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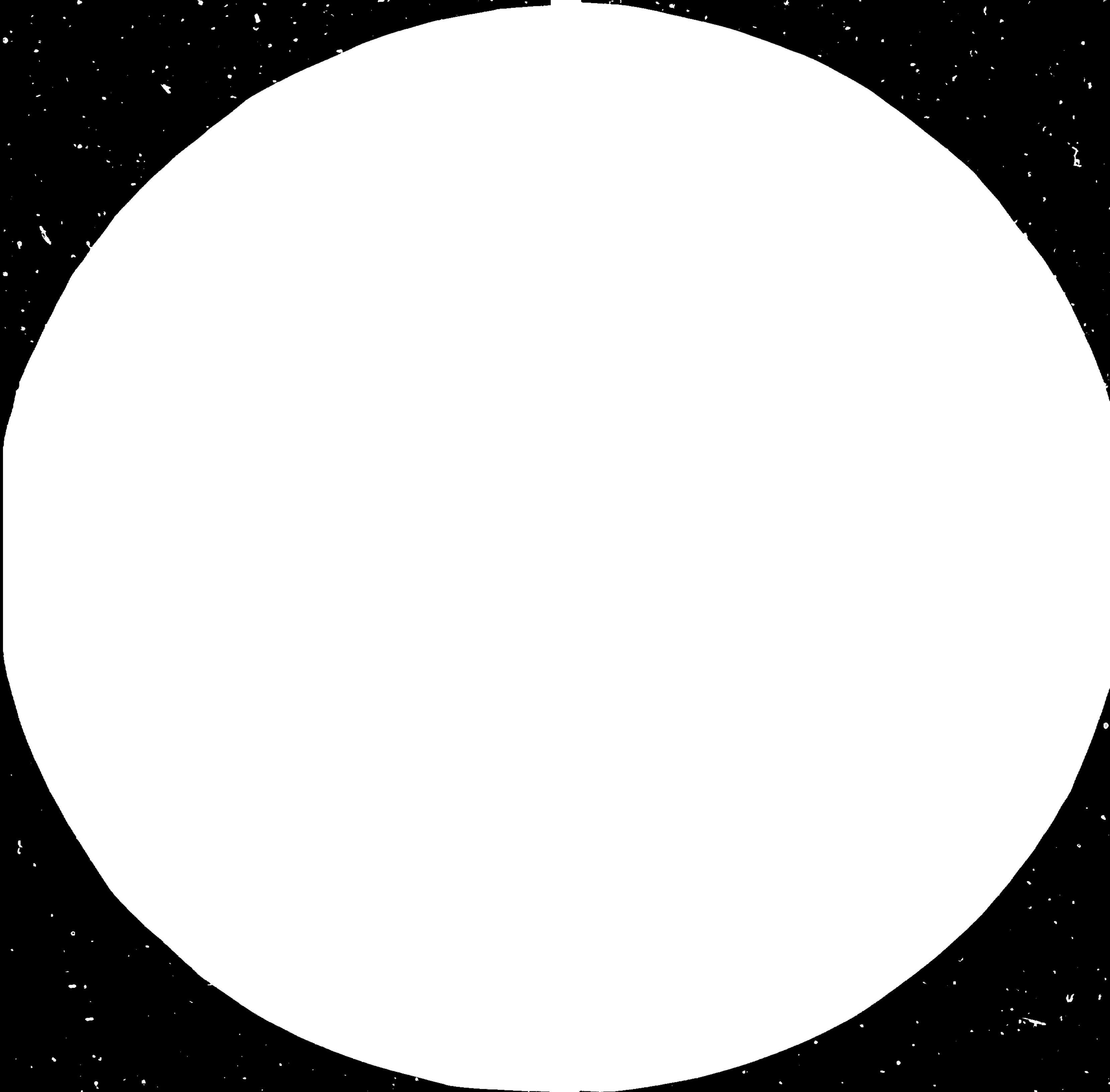

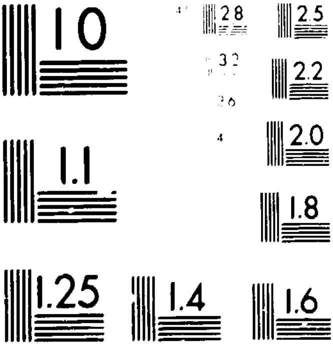

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TECHNICAL AND ECONOMIC VIABILITY OF COCONUT OIL AND/OR ITS DERIVATIVES AS A DIESEL SUBSTITUTE IN THE FIJI ISLANDS

SI/RAS/83/801

Technical report *

Prepared for the Government of the Fiji Islands
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Kenton R. Kaufman,
expert in the use of vegetable oils for fuel

United Nations Industrial Development Organization

Vienna

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EXPLANATORY NOTES

Currency Equivalents

US $1.00 = F $ 1.10

F $ 1.00 = US $ 0.95

F $ 1.00 = A $ 1.08

F $ 1.00 = WS $ 1.45

ABBREVIATIONS

ADO	Automotive Diesel Oil
API	American Petroleum Institute
ASTM	American Society for Testing And Materials
CI	Compression Ignition
DI	Direct Injection
ELEC	Electricity
FEA	Fiji Electricity Authority
IDO	Industrial Diesel Oil
IDI	Indirect Injection
IFO	Industrial Fuel Oil
KERO	Kerosene
LPG	Liquidfied Petroleum Gas
PWD	Public Works Department

GLOSSARY

DIRECT INJECTION DIESEL ENGINE - The entire compression volume is in one chamber formed between the piston and head. The fuel is injected directly into the combustion chamber. Also called a open-chamber diesel engine.

FATTY ACID - A carboxylic acid derived from or contained in an animal or vegetable fat or oil. Fatty acids may be saturated or unsaturated.

INDIRECT INJECTION DIESEL ENGINE - The compression volume is divided into a two (or three) distinct chambers, each separated by a restricting (throttling) passageway. The volume between the piston and cylinder is called the main chamber. The other volume is called antechamber. The fuel is injected into the antechamber. Also called a divided chamber diesel engine

SATURATED - The state in which all available valence bonds of an atom are attached to other atoms.

UNSATURATED - The state in which not all the available valance bonds are satisfied; in such compounds the extra bonds usually form double or triple bonds (chiefly with carbon).

Table of Contents

TABLES IN TEXT:

FIGURES IN TEXT:

EXECUTIVE SUMMARY

The short term performance of coconut oil in an unmodified diesel engine is satisfactory. There may be a 7% higher fuel consumption because of the lower calorific value of coconut oil. Long term engine trials with coconut oil as a fuel are very limited and the results are inconclusive. However, endurance tests with other vegetable oils may be used to indicate possible avenues for the successful use of coconut oil as a petroleum substitute.

Virtually all of the tests of vegetable oils and blends in the direct injection (DI) engines have produced rather heavy deposits on the injector nozzles and other engine components; including valves, cylinders, pistons, and rings; as well as contamination of the lubricating oil. A possible solution to the problems of long term operation of DI engines on vegetable oils may be achieved by the chemical process of transesterification. This involves modifying the vegetable oil by adding alcohol in the presence of a catalyst. The products of this chemical reaction are esters of the vegetable oils and glycerol. The glycerol is a high value material that may be exported. It is used for the manufacture of nitroglycerine. Many tests indicate that ester fuels can be used in DI engines without the carbon deposits which accumulate when straight vegetable oils and blends are used. Perkins Engines, Ltd. has indicated that they would be prepared to consider approval of a monoester of coconut oil as a fuel for their engines in Fiji. However, Fiji and other countries in the Pacific do not have a readily available, inexpensive supply of alcohol. The cost of obtaining alcohol for the transesterification process makes it uneconomical.

Research indicates that straight vegetable oil or blends with diesel fuel can be used in indirect injection (IDI) engines without carbon deposits or oil contamination problems, except possible in certain small single cylinder engines. Two engine companies will allow their engines to be powered with vegetable oil fuels. Klockner-Humbolt-Deutz, A.G. of Cologne, Federal Republic of Germany will extend their full factory guarantee on their indirect injection engines to cover fuelling with degummed sunflower oil. Caterpillar Tractor Company will offer IDI engines that will operate on 100% coconut oil.

The economic viability of using coconut oil for fuel is dependent on the locality. For most areas, it is not yet economically feasible to substitute coconut oil for diesel fuel. Presently, the price received from coconut oil in the edible market exceeds the price for which the coconut oil could be sold in the liquid fuel market. An economic analysis of small scale production on remote islands shows when coconut oil substitution would be economically feasible. Presently, it would be justifiable to use coconut oil as a liquid fuel on the Fijian island of Lakeba.

Based on this report, the following recommendations are made:

1. The Lakeba Cooperative Association should install a batch alkali refining tank and use alkali refined coconut oil to power their Caterpillar diesel-electric generator.
2. The Fiji Electricity Authority should set up one of their extra Caterpillar diesel-electric generators to operate with coconut oil. After proper operating procedures have been established, this system should be located at Savusavu.
3. The Public Works Department in Suva should test coconut oil as a petroleum substitute in their Toyota Land Cruisers, Hino trucks, and Caterpillar D6 dozers.
4. The Electric Power Corporation in Western Samoa should test coconut oil in one of their large slow speed Mirlees diesel-electric generators.

All of the above tests should use alkali refined coconut oil and total substitution. The tests should be carried out in cooperation with the manufacturers of their respective engines. Suggested test procedures are included in the report.

INTRODUCTION

Inexpensive oil was an important input into the relatively high economic growth of most countries over the years 1950 to 1973. Late in 1973, following the Arab-Israel war, Middle East oil producing countries through the Organization of Petroleum Exporting Countries (OPEC) collectively imposed a four-fold increase in crude oil prices. At the same time they temporarily reduced the supply of oil.

Although the oil was again available, the price for some developing countries was ruinous. Higher oil prices have led to a significant increase in external deficits of oil importing countries and have made them re-assess their economic situation and the use of their resources. To ease the foreign exchange constraint, attempts are being made to either reduce imported energy consumption through more efficient use and/or to develop domestic energy alternatives. It is in this context that the concept of using coconut oil as a substitute for diesel fuel has been developed in the Pacific Islands.

I. ENERGY SUPPLY AND USE IN FIJI

Fi ji is a small country of 660,000 people and 320 islands with a total land area of 18,300 sq. km. spread over 180,000 sq. km. of ocean excluding a 320 km economic zone. About a hundred islands are permanently inhabited. Approximately 90% of the population live on the two main islads of Viti Levu and Vanua Levu, with the greatest concentration (77%) on Viti Levu.

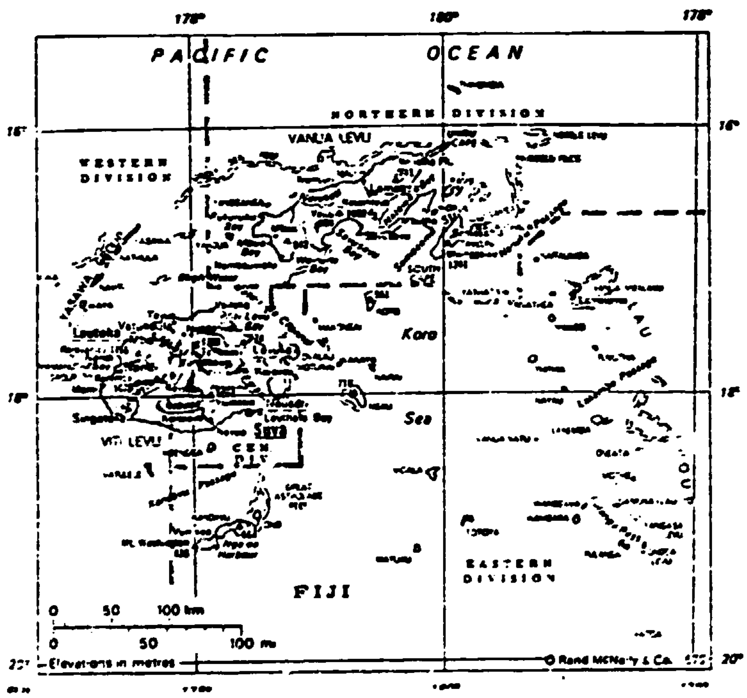

Figure 1. Map of Fiji

A. Energy Use in Fiji

A breakdown by sector of total estimated energy use in Fiji, in 1981, is shown in Table 1. The industrial sector is the largest consumer of energy (51%). Transportation is the next largest total energy consumer but it is the largest consumer (52%) of imported energy. Imported petroleum fuels and coal account for 45% of the estimated total energy use of nearly 26,000 terajoules. Further, all commercial energy is imported and consists of petroleum products and coal with petroleum comprising 96% of the imported energy.

Table 1. Total Energy Use by Sector in Terajoules (1981)

SECTOR	IMPORTED ENERGY					LOCAL ENERGY			TOTAL USE	
	Elec.	Petroleum Direct	LPG	Coal	(Total)	Bagasse	Wood	(Total)	TJ	%
Industry	830	910	10	480	(2230)	9910	988	(10898)	13,128	51
Transport	-	5965	-	-	(5956)	-	-	-	5,965	23%
Household	590	885	115	-	(1590)	-	3308	(3308)	4,898	19%
Commerce	1240	125	25	-	(1390)	-	-	-	1,390	5%
Govt & Misc	240	55	-	-	(295)	-	74	(74)	369	1%
Total	2900	7940	150	480	(11470)	9910	4370	(14280)	25,750	99%
%	11%	31%	1%	2%	(45%)	38%	17%	(55%)		100%

Notes: 1) 1 Terajoule is equivalent to about 27,000 litres of refined petroleum fuels.

2) Commercial energy is that normally purchased and used in the modern sector including petroleum, liquid petroleum gas, coal, nuclear, hydro and electricity. Non-commercial or traditional fuels are normally not traded internationally and include biomass, wastes, solar, wind, and other'renewables'. The distinction is not always rigorously maintained and categories are not rigid.

Source: Johnston, 1982.

B. Petroleum Imports

Petroleum imports have grown steadily in the past five years. The share of total imports accounted for by petroleum products increased by 81% from 1978 to 1982 (Table 2).

Table 2. Petroleum Import Costs

Year	Petroleum Imports (mm F$)	% of Total Imports by Value	Petroleum Imports as % of Total Export Earnings
1978	47.3	16	28
1979	72.4	18	34
1980	105.7	23	35
1981	138.5	26	52
1982	136.9	29	51

Source: Trade Reports, Bureau of Statistics, Suva, Fiji, 1978-1982.

C. International Comparisons

The extreme dependence of Fiji upon petroleum compared to other countries is shown in Table 3. Ninety four percent of the commercial energy use in Fiji comes from oil, all of which is imported. However, commercial energy use per person in Fiji is similar to other less developed countries and a tenth of developed countries.

Table 3. Commercial Energy Use: Fiji and Elsewhere (1978)

Energy Measure	World	Developed Countries	Less Developed	Fiji
GJ per capita	60.8	186.4	13.2	18.5
Oil as % at total	45%	52%	67%	94%
Avg. Annual Growth Rate	3.4%	1.9%	7.2%	6.1%
AAG per Capita	1.5%	1.0%	4.6%	3.9%

Source: Johnston, 1982

D. Petroleum Prices

The Government controls the maximum wholesale and retail prices of fuel products except for industrial diesel, fuel oil, and LPG. Motor gasoline is currently taxed at 16¢/liter and automotive diesel at 5¢/liter. Retail fuel prices are shown in Table 4. Because of tax differentials, initially there were large disparities between the price of gasoline, diesel oil, and kerosene. The trend has been to gradually remove these disparities. However, the current tax rates on gasoline and diesel continue to distrot relative retail prices of these products.

In real terms the price of oil products in Fiji nearly doubled between 1978 and 1982. In 1980, the Central Planning Office economic models indicated that this would result in a 6% increase in consumer prices, 19% increase in transport costs, 64% increase in electricity generating costs, 5% increase in overall construction costs, and 17% use in manufacturing costs. Agriculture, excluding sugar, would increase only 2%. No assessment was made of the impact on income distribution, employment, or economic growth. The current forecast of 2.3% real average annual growth in Gross Domestic Product from 1981 to 1985 is well below the projection of 4.7% made two years ago. It is not known how much of the reduction is due to energy prices.

Table 4. Retail Prices for Petroleum Products (F¢/liter)

December	Gasoline	Automotive Diesel	Kerosene	Premix
1978	28.7	14.9	18.0	18.3
1979	37.0	25.0	25.0	26.0
1980	44.0	31.0	32.0	33.0
1981	52.0	38.0	37.0	40.0
1982	55.0	43.0	43.0	48.5

Note: Premix is a blend of gasoline and lubricating oil for small transport boat outboard engines.

Source: World Bank, 1983.

E. Vehicle Means of Propulsion

In 1981 a survey of the vehicle population was done to determine the market available in Fiji for the use of ethanol as a fuel (British Petroleum, 1981a). Data on vehicle imports showed there had been a significant trend to diesel powered cars and light goods vehicles (Table 5). The major reason for

Table 5. Dieselization of Cars and Light Passenger Vehicles

	1978	1979	1980	1981*
Diesel Cars	56	151	208	364
Other Diesel Passenger Vehicles not exceeding 2t	97	100	217	-
Cars other than Diesel	911	1088	774	1423
Other Non-Diesel Passenger Vehicles not exceeding 2t	454	210	199	-
% of Cars Diesel	6	8	21	20
% of other Vehicles Diesel	18	32	52	-

Source: British Petroleum, 1981a

the purchase of a diesel vehicle is the lower cost of diesel fuel (Table 4). Diese is 12¢/liter chepaer than gasoline and additional mileage is obtained from one liter of diesel compared to one liter of gascline. Further, diesel cars purchased as taxis are eligible for a 25% discount which reduces their cost to a level comparable with gasoline cars. It is not known how far dieselization will progress, and what proportion of cars and light goods vehicles will ultimately be diesel powered. To a large extent this will depend on incentives offered by Government.

F. Trends in Demand

Annual sales of petroleum fuels in Fiji since 1978 are shown in Table 6. Motor spirit and kerosene demand, products purchased primarily by households, has dropped since 1980.

Table 6: Demand for Petroleum Fuels

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
	(million liters)									
Auto diesel	51.5	49.6	56.7	62.8	64.4	70.1	80.4	89.6	100.1	110.1
Motor spirit	51.3	48.9	51.2	50.2	54.7	58.3	60.1	57.1	56.1	55.1
Kerosene	20.6	19.1	21.6	21.8	22.4	22.4	23.5	21.7	20.1	19.9
White Benzine	3.0*	3.0*	3.0	3.5	3.6	4.2	4.0	4.4	4.3	4.2
LPG	4.0	3.9*	3.8*	3.7*	3.7	3.5	4.7	4.7	5.3	6.5
Ind. Diesel	62.0	58.7	68.3	70.9	88.2	82.2	85.5	88.2	92.4	75.4
Fuel oil	28.9	23.2	13.1	12.3	14.7	18.3	15.8	14.3	10.9	8.4
Total Ground Fuels	221.3	206.4	217.7	225.2	251.7	259.1	274.0	280.0	289.2	279.6
Avgas	1.3	1.3	1.2	1.3	1.6	2.1	1.6	1.0	0.5	0.7
Jet Fuel	150.8	120.1	99.6	98.2	88.2	89.8	93.3	94.5	84.7	82.4
Total All Fuel	373.4	327.8	318.5	324.7	341.5	351.0	368.9	375.5	374.4	362.7

Notes:
1. Data are annual sales as reported by suppliers, except for LPG where data are retained imports as reported by the Bureau of Statistics. An asterisk (*) indicates an estimate made in the absence of data.
2. Over three fourths of jet fuel sales are to foreign airlines

Source: Newcombe, 1982 and Tavanuvanua, 1983.

Automotive diesel demand has continued to increase. The average growth rate in total diesel use has been 5.8% p.a. although sales for 1982 showed a decline in demand for industrial diesel oil as the major construction activities at the Monasavu and Vaturu dams are completed. The average growth rate in total ground fuels sales from 1973 through 1982 was 2.8% p.a.

Fiji is divided by the oil companies into six market areas. The marketing and distribution efforts of the oil companies are concentrated in the major islands of Viti Levu, Vanua Levu, Taveuni, and Ovalau. All other outer islands are left to be catered by independent marketers. All the marketers, however, rely on the oil companies for supplies. Viti Levu alone accounts for over 92% of the total petroleum fuel consumption in Fiji. Out of this, the Suva area accounts for about 51%. Among other islands, the share of Vanua Levu is about 7%, comprising 5.7% in the Labasa area and 1% in the Savusavu area. Taveuni and Ovalau account for 0.1% and 0.99% of total sales in Fiji respectively.

G. Patterns of Use

As was stated before, all commercial energy is imported. Table 7 shows a breakdown of commercial energy use by sector. Transport and industry are the key users (71%) of commercial energy. Transport alone accounts for over half

Table 7: Commercial Energy Use by Sector in Terajoules (1981)

	PETROLEUM FUEL PRODUCTS							NON-PETR		TOTAL USE	
	Ind. Elec.	Distill. Direct	IFO	Aviation	ADO	PETR	KERO	LPG	COAL	TJ	%
Transport	-	-	66	144	3880	1875	-	-	-	5965	52%
Industry	830	550	350	-	-	-	10	10	480	2230	19%
Households	590	-	-	-	-	-	885	115	-	1590	14%
Commerce	1240	100	-	-	-	-	25	25	-	1390	12%
Govt.	240	5	30	-	-	-	20	-	-	295	3%
Total	2900	655	446	144	3880	1875	940	150	480	11,470	100%
%	25	6	4	1	34	16	8	1	4	-	99

Notes: 'Elec' is Industrial Distilla e used to generate electricity

Source: Johnston, 1982.

of Fiji's petroleum consumption. During the first full year of hydroelectric power production (1984) the share of transport in petroleum consumption is expected to exceed 75% of the total petroleum consumption. The bulk of transport fuel use will be automotive distillate. The reduction or replacement of transport fuel use is the key to future levels of petroleum use in Fiji. After the 80MW Monasavu hydro-electric station comes on line in 1983, a 3% reduction in transport fuel use would achieve the same savings as a 10% reduction in all other petroleum uses combined. The next largest use category is electricity generation which used about one-fourth of total petroleum fuel consumption in 1981. At present all generation is by diesel fuel, but the Monasavu hydro-electric scheme will displace well over 90% of the diesel use.

Energy Use in Trasnport

The reduction or replacement of transport fuel use is the key to future levels of petroleum use in Fiji. Transport fuel use is dominated by road travel (Table 8). Air and sea travel account for only 20% of total consumption and have remained static since 1978. Ground transport fuel use grew at an average annual rate of 9% between 1978 and 1981.

Table 8: Transport Fuel Use, 1978/1981

Year	Ground	Sea	Air	Total
1978	102	25	4	132
1981	133	25	4	162
AAGR	9%	0	0	7%

Note: Excludes international travel

Source: Johnston, 1982

The bulk of ground transport growth was in "miscellaneous" use of automotive distillates.(Table 9). Although distillate will continue to dominate transport fuel use, the high levels of recent years are due to temporary construction activities, such as Monasavu and Vaturu dams. A 6% reduction in ground transport fuel consumption would save $1.1m per year in Fiji's automotive distillate import bill at 1982 prices.

Table 9: Ground Transport Fuel Use: 1978-1981
(million litres)

YEAR	CARS	TAXIS[a]	GOODS[b]	BUSES	CANE	MISC[c]	TOTAL
1978	22	12	38	18	6	6	102
1981	22	12	45	22	6	26	133
AAGR	0	0	6%	7%	0	63%	9%

Notes:
- a. Includes rental & hire cars
- b. Includes commercial
- c. Includes agricultural use

Source: Johnston, 1982

Energy Use in Industry

The use and cost of commercial forms of energy within industry for 1981 is shown in Table 10

Table 10: Commercial Energy Use Within Industry, 1981

MEASURE	ELEC	IDO	IFO	ADO	PETROL	COAL	LPG	KERO	TOTAL
Consumption (TJ)	830*	550	350	1080	200	480	10	10	3510
TJ by %	24	16	10	31	6	14	-	-	100
Cost (F$M)	8.1	4.1	2.1	9.4	2.7	1.1	0.2	0.1	27.8
Cost by %	29	15	8	34	10	4	-	-	100
% of total National Cost	29	84	78	28	11	100	7	1	100

Notes: 1. - indicates less than 1%

2. * energy value of fuel used in generation: 12.4 MJ/kwh

Source: Johnston, 1982

The total cost of commercial energy use in 1981 was estimated at $27.8 million. Transport accounted for 44%, much of this being automotive distillate used in construction.

Energy Use in Households

The majority of kerosene and white benzene is used for domestic cooking and lighting in rural areas. This market is subject to change. The rural electrification program will bring electric light to many more rural communities thus reducing kerosene demand for lighting. In the period 1981 to 1985, the Eighth Development Plan for Fiji projects a $1.7 million expenditure on rural electrification. In fact, the FIJI Electricity Authority is spending well over $1 million/year and the Public Works Department is spending about $0.25 million/year. The number of households to be converted and the magnitude of the effect on kerosene consumption is not known. This is to be studied by an Asian Development Bank study to begin in September, 1983.

Wood is presently the most common cooking fuel in Fiji being used exclusively by 60% of the 67,000 rural households and 6% of the 49,000 urban households. In addition 28% of rural and 14% of urban households supplement wood with kerosene. Kerosene is the next most important cooking fuel in terms of quantity of energy though perhaps the most important fuel in economic terms. Kerosene is used exclusively by 10% of rural and 58% of urban households. Household cooking accounts for 13.3 ML or 66% of total national use.

H. Future Petroleum Demand

Future petroleum demand has been established by the Ministry of Energy (ME) in Fiji (Johnston, 1982) and by the World Bank (WB) (1983). Their estimates are shown in Table 11.

Table 11: Petroleum Demand Projections

	Actual	Projections (ME)		Projections (WB)			
Product	1981 (Mtoe)	1985 (Mtoe)	Growth (% p.a.)	1985 (Mtoe)	Growth (%p.a.)	1990 (Mtoe)	Growth (%p.a.)
LPG	3.6	-	-	5.3	10.2	8.5	9.9
Avgas	0.4	-	-	0.4	-	0.4	-
Gasoline	44.8	48.5	2.0	45.0	0.1	47.3	1.0
Kero/Turbofuel	25.9	27.0	1.0	24.0	(1.9)	26.0	1.6
ADO	92.7	107.2	3.7	92.0	(0.2)	101.6	2.0
IDO	84.9	23.0	(27.8)	22.0	(28.6)	24.0	1.8
IFO	10.6	10.6	-	10.0	(1.4)	10.0	-
Total	262.9	216.3	(4.4)	198.7	(6.8)	217.8	1.9

Note: Mtoe = 1000 tonne of oil equivalents = 10 billion kilocalories
Source: Johnston, 1982 and World Bank, 1983

Both sources indicated that the total petroleum demand in 1985 is expected to decline. There is a large decline in IDO due to replacement with hydroelectric power from the Monasavu Dam. The magnitude of their 1985 projections differ but they both indicate that ADO will account for 46% to 50% of the total petroleum demand in 1985. Further, ADO and IDO combined will account for 57% to 60% of the 1985 total petroleum demand. Therefore, it is prudent to seek a substitute for these products. Between 1985 and 1990, the World Bank estimates total petroleum demand to increase at about 1.9%p.a. Beyond 1985:

(a) gasoline demand is expected to increase at 1% p.a.,

(b) demand for distillate and kerosene is expected to increase at about 2% p.a.

(c) LPG demand will increase at 10% p.a., and

(d) residual fuel oil and aviation gasoline demand will remain static.

A forecast of future ADO demand has also been developed by British Petroleum 1981a. These projections are shown in Table 12. Beyond 1985, British Petroleum states that the estimates are no more than indications of possible trends. However, the relative importance of the various sectors are shown.

Land transport is the largest user of ADO, consuming over 60% of the projected demand, followed by marine trasnport and construction use. Therefore, the use of coconut oil as a substitute ADO should concentrate on these sectors of the market

Table 12: Projected ADO consumption in Fiji; 1985-2000
(Kilolitres)

YEAR	TRANSPOPT	AGRIC	MARINE	IND'L	CONSTRUCT	TOTAL	GROWTH % p.a.
1985	80400	8400	20600	600	16500	126500	2.6
1990	88800	10800	22800	700	20000	143100	2.5
1995	98000	13700	25100	900	24400	162100	2.5
2000	108200	17500	27800	1100	31100	185700	2.8

Source: British Petroleum, 1981a.

All three projections give different estimates of ADO demand in 1985. The Ministry of Energy estimates the 1985 demand to be 127.2 ML which is comparable to the British Petroleum estimate of 126 ML. The World Bank projects a more conservative demand of 109 ML. The 1990 demand projections for ADO are estimated at 143.1 ML by British Petroleum and 120.5 ML by the World Bank. Once again the World Bank projects a lower demand. However, both organizations have projected a similar growth per annum of 2.0% to 2.5%. For further analysis in this report, the more conservative World Bank demand projections will be used.

I. Future Petroleum Prices and Import Costs

Recent World Bank (1982), University of Hawaii's East West Centre (Johnston, 1982), and British Petroleum (1981b) analysis all indicate fairly constant real prices through 1985 followed by real increases of 3% per year through 1990. From experiences of the past decade, the c.i.f. price of refined products in Fiji can be expected to increase at least as rapidly as crude oil prices and probably more given Fiji's increasing use of ADO. Table 13 presents crude estimates of the cost (c.i.f. basis) of retained petroleum imports through 1990, in the absence of conservation.

Table 13: Cost of Retained Imports; 1982-1990
($Millions)

IMPORTS	1982	1985	1990
Volume (ML)	278	209	229
Cost ($M) 1982 constant Dollars	77.8	58.5	64.1
Cost ($M) Current Dollars	77.8	58.5	74.3

Notes: 1) 1985 & 1990 Volume taken from World Bank (1983) estimates

2) Inflation in imported oil assumed to be constant until 1985 and then 3% p.a.

3) Retained imports = total imports minus Re-exports
Re-exports = marine bunkers, international aircraft and sales to other Pacific Islands.

J. Effect of Coconut Oil Substitution for ADO

The future demand for ADO has been estimated at 46% to 50% of total future petroleum demand. The level of savings in petroleum import volume and cost due to 10% ADO substitution is shown in Table 14. The level of savings would be $3.0 million in 1985 and 3.9 million in 1990.

Table 14. Possible Savings in Petroleum Imports Due to Coconut Oil Substitution for Automotive Distillate; 1985 & 1990.

			Millions of Dollars Saved	
Year	Fuel Savings %	Fuel Savings ML	Constant 1982$	Current $
1985	10	10.9	3.0	3.0
1990	10	12.1	3.4	3.9

Notes: 1) Based on World Bank (1983) estimates and 1982 c.i.f. $0.28/L

2) Inflation in Imported Oil assumed to be constant until 1985 and then 3% p.a.

The above reductions in imports and savings do not reflect employment creation and foreign exchange savings due to substitution.

II. COCONUT OIL PROCESSING

A. Processing Objectives and Steps

Copra, the primary product of the coconut industry is produced by drying the kernel of mature coconuts. The quality of copra depends upon several factors, namely: the maturity of the nuts, the extent and conditions of drying, the storage and handling conditions, and to some extent, the variety of the coconut trees.

The overall objectives of extracting oil in the copra producing countries are to:

(a) Produce oil for further processing or utilization;

(b) Supply the demand for oil and meal both in the loacl and foreign markets;

(c) Achieve an economic advantage;

(d) Extend coconut storage life and reduce storage loss; and

(e) Achieve marketing flexibility.

The seven basic steps in the process of oil extraction are:

(1) Husking and drying

(2) Copra storage

(3) Preparation of copra

(4) Oil extraction

    Full-press method

    Prepress-Solvent Method

    Full-solvent method

(5) Processing of the extracted oil

(6) Processing of the meal

(7) Storage of products

Catanaoan and others (1980) have prepared an excellent report on coconut oil extraction. It should be referred to for details. This report only covers factors which may influence the quality and quantity of coconut oil as a liquid fuel replacement.

B. Husking and Drying

Although machines for the removal of the husk, and for both husking and splitting the nut, have been designed, none has so far proved very satisfactory and husking is more usually carried out by hand. The nut is impaled on a sharp iron or wooden stake fixed upright in the ground so that its point is about 80 cm above the surface. By giving the impaled nut three to four quick twists, the husk can be removed by hand. Alternately, the nut is not husked. The shell of the nut is cracked into two approximately equal pieces by means of a sharp blow on its 'equator' with a chopping knife, hatchet, or small axe.

Opened wet coconut is subject to rapid decomposition. Coconut meats containing 20 percent or more of moisture are susceptible to bacterial attack and this is quickly followed by the appearance of fungi. Some of the odors produced by fungi are attractive to insects. Insect attack increases the chances of further attack by fungi. It is therefore most important that the moisture content of the coconut meat be reduced as rapidly as possible after the coconut is opened, and the time elapsing between opening and commencement of drying should not be more than two or three hours. During drying, the moisture content of the coconut meat must be reduced from about 50 percent down to between 5 and 7 percent.

In order to produce a good quality copra, drying must be neither too slow nor too fast. The stages for successful drying are: (1) initial reduction of moisture content from about 50 percent to 35 percent, preferably within 24 hours, (2) reduction of moisture content to about 20 percent during a second 24-hour period, and (3) the reduction of moisture content to about 5 or 6 percent during a third 24-hour period. (Cornelius, 1973).

Sun-dried copra takes five to seven days to produce under good climatic conditions. Artificial drying methods include smoke curing or drying over an open fire in direct driers or kilns, and indirect drying either on a heated platform or in an enclosed chamber heated by flues. In practice, use of these artificial drying methods is often combined with sun drying. Indirect driers have the advantage over direct driers because the copra does not come in to contact with the combustion gases or smoke of the applied fuel. Many varieties of kilns or driers are available, constructed to suit local rural conditions.

Drying at too high a temperature results in the alteration of the texture of the meat and decomposition of the oil. Such 'case-hardened' copra is brown and has a 'burnt' odor which is transferred to the oil, making it less useful for edible purposes. It is prone to insect attack. Case-hardened copra also produces less oil in the press. Because of its elasticity, the copra cake may contain more than 7 percent of the oil instead of the usual 6 percent for double pressed cake. This means an appreciable loss in the output of oil (Cornelius, 1973).

C. Copra Storage

The main purpose of copra storage is to provide a buffer stock of copra to make up for differences between copra delivered and copra processed.

Incidentally, the storage performs two functions important for oil extraction: to dry the copra, and to equalize the moisture content of copra prior to processing.

Facilities for copra storage vary from plant, but the basic requirements for good storage are:

1. Protection from the elements and pests;
2. Adequate ventilation;
3. Sufficient storage space; and
4. Suitable equipment for handling and movement of copra

In large plants, a separate building is used for copra storage. In small plants, the copra may be stored in an empty space within the mill building. Piling of copra in large buildings is arranged to facilitate first-in, first-out withdrawals so that the copra with least moisture is processed first and the new copra deliveries allowed to dry in storage before processing.

D. Preparation of Copra

The purpose of copra preparation is to cut it to the right size, dry it to the required moisture content, heat it to the right temperature, keep it at the right temperature for a sufficient period of time, and form it to the right shape, before it is subjected to the extraction process. Grinding the copra opens the oil cells to expose the oil for extraction. Moisture content affects the efficiency of extraction. Increasing the temperature reduces the viscosity of the oil for easier flow, while keeping the material at a high temperature for a period of time coagulates the proteins to reduce resistance to oil flow through the material during extraction.

The equipment for size reduction and particle formation are hammer mills, peg mills, disk mills, rollers and flakers. The mills break the material to the desired sizes; the rollers break and compress large particles left out after crushing and grinding; the flakers compress the material into thin and firm flakes suitable for solvent extraction. The size reduction equipment should not generate too much heat to cause excessive temperature rise of the material which may cause darkening of the oil.

The equipment used for drying and preheating are dryers, cookers, and conditioners. The design of these equipments are of two general types: the multi-decked kettle type, with steam-jacketed pans and revolving stirrer-scrapers; and the horizontal drum type, with steam-jacketed wall and rotating stirrer-conveyor screws. They are equipped with vapor ducts and exhaust fans.

E. Oil Extraction

The oil in the copra is removed by either or both of the following processes: pressing or expelling; and solvent extraction or leaching. Pressing compresses the oil bearing material and forces the liquid (oil) to escape, but retains the solid (cake). By convention, the chunky residue extruded out of the expellers or press is called "copra cake" while the ground copra cake is called "copra meal". Others use the term copra cake for expeller residues regardless of size, while the residue from solvent extraction is called meal.

There are three general methods of oil extraction: the full-press or mechanical method; the preepress-solvent or mechanical-chemical method; and the full-solvent or chemical method. In the full-press method the prepared material is pressed between the screws (worm) and the cage (slitted steel bars). In the prepress-solvent process, the copra is partially deoiled by preliminary low-pressure mechanical extraction, then subjected to solvent extraction to remove most of the remaining oil. The equipment used for the prepressing may be similar to expellers for full-pressing (with adjustments for higher through-put) or a special prepressing expeller. The equipment for solvent extraction consists of two general types: the roto-cell type with cells revolving around a vertical axis; and the basket type, with baskets travelling horizontally; while the dissolving liquid is sprayed over the material in a counter-current flow. In solvent extraction, the oil in the material is leached with a suitable solvent under suitable conditions. In the process, oil (the soluble material) is dissolved by the solvent while the meal (the insoluble material) is retained unaffected by the solvent. The most common solvent used is hexane, because of its price, low toxicity, suitable boiling point for recovery and handling, and its availability.

F. Processing of the Extracted Oil

The oil from the expellers contains substantial quantities of solids (foots) that should be removed before the oil is pumped to the storage tanks. The oil is cleaned in two stages: First by settling and screening, and then by filtration. The screening equipment is a rectangular steel tank equipped with a continuous drag chain conveyor with scraper blades which scoop the settled solids and then lift them over a fine screen for drainage at one end of the screening tank and are conveyed back to the expellers to be mixed with the copra.

The filtering equipment is generally a plate and frame filter press with canvas filtering media. Some plants use leaf filters with perforated steel filtering leaves. The foots or filter cake from the filters are recycled to the expellers for oil extraction. The filtration is necessary to prevent plugging of fuel filters in the diesel engine. The filter should remove all particles greater than 4 micrometers in diameter. The oil product from solvent extraction is free of solids.

After setting and filtering, the oil contains triglycerides, free-fatty acids, and other fat-like material. The latter may cause gums to form in engines. So further processing is required before the oil is satisfactory for diesel engines. The need for refining is increased by the presence of mold or bacteria on the copra and high moisture content.

Vegetable Oil Refining

The term oil refining is usually meant to include four basic operations: neutralizing, winterizing, bleaching, and deodorizing.

Neutralizing, or alkali refining, removes the free fatty acids and phosphatides (gums). It also destroys any bacteria which may be present in the oil. Alkali refining consists of adding a calculated amount of alkali to the oil and then agitating the mixture to promote intimate contact of the two phases. Free fatty acids are saponified by caustic soda and are later separated in the water phase. Non-hydratable compounds (other than fatty acids) are also removed in this step. Further water washing is necessary to remove the last traces of soap in the oil. Centrifugation is the means of separating the two phases in this step.

After refining, edible oil is subjected to a series of polishing steps to improve characteristics such as color, odor, and stability. These include winterizing, bleaching, and deodorizing. Winterizing is done by cooling the oil to produce partial crystallization followed by separation of shortening or margarine solids. Bleaching is done to remove color constiuents. Deodorizing is performed by steam distillation to remove impurities responsible for taste and odor. Winterizing of the oil may be necessary for engine operation in cooler climates. Bleaching and deodorizing are not important for the production of a fuel oil.

The levels of refining of vegetable oils may be defined as follows:

1. Crude oil: raw oil removed from the vegetable oil seed and filtered. The extraction method used should be indicated; i.e. screw press, solvent extraction, etc.
2. Crude degummed oil: crude oil which has most of its gum removed. A small quantity of water is intimately mixed to hydrate the gums, which are then removed by centrifuging, settling, or cooling.
3. Alkali refined oil: oil which has been alkali refined. This is the minimum recommended level of refining for coconut oil which will be used for diesel engine fuel.

4. Fully refined oil: produced from alkali refined oil by bleaching, winterizing and deodorizing. This oil is suitable for human consumption.

Vegetable Oil Transesterification

The alcohol esters of vegetable oil are also being considered as a substitute for diesel fuel. The alcohol esters from coconut oil are produced by either an acid-catalyzed or base-catalyzed chemical combination of coconut oil and alcohol. The chemical reaction between coconut oil and ethyl alcohol which results in the production of ethyl esters may be represented by the following equation:

649.6 g coconut oil + 138 g ethanol =
691.3 g ethyl ester of coconut oil + 92 g glycerol

If methyl esters are desired, the chemical reaction between coconut oil and methanol is as follows:

645.6 g coconut oil + 96 g methanol = 649.6 g methyl
ester of coconut oil + 92 g glycerol.

The alcoholysis takes place at prevailing tropical ambient temperatures, or slightly higher but within solar range. Reaction time is about one hour. The by product is glycerol, a valuable material. Methanol appears to have an edge over ethanol for the transesterification reaction. Methanol can be more easily obtained in the desired anhydrous form and is cheaper than ethanol.

G. Processing and Using the Copra Meal

The copra cake leaves the expellers at about 110°C. It is cooled through a cake cooler. After cooling it is ground to fine particles by hammer mills or disk mills. The ground meal may be bagged for the local market or pelletized for export. As a rule the oil content of the copra meal should not exceed 10% and the moisture content should not exceed 12%. The sum of the oil content and the moisture content should not exceed 18% (Catanaoan, et al., 1980).

H. Copra Milling in Fiji

Oil milling in Fiji is done by four companies. Their total capacities and present volume of copra processing are shown in Table 15. All of these mills are full press mills. The total available capacity in the country is 56,500 tonnes of copra per annum. The capacity utilized is 45% due to insufficient copra production in Fiji.

Another copra plant is being built at Vanua Balavu. It will have a capacity of about 1,250 tonnes per annum. Punja and Sons could install 9000 tonnes per year of additional capacity if copra production is increased. Further, feasibility studies are being undertaken into the possibility of setting up a 6,000 tonne per annum coconut oil mill at Savusavu, VanuaLevu.

Table 15: Copra Milling Capacity in Fiji

Company	Available Capacity Metric Tonnes	1982 Volume Processed Metric Tonnes	Annual Usage, %
Island Industries, Ltd	42,000	16,138	38
Burns Philips South Sea Co.	8,000	4,800	60
Punja & Sons Ltd	4,500	4,000	89
Lakeba Co-operatives Assn Ltd.	2,000	694	35
TOTAL	56,500	25,632	45

I. Oil Refining in Fiji

Two companies are producing refined oils in Fiji. Their total capacities and present volume of production are shown in Table 16. The total oil refining capacity is 9600 tonnes per annum. The oil refining capacity is 85% utilized. An additional 2200 tonnes per annum could be neutralized and bleached by Punja & Sons, in a separate facility.

Table 16: Oil Refining Capacity in Fiji

Company	Available Capacity Metric Tonnes	1982 Volume Processed Metric Tonnes	Annual Usage, %
Fiji Food Ltd	7,000	5,400	77
Punja & Sons Ltd	2,600	2,400	92
TOTAL	9,600	7,800	85

III. COCONUT OIL AS A FUEL

It has been recognized for many years that vegetable oils can be burned in compression ignition engines. As early as 1900, a diesel engine was demonstrated running wholly on ground-nut oil at the Paris exposition (Nitske, 1965). However, vegetable oils have not been accepted as viable substitutes for diesel fuel because of inexpensive and abundant supplies of petroleum-based fuels.

A. Fuel Properties

Almost all of the fuels commonly used in diesel engines today are products of crude petroleum. In general, all crude petroleum has a molecular structure made up mainly of combined carbon and hydrogen.

Requirements for diesel fuel oils have been issued by the American Society for Testing Materials (ASTM) in a report titled "Standard Specification for Diesel Fuel Oils, " (ASTM 1978). The categories of diesel fuel most commonly used in Fiji are automotive diesel oil (ADO) and industrial diesel oil (IDO). Table 17 covers the limiting requirements, based on British standards, for these fuels. The technically identical ASTM standard is also listed. The ASTM standard specifies certain properties of diesel fuels as well as the standard tests for measuring these properties. Boldt and Hall (1977) have provided a detailed discussion of the significance of these standard tests.

The requirements for a good compression ignition (CI) fuel cannot be simply stated. Obert (1973) states "This situation arises because of the added complexity of the CI engine from its heterogenous combustion process. which is strongly affected by injection characteristics." However, he gives the following general observations which can assist in identifying good CI fuels:

1. Knock Characteristics. "The present-day measure is the cetane rating - the best fuel, in general, will have a cetane rating sufficiently high to avoid objectionable knock."
2. Starting Characteristics. "The fuel should start the engine easily. This requirement demands high volatility, to form a readily combustible mixture; and a high cetane rating in order that the self-ignition temperature will be low.
3. Smoke and Odor. "The fuel should not promote either smoke or odor from the exhaust pipe. In general, good volatility is demanded as the first prerequisite to insure good mixing and therefore complete combustion."

Table 17. Requirements for Diesel Fuel Oils

	ADO Clsss A1	ADO Class A2	IDO Class B1	IDO Class B2	Test Method
Kinematic Viscosity at 37.8C (100 F), mm^2/S min.	1.6	1.6	-	-	
max.	6.0	6.0	14	14	ASTM D445-IP71
Cetane Number, min.	50	45	35	-	IP41
Carbon residue, Conradson % by weight, max.	-	-	0.2	1.5	ASTM D189-IP13
Carbon residue, Conradson on 10% residue, % by weight, max.	0.2	0.2	-	-	
Distillation, recovery at 357°C or 675°F, % by volume, min.	90	90	-	-	ASTM D86-IP123
Flash Point, closed, Pensky-Hartens, min.	55°C or 130°F	55°C or 130°F	66°C or 150°F	66°C or 150°F	ASTM D93-IP34
Water Content, % by volume, max	0.05	0.05	0.1	0.25	IP74
Sediment, % by weight, max.	0.01	0.01	0.02	0.05	ASTM D473-IP53
Ash, % by weight, max.	0.01	0.01	0.01	0.02	ASTM D482-IP4
Sulphur content, % by weight, max	0.5	1.0	1.5	1.8	IP63
Copper corrosion test, max.	1	1	-	-	ASTM D130-IP154
Cloud Point, max. Summer	0°C (32F) March/Nov. Inclusive	0°C (32F) March/Sept. Inclusive	-	-	
Winter	-7°C or 20°F Dec/Feb Inclusive	-7°C or 20°F Oct/Feb Inclusive	-	-	ASTM D2500-IP219
Pour Point, max.	-	-	0°C or 30°F	3°C or 35°F	ASTM D97-IP15

4. Corrosion and Wear. "The fuel should not cause corrosion before combustion, or corrosion and wear after combustion. These requirements appear to be directly related to the sulphur, ash, and residue contents of the fuel."
5. Handling Ease. "The fuel should be a liquid that will readily flow under all conditions that will be encountered. This requirement is measured by the pour point and the viscosity of the fuel. The fuel should also have a high flash point since an advantage of the CI engine is its use of fuels with low fire hazards."

Vegetable oils differ in chemical composition from petroleum fuels. The former consists primarily of glyceryl esters of fatty acids, or triglycerides. Structurally, a triglyceride is one molecule of glycerol linked to three molecules of long-chain monocarboxylic (fatty) acids. The resulting vegetable oil molecule is much larger than petroleum molecules and, unlike petroleum, the vegetable oils also contain some oxygen.

The differences in chemical structure between vegetable oils and petroleum lead to differences in fuel properties. Table 18 lists some of the important fuel related properties of coconut oil and ethyl cocoate compared to diesel fuel.

Table 18: Fuel Properties

	Diesel Fuel (ADO)	Coconut Oil	Ethyl Cocoate
Density, kg/mm^3 @ 15 C	0.845	0.919	0.866
Gross Heating Value, KJ/L	38.2	35.6	33.2
Viscosity, mm^2/s @ 40^oC	1.6 - 6.0	28.3	2.75
Cloud Point, ^oC	-3	17.6	-14

Sources: Solly, 1980; British Petroleum, 1981a; Galloway and Ward, 1983

An important difference appears in the heat of combustion, or gross heating values. Coconut oil has 6.8% less energy content per liter than diesel fuel and ethyl cocoate has 13% less energy than diesel fuel. It would be expected on this basis that an increase in volumetric fuel consumption would be observed when an engine used coconut oil or the ethyl esters of coconut oil. The amount of decrease in energy content compared to diesel fuel is dependent on the type of vegetable oil. An empirical equation can be used to calculate the gross heat of combustion based upon the saponification value and the iodine value (Swern, 1979):

$$\text{Heat of combustion (cal/g)} = 11,380 - (\text{iodine value}) - 9.15^{*} (\text{saponification value}).$$

Probably the greatest physical difference between coconut oil and diesel fuel is their viscosities. Coconut oil is about 10 times more viscous than diesel fuel at 40°C while ethyl cocoate is about the same viscosity as diesel fuel. Viscosity is critically dependent on temperature, and the viscosity of vegetable oils is more seriously affected by temperature than that of diesel fuels. Figure 2 shows the relationship between viscosity and temperature for sunflower oil and diesel fuel.

Other physical property differences include higher densities along with higher cloud points for coconut oil. High densities result in greater weight per unit volume. The cloud point is defined as that temperature at which a cloud or haze of wax crystals appears at the bottom of a test jar when chilled under prescribed conditions. Higher cloud points may become a limitation for the use of coconut oil in colder temperatures.

B. Fuel Modification

Since most engines are powered by the more fuel efficient direct injection engine, and since the cost of modifying the engines would be prohibitive, the major emphasis in recent investigations has been in modifying the fuel. Three major proposals have been made to alleviate the problems associated with the use of vegetable oils as fuel.

First, heating the vegetable oils will reduce their viscosity to near that of diesel fuel (Figure 2). At 90°C the viscosity of vegetable oils is about 6.0 cSt which is the maximum recommended viscosity for diesel fuel (See Table 17). However, heating the fuel does require engine modifications.

Second, another method of changing the physical properties of a vegetable oil to become more comparable with those of diesel fuel is to dilute the vegetable oil with other less viscous liquid fuels thereby forming blends that have been termed hybrid fuels. The most popular hybrid fuel has resulted from blending vegetable oils with diesel fuel. Table 19 shows some of the properties of vegetable oi/diesel fuel blends. Another approach has been to incorporate aqueous alcohol into vegetable oils in the form of microemulsions that have good fuel properties. (Boruff, et. al., 1982; Schwab, et. al., 1982).

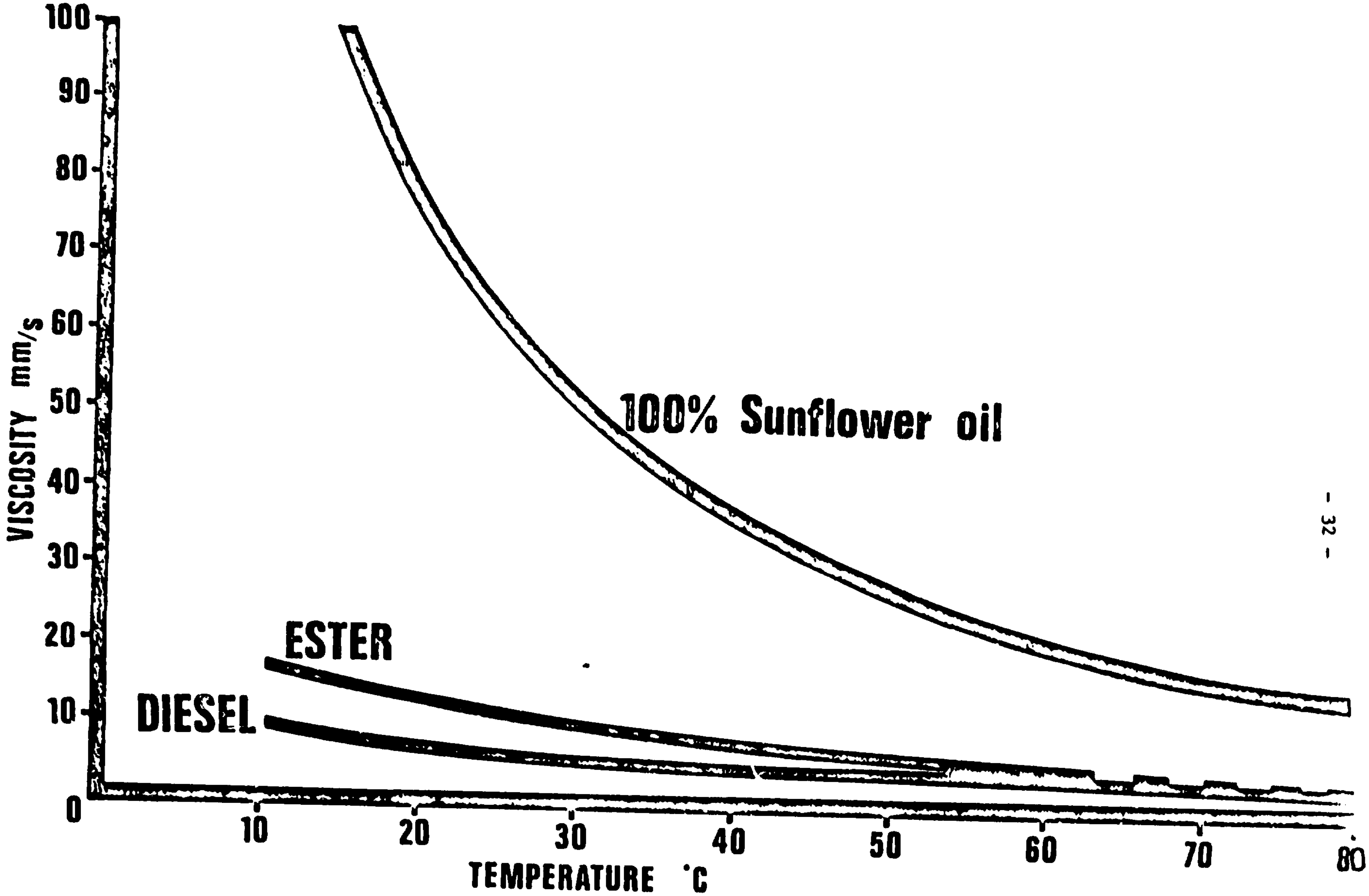

Figure 2. Relationship between Viscosity and Temperature for Sunflower Oil, Ester and Diesel Fuel.

Table 19. Vegetable Oil/Diesel Fuel Blend Properties

	Viscosity at 100°F, cSt	API Gravity at 60°F	Flash Point F(C)	Pour Point F(C)	Cetane Number	Gross Heat of Combustion, Btu/lb
Reference Diesel Fuel	3.46	32.0	159(71)	-58(-50)	44.3	19215
Peanut Oil						
25%	6.60	29.5		5(-15)	41.8	
50%	12.60	27.1	183(84)	16(-9)	40.5	
100%	39.51	22.7	622(328)	28(-2)	39.0	17045
Sunflower Oil						
25%	6.40	29.3		-4(20)	42.1	
50%	10.75	26.7	177(81)	-21(19)	40.8	
100%	33.45	21.9	608(320)	16(-9)	33.4	17010
Soybean Oil						
25%	6.25	29.3		-13(-25)	43.6	
50%	11.28	26.7	179(82)	-21(-19)	41.9	
100%	32.31	21.9	597(314)	16(-9)	41.5	1677

Note: Blends are % v/v.

Source: Southwest Research Institute, 1980

A third means of changing the properties of a vegetable oil to be more comparable with those of diesel fuel is by chemically converting the vegetable oil to simple esters of methyl, ethyl, or butyl alcohols. The simple esters have viscosities roughly on the same order as diesel fuel (Figure 2) and have much better volatilities compared to the original triglyceride (Pryde, 1981).

C. Engine Tests Using Coconut Oil as a Diesel Fuel

All documented studies known to the author in which coconut oil has been used as diesel fuel are outlined in the following sections.

Short-Term Tests

Extensive tests on coconut oil as a fuel have been done under the direction of Dr. Ibarra Cruz, Manager, Energy Research and Development Center, Phillipine National Oil Company.

The earliest experiments on the use of coconut oil as a diesel fuel were conducted in 1973 by Chirant Deranananth, a M.S. mechanical engineering student at the University of the Phillipines. His work involved mainly performance tests on an ASTM-CFR diesel engine using refined coconut oil and blends. His findings were that a mixture of refined coconut oil and diesel fuel at a 25:75 weight ratio was the best blend.

Crude coconut oil is potentially as good a fuel for diesel engines as diesel oil. Cruz (1976) studied the use of crude coconut oil as a fuel in a laboratory ASTM-CFR test engine. He showed that the performance of the engine when using crude coconut oil compared well with the engine performance when using diesel fuel. The average thermal efficiency was 33% when using coconut oil compared with 32% when using diesel fuel. For optimum engine performance the injection advance would have to be greater when using coconut oil. Nevertheless the engine could be run on coconut oil over a wide range of injection advances without markedly decreasing the efficiency.

In another test, Cruz (1977) used a Ducati IS-11 single cylinder diesel engine. This engine is commonly used for motor boats. No modifications were made on the engine when using either fuel. The results of the tests showed no significant change in the engine's performance when using either crude coconut oil or diesel fuel. The average brake thermal efficiency was 23.7% when using coconut oil as compared to 23.4% when using diesel fuel. Paired statistical t-tests showed no significant differences in these performance parameters. However, the brake specific fuel consumption for crude coconut oil was 12.5% higher due to its lower calorific value.

In 1977 and 1978, Cruz tested the performance of crude coconut oil in a 25kW diesel electric generator set using a 4 cylinder four stroke Ford diesel. Once again, results of the tests showed that the engine was comparable in efficiency when using crude coconut oil as compared to diesel oil. However, a major problem that was encountered was solidification of the coconut oil in cold weather. Several additives were studies to lower the solidification point of coconut oil: alcohol, turpentine, gasoline, and diesel oil. The best additive was diesel oil. A recommendation of the study was to use a mixture of 70% coconut oil and 30% diesel fuel to prevent solidification in cold weather. As part of this study, different mixtures of coconut oil and diesel fuel were tested in an ASTM-CFR engine at a fixed compression ratio of 17:1 and varying speeds and injection advance. There was an optimum injection advance setting under each set of operating conditions. However, it was noted that the efficiency of the engine was not changed significantly even if the injeciton advance was changed by 30% from the optimum value. This means that commerical diesel engines can be run on any combination of diesel/coconut oil mixture without any modification at all being made to the engine.

Ward (1978) tested pure, refined coconut oil in a 6 hp Yanmar TS60C single cylinder diesel. The engine ran smoothly with the fuel efficiency being about 90% of diesel. After twenty hours of operation the engine was disassembled. The cylinder walls, piston head, and injector seemed to be in excellent condition.

Solly (1980) tested coconut oil and "cocohol", a combination of ethyl esters of coconut oil and ethanol, in a 6 hp Yanmar TS60C single cylinder diesel. The fuel consumption increased 10% when using coconut oil and 13% when using cocohol. These differences closely reflect the differences in calorific values of the fuels.

The Electric Power Corporation of Western Samoa under the direction of John Worrall has tested coconut oil in three diesel engines. A 420 hp Mirlees J6 diesel engine connected to a generator was operated at various loads for four hours while using either crude unfiltered coconut oil or diesel fuel. This is probably the largest engine to be fueled by coconut oil. The engine took longer to start on coconut oil than it did on diesel. However, the compressed air system used for starting the engine was more than adequate to start the engine. The engine exhaust was almost clear while operating on coconut oil, but tended to be smokey on diesel fuel. The subjective opinion of the staff was that the engine was not as noisy while using copra oil. The engine exhaust temperature and cooling water temperature were identical on both fuels. The engine used about 10% more coconut oil by volume at light loads and about 6% more near full load. The biggest problem was that the fuel filter became clogged after three or four hours of running. However, the coconut oil had not been filtered.

For the tests on the other engines the coconut oil was filtered through an oil filter intended for filtering electrical transformer oil. A Toyota type B engine in a 3-ton DYNA TRUCK was operated for two weeks (1200 miles) on coconut oil. The truck was more difficult to start but it seemed to run more smoothly when using the coconut oil. The fuel efficiency was lower when using coconut oil; 20 mpg on diesel fuel vs. 13.5 mpg on coconut oil. Coconut oil was also tested in a Toyota type BJ40 engine in a Toyota Land Cruiser for about a week. This vehicle was almost impossible to start on coconut oil after standing overnight unless starting fluid was used. Once again the fuel consumption was higher while using coconut oil. The fuel consumption on diesel oil averaged between 22 to 25 mpg vs. 16.5 mpg on coconut oil. They concluded that the main problem in using coconut oil was in starting the engine especially in lower temperatures. However, the effect of coconut oil on engine durability was not studied.

Occasional use of 100% coconut oil in light diesel engined vehicles have also been reported in Vanuatu and Kiribati over the past two years, but these were brief and have generated no useful data.

Endurance Tests

Once again, the greatest amount of long-term tests using coconut oil as a diesel fuel has been done in the Philippines under the direction of Dr. Ibarra Cruz, Manager, Energy Research and Development Center, Philippine National Oil Company and Rufo Bernardo, Technical Manager, Philippine National Oil Company.

From 1977 to 1978 a series of road tests were done to determine the performance of 100% crude coconut oil as an alternative fuel in an Isuzu diesel engine of a passenger Jeepney. The Jeepney covered 20,000 km during one year of testing. There were no problems with carbon build up in the engine. The only problem was in cold weather when the coconut oil would congeal at temperatures below 20°C. This problem was solved by using two tanks: one contained coconut oil and one contained diesel fuel that was used to dissolve the congealed coconut oil. It was also found that there was no solidification problems when the coconut oil was blended with diesel fuel in a blend containing 80% or less coconut oil.

At this point the Philippine Government picked up the idea of using coconut oil as a diesel substitute because of the depressed market for coconut oil. They started by mixing the coconut oil with bunker fuel and burning it in power plants. However, this was expensive. So field tests were started with buses using a 30% blend of coconut oil in diesel fuel. Two buses were each driven 100,000 km. At the completion of the test, everything in the engines was normal with no excessive deposits. There was now increased confidence in the use of coco-diesel fuel. This confidence was expressed in the extension of warranties by at least three engine manufacturers to their engines when using a 5% blend of coconut oil in diesel fuel.

It was decided to fleet test buses using a 5% blend of coconut oil in diesel fuel. Problems with filter plugging started to emerge after a couple of weeks. The problems were due to microbial growth that formed a fibrous mat and plugged the fuel filters. This had not been a problem before because the coconut oil had not been stored long enough. But when the fleet tests were started, the residence time in storage was increased.

Analysis of the coco-diesel belnds revealed that the free fatty acid in the coconut oil had changed the water shedding properties of the diesel fuel, i.e. it took longer for any water present in the fuel system to settle out. This provided a water-oil interface where biological activity took place. Attempts to use biocides were moderately effective. Because of the fuel filter plugging problem, the Philippine National Oil Company has decided to use a coconut oil that has been alkali refined and bleached. Currently, they are using this oil in a 4.5% blend for a six month test involving 132 units of the Metro Manila Transit System.

Research is also continuing in the laboratory to convince engine manufacturers that they can use 30% coco-diesel blends. A six cylinder direct injection Isuzu diesel engine and a four cylinder indirect injection Isuzu diesel engine are each being tested for 1000 hours on a 30% coco-diesel blend. A test cycle prescribed by the Isuzu company is being followed.

Tests are also in progress on the methyl esters of coconut oil. A company, Globus Resources Ltd, Hong Kong, is proposing to sell a product called "dieselite" to the Philippine National Oil Company (PNOC). The product is advertised as an extender or replacement for diesel fuel. The product is basically methyl cocoate without the methyl laurate component. Globus Resources proposes to sell Dieselite to the PNOC at the current market price of diesel fuel. They will retain the methyl laurate and glycerol "by-products" of the dieselite production process and sell these as exports. The PNOC has started a test program involving 12 bus units for two months duration. The buses being tested use Isuzu, Hino, and M.A.N. engines. Concurrently, a 250 hour laboratory endurance test is being conducted.

Solly (1982) tested a 6 hp indirect injected Yanmar diesel engine for 130 hours with a 50% mixture of crude coconut oil in diesel fuel. At the start of the test the thermal efficiency was the same as that of diesel fuel. After 130 hours of continuous operation under a partial load the efficiency had decreased by 11% and the specific fuel consumption increased by 16%. The injector was removed and found to contain excessive deposits. The holes connecting the pre-chamber with the combustion chamber were partiy blocked with solid particles. No heavy deposits or scoring were seen on the upper cylinder walls or piston surface. Similarly, there were no heavy deposits on the valve surfaces or in the exhaust manifold.

The Department of Works and Supply in Papua New Guinea under the direction of Laurie King has done tests using crude coconut oil in a 6 kw Yanmar TS130C indirect injection engine. The main problem encountered during the trials was the formation of extensive deposits around the injector hole. They needed to clean the injectors every 100 hours when using neat coconut oil. A number of variations were investigated in order to minimize the formation of deposits on the injectors. The variations tested were as follows: 1) increasing the injection pressure from 140 atmospheres to 170 atmospheres, 2) increasing the back leakage, 3) cooling the nozzle by the use of a second water cooling system, 4) switching between diesel fuel and coconut oil, 5) using commercial fuel additives, 6) using a mixture of 10% ethanol in the coconut oil, and 7) using various blends of coconut oil and diesel fuel. They tested for over 1500 hours. The best alternative was to use blends of coconut oil and diesel fuel but this simply prolonged the time before problems occurred, i.e. a 50% blend would double the amount of time before problems occurred. None of the modifications to the fuel or the engine were sufficient to prevent buildup of carbon on the injector. They found that they could run for longer periods of time if the engine maintenance was increased. They have concluded that the engine manufacturers need to do detailed testing and supply information on how to use the fuel.

The Ponape Agricultural and Trade School in the Federated States of Micronesia is running a 1000 hour test using two 5 hp Yanmar TS50 diesel engines with direct injection. One engine is using diesel fuel while the other engine is using crude coconut oil. After 50 hours on the engines, sediment could be seen in the fuel filter bowl of the coconut oil engine. The bowl was removed and cleaned. The filter was removed and thoroughly washed in diesel. Small particles of vegetable matter and granular chips of carbon were noticed stuck to the filter. At 95 hours a small amount of raw fuel was noticed exuding from the muffler on the coconut oil fueled engine. To pinpoint this problem the engines were run an additional 18 hours. At this time it was determined that the problem was the injector nozzle. There was a small buildup of carbon on one side of the nozzle resulting in incomplete fuel atomization. Because of the injector problem, a slight carbon buildup could be seen on top of the piston and around the valve seats and faces. As a future precaution, extra maintenance was performed on the coconut oil fueled engine. This included 1) removing and washing the fuel filter after each 40 hours and 2) removing, inspecting, and cleaning the injector after each 100 hours.

At 400 hours of operation the engines were inspected again. On the coconut oil fueled engine, there was a light buildup of carbon around the injector orifices. Both fuel injectors were tested on an injector tester, using both fuels on each one. Both would form a perfect mist at 1800 psi. However, the one using coconut oil fuel showed a small "weeping" effect around the bottom orifices. At 2000 psi this "weeping" would stop. Both injectors were set at 2000 psi and re-installed. At the time of this report, the engines had operated for 600 hours with no change in fuel consumption and only those problems previously indicated.

A Toyota Land Cruiser has operated for two years in Noumeau, New Caledonia. The tests have been monitored by Mr. Haustraete of SOPRONER. The vehicle has been operated for 25,000 km with no trouble except for some trouble with starting in cold weather. It has used refined coconut oil in a blend with diesel fuel. In the summer the blend contained 80% coconut oil. In the winter the blend contained 50% coconut oil. No filter plugging problems were reported.

Electricite de Tahiti has tested a 40 kw stationary diesel generator on crude coconut oil. The engine was completely rebuilt before the test. Accurate fuel consumption measurements were made with the diesel-generator operating at a steady 50% load. The engine used 0.398 l/kWh while operating on diesel fuel and 0.432 l/kWh while operating on coconut oil, thus indicating a 8.5% decrease in fuel efficiency while using coconut oil. The engine has operated since April 1982. Oil samples have been taken. No wear has been detected by metal analysis of the lubricating oil and the carbon content was found to be very low.

Electricite de Tahiti has operated a Toyota Land Cruiser on coconut oil since April 1981. The vehicle had been driven for 200,000 km before the oil was used. For the first 3100 km, refined copra oil was used without any problems. A 2.5% increase in fuel consumption was measured. Since then the vehicle has used crude filtered copra oil for over 15,000 km. A small decrease in fuel

Consumption has been measured and clogging of fuel filters has been observed. The decrease in fuel consumption was probably caused by the fact that the car had been used previously as an emergency operation vehicle and the engine was often turned on for radio transmission purposes. After a year of service, the engine was disassembled and inspected. The engine was found to be clean and no abnormal wear was noticed. Further, no traces of corrosion could be found that might have been caused by oil acidity. The vehicle continues using coconut oil as a fuel.

D. Engine Tests Using Other Vegetable Oils

Short-Term Tests of Oilseed Fuels

Encouraging results have been obtained in short term testing of modern diesel engines fueled with vegetable oils. Short term testing usually lasts only several minutes to several hours. The results of a number of postwar short-term engine tests on straight oilseed fuels was summarized by Quick (1980). In summary, the short-term tests showed that power output, torque, and brake thermal efficiency on oilseed fuels equalled or was close to that on diesel fuel. Fuel consumption was invariably higher because of the lower calorific value of the vegetable oil.

Long-Term Tests of Oilseed Fuels

Although short-term combustion performance in an essentially unmodified diesel engine may be without incident, many researchers on vegetable oil fuels have found that the relatively poor thermal stability of vegetable oil leads to a buildup of deposits in the combustion chamber, especially injector nozzle coking in long-term tests. The resultant degradation in fuel atomization and combustion efficiency leads to further problems such as piston ring sticking, crankcase oil dilution, and gelation of the lubrication oil resulting in engine failure.

Use of Vegetable Oils in Direct Injected Engines.

There are three methods that show promise for using vegetable oils in direct injected (DI) diesel engines -- heating the fuel, using a saturated vegetable oil, or using a simple ester of the vegetable oil.

Wagner and Peterson (1982) reported that heating the fuel to raise the temperature of the fuel at the injector pump did not result in a corresponding increase in injector fuel temperature. It was found that the rapid transfer of heat away from the injectors to the engine head and away from the fuel lines prevented the fuel temperature at the injector from increasing significantly. A 77°C increase in fuel temperature at the injector pump resulted in only a 25°C increase at the injector. Nevertheless, there is some merit in heating the fuel. Ryan (1982) studied the injection characteristics of vegetable oil fuels in a high-temperature, high-pressure, quiescent, inert atmosphere chamber. He reported that at 145°C the fuel spray did not penetrate to the opposite wall of the chamber and the carbon deposits were less than when the fuel was injected at normal temperatures (40°C). In any case, heating the fuel does require engine modifications.

A saturated vegetable oil has been shown to produce much less injection nozzle coking than an unsaturated fuel. Bacon and coworkers (1981) evaluated the polymerization effects of sunflower oil, coconut oil, and hardened tallow in a single cylinder version of a typical direct injection diesel engine (Perkins 4.236). The engine was run continuously at part load, mid speed for two hours. These conditions were established by previous tests to produce the most recognizable coking tendencies. The vegetable oils were chosen because they represented a range from full saturated to highly unsaturated. The saturated fuels (coconut oil and hardened tallow) produced much less injection nozzle coking than did the unsaturated fuel (sunflower oil).

Galloway and Ward (1982) tested a Lister ST 1 single cylinder, direct injection diesel engine using a 20/80 peanut oil/distillate blend, a 20/80 coconut oil/ diesel blend, and a 35/65 cocodiesel blend. The engine was run at full load. The test program was terminated after 40 hours on the peanut oil blend due to injector coking whereas the test on the 20/80 cocodiesel blend operated until the targed time of 120 hours was reached. There was also nozzle coking when the 20/80 cocodiesel blend was used but it was not as bad as when the 20/80 peanut oil blend was used. The authors felt the highly unsaturated peanut oil indicated a considerable contribution towards its coking by the chemical instability of the unsaturated triglyceride, while the saturated coconut oil had little contribution to coking by polymer generation but that coking resulted from secondary injection due to wave propagation in the delivery line. The improved running on the 20/80 cocodiesel blend as compared to the 20/80 peanut oil/diesel blend encouraged further testing with a 35% coconut oil and 65% distillate blend. The engine again completed the 120 hour full load test with the 35/65 cocodiesel blend. Injection coking was observed but it did not appear to impair the fuel spray pattern.

Ziejewski and Kaufman (1983) endurance tested a 25% high oleic safflower oil blend in a 4-cylinder direct injected diesel engine. Only one set of injection nozzles were used with no deterioration in performance. Engine inspection after the test, as compared to diesel fuel, revealed: 1) similar carbon buildup on the intake valve tulips and intake ports, 2) heavier lacquer residue and polish traces on the exhaust valve stems. 3) normal carbon buildup on the cylinder liner above the ring travel, 4) lighter top groove carbon filling, 5) heavier second groove carbon filling and 6) similar carbon residue on all piston lands. Overall, the results were very favorable. These studies serve as evidence for the chemical hypothesis of nozzle coking. However, on a practical basis, highly saturated oils may be solid at normal ambient temperatures excluding them from use in diesel engines.

Results to date indicate that the ester fuels are superior alternate fuels for direct injection diesel engines. McCutchen (1981) durability tested a turbocharged Caterpillar 3306, direct injection diesel engine using methyl ester of rapeseed oil for 150 hours. At the end of the test the pistons were clean. The injectors had deposits but no performance deterioration was observed. Bacon and coworkers (1981) evaluated the nozzle coking problems of methyl stearate, ethyl oleate, and ethyl ester of sunflower oil. The injector nozzles of the saturated fuels had much less injector coking than the unsaturated fuel. Results also indicated that the injector coking problem was less severe than with unmodified vegetable oils. Fort and coworkers (1982) endurance tested transesterified cotton-seed oil (methyl ester). When the engine was disassembled, a ring groove deposit effect was noted but in general the appearance was about the same as when diesel fuel was used. Hawkins, Fuels, and Hugo (1983a) reported completing 1500 hours on a Massey Ferguson tractor with a Perkins 4.236 direct injection engine running on an ethyl ester of sunflower oil. There were no problems and the engine was still performing as at the beginning of the test. Engine inspection after the test showed no difference from what could be expected from such a test carried out with diesel fuel Quick and coworkers (1982) studied the propensity of linseed oil to foul injectors using a Lombardini single cylinder, air cooled, direct injected engine. The engine power was down 10% after just 7 hours of operation using filtered raw linseed oil. However, using a methyl ester of linseed oil the engine had operated for over 200 hours at the time the paper was submitted. All these tests confirm that transesterified vegetable oils are a good fuel for direct injected engines.

It should be noted that the iodine numbers are not changed by converting a vegetable oil to a methyl or ethyl ester. The reactive double bonds present in the vegetable oil remain in the ester. It appears that the greatly reduced viscosity, increased volatility, and improved cetane number of the ester compared to the neat vegetable oil leads to more efficient injection and combustion.

Yet there are problems associated with the use of transesterified vegetable oils. A high esterification yield on the order of 90% must be obtained.

Tests conducted with an ester yield of 70% revealed unacceptable coking within 50 hours under part load conditions (Hawkins and Fuels, 1982). Dilution and subsequent chemical degradation of the lubricating oil has been reported (Hawkins and Fuls, 1982 and Geoffrey and coworkers, 1982). Esters, in general, are effective solvents and will dissolve the glue and other elastomers from some fuel systems (Solly, 1982). Further, Hawkins, Fuls, and Hugo (1983a) reported that ester fuels may effect the plastics and rubbers in the fuel system.

Engine Tests Using Fuel Additives for Vegetable Oil Fuels:

Various researchers have tried to use fuel additives to reduce the carbon buildup associated with the use of vegetable oil fuels. Van de Walt and Hugo (1982) tested 19 different fuel additives in 26 tests. They tried to assess the ability of the fuel additives to prevent injector coking in a direct injection diesel engine. The engine was run on sunflower oil. Any additive that could significantly reduce coking in this test, was considered promising enough to be evaluated on a cyclic load for a longer period of time. Of the 26 additives tested, only three additives showed any promise.

Baldwin and coworkers (1982) tested three fuel additives in a 3-cylinder, 3.3 liter diesel engine. The injectors were removed at 50 hours, photographed, and the testing was resumed. At the end of 100 hours, the injectors were again removed and photographed. Three fuel additives were tested. Each of the additives was added to 20% soybean oil/80% diesel oil fuel blends. None of the three additives selected provided an overall reduction in injector deposits, instead they resulted in greater deposits.

Wagner and Peterson (1982) endurance tested safflower oil, winter rape oil, and a commercial fuel additive. Two Yanmar Model TS70C, 376cc, single cylinder water cooled diesel engines with precombustion chambers and pintel type injectors were used for these tests of 830 hours duration. In one engine, 70% winter rapeseed oil and 30% diesel was used while in the second engine the same fuel blend with a Dupont FOA-2 additive was used. Oil analysis measurements and engine performance indicated that the fuel additive was detrimental to the engine. However, the additive did appear to drastically decrease fuel filter plugging.

Endurance Tests of Vegetable Oil in Indirect Injected Diesel Engines. Promising results have been obtained while using neat vegetable oils in multi-cylinder indirect injected diesel engines. McCutchen (1981) durability tested naturally aspirated and turbo-charged prechamber versions of a Caterpillar 3306 diesel engine using crude degummed soybean oil. A variable load cycle which was an approximation of field operation was used. Naturally aspirated prechamber operation resulted in pistons and rings cleaner than would have been expected from burning diesel fuel in sharp contrast with similar tests previously described on the direct injected model 3306. A slight carbon buildup on the fuel nozzle tip seemed to stabilize. The inside of the prechamber was coated with a soft carbon that seemed to buildup, flake off, and rebuild. The comparable diesel prechamber had a thin hard carbon coating that also flaked off and rebuilt. At 200 hours of operation, piston, ring, and liner wear was too small to measure. There was no fuel dilution of the lube oil. Mixtures of 30% soybean oil/70% diesel fuel and 100% soybean oil both gave excellent results. Turbocharged operation with a mixture of 30% crude degummed soybean oil/70% diesel fuel caused problems. The wear rates at higher engine ratings were excessive. However, the wear rates at lower ratings approached those expected in some fuel short areas where petroleum sulfur levels exceed 1%. The 3306 engine has a single inlet exhaust valve with the prechamber offset and tilted away from the valves. The greatest cylinder line wear plus a tendency for scuffing at high ratings occurred on the side nearest the prechamber and opposite the valves. McCutchen's theory is that the vegetable oil burns more slowly than diesel fuel and that partially burned oil is quenched on the cylinder liner in the highest wear areas. The fuel/oil/air mixture directed across the cylinder from prechamber has a longer time for combustion, so less partially burned carbon is deposited on the liner.

Van de Walt and Hugo (1981) subjected a Duetz F3L912W indirect injection engine to the manufacturer's cyclic load for 600 hours duration running on neat, degummed sunflower oil in the laboratory coupled to a PTO dynamometer. On completion of tests, the engine was dismantled and inspected in detail by an expert from the manufacturer. It was reported that there were no signs indicating that sunflower oil was not a suitable fuel for the engine. This test is being repeated. In another test, the same type of engine was subjected to 70% maximum power load, running continuously for almost five months. Normally the engine was only stopped for routine maintenance and oil sampling. Apart from a burnt exhaust valve on one cylinder after 1000 hours, and again a burnt exhaust valve in another cylinder after a total of 2000 hours, the engine ran without problems. After 2300 hours the engine unfortunately overheated due to a fault in the fresh air supply, and the test is being repeated.

Hawkins, Fuls, and Hugo (1983b) carried the above tests a stage further. Both Deutz F3L912W indirect injection engines were rebuilt and again submitted to the same load conditions, i.e. one engine on the 600 hour cycle.

load and the other on 70% full load continuously. The objectives were to obtain three full load cycles (1800 hours) on the first engine and to see how long the other engine could continue at 70% load without deterioration in performance. The engine under cyclic load completed 1800 hours without problems. The manufacturer considers this test to be equivalent to the normal farm life of such an engine. As a result of this test, the manufactuer, Klockner-Humbolt-Deutz A.G. of Cologne, Federal Republic of Germany, has decided to extend their full factory guarantee world-wide on their indirect injection engines to cover fueling with degummed sunflower oil.

Other tests with small single-cylinder indirect injected engines have not been as promising.

Peterson and coworkers (1981) ran two single cylinder, water cooled, indirect injection Yanmar diesel engines in an endurance test. One engine was operated on diesel fuel for 840 hours. The other engine was operated on 100% safflower oil for 830 hours. In general, the results showed the safflower fueled engine to have a wear rate of about twice the rate of the diesel fueled engine but at a rate such that all components were still within acceptable limits. The safflower fueled engine showed more carbon in the exhaust ports, the combustion chamber, on the piston rings, and on the injector nozzles.

Borgelt and Harris (1982) tested three Onan 5kW (6.7 hp) single cylinder air cooled, prechambered engines for 1000 endurance runs at 50 and 55% of rated power. Each engine operated on a different fuel. One engine used 100% No. 2 diesel fuel as a baseline. The other two engines used a 25/75 soybean oil/diesel fuel blend and a 50/50 soybean oil/diesel fuel blend respectively. No significant difference between the engines occurred regarding ring, cylinder, bearings, and general wear. Some increase in carbon was observed on the engine heads as the percent of the soybean oil increased. The intake valve stem and port of the 50/50 engine did show considerable buildup of carbon over the other two engines. Pistons and rings showed no evidence of carbon deposits, sticking parts, or other detrimental effects. Upon disassembly of the injectors, both the 25/75 and 50/50 engine injectors displayed varnish and gum deposits.

Yarborough and coworkers (1981) evaluated six sunflower seed oils in a Yanmar TS50C single cylinder, water cooled, precombustion chamber diesel engine. The test fuels were 100% diesel, 75% diesel/25% crude filtered sunflower seed oil, 50% diesel/50% crude filtered sunflower seed oil, 25% diesel/75% crude filtered sunflower seed oil, 100% crude filtered sunflower seed oil, 100% degummed sunflower seed oil, and 100% degummed dewaxed sunflower seed oil. All of the sunflower oil fuels deposited more carbon on the injector tip, precombustion chamber and main combustion chamber than diesel. Carbon deposits were also found inside the intake port when operating with sunflower seed oil fuels. This was much more noticeable with mixtures of crude sunflower seed oil. The 100% degummed, dewaxed sunflower seed oil fuel and 100% degummed sunflower seed oil completed a 40 hour constant load test with no major problems. Of the six alternate fuels tested, 100% degummed sunflower seed oil and the 100% degummed dewaxed sunflower seed oil were found to be more desirable than any of the fuels containing percentages of crude sunflower seed oil or the 100% crude sunflower seed oil from the standpoint of engine performance. Contamination of lubricating oil was found to be a problem, even with the degummed dewaxed fuel. Lubrication oil would need to be changed two to three times more frequently than the manufacturers recommended interval to prevent dangerous buildup of total solids in the oil.

Yarborough and coworkers (1982) tested cottonseed oil subjected to various levels of processing in a Yanmar TS50C single cyclinder, water cooled, precombustion chamber diesel engine. Tests were run on crude cottonseed oil, degummed cottonseed oil, and alkali refined cottonseed oil. The alkali refined cottonseed oil was the only fuel to complete the 40 hour test without major problems. With degummed cottonseed oil fuel, the engine test was terminated at 25.5 hours. Crude cottonseed oil was not used in this 40 hour test, since severe injector coking and carbon deposition occurred in the performance characterization tests. These tests have shown the need for increased processing of vegetable oil fuels prior to using them in an engine. Increased processing of cottonseed oil decreased injector coking and engine carbon deposits, but did not decrease them to the level of diesel fuel deposits.

E. Use in Domestic Lamps and Stoves

Solly (1981) studied the feasibility of using the ethyl esters of coconut oil as a fuel for domestic cooking and lighting in the low cost lamps and stoves used in rural and peri-urbain areas of the small Pacific island nations. Esters were shown to be equally efficient as kerosene for fueling pressure lamps and stoves and wick stoves. Satisfactory performance was obtained in pressure incandescent mantle lamps although the light emitted decreased by 30%. The ethyl esters were found to yield virtually no light output from wick lamps because a consistent flame could not be maintained. The combustion of the ehtyl esters in a Primus type pressure stove was equally efficient to that of kerosene. Tests carried out with a multi-wick stove showed that the fuel consumption while using esters was approximately three times that with kerosene. A 20% kerosene-ester mixture reduce the amount of fuel consumed to a level comparable to normal kerosene use.

F. Synopsis

Modern diesel engines have been designed to operate on standard diesel fuel. Diesel engines require fuels which self-ignite readily at compression ignition temperatures. Vegetable oils have surprisingly good fuel properties for application to compression ignition engines. They are safe to store and handle. They are the only renewable fuel which can currently power compression ignition engines with some expectation of success. The short term performance of up to two hours in an unmodified diesel engine is satisfactory. There would be a higher specific fuel consumption because of the lower calorific value of vegetable oils. Approximately 1.07 L of coconut oil is equivalent to 1.0 L of diesel fuel.

However, there are problems associated with the long term use of vegetable oil fuels, because of physical and chemical properties of vegetable oils that differ considerably from those of diesel fuel. The major technical problems with vegetable oils are their high viscosity, unsaturation, very low volatility and tendency to form residues on combustion. Based on chemical structure, coconut oil is the best of the vegetable oils for use as a fuel because it has a high degree of saturation. However, the cloud point of coconut oil is unfavorable compared to the other vegetable oils. For coconut oil, the cloud point is 20° to 25°C depending on the purity. This will cause problems in the cooler areas of the tropics and in all temperature areas. Mixing the coconut oil with distillate will reduce the cloud point to about 15°C. Another approach is to preheat the oil in the fuel line of the engine.

Growth of fungi in the coconut oil is another problem which will lead to filter plugging. The fungi are present on copra and get into the oil during the expelling process. Tests in the Philippines have shown this to be a problem when the fuel is used in public transport. A solution is to alkali refine the coconut oil before using it as a fuel. Field tests at North Dakota State University (Aakre 1983) have shown that when sunflower oil was alkali refined before use as a liquid fuel there were not problems with filter plugging.

Long term engine trials with coconut oil are very limited. The Philippines probably have the largest mileage but have not published any information, particularly data on engine inspections. The Electricity Commission in Tahiti and SOPRONER in New Caledonia have both operated Toyota Land Cruisers on coconut oil for several thousand kilometers with no apparent problems. The Public Works Department in Papua New Guinea has done extensive tests on a Yanmar single cylinder indirect injection diesel engine without success in reducing nozzle coking. Thorough tests with coconut oil have been done by Galloway and Ward (1982) using a direct injection Lister engine which also suffered from injector coking after 120 hours. In brief, there is a need for more well-documented studies on coconut oil as a fuel.

However, long term tests with other vegetable oils may be used to indicate possible avenues for the successful use of coconut oil as a petroleum substitute.

Virtually all of the tests of vegetable oils and blends in direct injection (DI) engines have produced rather heavy deposits on the injector nozzles. In addition, most tests resulted in substantial deposits of carbon or varnish on other engine components including valves, cylinders, pistons, and rings. These deposits are believed to be caused by the high viscosity of the vegetable oils which leads to poor atomization of the fuel and inefficient combustion. Residues of partially combusted fuel remain in the engine to form deposits and/or contaminate the lubricating oil. Some of the tests have indicated serious contamination of the lubricating oil with unburned, polymerized fuel and/or metals. There are indications that the problems of engine deposits and lubricating oil contamination are more serious with vegetable oils that have high iodine values. Coconut oil has a low iodine value which may account for less engine deposits as reported in the Philippines and by Bacon, et. al. (1981), and Galloway and Ward (1982).

A possible solution to the problem of long term operation of direct injection engines on vegetable oils may be achieved by the chemical process of transesterification. The esters have low viscosities, due to removal of part of the molecule in the form of glycerol. Many tests indicate that ester fuels can be used in DI engines without the carbon deposits which accumulate when straight vegetable oils and blends are used. Yet, problems with chemical degradation of the oil have been reported. There is also a materials compatability problem.

On the other hand, research indicates that straight vegetable oils or blends of these oils with diesel fuel can be used in indirect injection (IDI) engines without carbon deposits or oil contamination problems except in some small single cylinder engines. Presently, Caterpillar Tractor Company is permitting the use of 30% mixes of any one of soybean, sunflower, peanut, or rapeseed oils with diesel fuel in their precombustion chamber engines in construction machinery operating in Brazil only without voiding warranties. This was done after considerable testing and after consideration of the ratings and duty cycles of the engines involved. Effective in September 1983, Caterpillar will be willing to offer precombustion chamber engines in the South Pacific that will operate on 100% coconut oil (See Appendix 2). Further, Klockner-Humbolt-Deutz A.G. has concluded that degummed sunflower oil is a satisfactory fuel for their indirect injection engines and will offer a full factory guarantee world wide on this fuel. (See Appendix 2).

IV. POTENTIAL FOR COCONUT OIL AS A DIESEL FUEL IN FIJI

The use of coconut oil as a substitute for diesel fuel in Fiji raises four questions. The questions relate to (1) the adaptability of coconut oil as a fuel for modern diesel engines, (2) the type and degree of refining needed for the oil (3) the uses that can be made of the accompanying meal by-product and (4) the possibility of economically viable systems for producing and using fuel.

A. Technical Adaptibility

The evidence in Chapter 3 indicated that while indirect engines will burn both alkali-refined and transesterified coconut oil, direct injection engines can use only transesterified coconut oil without trouble. There are presently two engine manufacturers, Caterpillar Tractor Company and Clockner-Humbolt-Deutz A.G., that will provide warranties for their indirect injection engines while using vegetable oil for fuel. The Deutz warranty applies to degummed sunflower oil only. Caterpillar Tractor Company is the only company at present to permit the use of 100% coconut oil in their indirect injection diesel engines. There are no companies at present that will warranty their engines while using the esters of vegetable oil for fuel. However, Perkins Engines, Ltd. has indicated that they would be prepared to consider approval of a monoester of coconut oil as a fuel for their engines in the Fiji Islands (See Appendix 2).

B. Refining Needed

The refining process to select depends upon 1) the types of engines to be used, currently and in the future,and 2) the economics of alkali refining versus transesterifying the coconut oil. There is no data presently available to indicate what types of engines are used in Fiji. A survey should be done by the Ministry of Energy to gather this data. Further, no studies are available in the literature documenting the cost of transesterification of vegetable oils. However, this topic is being researched by Dr. Delmer Helgeson of the Agricultural Economics Department at North Dakota State University, Fargo, ND, 58105, USA. His report will look at commercial size plants and will be available in 1984. There are two companies that are presently refining vegetable oils in Fiji. Their estimates for alkali refining of coconut oil are included in this report.

Even though economic studies are not available to compare these two processes, the relative costs of raw materials for processing one tonne of coconut oil would be as follows:

1.	Alkali Refining	Amount	Cost
	Caustic Soda	5 kg @ $482/tonne	$2.41

(Assuming a typical 2% free fatty acid content express as lauric acid and allowing for a 25% margin).

2.	Transesterification	Amount	Cost
	Ethanol, 200 proof	298 L @ $230/200L drum	$342.70

(Allowing for a 10% excess)

Some benefit would accrue from the by-products of soap stock in the alkali refining process and glycerol in the transesterification process. Glycerol is a high value export item bringing $0.70 to $0.90 per kg. One tonne of transesterified coconut oil would yield 143 kg of glycerol or 143 x 0.90 = $128.70. This makes the net cost of materials for transesterification $214.00, which is still considerably higher than the equivalent raw material needed for alkali refining.

Other conditions existing in Fiji do not favor the transesterification process for liquid fuel production. Firstly, Fiji presently has only one distillery producing about 420 to 560 kL of ethanol per year. While the raw materials exist for an ethanol industry, it has not proven economically viable to establish one at present. So if the coconut oil was to be transesterified it would be necessary to import ethanol or, alternately, to import methanol. The production of methyl esters, rather than ethyl esters, is presently being done commercially because of the price advantage of methanol over ethanol. The latter alcohol is more expensive because of the demand for manufacture of alcoholic liquors. Methanol is synthesized from coal which is relatively cheap compared with molasses and grains from which ethanol is produced. Secondly, the plants already exist in Fiji for refining coconut oil. These plants have considerable excess capacity which could be utilized. Alkali refining of coconut oil for fuel would not require construction of new plants. However, if transesterified coconut oil is desired, it would be necessary to construct additional plants. Thirdly, with the existing oil refining plants, the use of coconut oil for a liquid fuel could be viewed as a price support program for copra production. The existing marketing chain could remain unaltered and the decision to use coconut oil as a petroleum substitute would depend on the relative economic value of coconut oil versus distillate.

All of the above factors support the position that with the present industrial base in Fiji the coconut oil should be alkali refined instead of transesterified. In the future, if a large ethanol industry is established, this decision should be re-evaluated. On the other hand, if there is sufficient interest in producing the esters of coconut oil, then Globus Resources, Ltd., Hong Kong, should be contacted. Arrangements should be made with Globus Resources Ltd. to sell "dieselite" at the cost o diesel just as they are proposing in the Philippines. Before this would be done, however, the engine companies should be contacted to determine if the use of dieselite would invalidate engine warranties. A technical advantage of producing esters of coconut oil is that they could be used for home cooking and lighting, but at a higher price than kerosene.

C. Coconut Meal By-Product

The coconut meal produced locally can be used as an input to feed poultry, swine and cattle. Because the protein content is about 20% copra meal is classified as a good source of protein. One of the objections to the use of high levels of copra meal for feed is its deficiency in certain amino acids, notably tryptophan, lysine, methionine, and histidine. However, Fiji already is using coconut meal for animal feed and the market is almost saturated. Any additional meal produced would probably be exported, which is the current practice.

D. Economic Assessment

The conomic viability of coconut oil fuel is largely dependent on the market prices of copra, refined coconut oil, diesel fuel, the value of the copra meal by-product,and the degree of compatibility of the fuel with diesel engines. This study is not intended to be comprehensive but rather a preliminary analysis to examine the overall economics of vegetable oil substitution for imported petroleum.

Large-Scale Production

Fiji no longer exports any copra. All of the copra is converted to oil which is then exported,with a small amount used locally. There are four milling companies as discussed in Chapter II, Section H. An economic assessment of vegetable oil production on a large scale needs to compare the relative value of coconut oil as a fuel and as an edible product. If the price received from coconut oil in the edible market exceeds the price for which the coconut oil could be sold in the liquid fuel market (the latter being constrained by the price of diesel oil), there would be no economic reason to sell coconut oil as a diesel fuel.

The export prices of coconut oil are compared to import distillate prices in Table 20. Data is presented for both ADO and IDO. The price ratio shows the relative disparity between coconut oil and diesel oil prices. Since 1979 the price difference has steadily declined (See Figure 3). In the first quarter of 1983, coconut oil was only 15% to 17% more expensive than diesel oil.

Table 20. Oil Price Comparison

Year	Coconut Oil Export Price, c/L f.o.b.	Distillate Import Price, c/L c.i.f.		Price Ratio Coconut/Distillate	
		ADO	IDO	ADO	IDO
1973	28.03	3.92	3.34	7.15	8.38
1974	69.00	7.98	9.30	8.65	7.42
1975	29.02	9.78	9.41	2.97	3.09
1976	29.10	12.01	11.29	2.42	2.58
1977	46.47	10.62	10.15	4.37	4.58
1978	46.25	10.01	9.67	4.62	4.78
1979	70.54	13.96	13.84	5.05	5.10
1980	47.32	21.60	20.56	2.19	2.30
1981	42.29	26.33	25.89	1.61	1.63
1982	37.96	27.83	27.28	1.36	1.39
1983*	32.57	28.44	27.93	1.15	1.17

Note: * First Quarter only
Source: Trade Reports, Bureau of Statistics, Suva, Fiji, 1973-1983.

These prices do not take into account the increased employment, regional development, and self-reliance if additional copra is produced to provide a liquid fuel. Further, the price of petroleum has risen steadily over the past 10 years while the price of coconut oil has varied sharply. The World Bank (1982) estimates that the price of coconut oil will continue to rise (Table 21). In contrast, the assessment of Santaiapillai and Yeats (1980) was that the price of copra and coconut oil would be unlikely to return to previous higher prices, and the long term trend may be for prices to settle lower than at present. Any alternate market that would reduce the supply of coconut oil on the world food market would help to stabilize prices for the rural producer.

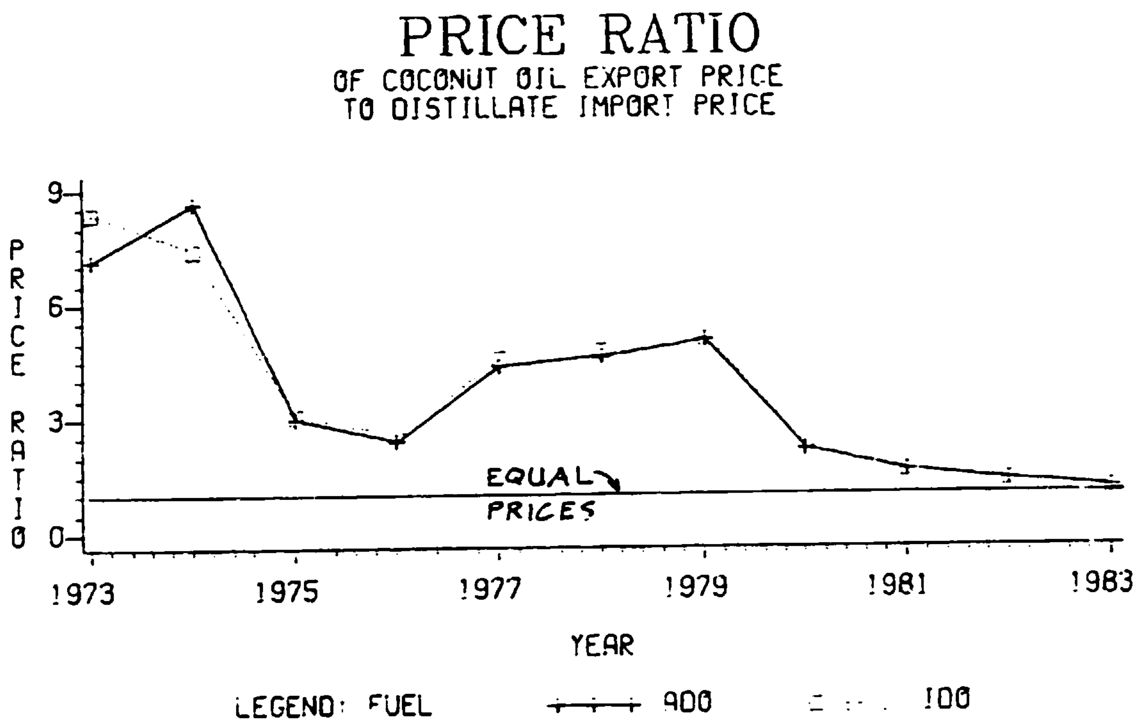

Figure 3. Price Ratio of Coconut Oil Export Price to Distillate Import Price

Table 21. Commodity Price Projections for Coconut Oil

Year	Price Projection, US$/MT Current Dollars	1981 Constant Dollars
1960-1970 Avg.	323	1101
1981	570	570
1983	570	517
1985	889	701
1990	1181	696
1995	1560	687

Source: World Bank, 1982.

The coconut oil prices presented in Table 20 are for crude coconut oil. Alkali refining would be necessary before the oil could be used as a liquid fuel. The two companies in Fiji presently refining vegetable oils estimated the cost of neutralizing to be $35 to $55 per tonne (4¢ to 6¢ per liter). At least this amount should be added to the coconut oil export price because it must be alkali refined before being used as a liquid fuel. This makes coconut oil, even at 1983 prices, still uneconomic as a substitute for diesel fuel. From the government's point of view, substitution of ADO by coconut oil will mean a loss of 5¢ per liter on diesel import duty plus the loss of the 2% export tax on coconut oil. The price differential will have to alter a great deal more in favor of coconut oil before it becomes attractive to use coconut oil as a petroleum substitute.

However, from an individual point of view, isolated cases of substituting coconut oil for diesel fuel can be economical with 1983 prices. These cases are worth identifying and using as pilot studies for building of valuable experience. One such case is the oil mill at Lakeba. Currently, the oil mill at Lakeba is selling coconut oil at $500/tonne or 46¢/liter. At the same time they are purchasing diesel fuel for 47.83¢/liter. The coconut oil they produce is crude and would need to be alkali refined before it could be used as a liquid fuel.

Small-Scale Production

It has been suggested that the most profitable and appropriate area to evaluate the use of coconut oil as a fuel may be in the outer islands away from the main ports. It is on these islands that freight costs are a major determinant of coconut oil profitability. A coconut oil industry set up for producing a diesel substitute immediately minimizes freight costs since all products are made and utilized locally. This has major effects both on economic and social acceptability. The farther one is from an international port, the higher the cost of diesel, the lower the effective price of copra, the more doubtful the arrival of a ship at the right time for either, and the smaller the incentive for a village to make major changes to its way of life.

The coconut oil produced on these outer islands could be used to power diesel electric generator sets. The standard unit in use is a 7.5 kW Lister or Petter engine which at full load utilizes 2.5 L/h x 4h/day x 365 days/yr = 3650 L/yr of diesel fuel or 3917 L/yr of coconut oil (allowing for the calorific difference). Assuming a press would operate six hours per day and 260 days per year, it would be necessary to purchase a press that would process 3917 L/yr x yr/260 days x day/6 hr x 0.92 kg/L = 2.3 kg of oil per hour. There is no commercially available press that would be small enough to fulfill these requirements. So it would be necessary for several villages to join together to utilize the coconut oil produced from a press.

There are several locations in Fiji that are sufficiently populated to consider one multi-village oil processing plan. They are as follows:

- Koro Island
- Rotuma Island
- Kadavu Island (Tavuki Tikina)
- Rabi Island
- Vunidaw - Naitasiri
- Korovou - Tailevu
- Seaqaqa - Vanua Levu

Further, these locations are in areas where the Fiji Electricity Authority mains cannot be made available at an acceptable cost. These schemes are estimated by Jon Abramski, Power Systems Planner for the Ministry of Energy, to have a peak load of approximately 40 kVA during four hours each night and a base load of 10 kVA for 20 hours each day. A common engine used for this application would be a 50 kW Lister air cooled diesel. It would have a diesel fuel consumption of about 128 L/day x 365 days/yr = 46,720 L/yr or 49,990 L/yr of coconut oil.

These calculations do not include the power requirements for the processing of the coconut oil. If the processing system was used during off-peak demand hours, the diesel electric generating system should operate more efficiently and actually use less diesel fuel. However, these calculations are only approximate. It will be assumed that the reduced fuel consumption would be offset by spillage losses during the processing of the coconut oil. An estimated demand of 50 kL of coconut oil per year will be used for further calculations.

There are several presses capable of producing this amount of oil per year. Japanese "Hander" equipment was used for this analysis because it has a proven reliable record in the region. The Hander system analyzed uses dried copra as a raw material rather than wet coconut meat. This system is capable of processing 40 kg/h of dried copra at an extraction efficiency of 55% thereby producing 22.0 kg/h (23.91 L/h) of oil when the copra is preheated. If the copra is not preheated, tests by P. Perelini of the Electric Power Corporation in Western Samoa have shown that a machine by this manufacturer achieves a 47% extraction efficinecy. So, without preheating, this system would produce 18.8 kg/h (20.43 L/h) of oil. Therefore, to produce 50 kL of coconut oil per year, this machine would need to operate (50 kL/yr) (23.91 L/h) = 2091 hr/yr. with preheating (system A) or 50,000/20.43 = 3447 hr/yr without preheating (system B). During this time, system A would process 83.64 tonnes of copra and produce 37.63 tonnes of meal while system B would process 97.88 tonnes of copra and produce 51.87 tonnes of meal. The economics of both systems will be analyzed.

System A would operate 7 hours per day, 6 days per week with an addiitonal hour for starting and stopping the system. It would require one semi-skilled laborer (Flynn, 1973). System B would operate 10 hours per day, 5 days per week. It would require 2 shifts of 8 hours each and one worker per shift. The cost of semi-skilled labor was set at $0.72 per hour which is the wage currently being paid in Lakeba for this type of labor. A manager would also be employed and would receive $6000 per year which is comparable to the wage received by the manager of the Lakeba Cooperative. This manager would be responsible for both the oil processing and the diesel electric generator systems. Hence, half of his salary will be charged to each system.

The equipment is powered by electric motors. The sizes of motors are as follows: grinder - 2 hp, cooker - 1 hp, expeller - 3 hp and filter - ½ hp. Tests by P. Perelini in Western Samoa showed the expeller to be operating at a 60% load factor. For a safety factor, all motors will be assumed to operate at 75% load. hence, system A will require 3.6 kW and system B will require 3.1 kW per hour. A building size of $38 m^2$ is required to house this equipment (Flynn, 1973). Capital investments are shown in Table 22.

Table 22. Capital Investment for a Small Scale System to Extract Coconut Oil

Item	System With Preheating	System Without Preheating
	F$	
Equipment		
Power Chopper New Type 'CA'	$4713	$ 4713
Seed Scorcher Type 'L'	4766	—
Hander Copra Expeller New Type 52	4168	4168
Filter Press Type 'A'	3957	3957
Oil Storage Tank	1000	1000
Total Equipment Investment	$18,604	$13,838
Building, 38 m^2	$11,400	$11,400
Total Capital Investment	$30,004	$25,238

Source: Newcombe, 1982 and Public Works Department, Fiji, 1983

Maintenance and insurance per year was estimated to be 18.5% of installed cost (Flynn, 1973). These maintenance figures may be higher than expected. The reasoning is that supply lines are not readily available and, consequently, spare parts are not always going to be available when they are needed. Maintenance costs will, however, depend mainly on whether or not a good mechanic is locally available. An additional charge of 3% of new equipment cost should be used for replacement of filter paper (Flynn, 1973).

The equipment was amortized over a 10 year period. No salvage value was taken since after 10 years new technology may leave the equipment with little value to recover. The building was amortized over a 25 year period. An interest rate of 11% was used. This is the current interest rate charged by the Fiji Development Bank for a Fijian commercial venture.

The current price for copra in Lakeba is $254.45 per tonne and the copra meal is currently sold for $120.00 per tonne. Using these parameters, the estimated processing costs were calculated and are given in Table 23.

Table 23: Estimate Processing Cost for Crude Coconut Oil

	System	
	With Preheating	Without Preheating
	F$	
Variable Costs		
Maintenance and Insurance	$5551	$4669
Filters	558	558
Electricity @ 25¢/ kWh	1882	1896
Labor @ $0.72/h	1797	2995
Copra @ $254.55/tonne	21291	24915
Total Variable Costs	$31,078	$35,034
Fixed Costs		
Equipment Amortized for 10 yrs @ 11%	3159	2350
Building Amortized for 25 yrs @ 11%	1354	1354
Manager	3000	3000
Total Fixed Costs	$7513	$6704
Total Processing Costs	$38,591	$41,738
Credit for Meal @ $120/tonne	$4516	$6224
Net Processing Costs	$34,076	$35,514
Total Liters of Coconut Oil Produced	50kL	50k/L
Cost per liter	$0.68	$ 0.71

Coconut oil produced from a small scale system would cost $0.68/L if the copra was preheated before processing or $0.71/L if the copra was not preheated. In either case the cost of coconut oil is clearly more expensive than the cost of coconut oil from a larger system as given in Table 20. Flynn (1973) showed that there are economies of scale for coconut oil processing plants up to about 26 tonnes per day (24 hours). Beyond this there appears to be some leveling out of the cost curve. In addition, the costs shown for the small scale system do not include additional processing, i.e. alkali refining or transesterification, necessary to make the coconut oil acceptable as a liquid fuel for diesel engines.

In order to account for fluctuating market prices, the economic analysis was expanded to include a range of copra values from $50 to $500 per tonne.

This range includes all prices paid for copra in Fiji over the past ten years (Table 24). Further, the cost of electricity was varied from 5¢/kWh to 50¢/kWh to include a range of reasonable costs for this size system.

Table 24. Average Annual Copra Price in Fiji, 1972-1982

Year	Price, $ Per Tonne
1972	69
1973	143
1974	453
1975	124
1976	127
1977	253
1978	255
1979	439
1980	198
1981	158
1982	128

Source: Coconut Board Annual Report, Fiji, 1982.

The results of the economic analysis for a small scale system are presented in Figure 4. Using the current value for diesel fuel in Lakeba (47.83 ¢/L), allowing 5¢/L for alkali refining, and accounting for the difference in energy contents of the two fuels, the crude coconut oil produced by this system would need to cost less than 40¢/L to be economically competitive with diesel fuel. In order to achieve this price if the cost of electricity was 25¢/kWh, the cost of copra would need to be less than $100/tonne. Reviewing the average annual copra prices in Fiji (Table 24), 1972 was the only year when the average copra price was less than $100. Although, the price of $128/tonne for copra in 1982 would have resulted in a fuel cost of approximately 46¢/L. Due to the higher value of cocnut oil as an edible product, it is probably not economically justifiable to purchase a small scale system for coconut oil fuel production. The use of coconut oil as a liquid fuel could only be supported on the outer island of Lakeba as discussed previously.

However, inspection of the petroleum and coconut oil price trends, Figure 3, does suggest that the use of coconut oil for fuel may become

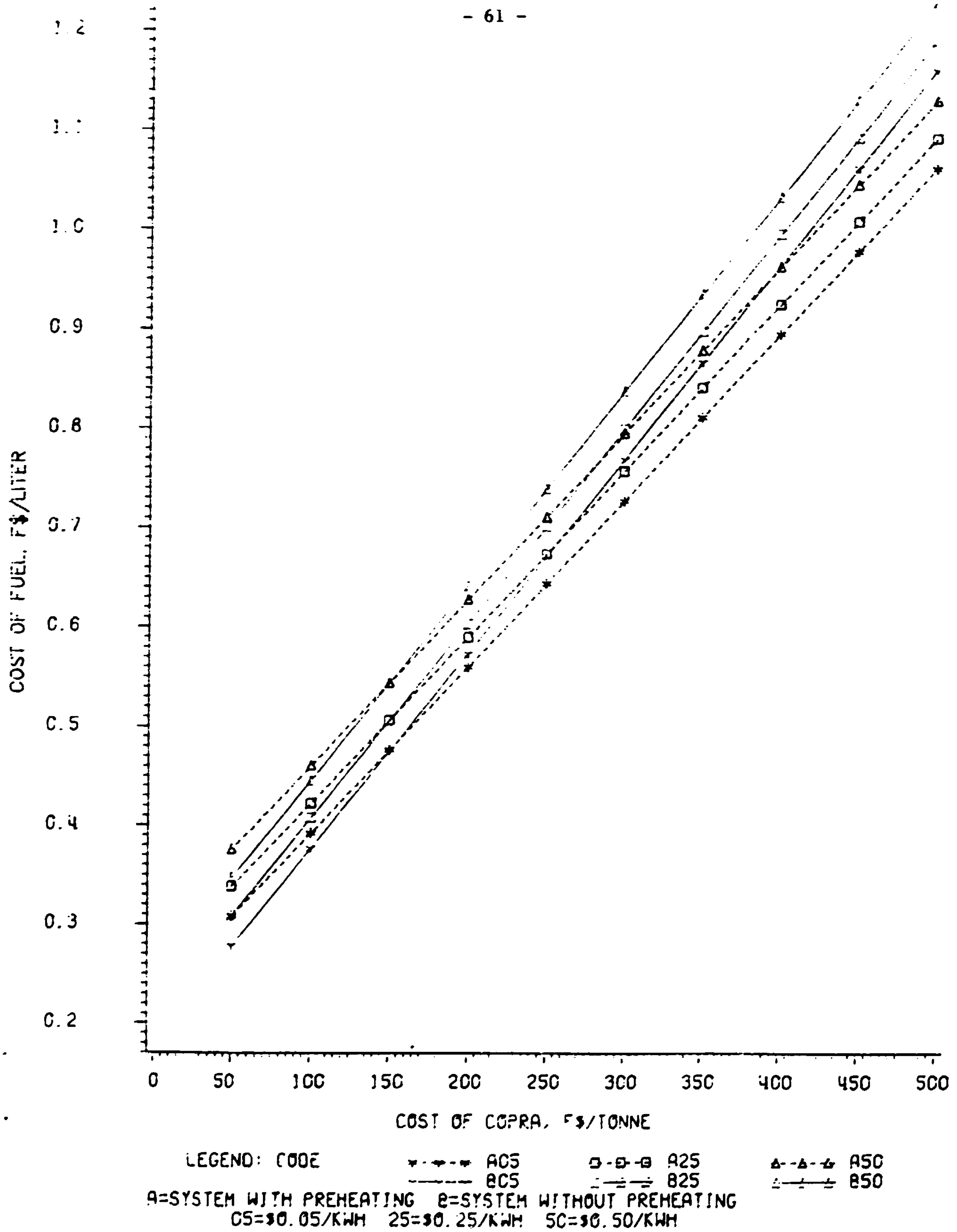

Figure 4. Processing Cost for Crude Coconut Oil From a Small Scale System

economically justifiable in the future. Hence, tests should be conducted to determine technically and economically feasible systems for using coconut oil as a petroleum substitute.

E. Potential for Coconut Oil Substitution

Before excessive enthusiasm is generated for vegetable oils as a panacea for petroleum oil supply problems, it is necessary to establish a perspective on local production potential. Setting aside some arguments on burning food in motor vehicles, the intractable problem of matching fuel consumption to potential coconut oil fuel production remains. Annual copra production in Fiji since 1973 is shown in Table 25. These figures do not include the coconuts that were harvested for human consumption. The author believes that the coconuts used for human consumption in Fiji should not enter into this proposal. The average copra production for the past 10 years is 24,694 tonnes.

Table 25. Annual Copra Production in Fiji 1973-1982

Year	Copra Production Tonnes
1973	26,370
1974	27,141
1975	23,496
1976	26,510
1977	30,646
1978	26,092
1979	21,729
1980	22,525
1981	20,371
1982	22,056
Average	24,694

Source: Coconut Board Annual Report, Fiji, 1982

A Tree Crop Development Program (TCDP) funded by the World Bank will be started in 1984 to revitalize the coconut industry. A major component of the project will be rehabilitation of tree groves under 40 years and by felling and replanting of senile trees with high yielding hybrid trees where appropriate. Estimates of the future copra and coconut oil production are shown in Table 26. These projections are based on the average copra production for the past 10 years and the incremental production of coconuts resulting from the TCDP.

Table 26: Projected Fiji Copra and Coconut Oil Production, 1985-1999

Year	Copra Production Tonnes	Coconut Oil Production ML
1985	24,696	16.78
1990	27,514	18.69
1995	31,474	21.38
1999	40,754	27.69

Assumptions: Copra is 62.5% oil and 100% extraction efficiency is achieved
Source: Central Planning Office, Fiji, 1983

The World Bank (1983) estimates ADO demand to be 109.2 ML in 1985 and 120.5 ML in 1990. If all of the coconut oil produced in Fiji was substituted for ADO, it would only be possible to replace about 15% of the total projected ADO demand.

Using all of the coconut oil produced in Fiji as a petroleum replacement is not feasible. So it will be necessary to select several strategic areas where it would be desirable to replace petroleum fuel with a coconut oil substitute. Several suggestions are presented in the next chapter.

V. RECOMMENDED TESTS

Engine tests need to be done to determine if it is possible to achieve total substitution on outer islands or if it is more feasible to replace part of the fuel demand on the larger islands.

A. Outer Islands

Copra production is the main cash income of the population on outer islands. Rural dwellers use a considerable amount of their cash income for the purchase of petroleum fuels, including diesel oil. If coconut oil could be used directly to substitute for diesel oil, it would be possible to power diesel electric generator schemes to provide electricity for many remote areas. Presently, the routine maintenance of the rural electrification program is expensive and heavily subsidized. There is a question of whether a small scale mill and diesel electric generating system could be established with little experience, unskilled labor, and little support service.

The Lakeba Co-operative Association Oil Mills is situated in Lakeba, an outer island in the Lau group. The mill sells coconut oil at a lower price than it pays for diesel fuel. The power for this plant is provided by a Caterpillar diesel engine with a precombustion chamber. The engine should be able to use 100% coconut oil for fuel. The oil from the expellers will need to be filtered and alkali refined before being used in the engine. The soap stock produced from the neutralized oil could be used to produce soap for local consumption. A batch alkali refining tank will need to be purchased commercially or fabricated locally. Technical assistance should be made available to train the local people in the proper production procedures and routine maintenance of all equipment. It is absolutely essential that the quality of the coconut oil be strictly controlled. Presently, diesel fuel must meet strict specifications. It would be unrealistic to assume that the engine manufacturers would tolerate less stringent controls on the quality of the coconut oil being used as a liquid fuel. (See letter by K. Walker, Perkins Engines, Appendix 3).

This pilot project will enable the Fiji government to determine 1) the suitability of this machinery for local conditions, 2) the social factors involved, 3) the logistics 4) any potential problems and 5) the cost effectiveness of such an operation. A person will need to be appointed by the Lakeba Cooperative Association to oversee this project. When necessary, appropriate advice should be sought from Mr. D. M. Rao, Fiji Foods, Ltd and Mrs. Suliana Siwatibau, Ministry of Energy.

The Fiji Electricity authority (FEA) is also interested in testing coconut oil as a fuel for outer islands and remote areas. Once the Monasavu Dam hydro electric scheme comes on line, later in 1983, nearly all of the electrical demand on Viti Levu will be taken care of. There will be eight to twelve Caterpillar diesel-generator sets that were generating elecrricty on Viti Levu which will no longer be needed. Tests should be conducted with these engines at the FEA National Control Center near Lautoka to determine if it is possible to run them on coconut oil fuel. The alkali refined coconut oil for these tests can be purchased from Punja & Sons in Lautoka. The FEA has well-trained engineers and skilled diesel mechanics to monitor these tests. These poeple could develop operating manuals with the correct methods to place the diesel engines in the field that would operate on 100% coconut oil. One possible site is Savusavu where the FEA would like to set up an engine to operate on coconut oil fuel. This would complement the proposed oil mill at Savusavu. This engine would be operated under radio control as is presently being done at Rakiraki. The test work at FEA should be coordinated by John Pirie, the Chief Power Engineer.

B. Main Island

As stated before, Vitu Levu alone accounts for over 95% of the total petroleum fuel consumption in Fiji. Efforts should be made to look at alternatives for this market. The best place to use alternate fuels would be in the Public Works Department (PWD) because they do not pay any import duty on fuel. The use of alternative fuels by PWD would not decrease the revenue received from import duties but would reduce total petroleum imports of the country. Further, the PWD has well-trained engineers and skilled mechanics to monitor tests. They presently keep accurate records and would be able to determine if engine problems were developing in test vehicles.

The vehicles to be tested with coconut oil as a petroleum substitute should be the Toyota Land Cruisers, Hino Trucks and Caterpillar D6 Dozers. Most of these vehicles have indirect injection fuel systems and should be able to operate on alkali refined coconut oil as a liquid fuel. The alkali refined oil can be purchased from Fiji Foods in Suva. These tests should be coordinated by Mohan Narayan, Principal Mechanical Engineer, PWD, Suva.

C. Budget

There is approximately $150,000 available to Fiji under the SPEC-administered Pacific Regional Energy allocation of the European Economic Community aid program. A proposed budget follows for the tests recommended above.

Organization	Item	Cost	
Lakeba Cooperative	1½ tonne batch Alkali Refining System	$64,000	
	Lab Analysis	3,000	
	Maintenance and Repair	3,000	
			$70,000
FEA	Fuel: 2 CAT 3406's @ 60 L/h * 1000h = 120 kL @ 20¢/L subsidy	24,000	
	Lab Analysis	3,000	
	Maintenance & Repair	6,000	
			$37,000
PWD	Fuel: a) 3 Toyota Land Cruisers @ 10.75 km/L and 43,000 km/yr = 12,000L b) 3 Hino trucks @ 8.25 km/L and 33,000 km/yr = 12,000 c) 2 CAT D6 Dozers @ 22.5 L/h and 1200 h/yr = 54,000 L		
	TOTAL = 78,000 L @ 20¢/L subsidy	15,600	
	Lab Analysis	6,000	
	Maintenance & Repair	10,000	
			31,600
Fiji Government	Consulting		11,400
			$150,000

The batch alkali refining system to be used at the Lakeba Cooperative Association is commercially available from Simon Rosedowns, U.K. This equipment would be compatible with the Simon Rosedowns screw expellers presently being used at the site. The lab analysis costs should be used to pay for fuel analysis and lubricating oil analysis. Attempts should be made to coordinate the testing at all sites and use a comparable quality coconut oil. The maintenance and repair should be used to rebuild the test engines prior to testing time with coconut oil fuel. No provision was made to cover fuel expenses at Lakeba since the coconut oil produced should be comparable in value to the diesel fuel presently being purchased. In contrast, at the other test sites it will be necessary to subsidize the cost for the coconut oil fuel to bring it in line with current diesel fuel prices. Further, it is assumed that the organizations will be utilizing these engines and so it will only be necessary to subsidize the price of diesel fuel used. If this is not the case, then the number of test engines will need to be reduced and the fuel price will need to be paid completely. A provision has also been made to allow for an independent consultant to evaluate the results of these tests and make further recommendations to the Fiji government.

VI. VIABILITY IN WESTERN SAMOA

The Electric Power Corporation (EPC) in Western Samoa has already conducted its own test program using coconut oil in both stationary and mobile diesel engines. The results of these tests are outlined in Chapter III of this report. The EPC has also investigated producing coconut oil from a small scale expeller for use in a coconut oil fueled diesel electric generator. Data from their investigation was utilized in this report (Chapter IV) for the economic analysis of a small scale coconut oil extraction system.

A. Economic Feasibility

Currently, the retail price of distillate in Apia is 82 sene/liter, the wholesale price is 74 sene/liter, and the import price c.i.f. is 61 sene/liter. The wholesale price at the village level is 84 sene/liter. There is one large coconut oil processing plant near Apia that can process 75 tonnes of copra yielding 42 to 46 tonnes of oil per day (24 hours). The coconut oil sells for US $675/tonne f.o.b. (96 sene/liter). The break even price for the mill is 70 sene/liter. Hence, coconut oil is considerably more valuable as an export item on the edible market than as a local substitute in the liquid fuel market. The coconut processing plant will be adding a refining plant by 1985. They estimate that it will cost about US $15/tonne to refine, bleach, and deodorize the coconut oil. Further, they estimate these refining steps will add US $100/tonne to the value of coconut oil.

The EPC has investigated the feasibility of coconut oil for fuel in the remote location of Fagmalo-Satoalepai. They estimated the cost of production was 30 sene/kWh for the coconut oil fueled generator and 37 sene/kWh for diesel. However, these costs do not include repair and maintenance, indirect costs, or a credit for the meal by-product.

B. Technical Feasibility

The comments made in Chapter III with regards to technical feasibility would also apply to the situation in Western Samoa, with one additional comment. There are no studies in the literature that address the technical feasibility of using vegetable oil as a fuel in large, slow speed diesel engines. All long term studies of vegetable oils for diesel fuel have used either high speed multi-cylinder or single cylinder diesel engines. These engines have been used because of 1) the smaller quantities of costly alternate fuels required to power these engines and 2) the applicability of the research results. The increased time for combustion in these slow speed diesel engines may enable the coconut oil to burn more completely thereby eliminating carbon buildup problems due to incomplete combustion.

C. Recommended Tests

The EPC uses several large slow speed diesel engines for electric power generation. They are willing to conduct a long term test using coconut oil in a Mirlees type J6 420 bhp stationary diesel engine which they use for driving an electricity generator. Information gained from this test would add greatly to the volume of knowledge on using vegetable oils as diesel fuel. Currently, there is A$62,500 available from Commonwealth Heads of Government Regional Meeting (CHOGRM) funds that could be used for these tests. This money should be given to the EPC to conduct a long term test of coconut oil as a fuel in the Mirlees diesel engine.

VII. ENGINE TEST PROCEDURES

Testing of renewable fuels has been done at numerous locations. Many studies have limited value because the test conditions and procedures were unique to each test. An advisory committee was set up in the United States to advise on procedures for engine tests of renewable fuels. The Engine Manufacturer's Association, a trade association of 21 international engine manufactuers, has proposed a 200-hour preliminary durability screening test to assess the potential impact of alternate fuels on diesel engine durability. The test is intended to initiate durability problems in a reasonable amount of time (200 hours). However, successful completion of the test does not assure that the fuel will be acceptable. Details of this test procedure are presented in Appendix I. The test procedure is intended to evaluate engine durability and reliability on a laboratory dynamometer. Even though the engine tests recommended in this report will be done in the "field", the fuel characterization, engine wear measurements, and fuel/engine failure criteria should still be used to provide reliable test data.

Several points not covered in the attached test procedures need to be mentioned. All coconut oil to be used as a liquid fuel needs to be filtered though a 4 micrometer filter prior to use to prevent engine fuel filter plugging problems. The bacterial level of the coconut oil in storage should be monitored to determine if bacterial growth is a problem. Accurate records of hours run, power or workload, fuel consumption, and maintenance performed should be kept daily. The engine should be serviced as recommended by the manufacturer for 1) air cleaner element change internal, 2) oil change internal, 3) oil filter element change internal, 4) fuel filter element change internal, 5) injection nozzle and 6) valve train adjustments. The engine lubricating oil should be sampled at normal operating temperatures before each oil change. It should be analyzed for wear metals, viscosity, fuel dilution, and Total Base Number. The coconut oil fuel should also be sampled and analyzed as specified in Appendix I. The fuel and lube oil analysis can be performed in the South Pacific by:

The Institute of Natural Resources
University of the South Pacific
P. O. Box 1168
Suva, Fiji

The cetane number of the fuel will need to be determined by Southwest Research Institute, San Antonio, Texas, USA because a special procedure is required.

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PERSONS INTERVIEWED

FIJI ISLANDS

1. Herbert Wade, Acting Director, Ministry of Energy

2. Richard Haist, Acting Chief Energy Analyst, Ministry of Energy

3. Peter Johnston, Project Manager, U.N. Pacific Energy Development Program

4. Anthony Weir, Senior Energy Officer, South Pacific Bureau For Economic Cooperation, Suva

5. Tom Scanlon, Energy Officer, South Pacific Bureau for Economic Cooperation, Suva.

6. Anthony Amputch, General Manager, Island Industries

7. Daryl Tarte, Executive Secretary, The Coconut Board

8. Bhuwan Dutt, Permanent Secretary, Ministry of Energy and Mineral Resources.

9. Peter Stinson, Honorable Minister of Energy and Mineral Resources and Jone Naisara who replaced him in July, 1983.

10. D. M. Rao, General Manager, Fiji Foods

11. Ami Chand, Production Manager, Fiji Foods

12. Marika M. Tukituku, Permanent Secretary for Works

13. Nelson H. delailomaloma, Director, Ministry of Rural Development

14. Dr. Andrew McGregor, Acting Director of Economic Planning, Central Planning Office.

15. James Makasiale, Permanent Secretary of Agriculture and Fisheries

16. Dr. John Morrison, Director, Institute of Natural Resources, University of the South Pacific

17. Mohan Narayan, Principal Mechanical Engineer, Public Works Department, Ministry of Works

18. Captain Mickey Joy, Director of Marine, Ministry of Transport

19. Robert A. Kahn, Rural Development Assistant, South Pacific Regional Development Officer, USAID

20. Jeremaia R. Nacoke, Director & Registrar of Cooperatives, Ministry of Cooperatives

21. Bill Smith, Peace Corp Volunteer, Ministry of Cooperatives

22. Vernon Hawksley, Administrative Manager, Burns Philp (South Sea) Co., Ltd.

23. Dr. John Tan, General Manager, Castle Trading (SP) Ltd.

24. S. Naidu, Statistician, Trade and Balance of Payments, Bureau of Statistics, Ministry of Finance

25. Dr. David Woodward, Head, Economic Analysis Unit, Ministry of Finance

26. Dan Ellison, Manager Special Projects, Fiji Sugar Corporation, Ltd.

27. Hari Punja, Managing Director, Punja & Sons, Ltd.

28. S. B. Seth, Production Manager, Punja & Sons Ltd.

29. John Pirie, Chief Engineer for Power, Fiji Electricity Authority.

30. Jan Abramski, Prinicpal Energy Analyst, Department of Energy

31. Suliana Siwatibau, Energy Consultant (Project Director; Greater Suva Energy Study), Ministry of Energy

32. Nemani Buresova, Principal Economist, Ministry of Ag. and Fisheries

33. Jeroni Vitu, Research Officer, Fiji Development Bank

34. Ratu Afatariki Waqabaca, Chief, Waciwaci Village, Lakeba

35. Ratu Tevita Afoka, Chief, Yadrana Village, Lakeba

36. Jone Toa Koroivuki, Secretary, Lakeba Cooperative Association

<u>Other Countries</u>

37. Rufo S. Bernardo, Technical Manager, Philippine National Oil Company

38. Dr. Ibarra E. Cruz, Manager, PNOC - Energy Research and Development Center

39. Eduardo H. Qadur, Trade & Markets Department, Philippine Coconut Authority

40. Tom Hall, Energy Advisor, Department of Resources & Development, Federated States of Micronesia Government.

41. Dr. J. F. Ward, Physics Department, James Cook University of North Queensland

42. Mr. Haustraete, SOPRONER, Noumea, New Caledonia

43. Vincent Coutrot, Tahiti, French Polynesia

44. John Worral, General Manager, Electric Power Corporation, Western Samoa

45. Neville A. Bersch, Chief Engineer - Development, Electric Power Corporation, Western Samoa

46. P. Perelini, Mechanical Engineer, Electric Power Corporation, Western Samoa

47. Ernesto C. Bauzon, Mill Consultant, SPCL, Western Samoa

48. Dr. Richard Solly, Head, Liquid Fuels Research Group, Materials Research Laboratory, Melbourne, Vic. Australia

49. Laurie King, Research Engineer, Plant and Transport Branch, Papua, New Guinea

50. Michel Tilche, Product Manager, Oilseed Processing, Henry Simon, Australia

51. Paul Tatireta, Permanent Secretary, Ministry for Works and Energy, Kirbati

52. John Bailey, Program Manager, Research Department, Caterpillar Tractor Company, USA.

53. Ralph Matthews, Manager Vehicle Systems Technology, Advanced Technology Center, Allis-Chalmers, USA.

54. Dr. Everett Pryde, Research Leader, Oilseed Crops Laboratory, USDA

55. Norman A. Sauter, Senior Scientist, Product Technology, Deere & Company, USA

56. Robert Tupa, Product Manager, Lubrizol Corporation, USA

57. Dr. Carl Zilch, Director of Research, Emery Industries, USA

58. Dr. Richard Dabeck, Product Group Manager - Methyl Esters, Emery Industries, USA

59. Dr. Martin Gluckstein, Research Supervisor, Petroleum Chemicals Research, Ethyl Corporation, USA.

60. Stanley Fine, Senior Vice President, Globus Resources Ltd., Hong Kong

61. Christian Kristoff, Senior Consultant, Globus Resources, Ltd., USA

62. James Law, Olson Engineering Automotive Research Center, USA

Northern Agricultural Energy Center
1815 N. University Street
Peoria, IL 61604 Telephone: 309-685-4011

Date: September 1, 1982

200-HOUR SCREENING TEST for ALTERNATE FUELS

Research on/or testing of renewable fuels (i.e. vegetable oils—neat, blended or modified) for diesel engines is in progress or being planned at many locations. Previous studies have limited value because conditions and procedures were unique to each test.

An advisory committee with representation from USDA, agricultural experiment stations, engine (tractor) manufacturers and fuel additive suppliers to advise on procedures for engine tests of renewable fuels has been organized and is coordinated from NAEC, Peoria.

The Engine Manufacturer's Association (EMA), a trade association of 21 international engine manufacturers, has proposed at the request of the United States Department of Agriculture, a 200-hour preliminary durability screening test to assess the potential impact of alternate fuels on diesel engine durability.

The test is intended for research and development purposes and is designed to try to initiate durability problems in a reasonable amount of test time. Successful completion of the test is no assurance that the fuel will be acceptable. However, the test will eliminate some candidate fuels, and patterns of performance and engine durability will be uniformly evaluated for all test fuels.

The advisory committee has adopted the EMA 200-hour screening test for farm tractor engine studies. Anyone contemplating engine testing of renewable fuels, or in an advisory or consultative role to such a project, is encouraged to follow this test procedure:

1. FUEL TEST SERIES:

A fuel test series shall include a 200-hr. baseline test of the engine, followed by one or more 200-hr. tests of alternate fuels for comparison under similar conditions.

2. FUELS TO BE TESTED:

a) Baseline test fuel: Phillips 2D Reference Fuel (P2D).

b) Vegetable oil/P2D blends and modified or hybridized fuels should be specified and tested, starting with the experimental fuel least likely to cause engine damage followed by tests with fuels in order of increasing likelihood of engine damage.

(NOTE: Commercial grade diesel fuels are not advised by the committee for the official 200-hr. screening test because of their variable properties. If commercial grade fuel must be used, its properties should be extensively tested and reported with the engine test results.)

c) Fuel additives: to be determined and specified.

3. FUEL CHARACTERIZATION AND DESCRIPTION TO INCLUDE:

a) Generic name, degree of refinement, source, percent of total mix for each energy component.

b) Gross caloric value; net caloric value. (May be specified as Btu/lb or Btu/gal.)

c) Viscosity at 100C and 40C.

d) Cetane number; Iodine Value; Wax Content; Phosphatide Content; Fatty acid profile by gas chromatography.

4. ENGINE WEAR OBSERVATIONS AND MEASUREMENTS:

a) Each 200-hr. fuel test to commence with new liners, rings, pistons, injector tips, valves, valve seat inserts and guides. (Other parts to be in good condition.)

b) Dimensions of liners and rings, and weight* of rings (and other parts as experience may indicate) to be measured before and after each 200-HOUR TEST.
*Weight to be determined after removal of any deposits.

c) All components of the engine that are likely to be affected by use of the fuel are to be observed, checked, and measured for proper function and for specification tolerances. Included are upper cylinder, cylinder head, induction and exhaust systems, turbo-charger, fuel injection system, and the entire lubrication system.

d) Components such as cylinder heads, injector bodies, valve lifters, cam shaft and bearings, and turbo charger can be cleaned and reused if within manufacturer's specifications.

e) Injectors (tips) will be inspected and performance checked after each test.

f) Parts that fail due to non-fuel related causes are to be replaced and the test continued.

g) There are to be no engine or parts modifications during a fuel test series.

5. CRITERIA FOR FUEL/ENGINE FAILURE:

a) Performance: A drop in power of 5% or more that cannot be corrected with minor adjustments (normal field adjustments) during the 200-hr. test. (Injector nozzles may be replaced to complete a test but this would constitute a failure.)

b) Durability:

1. Failure to complete 200 hours of EMA TEST CYCLE for any reason related to the test fuel.

*2. Measurement of blowby during testing is a convenient way of monitoring gross changes in engine performance which may be due to events such as ring sticking. Blowby measurement is optional and, if desired, need only be performed periodically (every 50 hours).

*c) Lubricating Oil (checked daily after warm-up):

1. Viscosity: A change of 50% from new oil value.

2. Dispersancy: Any indication of failure of dispersion. (Blotter spot test acceptable.)

**d) Engine Life (post inspection): Excessive wear that would extrapolate to a 50% or greater reduction in engine life based on the manufacturer's guidelines and experiences. Wear inspection should include, but is not limited to:

1. Piston, ring and liner wear or scuffing
2. Bearing wear
3. Cam and follower wear
4. Valve guttering.

*Category (b) 2 and (c) will allow termination of the test just prior to a total engine disaster.

**Category (d) will require knowledge of normal engine wear in that area of the world where the alternate fuel is being considered, recognizing geographic variability of diesel fuel quality and the kinds and amounts of impurities.

6. LUBRICATING OIL:

a) High detergent type CD to be used.

b) One lot of lube oil sufficient for the test series should be procured.

c) Physical properties and engine wear contaminants (by chemical analysis) to be recorded at 0, 50, 100, 200 hours.

d) Crankcase level to be checked before each cold start. If oil is low oil should be added. Records of oil consumption should be kept.

e) Oil and oil filter change interval to be as recommended by the engine manufacturer, but not less than 100 hours.

7. EMA BREAK-IN SCHEDULE (90 minutes). A new or re-built engine is to be broken in with P2D fuel before each test as follows:

STEP	SPEED	POWER	MINUTES
1	Low Idle	Idle	10
2	1/2 Rated	Idle	10
3	3/4 Rated	1/2 Rated	15
4	Rated	Rated	55
			90

8. POWER AND FUEL CONSUMPTION TESTS:

To be in accord with SAE test procedures.

9. EXHAUST EMISSIONS:

a) Emission measurements for HC, CO, NO_x, and Smoke are optional. If undertaken, measurements should be made before and after each 200-hour test.

b) The following engine operation modes should be used.

(1) low idle speed, zero load
(2) peak torque speed (*) at zero load
(3) peak torque speed (*) at 50% load
(4) peak torque speed (*) at 100% load
(5) rated speed at zero load
(6) rated speed at 50% load
(7) rated speed at 100% load

*Advertised peak torque speed or 60% of rated speed; whichever is higher.

10. FUEL PRESSURE:

To be monitored continuously and filters replaced as needed.

11. EMA TEST CYCLE (3-hours):

STEP	SPEED	TORQUE	POWER	DURATION-MIN
1	Rated	—	Rated*	60
2	85%	Max	~95%	60
3	90%	28%	25%	30
4	Low Idle	0	0	30
				180

Weighted averaged power = 69%

*Turbocharged engines should be tested at their highest power rating (use of derated engines is not advised).

12. PRELIMINARY DURABILITY SCREENING TEST (200 hours):

Five consecutive test cycles are to be run without stopping the engine, followed by a nine hour (or longer) cold shut down (normal interior ambient temperature). Test duration is 200 hours of EMA cycle operation.

NOTE: Engine Manufacturers Association (EMA) and its members disclaim liability from any cause whatsoever related to the use of this test procedure.

(The EMA 200-hour fuel screening test would be only preliminary to many more specific tests were an engine manufacturer to consider commercial applications of its equipment on non-specification fuels.)

Specific further information is available from Northern Agricultural Energy Center, 1815 N. University Street, Peoria, IL 61604.

ENGINE DIVISION

Peoria, Illinois 61629

September 26, 1983

Mr. Kenton R. Kaufman
Assistant Professor
Agricultural Engineering Department
North Dakota State University
Fargo, ND 58105

Dear Professor Kaufman:

LeRoy Thompson asked that I write you to verify Caterpillar's position on the use of vegetable oil fuels.

The use of up to 30% vegetable oil is currently approved for use with our construction equipment engines (precombustion chamber type only) in Brazil. Patents are being sought for recent developments which enable our precombustion chamber engines to burn 100% vegetable oils. These engines run well on soybean oil and similar performance is expected with coconut oil.

Caterpillar manufactures engines with both direct injection and prechamber combustion systems. Our experience to date strongly suggests the prechamber design is more readily adapted for use with vegetable oils because the fuel is more completely burned and does not dilute the lube oil. We do not recommend the use of vegetable oil fuel in direct injection engines because of nozzle plugging and lube oil dilution.

Caterpillar currently expects to continue the manufacture of prechamber engines in the 80-270 hp range through 1988. This position is subject to change but is our best estimate of long-range prechamber engine availability.

Current prechamber engines (80-1125 hp) could be modified to use 100% vegetable oil by our dealers. We would consider conversion kits if sufficient demand is generated.

I trust this information is useful in your work with countries wishing to evaluate the use of vegetable oils. Please do not hesitate to contact either LeRoy or myself if you require further information.

Very truly yours,

Assistant Manager
Product Division
Sales Development Department

WEMcCandless
Telephone: (309) 578-6766
bjd

cc: LeRoy Thompson - Engineering, Bldg. VV

WEM253

ANNOUNCEMENT

KHD S.A. (Pty) Ltd announces a full factory warranty on all Deutz indirect injection engines fuelled by degummed sunflower oil and used in Deutz-Fahr agricultural equipment.

This recognition of pure sunflower oil as an alternative to diesel fuel follows three years of intensive research by the division of agricultural engineering in South Africa and KHD's Research and Development Centre in West Germany.

This warranty is in keeping with the pioneering tradition of KHD, the world's largest manufacturer of air cooled diesel engines. We were the first manufacturer of production diesel engines and the warranty cover for sunflower oil is another world first.

Now the wheels of SA agriculture can keep turning even if there was an unforeseen diesel fuel shortage. That's comforting, isn't it?

Date 19th September 1983

Reference ED/AE/2.11/KLW/977

Mr. K. R. Kaufman,
Asst. Prof. Agricultural Engineering Department,
North Dakota State University,
of Agriculture and Applied Science,
P.O. Box 5626,
Fargo,
North Dakota 58105.
U.S.A.

Dear Mr. Kaufman,

Thank you for your letter of 1st September enquiring about the use of transesterified coconut oil in Perkins engines.

We do not offer blanket approval of our engines operating on monoester type fuels produced from vegetable oils. This has nothing to do with the ability of our engines to operate satisfactorily on such fuels, but arises because there is no recognised specification nor quality standards for the production of such fuels. With diesel fuels all manufacturers relate their approval of fuel to meet warranty to at least one appropriate and recognised fuel standard to which oil companies supply fuel. Without such a standard there is no control over what type and condition of fuel that is used,that can relate to warranty or even general reliability.

We have, however, made an intensive study of fuels over the last few years including the whole range of monoester derivatives of vegetable oils. From this we have a clear view of the fuel quality standard required and the limitations in use, if any, in comparison with petroleum based fuels. As a result we are in a position to appro e certain fuels on a locally sourced basis, provided that we can assure ourselves of the standard of fuel being produced and the measures installed to maintain that standard.

If, therefore, there are serious intentions to produce a monoester of coconut oil in the Fiji Islands, we would be prepared to consider approval, provided the conditions of specification and quality were met. As you will be aware, many of the monoester fuels are potentially quite satisfactory alternative fuels. We are, of course, aware of Richard Jolly's work in this field, including his recent publications in Australia.

If there is likely to be any serious interest, I would be able to put the Fiji Island authorities in contact with a group of consultants who are specialising in feasibility studies, subsequent design and installation of fuel production plants and even the ongoing management of them and feedstock plantations, if required.

We do have engines operating in the Fiji Islands and if you can provide us with any further information, we would be grateful, as well as an indication of any mutually beneficial opportunities to work with the Fiji Islands either directly, or through the U.N.I.D.O. I look forward to hearing from you.

Yours sincerely,

K. L. Walker
Chief Engineer
Advanced Engineering

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AD.85.03