Coconut Oil as a Biofuel in Pacific Islands– Challenges and Opportunities

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In the Pacific, there are opportunities to utilise coconut oil and other vegetable oils as a fuel for transport and electricity generation. Technologies exist to combust crude coconut oil in adapted compression engines or by means of esterification into biodiesel, using standard compression engines.

The initiatives undertaken in the Pacific to utilise coconut oil in cars and generators have had different degrees of success. The technological challenges can be solved and economic applications can be found, if the supply of oil is secured. Economically attractive niches can be found in the use of raw coconut oil in adapted engines in remote communities with an abundant supply of coconuts and milling capacity.

The production of biodiesel from coconut oil in combination with other (used) vegetable oils can be set up commercially in larger communities for provision of cleaner fuels in cars and electricity generators.

1. Introduction

The use of biofuels is nearly as old as the diesel engine itself, as Mr. Diesel designed his original engine running on peanut oil. During periods in history when regular diesel supply was hampered seriously such as WW-II, throughout the world vegetable alternatives from different sources and in different forms have been used.

In the Pacific, only recently has there been renewed interest in the use of coconut oil as a biofuel. The need to substitute for diesel imports, safeguard the local agricultural industry and reduce the impact of diesel exhaust on the environment, has led to a range of initiatives using coconut oil as a biofuel in the past 10 years.

Figure 1: Coconut: "The Tree of Life"

In this report, first an overview of worldwide research and experience using vegetable oils, including coconut oil will be given. This will lead to recommendations on the best technical application of coconut oil in compression (diesel) engines. After that, economic issues including the price and supply of oil will be highlighted. Lastly, the specific challenges and opportunities for the Pacific islands will be discussed.

2. Objective

The objective of this paper is to seek economic opportunities in the Pacific for the use of environmentally friendly coconut oil to replace diesel in compression engines. This will be done through collecting experience throughout the region and analysing results in a Pacific context.

3. Coconut Oil Fuel Technology

First, the study on the use of coconut oil as part of the research on straight vegetable oils as fuel will be described. Secondly, possible adaptations to diesel engines are listed to enable coconut oil to be used in compression engines. Thirdly, the use of biodiesel in unmodified engines will be discussed (Figure 2).

3.1. Use of Pure Coconut Oil in Unmodified Engines

Many studies involving the use of un-modified vegetable oils (including copra[1] oil) were conducted in the early 1980s. Short-term engine testing indicates that vegetable oils can readily be 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 contain more than 20% vegetable oil [1, 11, 12].

The lower iodine value of coconut oil compared to other vegetable oils works favourably for its lower carbon deposits, however not many successful experiences have been found [3]. Deposits on the pistons, valves, combustion chambers and injectors, in particular, can cause severe loss of output power, engine lubricant deterioration or even catastrophic failure to engines [11].

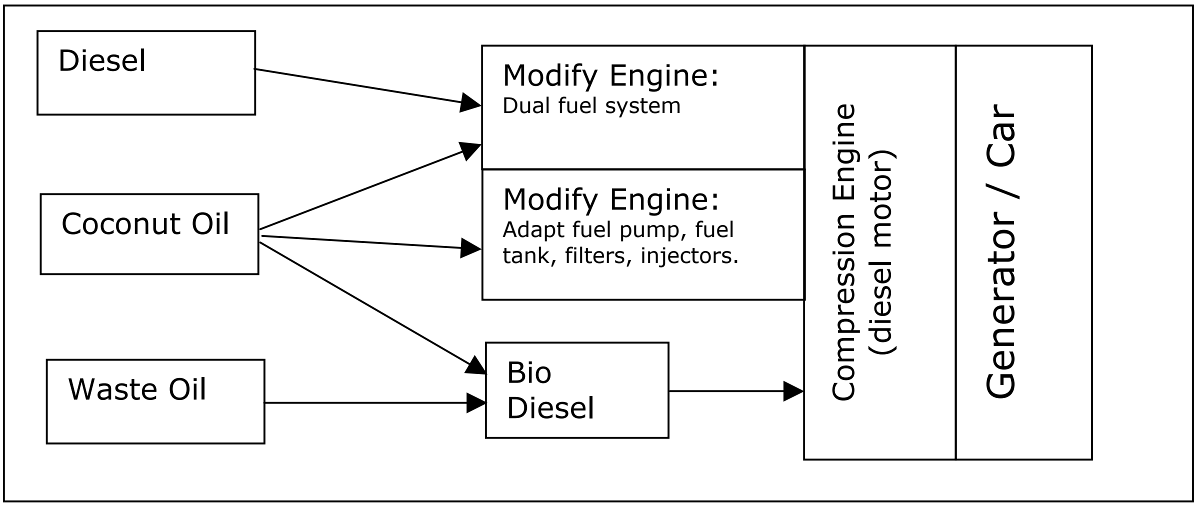

Figure 2: Overview of Biofuel Choices for Compression (Diesel) Engine

Under specific circumstances unmodified engines have been running on 100% copra oil [17,20]. Key variables for successful operation on raw copra oil include:

1) Stable and controlled copra drying / milling process;
3) Removal of water, Free Fatty Acids (FFA) and solids;
4) Filtration up to 1 micron;
5) Pre-heating of copra oil up to 70 ^{0}C;
6) Blending with regular diesel or kerosene for better viscosity;
7) Application of engine in upper load curve (>70%);
8) Use in Direct Injection[2] system.

The long-term use of raw coconut oil in unmodified diesel engines is currently such a specialised case that it is not recommended without special technical supervision. Further research should describe and define the key variables in order to minimise modification costs to engines. Current experiences in Vanuatu

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[1] Copra Oil is coconut oil produced in the traditional manner of husking, shelling coconuts, drying on a smoky fire and finally pressing the oil out by means of an expeller. The bulk of coconut oil is still produced in this way, however in the last 10 years other ways to produce oil have been explored, including Direct Micro Expelling (DME) in which the copra is grated, dried and expelled batch-wise in a metal cylinder. This process, even though more labour-intensive, produces higher quality oil with less Free Fatty Acids.

[2] Most modern car engines employ an indirect injection system that yields higher efficiencies through greater compression ratios. The use of the pre-combustion chamber in this engine can lead to greater deposits when using vegetable oils as fuel. Older cars and most stationary generators make use of the direct injection system that creates less deposit problems.

in the transport sector are promising and deserve follow-up activities in other Pacific island countries.

3.2. Use of 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 modifications to an engine: firstly to add an extra fuel supply system to the existing diesel supply and secondly to adapt the fuel supply system and injectors.

As coconut oil has up to 30 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 [13].

3.2.1. Dual Fuel systems

These systems start and stop on regular diesel. As soon as the engine is rated at operating 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 residues in the fuel system.

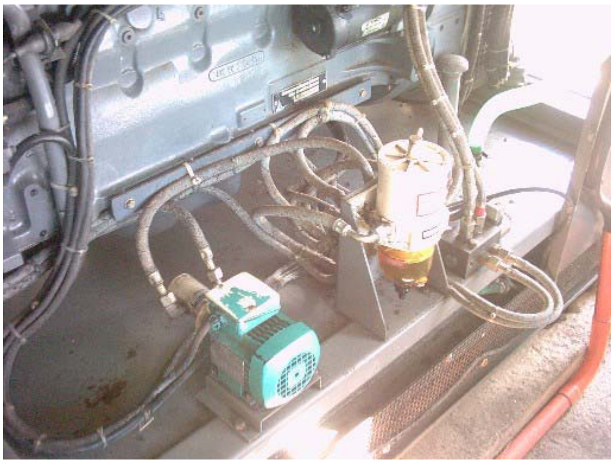

Figure 3: Extra fuel pump and fuel filter for generator in Welagi, Fiji

In some areas there is also an electrical heater incorporated in 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 the village electrification system in Welagi, Taveuni, Fiji Islands (Figure 3), that uses a dual-fuel system for both diesel and copra oil fed into a 55 kVA diesel generator. As part of the French funded project, the village obtained a small copra oil press enabling the local small-scale oil production by means of dried copra from the Mataqali's[3] pastures. Technically this system has proven to operate with little problems.

This generator has however suffered from problems related to spare parts but 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 Mataqali 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 has also proven to be a very laborious process, that can only be maintained with a strong community commitment.

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[3] A Mataqali is an important unit in the Fiji social system that can comprise of one or more extended families.

Because the generator has often only been used for a small portion of its design load (as low as 17%), excessive carbon deposits have been found on 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 promotional projects such as the Veggie Van in the US and the VegBurner in the 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 into 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 [14].

3.2.2. 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. The quality of the coconut oil is not always stable, especially if it is manufactured locally on a small scale. Regular quality control and a number of filtering stages are therefore essential to long service of this type of system. Often an electrical-operated fuel-heating system is incorporated for ambient temperatures below 25^{o}C.

A good example of this is the pilot plant in Ouvea implemented by SPC and 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 [18].

3.3. The use of Biodiesel in unmodified engines

Biodiesel is a standardised fuel that consists of vegetable oil Methyl Ester. It is a product of crude 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[4] (VOME), also called biodiesel.

There are two fully-developed standards of biodiesel, ASTM-D6751 in the United States and EN 14214 in the European Union. If these standards are followed, the validity of all manufacturer guarantees remains sound if used up to 5% [7]. Individual manufacturers have declared certain models can be run with remaining guarantee up to 20% and some even 100%. 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 [4,12,21].

The use of biodiesel is becoming more mainstream practice in the US and the EU Total production in the EU grew 35% in 2003 to 1.44 million tonnes and in the

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[4] If the basis for biodiesel has been coconut oil, often the abbreviation COME, Coconut Oil Methyl Ester, is used. With waste vegetable oil as the basis for biodiesel, Fatty Acid Methyl Ester (FAME) is used.

US to 83,270 tonnes[5]. It is mostly mixed in regular diesel in low blends. In Germany only, there are already 800 biodiesel refuelling stations. In Hawaii, 1,2 Ml of biodiesel is produced annually from used vegetable oil and sold as B1 (1%) B20 (20%) or B100, 100 % biodiesel. In winter time, blend ratios 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 per litre is estimated to be three times as high as the selling price of regular diesel. Because of return on the associated by-products, a Canadian study has estimated that biodiesel cost tend to be equal to the price of the original vegetable oil [4]. If the biodiesel is produced from waste vegetable oil or beef tallow in large volumes, the price might come down to twice the cost of regular diesel. There are also options to produce biodiesel on a very small scale, as has been done in the Philippines [2] – however it does not appear to be attractive for small island communities because of the use of potentially dangerous chemicals in a high-hygiene working environment.

3.4. Conclusion

Table 1 below gives an overview of the advantages and disadvantages of the options discussed above.

Table 1: Pros and Cons of different Coconut Oil uses in Compression Engines

	Advantages	Disadvantages
Straight Coconut Oil in Unmodified Engine	Low cost of fuel No modification costs	Works only in certain cases High Quality Oil Required
Coconut Oil in Modified Engine – Dual Fuel	Lowest-cost fuel can be chosen Flexible	Continued diesel imports Extra components risk extra failure Possible contamination of fuels
Coconut Oil in Modified Engine – Pure	100% Renewable Low cost of fuel Small island communities can produce own fuel for electricity	Dependence on local oil production Non-standard components Requires heating under ambient temperatures of 25^{0}C
Biodiesel	Standardised, Guarantee remains Opportunity to co-source used oil	Chemical Facility required Some rubber parts need replacement

Technically speaking, the production of biodiesel is the best way to use vegetable oils in compression engines. Because of the high production cost of biodiesel, niches for modified engines and dual-fuel systems can be found, depending on the location and the availability and quality of coconut oil. The use of straight coconut oil in unmodified engines is not recommended without strict technical supervision.

4. Coconut Oil Economics

In every consideration for the use of biomass resources in energy technology, the steady supply of fuel must be safeguarded. Quite a number of initiatives on the use of biofuel have been experiencing difficulties through hampered supply. Mills stop production, coconut trees become senile[6], rural farmers switch to other forms of income-generating activities. These socio-economic changes all have their impact on local availability of coconut oil. First, let us have a look at the global copra oil market.

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[5] Source: European Biodiesel Board, National Biodiesel Board, U.S. (2004).

[6] Coconut trees have a hyperbolic yield graph with growing number of coconuts in the first years after planting and slowly decreasing after 20-30 years.

4.1. Global Copra Oil Market supply

The world production of coconuts in copra equivalent has been floating around 10 million tonnes. Of this market between 1 and 2 million tonnes has been traded on the world market as oil in the last 5 years. Figure 4 shows the volume of the global copra oil market and the associated price per litre.

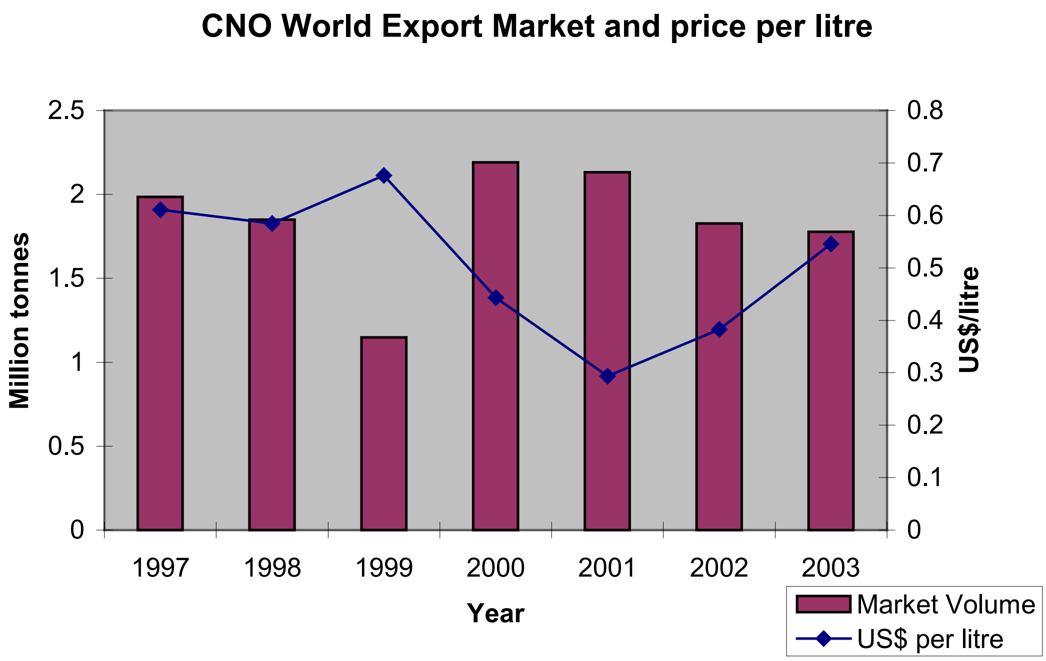

Figure 4: Copra Oil World Export Market and Price

As can be seen from the graph, the price fluctuation is significant, between 0.3 and 0.7 US$/litre. However, the volumes seem to be relatively constant, around 2 million tonnes. The trading volume of copra oil tends to go up when its price goes down, as it replaces the use of other vegetable oils in industrial processes.

Since the Pacific island countries only produce a small percentage of the world supply (PNG: 2.2%, Solomon Islands: 1% Samoa 0.4%, Fiji 0.3%), it can be safely stated that any increase or decrease in production in the Pacific will not significantly alter the world price. Therefore, the opportunity costs for selling coconut oil as biofuel locally as opposed to exporting oil for the copra mill are determined by the world price minus the cost of transporting and financing the oil.

4.2. Local Copra Oil Market supply

Local coconut supply on remote islands can be an interesting source of copra for small- to medium-scale copra oil production. Especially if the transport costs for both copra export and diesel import are significant, a niche application can be identified. The challenge has been proven to be the safeguarding of the supply chain throughout the lifetime of the project.

Figure 5 gives an overview of the supply chain and the steps required to obtain oil at a generator or fuel pump. At each stage a number of important aspects is included. From the plantation the nuts are collected and transported to a dryer. There they are cut and the copra is separated from the husk and the shell. After drying, the copra is collected in bags and transported to the mill, where it is stored in bulk for milling. The mill processes the copra by means of heat, steam, grinding and pressing the oil. After milling the oil will be filtered from solids and

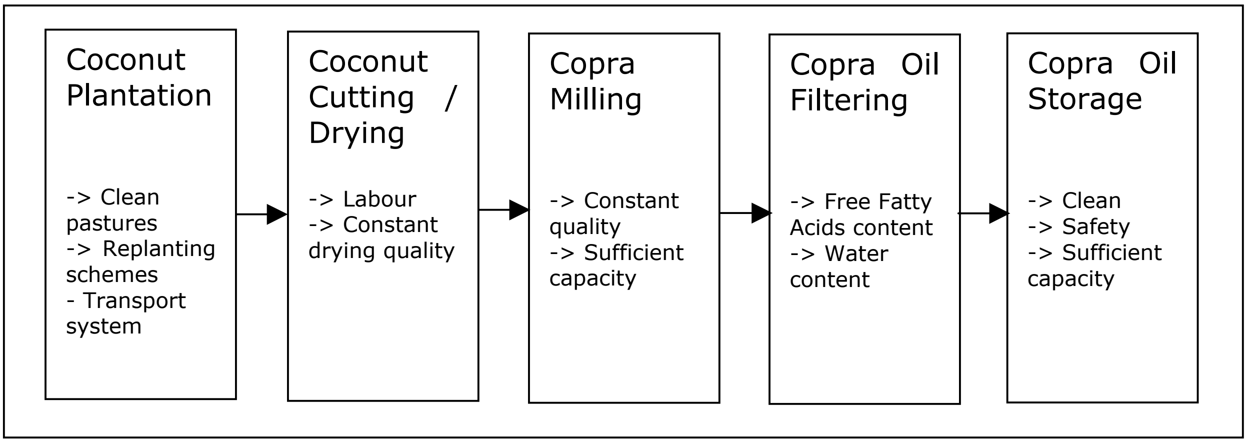

Figure 5: Traditional Supply Chain Copra Oil with points that determine quality

water. Often, for edible oils and cosmetics, the Free Fatty Acids (FFA) are reduced through purification stages, deodorising and bleaching.

4.3. Copra Oil Price

Table 2 shows the composition of the price of crude exported copra oil throughout distinctive stages in the supply chain. As can be seen in the table, the most labour-intensive activity of cutting and drying the copra is responsible for 43% of the value of a litre of oil produced – however, the reward for the labour is very low.

Table 2: Traditional Copra Price Composition[7]

	Price in Oil Equivalent [US$/l]	Value added in Oil Equivalent [US$/l]	Share of Crude Export Oil [%]
Coconuts collected on field	0.224		39
Copra cutting and drying		0.245	43
Copra drying at mill	0.469		81
Copra Milling and Filtering		0.107	19
Crude Copra Oil	**0.577**		**100**
CIF Cost Export		– 0.120	– 14
Benefit to PIC	0.497		

Other emerging alternative sources of rural income, has contributed to the deterioration of the copra industry in a number of Pacific islands. In most countries, significant replanting is necessary to get back to the pre-1990 production levels by 2010. To revive the industry on the supply side, there are two options that can be considered.

The first option is to increase the payment for dried copra to increase the reward for the cutting / drying of copra. This can be done by either a subsidy[8] or by means of further rationalising the milling process, and thus decrease its operational margin. This however will both push up the price of the end product and will make it more difficult to compete with both the price level of diesel fuel and the export oil markets. A further disadvantage is that it will require government involvement and possibly further politicise the coconut market.

[7] Based on prices in Fiji and FOB prices Rotterdam, July 2004.

[8] Subsidies have been a traditional measure by governments in the copra sector as an 'alternative social security system' in a range of Pacific island countries, especially during times of low copra prices on the world market. With the current regional trade agreements being implemented in the Pacific, subsidies are becoming increasingly difficult to apply.

Secondly, a more mechanised and rationalised process might be looked into, where the coconuts are collected, transported to the mill where they are cut for copra and dried in a mechanised process. However, such a process requires significant investment in machinery and transport equipment. A second disadvantage is the cost of transporting whole coconuts instead of dried copra, adds to the overall cost of the production process.

4.4. Copra Oil vs. Regular Diesel

Given the volatility of both the world market price for copra oil and diesel, the best option seems to be a dual-supply system. This could facilitate the use of copra oil in times of high supply and low world prices and also provide a cushion for times when copra oil ceases to be produced as has happened in a number of previous projects. Figure 6[9] shows the retail and wholesale prices of Diesel (ADO) in the region.

The line in the graph depicts the benefits[10] of exporting the copra oil versus using it locally as a fuel. The benefits will differ from country to country and increase as transport costs to remote islands increase.

This analysis does not take into account the benefits that an individual country might gain from exporting goods and therefore improving their balance of payments.

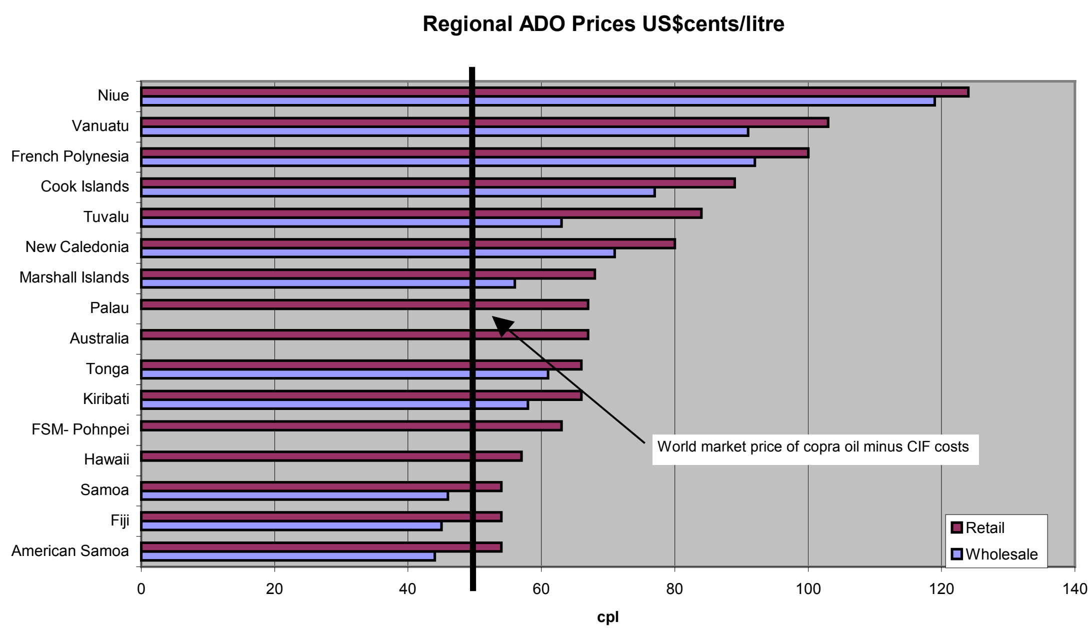

Figure 6: PIC Diesel Prices and the World Market Price of Copra Oil

4.5. Conclusion

The copra oil world market price is variable, however the long-term expectation is in the range 0.4 – 0.6 US$ per litre. The reward for the labour involved in the traditional copra process is too low to safeguard the long-term supply in most Pacific islands. Given the low benefits for exporting copra oil in most Pacific islands, there is a strong case for using copra oil locally instead of exporting. This does not necessarily mean the reward for copra production sold locally is enough

[9] Source: PIFS Fuel Price Monitor May-June 2004.

[10] Based on FOB prices Rotterdam July 2004, minus Freight, Insurance, Finance and destination charges from Fiji.

to sustain sufficient supply and therefore has to be looked into on a case-by-case basis. The further rationalisation and mechanisation of the coconut oil supply chain will increase the security of supply, however this requires significant investment in the coconut oil sector.

5. Opportunities for Coconut Oil as a Biofuel

From the above, it can be concluded that there are three niches for coconut oil as a biofuel.

Table 3: Niches and Risks for Coconut Oil as a Biofuel

	Size	Niche	Challenge
1. Pure Coconut Oil	Small Scale	Small Island with absolute abundance of coconut oil and own milling facility	Keep the copra supply going; Keep components standard and available
2. Dual Fuel	Medium Scale	Small Island with high transport cost (partly) displacing diesel fuel.	Earn back investment while prices of oils fluctuate
3. Biodiesel	Large Scale	Larger Islands and urban centres with access to industrial milling capacity	Achieve sufficient economy of scale

For coconut oil as a fuel to be a sustainable alternative to diesel fuel in the Pacific on a large scale, a restructuring of the coconut industry and replanting is required. Seeking alternatives from the traditional copra-based, government-controlled industries toward more de-centralised production of oil, including high quality control.

The technological challenges can be solved and economic applications can be found, if the supply of oil is secured. Economically attractive niches can be found in the use of raw coconut oil in adapted engines in remote communities with an abundant supply of coconuts and milling capacity, or the combination with recycled waste vegetable oil to produce biodiesel for low blends in transport and electricity generation.

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Related Links

Australian Biodiesel Board	http://www.biodiesel.org.au
Australian Biodiesel Standards	http://www.deh.gov.au/atmosphere/biodiesel/index.html
Biodiesel Production Equipment	http://www.biodieselgear.com
Driving on Biodiesel	http://www.veggievan.org
Driving on Biodiesel / Forum	http://www.vegburner.co.uk
Hawaii Biodiesel Production	http://www.biodiesel.com
Literature on Biofuel	http://www.journeytoforever.org/biofuel_library.html
SOPAC work on Biofuels	http://www.sopac.org/tiki/tiki-index.php?page=Energy+Projects+COPRA
Straight Vegetable Oil Technology	http://www.greasel.com

International Commercial Terms (INCOTERMS) and other Acronyms used in this report

ADO	–	Automotive Diesel Oil
ASTM	–	American Society for Testing and Materials (original name)
CIF	–	Cost, Insurance and Freight
CIRAD	–	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CNO	–	Crude Coconut Oil
COME	–	Coconut Oil Methyl Ester
DME	–	Direct Micro Expelling
EMA	–	Engine Manufacturers Association (US)
EU	–	European Union
FAME	–	Fatty Acid Methyl Ester
FFA	–	Free Fatty Acids
FOB	–	Free On Board
GCSI	–	Global Change Strategies International Inc.
GEF	–	Global Environment Facility
ICCEPT	–	Imperial College Centre for Energy Policy and Technology
PIC	–	Pacific Island Country
PIFS	–	Pacific Islands Forum Secretariat
PNG	–	Papua New Guinea
SPC	–	Secretariat of the Pacific Community
UK	–	United Kingdom
UNDP	–	United Nations Development Programme
US	–	United States of America
USP	–	University of the South Pacific
VOME	–	Vegetable Oil Methyl Ester

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