injectors, adapted pistons, injector pump and storage tank. The advantage of this option is that operation is more reliable than the first option, however there are significant up-front costs associated with adapted engines. This option is most applicable for medium- and large-scale power applications.

The third option is to convert vegetable oil into biodiesel by producing methyl esters. The resulting biodiesel should at least match or exceed the biodiesel standards as laid out in Annex 2. The advantage of this option is that standard diesel engines can be used, however it will come at a significant production cost of 0.3 – 0.6 US$ per litre. The processing of biodiesel is not fit for rural or remote applications due to the use of hazardous chemicals and the creation of side products. The production of biodiesel is the only reliable way to utilise vegetable oils on a national scale in transportation.

Ethanol is a biofuel option for larger Pacific Islands Countries that can grow sufficient amounts of sugary or starchy crops. Ethanol can be used in different blends in cars to replace petrol. Advantages include a reduction in overall emissions, the reduction of dependence on foreign imports of petrol and could provide support for sugar or starchy crop prices.

Ethanol blends of above 10% require cars to be monitored and above a blend of 22%, car engines need to be modified. Ethanol production in quantities of up to 10% of the fuel demand of Pacific island economies are bound to be more expensive than petrol under world oil prices below US$ 100 per barrel.

The majority of Pacific Islands Countries are experiencing acute balance of payments deficits. This can be attributed not only to small country size, country endowments, level of economic development and geographical isolation, but also to heavy dependence on petroleum imports. Moreover, the value of petroleum imports has been increasing over time with increased demand and rising oil prices.

Most PICs have the potential to produce large amounts of coconut oil biofuel, and ethanol in the case of Fiji, which can serve to reduce dependence on energy imports and address balance of trade problems. Demand for coconut oil could also help to stabilize the price that domestic producers receive for their output, thereby avoiding the uncertainty created by volatile price movements in international primary commodity markets or drain Government Stabilisation Funds.

If ten percent of diesel imports were replaced with domestically produced coconut oil, the average value of PIC imports could be reduced by two percent; and if fifty percent of diesel imports were replaced, the average import bill would fall by ten percent.

Countries should also consider the impact of such import-substitution policies on exports earnings and government revenue from taxes and customs duties on imported fossil fuels. The figures in this study suggest that some duty on locally grown biofuels will be required to offset this loss.

Import substitution can have a positive impact on government revenues if the impact on trade balance, duties and taxes are taken into account. Partial duty exemption should take into account the environmental and foreign exchange advantages of biofuel production and use.

Biofuels have positive effects on the environment because they produce much lower CO_2 emissions in their life cycle compared to fossil fuels. Biofuels, through their oxygen content, lead to cleaner combustion and therefore have lower overall emissions than their fossil-based counterparts. They are biodegradable which makes them very suitable for use in fragile reef environments, often found in the Pacific island region.

The environmental benefits of biofuels, especially their lower carbon dioxide emissions can be turned into financial support through the Clean Development Mechanism.

Increasing demand for biofuels has also lead to a number of detrimental effects on the environment in their production and transport stages with subsequent higher prices in agricultural commodities, which might affect the poor.

Pacific Islands Countries have gained wide experience with the use of vegetable oils as a diesel replacement. In addition, the use of ethanol as a petrol replacement has been considered in the larger countries.

Experiences indicate that there are technical and economically viable options in small power applications in remote islands where diesel prices are high. Local production of coconut oil that is burnt in a special generator can cut expenditure on fuel, provides local jobs and has positive impact on the island environment. Refined coconut oil in large-scale power applications is proven to be viable in machines that are fit to run on heavy fuel cost effectively. Biodiesel production for use in nation-wide applications is being studied around the region and will only be viable if Governments support this in years to come.

7.2 Recommendations

Investigation into outer-island production and utilisation of coconut oil should continue looking at opportunities for sustainable economic applications where resource is abundant and fossil fuel prices are high.

Government support should be directed towards power utilities in their search to diversify fuel sources to include biofuels.

Government support, through tax and partial duty exemption, should be established and/or continued to enable national initiatives in establishing biofuel industries based on biodiesel and ethanol because of their benefits through job creation, positive effect on the environment and balance of payments.

Government support should be established and/or continued to enable long-term experiments with the use of filtered coconut oil in adapted vehicles under strict technical supervision.

National and/or regional standards on biofuel quality should be established for biodiesel, vegetable oil fuel and ethanol to ensure trust by consumers and further the establishment of a biofuel industry.

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RECOMMENDED WEBSITES ON BIOFUEL

If you are reading this as a digital document, you may click on the hyperlinks below to view the respective recommended websites on biofuels. Otherwise, you will find the site through typing the keywords into a search engine.

APCC - Asian Pacific Coconut Community

Biodiesel Australia

Biodiesel Production Equipment from BiodieselGear

Biodiesel Production Equipment from BiodieselNow

Coconut Oil Processing Equipment

CocoGen Project

Frybrid Vegetable Fuel Systems

Sugaronline.com

Unitec NZ - Biofuels

ELSBETT SVO Conversion Technology-OnlineShop

Greasel.com - an SVO information source

Hands On Coconut Crude Oil in Vanuatu

Honolulu Clean Cities Factsheet - Biodiesel Fuel

Jatropha - Biofuel Grown in the Desert

Kokonut Pacific - developers of DME virgin coconut oil

Make your own biodiesel Journey to Forever

US National Biodiesel Board

Neoteric Biofuels Converion Technology, Canada

Novem GAVE, Climate neutral gaseous and liquid fuels - biofuels

Pacific Biodiesel, Inc. Hawai'i

Philippine Coconut Authority

SOPAC project on Copra Oil

Tinytech Plants - Tiny Oil Mill - oil expeller, machinery from India Rajkot

Vegetable oil yields, characteristics Journey to Forever

Veggie Van

GLOSSARY

Biomass – Material that is derived from nature (trees, grasses, agriculture crops) that can be used for energy conversion, included biofuel.

Biodiesel – A standardised fuel comprising of Vegetable Oil Methyl Ester that is made from a combination of vegetable oil, alcohol and lye. Biodiesel can be used in most diesel engines with no adaptation.

Copra Oil – Coconut oil made from expelled dry copra.

Compression Ignition Engine – Combustion motor that works on the principle of compressing air to achieve the ingnition temperature of the fuel, mostly diesel. See paragraph 2.1 for operation.

Carbon Credits – Proof of emissions reduction of Greenhouse gases as compared to a baseline, associated with an intervention or project.

CDM – Clean Development Mechanism; agreement between Annex I countries (developed countries that have signed on to the Kyoto Protocol) and Annex II countries developing countries that have no commitments under the Kyoto Protocol) to enable sale of carbon credits with accompanying sustainable development dimensions.

De-nature – blending of alcohol with a poisonous substance that is not easily removable from the alcohol in order to avoid abuse through tax evasion.

DME Oil – Coconut oil that is produced using the Direct Micro Expelling method; scraped wet copra is dried on a stainless steel plate above a fire, after which oil is pressed out. It is also referred to as “virgin coconut oil”.

Ethanol – Ethyl Alcohol (C_2H_6O) that can be used as a fuel to replace petrol.

Greenhouse Gases – gaseous substances in the atmosphere that block infrared radiation back to the earth; these include CO_2, CH_4 and water vapour.

Import Substitution – Replacement of goods that imported by goods that are produced locally.

Opportunity Cost/Benefit – the price at which a good or service could have been sold in the local market as opposed to other markets.

ANNEXES

1 Vegetable Oil Fuel Standard DIN V 51 605
2 Philippine Biodiesel Standard
3 Ethanol Fuel Standards

ANNEX 1

Vegetable Oil Fuel Standard DIN V 51 605

Quality Standard for Rapeseed Oil 05/2000 (Source: LTV Work Session on De-central Vegetable Oil Production, Weihenstephan).				
Property	Unit	Min Value	Max Value	Testing Method
Density	Kg/m^3	900	930	DIN EN ISO 3675 DIN EN ISO 12185
Flash Point	^oC	220		DIN EN 22719
Calorific Value	kJ/kg	35,000		DIN 51900-3
Kinematic Viscosity	mm^2/s		38	DIN EN ISO 3104
Cloud Point				Report
Cetane Number		40		–
Carbon Residue	mass-%		0.4	DIN EN ISO 10370
Iodine Number	g/100	100	120	DIN 53241-1
Sulphur Content	mg/kg		20	ASTM D5453-93
Contamination	mg/kg		25	DIN EN 12662
Acid Value	mg KOH/g		2	DIN EN ISO 660
Oxidation Stability (110 ^oC)	h	5		ISO 6886
Phosphorus Content	mg/kg		15	ASTM D3231-99
Ash Content	mass-%		0.01	DIN EN ISO 6245
Water Content	mass-%		0.075	pr EN ISO 12937

This standard is often referred to as the “Weihenstephan” standard, named after the company who was actively involved in its development. It was adopted as the German standard for use of vegetable oil in modified engines.

ANNEX 2

Philippine Biodiesel Standard

Source: Philippine National Standard PNS 2020:2003, Department of Trade & Industry, Philippines

Standard properties for 100% biodiesel B100 Coconut Methyl Ester (CME). CME is defined as fatty esters derived from coconut oil whose alkyl groups range in varying percentages from C_8 to C_{18} suitable for compression ignition engines and other similar type engines.

Property	CME Limit	Test Method
Flash Point	100	ASTM D 93
Water and sediments %vol, max.	0.050	ASTM D 2709
Kinematic viscosity at 40 ^{O}C, mm^2/s	2.0-4.5	ASTM D 445
Sulfated Ash % mass max	0.020	ASTM D 874
Sulfu mass max	0.050	ASTM D 2622, 5453, 4294, 1266
Copper strip corrosion 3 hrs at 50 ^{O}C max	No. 3	ASTM D 130
Cetane number, min	42	ASTM D 613
Cloud Point, ^{O}C, max.	*Report*	ASTM D 2500
Carbon Residue, 100% sample, % mass, max.	0.050	ASTM D 4530
Acid Number, mg KOH/g, max.	0.5	ASTM D 664, 974
Free Glycerin, % mass, max.	0.02	AOCS Ea 6-51
Total Glycerin, % mass, max.	0.24	AOCS Ca 14-56
Phosphorus, % mass, max.	0.001	ASTM D 4951
Distillation AET 90% recovered, ^{O}C, max.	360	ASTM D 1160

CME is mandated to 1% (B1) in all diesel distributed around Philippines in 2007.

ANNEX 3

Ethanol Fuel Standards

Source: *Australian Proposed Standard for Fuel Grade Ethanol, Department of the Environment and Heritage*

Parameter	Standard	Test Method
Ethanol content	99.0 vol % min (prior to denaturing) 94.0 vol % min (after denaturing)	ASTM D5501
Methanol content	0.1 vol % max	ASTM D1152
Non-volatile matter	2.5 mg/100ml max	ASTM D1353 BP2002
Water content	1 vol % max	ASTM E203 ASTM E1064
Denaturant Content	1 vol % min 5 vol % max	Report
Copper	0.1 mg/kg max	ASTM D1688A (modified)
Acidity	0.007 mass % max	ASTM D1613
pHe	6.5-9.0	ASTM D6423
Appearance	Clear without particles	ASTM D2090
Sulphur	50 mg/kg max	ASTM D5453-93
Phosphorus	0.5 mg/L	ASTM D3231 (modified) EN 14107 (modified)

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