BIOFUELS FROM COCONUTS

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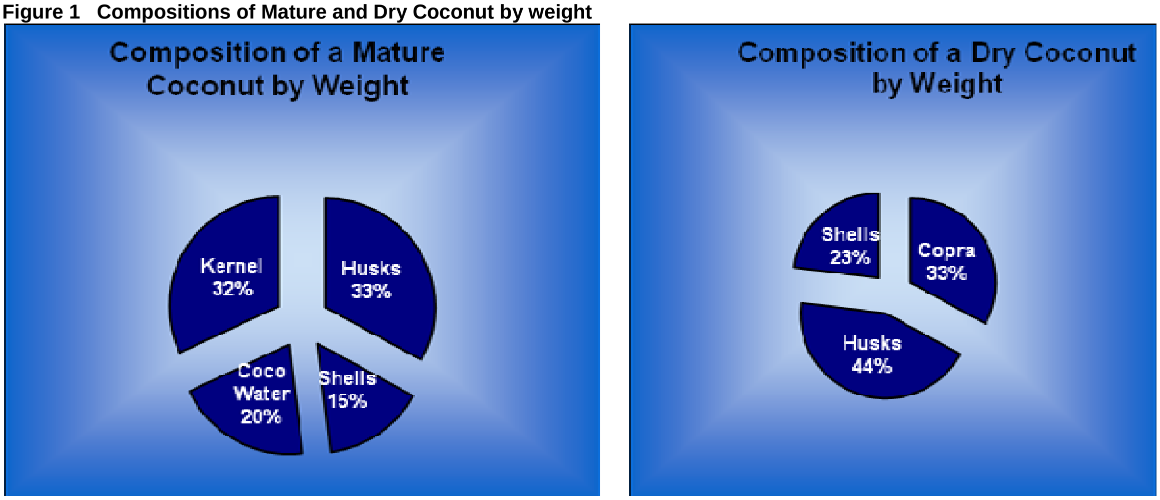
1 POTENTIAL FOR BIOFUELS FROM COCONUTS

1.1 Quantity and Energy content of parts of the Coconut Palm

When a mature coconut is harvested after 11 or 12 months, it is filled with coco water and its kernel, shell and husk are in a wet condition. Generally, the coconut is dehusked and the shell split open so that the kernel can be taken out and dried into copra. In some countries, especially in the Pacific, the whole nut is split open without dehusking. Compositions of both the mature coconut when harvested and after it has been dried are shown in Figure1.

Figure 1 Compositions of Mature and Dry Coconut by weight



<u>Note</u>: Husks are composed of Coir and Coir dust.

The weight of a coconut depends on the cultivar or hybrid. The break-up into its components of an average coconut that weighs 1.2 kgs is given in Table1.

Table 1 Composition of one mature Coconut by Weight

	Part	*Weight [kgs]*
	Whole Coconut	1.2
1	Husks (Coir + Coir dust)	0.39
2	Shells	0.17
3	Coco water	0.24
4	Green Copra	0.37
4a	Dry Copra	0.2
4b	Moisture	0.17
4a-1	Copra Meal	0.08
4a-2	Copra Oil	0.12

Note: Average values for 1,000 nuts
Source: Cloin, 2005

Copra, the dried kernel that is used to extract coconut oil, is the most important product from the coconut, and coconut production is very often given in tonnes of '*copra equivalent*'. The ratio of weights of the different parts of a coconut palm to the dried kernel is shown in Figure2 and Table2. The fronds (leaves) have the maximum weight at over 4 times the weight of the kernel, and roughly one new leaf is produced and an old one drops once every month. The trunk (stem) is next at 1.45 times the kernel, but the stem can only be harvested once at the end of its lifetime. The weight of the husk (coir + coir dust) is 1.3 times and of the shell is 0.9 times the weight of the kernel, all three being produced together in one nut. Finally, the kernel itself consists of two parts:

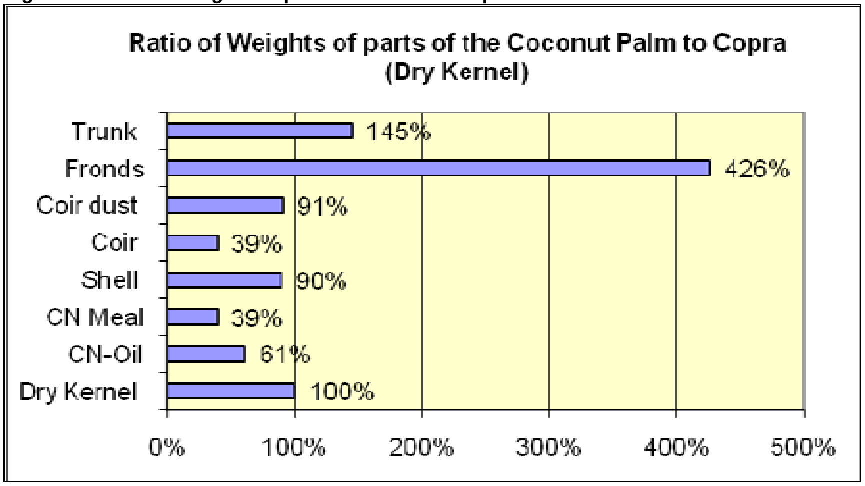
- **Coconut Oil** is roughly 60%;
- **Coconut Meal** (or **Oil Cake**) that remains after the oil is extracted weighs about 40%.

Table 2 Quantity and Energy Content of parts of the Coconut Palm

	Dry Kernel	CN-Oil	CN Meal	Shell	Coir	Coir dust	Fronds	Trunk	Combined
Ratio to "Dry" Kernel (%) (@ 4% moisture content)	100%	61%	39%	90%	39%	91%	426%	145%	991%
Energy Content (GJ /t)	29.1	37.7	15.7	18.2	16.7	16.7	16.7	16.7	16.2

Source: Hagen, 1995

Figure 2 Ratio of weights of parts of the coconut palm



Source: Data from Hagen,1995.

1.2 Potential for Power Generation from Unused Coconut Biomass

Global annual production of coconuts in 2005 was around 59.6 billion nut equivalent or 11.9 million tonnes copra equivalent harvested from 1.2 billion palms on 12.2 million ha (APCC, 2006). The total biomass production (excluding the coco water but including the kernel) is 106,100 kilotonnes, of which 60.5% amounting to 64,200 kilotonnes is unprocessed. To estimate the power that can be generated from unused coconut, the following procedure has been followed (Hagen,1995):

1. Estimate the quantity of biomass produced by the components (CN oil, CN meal, shell, husk consisting of coir and dust, fronds i.e. leaves, and trunk) .
2. Estimate reported industrial production of components.
3. The unused coconut biomass from the palms processed is taken as industrial waste.
4. Estimate the quantities used by small-holders.
5. The remainder is "Available Unprocessed Biomass".

6. Multiply unprocessed portion of each component with its Energy Content to give the "Global Unused Biomass Energy".
7. Estimate the biomass energy available for electricity generation as 70% of the unprocessed biomass.
8. Calculate the Electricity Generation Potential in Giga Watt Hours (GWh) based on the Net Efficiency of the technology used for power generation (Steam engines: 10%; Gasifier + IC engine: 18%)
9. Estimate the total capacity of power generation in Mega Watts (MW) by taking a Load Factor of 50%.

Figure 3 Energy from Unused Coconut Biomass

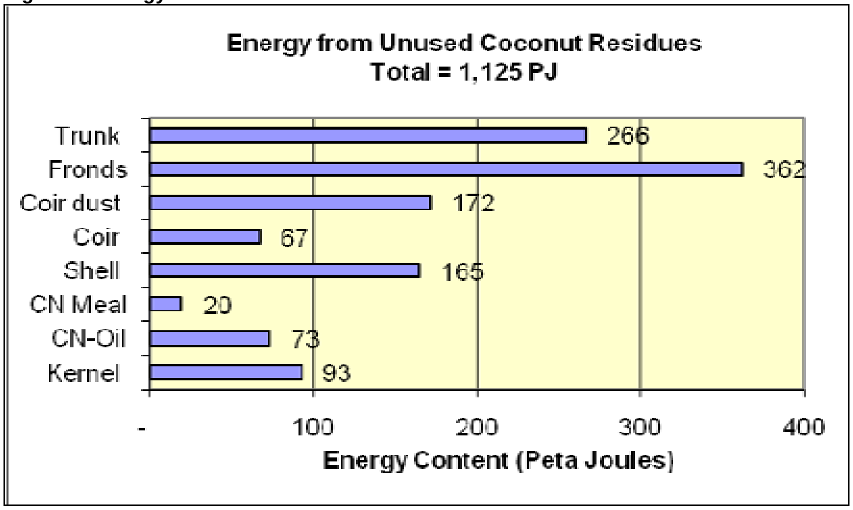
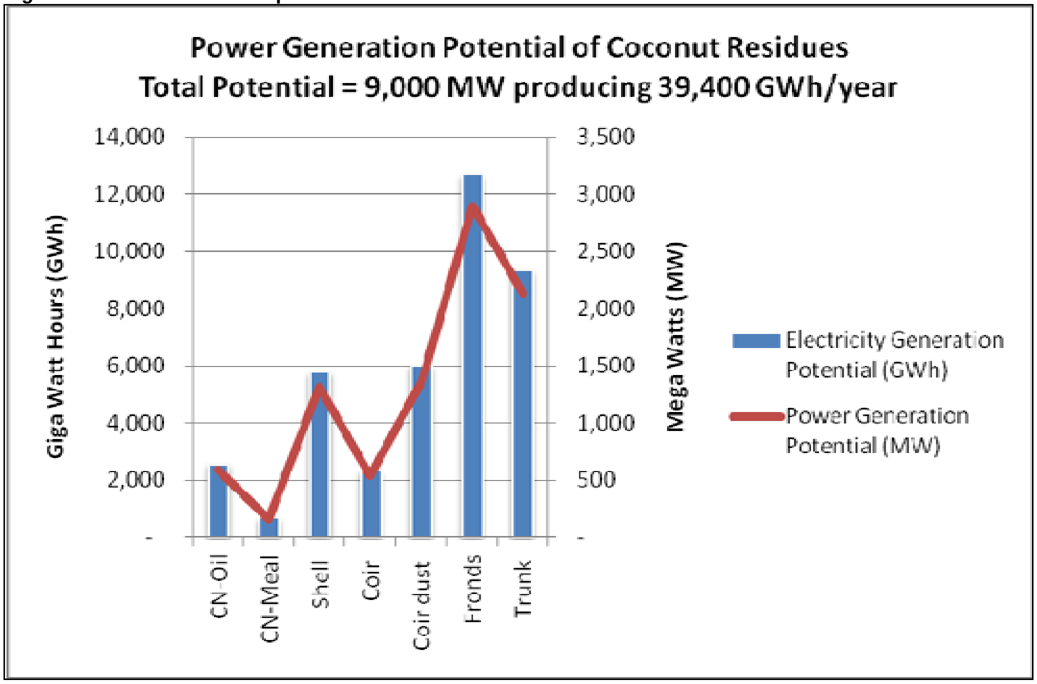


Figure 4 Power Generation potential of Coconut Residues[1]



[1] As per Systeme International (SI) usage, tonne refers to the metric ton of 1,000 kg; PJ = petajoule = 10^{15} Joules. TJ =terajoule = 10^{12} J; GJ = gigajoule = 10^{9} Joules; MJ = megajoule = 10^{6} Joules.

The results are given in Table3:

- The Global Unused Biomass Energy is 1,125 Peta Joules (PJ) of which 70% amounting to 788 PJ is assumed available for power generation.
- If this biomass is burned in a steam engine, it can generate 21,900 GWh of electricity. If it is burned in a gasifier it can generate 39,400 GWh.
- At a 50% Load Factor (12 hours per day), the total power generation capacity is 5,000 MW using efficient steam engines. However, by gasifying the biomass and using Internal Combustion engines, the total capacity is 9,000 MW.

Table 3 Potential for Power generation from Coconut Residues

PORTION --->			Kernel	CN-Oil	CN Meal	Shell	Coir	Coir dust	Fronds	Trunk	Combined
Air Dry Matter/Fresh Weight assumed *	%					95%	62%	62%			
Ratio to "Dry" Kernel (@ 4% MC) *	%		100%	61%	39%	90%	39%	91%	426%	145%	
Total Global Coconut Production	kt		11,913	7,267	4,646	10,722	4,646	10,841	50,749	17,274	106,144
Industrial "Production" % of Total*	%		43%	43%	43%	55%	55%	55%	55%	55%	
Industrial "Production"	kt		5,145	3,138	2,007	5,897	2,555	5,962	27,912	9,501	56,972
Commercial Consumption Copra	kt		4,776	2,917	1,761	843	291	5	11,410	356	17,377
Desiccated CN+CN Cream	kt		323								
% Commercial/Total *	%		40.1%	40.1%	37.9%	10.5%	8.4%	0.1%	30.0%	2.7%	21.8%
% Commercial/IIndustrial	%		99.1%	93.0%	87.8%	19.1%	15.2%	0.1%	54.6%	5.0%	40.0%
Industrial "Waste"	kt		46	221	245	4,771	2,167	5,956	12,672	9,026	35,058
% Industrial "Waste" *	%		0.9%	7.0%	12.2%	80.9%	84.8%	99.9%	45.4%	95.0%	61.5%
Small-holder eating/cooking etc.	kt		3,574	2,180	1,394	536	232	542	13,854	864	19,602
% Small holder use*	%		30.0%	30.0%	30.0%	5.0%	5.0%	5.0%	27.3%	5.0%	18.5%
Available Unprocessed Biomass	kt		3,194	1,948	1,246	9,060	4,023	10,288	21,670	15,944	64,179
Global Portion Unprocessed	%		26.8%	26.8%	26.8%	84.5%	86.6%	94.9%	42.7%	92.3%	60.5%
Energy Content *	GJ/t		29.1	37.7	15.7	18.2	16.7	16.7	16.7	16.7	16.2
Global Unused Biomass Energy	PJ		93	73	20	165	67	172	362	266	1,125
Biomass available for Electricity @70%	PJ		65	51	14	115	47	120	253	186	788
		NE									
Electricity Generation Potential	GWh	***10%***	1,809	1,429	381	3,209	1,308	3,343	7,042	5,181	21,893
	GWh	***18%***	3,256	2,573	685	5,776	2,354	6,018	12,676	9,327	39,408

Power Generation Potential @ 50% Load factor	MW	***10%***	413	326	87	733	299	763	1,608	1,183	4,998
	MW	***18%***	743	587	156	1,319	537	1,374	2,894	2,129	8,997

Table 4 Power Generation Potential from Unused Residues (1,000 tons copra equiv./year)

Portion >>			Kernel	CN-Oil	CN Meal	Shell	Coir	Coir dust	Fronds (Leaves)	Trunk	Combined
Equivalent Mass Rate @ 50% Load factor	kg/hr		228	139	89	205	89	208	973	331	2,988
Equivalent Heat rate	kW		1,846	1,458	388	1,036	412	960	4,504	1,535	13,445
Minimum Energy Available	%		15.1%	15.1%	15.1%	79.4%	0.0%	99.0%	42.7%	50.0%	37.7%
Power with Gasifier Genset	kW	***18%***		40	11	148	-	172	347	138	855

Source: Author's calculations with Assumptions (*) from Hagen, 1995;
Note: (a) *NE* = Net Efficiency; (b) As per Systeme International (SI) usage, tonne refers to the metric ton of 1,000 kg; PJ = petajoule = 10^{15} Joules. TJ =terajoule = 10^{12} J; GJ = gigajoule = 10^{9} Joules; MJ = megajoule = 10^{6} Joules.

1.3 Decentralised Power Generation from Coconut Residues

Generally, the farmer dries the kernel and sells the copra through middlemen to the large coconut oil mills that are located in urban areas and process copra into coconut oil and meal (oil cake). For example, around 100 coconut processing plants in the Philippines are generally very large (500,000 to 5,000,000 nuts/day or 30,000 to 300,000 tons copra/year). However, over 90% of coconuts are grown by smallholders many of whom do not have power supply. Coconuts can be processed locally in smaller processing plants, and the energy of the unused biomass can be used to generate power for the population residing nearby.

A small processing plant that coverts 1000 tonnes copra equivalent per year is analysed in Table4. On an average, 5 million nuts are required to produce 1000 tonnes copra (5 nuts per kg copra). This can come from 1,000 smallholders each producing an average of 1 tonne copra per year, or from 2,000 smallholders each producing an average of 0.5 tonne copra per year. If 70% of the unused biomass is used for power generation in a Biomass Gasifier + IC engine system operating at a net efficiency of 18%, 1,000 kW of electricity can be generated for 10 hours every day (50% load factor). If 25% of the world's coconut production is processed in this way, there is a global potential for nearly 3,000 such decentralized power plants of 1 MW capacity.

Even smaller *micro* scale processing units may be the most appropriate solution in many locations especially on small tropical islands most of which grow coconuts. The gasifier+IC engine system also produces waste heat that can be used for drying the copra. For example, in combination with an oil mill processing 10 tonnes of copra /year, a 10 kW gasifier + gas engine power plant can be installed. This will utilize the coconut production of about 20 smallholders and cater to their electricity needs as well. If only 1% of the global coconut production is processed in such micro oil mills, there is a potential for 12,000 power plants of 10 kW capacity that can provide power to 240,000 smallholders.

Small-scale power generation in the rural areas can stimulate development of small and medium scale industries that add value to locally available raw materials. By providing additional employment opportunities and income generation it can alleviate poverty.

1.4 Diesel savings and Emissions Reductions

Diesel Savings

If electricity from diesel power plants is displaced by the electricity produced from coconut residues, then 11.8 billion litres of diesel (74 million barrels) can be saved in a year. This will lead to a reduction in greenhouse gas emissions of 32 million tonnes of CO2 (Table 2).

Table 5 Diesel savings

Electricity produced from Residues	39,408	GWh /year
Diesel savings	11.8	billion litres /year
=	74	million barrels /year

Assumptions:

Diesel usage for electicity generation = 0.30 litres /kWh

The value of 11.8 billion litres of diesel at various crude oil prices is given in Table 3. The value of diesel is 5.2 and 10.4 billion US$ at a crude oil price of 50 and 100 US$ /barrel respectively.

Table 6 Diesel Price and Savings

Crude Oil	Diesel	Diesel savings
US$ /bbl	US$ /litre	billion US$
50	0.44	5.20
100	0.88	10.41
150	1.32	15.61
200	1.76	20.82

Assumption: Diesel Price is 40% more than Crude Oil price
(Refining & Profit = 32%; Distribution & Marketing = 8%)
Source: EIA, USA

Emissions Reductions

At a reduction of 2.7 kg carbon dioxide (CO_2) for every litre of diesel saved, the total emissions reductions from the diesel savings alone will be 32 million tonnes CO_2 /year.

However, this is not the total CO_2 emissions reductions resulting from electricity generation using biofuels from coconut instead of diesel. There are CO_2 emissions during the production and processing of coconuts, and usage of coconut biofuels in engines that have to be taken into account. These emissions are due to fossil fuels used in:

- Production of coconuts - from fossil fuels used to produce fertilisers used, in farm mechanisation, etc.;
- Processing coconuts - from fossil fuels used for transportation of coconuts and its products, and for producing heat & electricity at oil mill, etc.;

- Engine modifications – from fossil fuels used in producing biomass gasifiers, components used to modify engines to run on coconut oil, etc.

To get a fair picture of carbon savings by replacing diesel by coconuts, a full lifecycle analysis of the coconut fuel chain has to be carried out in which all these CO_2 emissions have been accounted for.

2 POST HARVEST TREATMENT AND PROCESSING

2.1 Nut Storage

Nuts are generally dehusked soon after harvesting, if possible on the same day. Storage of the nuts is not really required before dehusking, except for very green nuts which are easier to dehusk after some storage. During periods of peak harvests, not all nuts harvested daily can be dehusked the same day, and storage will be necessary. To maintain a certain stock may also be necessary to keep the dehusking team constantly supplied with coconuts.

Storage of nuts should be done in as dry conditions as possible, preferably under a roof and close to the dehusking site. To reduce transportation costs, nuts are sometimes stored under the trees for local dehusking, but this increases the risk of nut theft and rodent attack. Local experience is the best indicator of the possibilities for storage during the wet and the dry seasons.

Table7 gives the effects of storage time on the germination, moisture content and formation of ball copra.

Table 7 Effects of Storage Time on Dehusked Nuts

Storage Time (months)	Germination	Moisture Content
1	1 %	80 %
2	9 %	66 %
3	27 %	55 %
	Ball Copra Formation	
6	10 %	
7	33 %	
8	70%	
9	100%	

Source: (Ohler, 1999)

The advantages of storing or 'seasoning' harvested nuts before they are processed further are:

- Moisture content of the meat decreases;
- Germination percentage increases;
- More uniform copra quality;
- Dehusking becomes easier especially with the greener coconuts. Trials indicated that whole 12-month-old nuts dried sufficiently within two months to facilitate husking and copra extraction.
- Shelling becomes easier and cleaner;
- Greater meat resistance to bacterial sliming during sundrying;
- Under very dry conditions nuts may dry out during storage without germinating. This may facilitate dehusking and scooping out of the copra from the shell.

(Ohler, 1999)

2.2 Dehusking

The simplest method of removing the kernel from the nut is by splitting the nut into two halves or three parts with the use of a axe without dehusking, and this is done in several islands in the Pacific. The kernel can then be scooped with a knife out to be sun dried or taken to the kiln, but more often it is transported directly to a processing factory with hot air dryers for copra manufacture. The husk with the shell attached to it is used as fuel for the dryer – typically about 50% is required for drying.

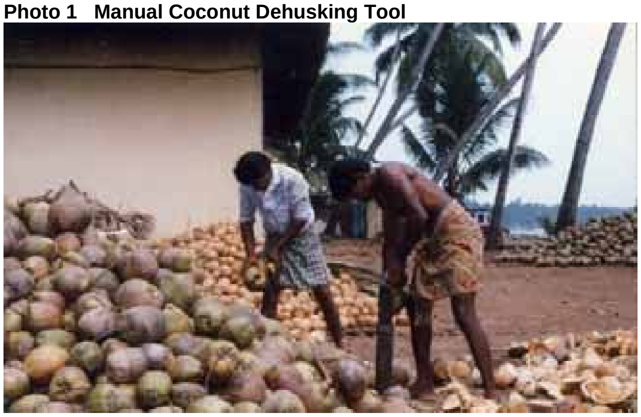
This method has several drawbacks:

- The wet endosperm sticks to the shell and cannot be removed in halves or large pieces. The kernel is scooped out with a flat metal implement resulting in 'finger cut' kernels.
- The increased surface of the cut endosperm exposed to the air increases deterioration.
- There is also an increased risk of contamination with dirt in the plantation.
- When the endosperm is transported in bags and pounded to reduce its volume, deterioration will be much increased, particularly if these bags have been used before for the same purpose.
- Both husks and shells not used as fuel remain in the field. The shell will take a long time to decompose and may become a nuisance.

In most of the coconut growing countries, the first step in the post-harvest treatment of coconuts is dehusking, often done in the neighbourhood of the copra kiln.

- This is hard work and is traditionally done manually by labour experienced in dehusking.
- Dehusking reduces the weight of nuts by about 40% and the volume by about 60%.
- The cost of nut transportation to the kiln can be reduced by dehusking the nuts under the trees, so that only the unopened nuts in shells have to be transported to the kiln. The husks remain in the field for use as an organic mulch and fertilizer since it is rich in plant nutrients and decomposes easily. When nuts are dehusked in the field, they must be shaded, so that they do not burst when heated by sunshine.
- However, if the husks are also to be used as fuel for drying then dehusking might as well be done near the kilns or hot air dryers.

Photo 1 Manual Coconut Dehusking Tool



Source: FAO

The most frequently used dehusking method is by the use of a pointed metal spike, secured in the ground in a slightly slanting position, with the point upwards (Photo1). The nuts are brought down with force on the spike, followed by twisting the nut sideways against the spike, loosening the husk. This movement is repeated once or twice for the total removal of the husk. Care is taken that the point of the spike enters the husk at the stalk end so as to avoid the damaging the shell.

Dehusking is hard work; it is low paying and not very popular, so it is often difficult to find labour for this operation even though it can provide jobs for the unemployed. The number of nuts one man can dehusk per day depends very much on the type of the nuts, the thickness of the husk, and the skill and energy of the operator. An average experienced worker is capable of dehusking 1200 to 1500 nuts per day. An average worker in Malaysia generally manages to process 1000 Malayan Tall nuts, 1200 MAWA hybrids or 1500 Malayan Dwarf nuts per working day. In most countries, dehusking and splitting are performed by different labour.

Various mechanized systems have been developed during the past decades, but no system really made an impact and dehusking is still done manually in most places. Major problems for mechanical dehusking include different sizes of nuts and shells, and the different stages of maturity of the harvested nuts (this can be overcome by storing the nuts for a few weeks). Development of dehusking machines has been carried out in Malaysia, the UK, India and Trinidad and Tobago but usage in large numbers has been slow. Reasons for low acceptability of the machines include low processing capacity and high labour and other operating costs. (Ohler, 1999)

The “CoCoMaN” dehushing machine available from Method Machine Works Sdn Bhd in Malaysia is shown in Fig . (http://www.coconutmachine.com/). FOB cost in 6,500 – 7.500 USD.

Photo 2   “CoCoMaN” dehushing machine

Source: http://www.coconutmachine.com/

2.3 Nut Transportation

The system of nut transportation depends on the volume of nuts to be handled and the distance over which this volume has to be transported. In small coconut farms, the farmer transports the nuts to his house himself. As the size of the farms and the number of nuts increases, other modes of transportation are used including large baskets on bicycles, horses or donkeys and animal-drawn carts. In large holdings nuts are transported by tractor-drawn carts to the drying kiln where they are split and drained before being placed in the kiln. In some large plantations, nuts are broken immediately and placed in bags holding about 40 broken nuts each. However, transportation has to be readily available and waiting hours at the kiln must be low, otherwise opened nuts will start moulding within one day. Trucks are normally used for transporting nuts to a central factory outside the plantation.

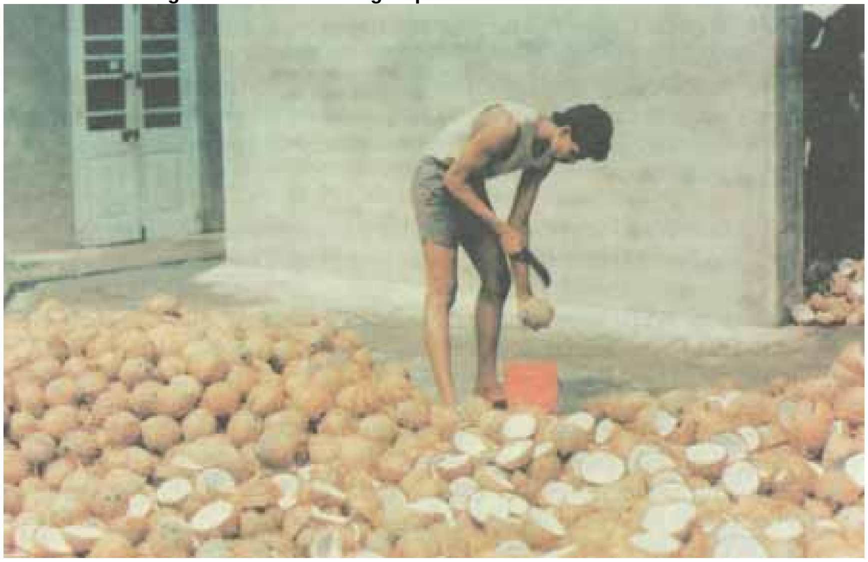
2.4 Cracking

The second solid biofuel from the coconut is the shell. The shell is separated from the kernel by:

- cracking - if copra or virgin coconut oil is to be produced; or
- shelling – if dessicated coconut is to be produced.

Dehusked coconuts are cracked or split into two halves along the 'equator' with a steel rod or heavy knife. This is done for making copra or to facilitate grating for domestic uses or for production of virgin coconut oil. Cracking is carried out manually, and there is no need for mechanization.

Photo 3 Breaking coconuts for making Copra



Source: Breag et al, 1994

2.5 Copra Manufacture

Coconut oil is mostly produced made in large mills from the dried kernel called copra. When making mill copra, the objective is to dry the kernel of the freshly opened nut from the 50%

moisture level down to 6% as fast as is practically possible. The high moisture content and presence of protein and sugar makes the fresh kernel an ideal medium for the development of bacteria and fungi. It is therefore liable to deterioration and very susceptible to attack by microorganisms, with the development of free fatty acids and rancidity that degrade the fuel quality of the oil, and also the formation of aflatoxin which is a highly poisonous chemical.
Since copra is considered as a low value product, it is not economically viable to use sophisticated dryers, or even the use of blowers for a more constant airflow. Therefore, for making copra, natural draft dryers are used. Common methods of drying can be classified as:

1) Using Heat from the Sun
    a) Sun drying
    b) Solar drying

2) Using Heat from burning Biomass
    a) Kiln drying using Smoke - Direct or Semi-direct drying
    b) Indirect drying using Hot-air

Drying methods for production of copra are described in Annex-2.

In addition to the mill copra which is milled for oil and cake, there are two other types of copra produced in much smaller but significant quantities for edible purposes:

- Ball Copra - drying is carried out mainly by storage on the platform under complete shade for periods of 6 - 8 months. During the rainy season artificial drying is done.
- Edible Copra - the fuel used for drying is coconut shell charcoal, which produces an even cleaner direct heat. Sometimes a small amount of sulphur is burnt to obtain an attractive white colour.

Photo 4 Edible Ball copra – whole and cut into halves

Source: Rethinam et al, 2002

3 COCONUT OIL - COMPOSITION AND PROPERTIES

3.1 Composition

Coconut oil is a mixture of chemical compounds called glycerides containing fatty acids and glycerol. The different fatty acids present in coconut oil range from C6 - C18 carbon atom chains. The oil is contained in the kernel or meat of the nut. Coconut nut oil and Palm kernel oils are called lauric oils since the main component (over 50%) is lauric acid.

Table 8 The chemical composition of coconut oil

Component	Fraction %(1)	Chemical Formula	*Systematic name*[a]	*Acronym*[b]
Lauric acid	51.0	$CH_3(CH_2)_{10}COOH$	Dodecanoic acid	12:0
Myristic acid	18.5	$CH_3(CH_2)_{12}COOH$	Tetradecanoic acid	14:0
Caprilic acid	9.5	$CH_3(CH_2)_6COOH$	Octanoic acid	8:0
Palmitic acid	7.5	$CH_3(CH_2)_{14}COOH$	Hexadecanoic acid	16:0
Oleic acid	5.0	$CH_3(CH_2)_7CH = CH_3(CH_2)_7COOH$	9*Z*-Octadecenoic acid	18:1
Capric acid	4.5	$CH_3(CH_2)_8COOH$	Decanoic acid	10:0
Stearic acid	3.0	$CH_3(CH_2)_{16}COOH$	Octadecanoic acid	18:0
Linoleic acid	1.0	$CH_3(CH_2)_4CH = CHCH_2CH= CH(CH_2)_7COOH$	9*Z*,12*Z*- Octadecadienoic acid	18:2

Source: Knothe et al, 1997 except (1) Hilditch, 1956.

Note: a) *Z* denotes *cis* configuration; b) The numbers denote the number of carbon atoms and double bonds in one molecule. For example, in oleic acid, 18:1 indicates that each molecule contains eighteen carbon atoms and one double bond.

3.2 Fuel related Properties

The properties of coconut oil relevant for its use as a diesel substitute are:

Specific Energy – indication of the fuel's energy released when it is burned. Coconut oil's energy (38.4 MJ/kg or 34.9 MJ/liter) is a little less than petro-diesel (46 MJ/kg or 38.6 MJ/liter). The energy content of one liter of coconut oil is typically 92% of that of one liter of diesel.

Cetane Number (CN) – indication of the fuel's willingness to ignite when it is compressed. Coconut oil's CN (60) is the highest.

Viscosity – indication of the fuel's ability to atomize in the injector system. Coconut oil's viscosity is comparable with other oils but is several times higher than petrodiesel. Higher viscosity will cause poor volatilization of the fuel in the injector system and poor spray pattern. The viscosity of plant oils such as coconut oil can be reduced by heating, blending or trans-esterification.

Solidification Point – indication of the temperature at which the fuel will turn solid. Coconut oil's solidification point also called freezing point is around 24°C so it freezes during winter time even in some tropical countries.   Solidification can be prevented by blending it with diesel or kerosene. Removing the residual water and free fatty acids found in mill refined coconut oil also reduces the freezing point to some extent.

Iodine Value (IV) – gives the degree of unsaturation of a fat and is an indication of the ability of the fuel to polymerize due to the fuels' degree of bonds available. Coconut oil's IV (=10) is the lowest among all the plant oils shown in Table , so it is less likely to cause problems associated with polymerisation of a plant oil in the engine.

Saponification Value (SV) – indication of the fuel's ability to vaporize and atomize due to the fuels carbon chains. Coconut oil has the highest SV (268), so it will ignite more quickly than other plant oils. SV is measured by the number of milligrams of potassium hydroxide required to convert 1 gram of fat into glycerine/soap.

Table 9 Fuel-related properties of vegetable oils and petroleum diesel

	Specific Energy, Gross (MJ/kg)	Cetane Number	Kinematic Viscosity@ *40°C* (cS)	Solidification Point (C)	Iodine Value	Saponification Value
Petroleum Diesel	41 - 49	45 – 55	4	-9	-	-
Coconut Oil	**42.0**	**60**	**20**	**24**	**10**	**268**
Palm Oil	39.6	-	37	35	54	199
Rapeseed Oil	39.7	38	37	-10	125	175
Soybean Oil	39.6	37.9	33	-16	130	191
Linseed Oil	39.7	-	29	-24	179	190

Source: Bradley, 2004

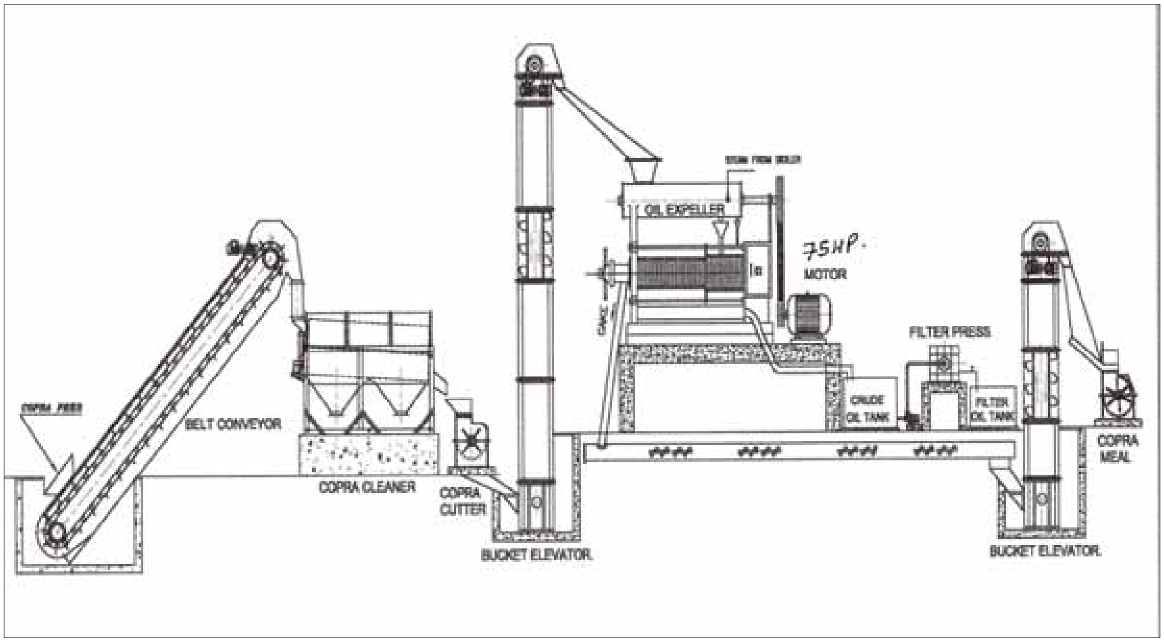
4 OIL PRESSING & REFINING

Technologies for producing coconut oil fall under two categories:

- **<u>DRY PROCESS</u>** The oil is extracted from the dried coconut kernel called copra. This can be done in large oil mills (1000 litres oil per hour or more) or in Mini-mills (10-100 litres per hour). Oil mills are mechanised and need their own power supply to operate the equipment.
- **<u>WET PROCESS</u>** The oil is extracted from the fresh kernel after grating in its wet or a semi-dried state. The Ram press and Direct Micro Expeller (DME) have been used to produce Virgin Coconut Oil (VCO) using hand operated presses suitable for household or community scale. However, VCO sells at a price that is more than double the price of oil from the dry process, and is therefore too expensive to be used as a fuel.

4.1 Dry Process and Oil Refining

Figure 5 **Schematic of dry process for coconut oil extraction**



Source: Cottor International

Dried Copra from the farm is stored in warehouses, sometimes upto 2 to 3 months, before it is processed in a medium or large scale oil mill where it undergoes the following main steps:

- <u>Cleaning</u>: Copra is transferred from the warehouse to a mill by a series of floor conveyors, rotor-lift and overhead conveyors. Copra is cleaned of metals, dirt and other foreign matter manually by picking or by means of shaking or revolving screens, magnetic separators and other similar devices.
- <u>Crushing / Cutting</u>: Copra is broken into fine particle sizes of about 1/16" to 1/8" by high-speed vertical hammer mills or cutters to facilitate oil extraction;
- <u>Cooking/Conditioning</u>: The crushed copra that has about 5-6 percent moisture is passed through a steam-heated cooker. This brings the temperature of the copra to the

conditioning temperature of about 104°C. At the conditioner, the copra is maintained at about 104-110°C for about 30 minutes to insure uniform heat penetration before oil extraction. Moderately high temperature facilitates the expelling action. Oil is able to flow out more easily due to decrease in viscosity. Moisture content of copra is about 3 percent when it leaves the conditioner.

- Oil extraction: In the expeller, the milled copra is subjected to high-pressure oil extraction, first by a vertical screw, and finally by a horizontal screw. To control the temperature during extraction, the main shaft is provided with water-cooling and cooled oil is sprayed over the screw cage bars. The temperature of the oil should be kept at about 93-102°C to produce light coloured oil and effect good extraction.
- Screening: The oil extracted in the expeller flows into the screening tanks to remove the entrained foots from the oil. The foots settle at the bottom and are continuously scooped-out by a series of chain-mounted scrapers which lift the foots to the screen on top of the tank. While travelling across the screen, oil is drained out of the foots. The filtered oil flows into a surge tank from where it is finally pumped to the coconut oil storage tank.
- Filtration: Preliminary filtration is done in one of more settling tanks. The oil taken from the top of the settling tank is passed through a plate and frame filter press to further remove the solids in the oil. Maximum filtering pressures reach about 60 psi. The filtered oil flows into a surge tank from where it is finally pumped to the coconut oil storage tank.

Coconut oil refining

Good quality coconut oil is low in fatty acids and has a good aroma – it can only be produced from good quality copra. However, after several weeks or months in storage and transportation, copra is likely to be dark, turbid, high in free fatty acids (FFA), phosphatides and gums, and have an unpleasant odour. The oil from such low quality copra has to be refined to produce clear, odour-free edible oil. Losses during the refining process can be 5 to 7.5 percent of the weight of the crude oil. The main steps in the refining process are:

- Physical refining: A weak solution of phosphoric acid is added to remove phosphatides and gums which are separated from the oil by centrifugation or by decantation.
- Neutralisation: Sodium hydroxide is used to convert free fatty acid into an oil-insoluble precipitate called soapstock which settles down and is removed.
- Bleaching: improves the color of crude oil by heating ed to remove excess moisture and then adding either activated carbon or bleaching earth such as bentonite. The bleaching agents are then removed by passing the oil through a filter press.
- Deodorisation: removes volatile odours and flavours as well as peroxides that affect the stability of the oil thereby improving the shelf-life of the oil. The oil is heated to a temperature between 150-250°C and contacting with live steam under vacuum conditions.

Mini Mills

"Mini Mills" can be used to produce coconut oil on a small scale from copra using the Dry process (10 – 100 litres oil per hour). If good quality copra is used then the refining process is not necessary and only filtration is required to produce fuel grade oil that is low in free fatty acids, moisture and particulates. An excellent discussion on Mini-Mills is given in the World Bank publication "*Coconut Oil Power Generation – a how-to guide for small stationary engines*"

(World Bank, 2009). Details of mills available from manufacturers in China, India and other countries are provided. Indian Mini-Mills are designed for copra feedstock but the Chinese mills, which are cheaper, are designed for smaller and harder oilseeds and so they have to be modified for use with copra to avoid jamming the expeller. The World Bank guide explains the modifications to be carried out on the Chinese Mini-mills so that they can be used for copra.

4.2 Wet Process

In the wet process the coconut kernel is grated and dried to a moisture content of around 12-14% on sheet metal plates heated from below. At this moisture level it is possible to use hand operated presses to extract the oil from the grated coconuts. Two types of equipment have been used:

- Ram Press
- Direct Micro Expeller (DME)

4.2.1 Ram Press

Ram press (also called Bielenberg Press) is a method of expelling oil from a range of oilseeds including dried coconut either in the form of dried fresh coconut gratings, copra or dried residue from aqueous coconut processes. In aqueous processes coconut milk is removed from fresh coconut gratings leaving behind coconut residue containing 47% to 57% oil and 4% moisture. This residue can normally be sold at a low price, and processing it in the ram press to yield oil can provide higher returns.

Photo 5 Coconut oil extraction using the Ram Press

Source: CFC, 1998

The Ram Press is a manually operated, semi-continuous, low-cost oil press designed to be used by smallholder farmers. It can be fabricated and maintained by most village workshops and the smaller version can easily be operated by individual women.

Feedstock preparation

Both freshly dried coconut gratings and ground/grated copra can be processed in the ram press but the financial return from the coconut residue is higher than from copra. The cost of copra is much higher than that of coconut residue from the aqueous process and the difference is not compensated by the slightly increased oil recovery.

Coconut residue from the aqueous process is usually allowed to dry out in heaps with little care or attention. Residue dried in this manner produces oil with a high level of free fatty acid that is not suitable for direct edible consumption. In order to yield oil of edible quality, the residue has to be carefully dried soon after production by spreading it out in thin layers in direct sunlight. A thin layer of coconut residue will require about four hours in direct sunshine to bring the moisture content down to a satisfactory level.

Product Recovery

Typically it is possible to achieve a throughput of 4 kg coconut residue per hour. 10 kgs of residue can produce 3.9 litres of oil and 6.1 kg of cake. About two thirds of the oil originally present is extracted and approximately 1.65kg (1.8 litres) of oil remains in the cake.

Oil from good quality copra, freshly dried coconut gratings or freshly dried coconut residue can be used as fuel or consumed as cooking oil or used for cosmetic purposes. Poor quality oil can be used in the manufacture of soap. The ram press cake from coconut gratings, coconut residue or copra can be used as a component of animal feeds.

Further details of the Ram Press can be found in the FACT Jatropha Handbook Vol.4 (FACT, 2009) and in the World Bank Coconut Guide (World Bank, 2009).

4.2.2 DME - Direct Micro Expelling

The DME process extracts coconut oil from freshly grated coconut kernel that has been dried to a moisture content of 9-12%. The semi-dried grated coconut enters the DME equipment at a temperature of 45-60^{0}C for oil extraction. Filtration is done by keeping the oil in settling tanks for a week.

The DME equipment consists of a rack and pinion press with interchangeable stainless steel cylinders and pistons, an electrical- or engine-powered grating machine and a surface dryer. The Australian company 'Kokonut Pacific' who developed the DME process is the only known supplier of small-scale DME equipment and training services. Typically, Kokonut Pacific DME equipment can process 3.5 kgs of grated coconut per batch to extract around 1 litre of coconut oil with an oil extraction efficiency of around 80%. Under normal conditions, it is possible to process up to 300 – 600 nuts daily with an output of 20 – 50 liters (L) of oil. Each DME unit requires 3 to 5 workers. Skills required to operate the equipment are simple and can be easily learned.

Kokonut Pacific is also trying to help coconut farmers sell the virgin coconut oil from DME after local demand is satisfied. They ensure quality, purchase the oil from the farmers and export it to European and other countries, much of it going to the cosmetics industry. Further details can be found in their website www.kokonutpacific.com.au/.

5 UTILIZATION OF LIQUID BIOFUELS

5.1 Coconut Oil for diesel engines

"*The use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in the course of time as important as petroleum and the coal tar products of the present time*." - Rudolf Diesel (1912)

The use of plant oils in diesel engines is as old as the diesel engine itself. In 1896 when the inventor of the diesel engine Rudolf Diesel first demonstrated his engine in Paris, he ran it on peanut oil. However, the diesel engine as it has evolved till today is optimised and meant to use diesel fuel, and so plant oils could damage the engine if care is not taken.

5.1.1 Internal Combustion Engines

Internal combustion engines (IC engines) now power most of our land and sea transport and some of our air transport and power plants as well. IC engines are classified primarily by the method of ignition used:

a) ***Spark ignition*** **(SI)** engines that generally use gasoline/petrol as fuel; these engines are used in automobiles, small boats, aircraft and small electricity generating sets; natural gas engines are also SI.

b) ***Compression ignition*** **(CI)** engines that generally use diesel as fuel; these engines are used in medium and heavy duty trucks and buses, smaller automobiles, boats and ships, and diesel power plants.

There are two types of liquid fuels derived from plants that can substitute gasoline/petrol and diesel:

- Ethanol produced from: sugar (sugarcane, sugar beet), starch (maize, cassava), or cellulose (bagasse, straw, wood).
- Plant oils such as rape seed oil, sunflower oil, cotton seed oil, coconut oil, etc. and their derivatives such as biodiesel produced by esterification of these oils.

While the technology for using ethanol in both SI and CI engines is well developed, pure plant oil and biodiesel can, at present, be used only in CI engines. In this section we look at the use of coconut oil in CI engines. Section 5.2 looks briefly at biodiesel produced from coconut oil.

A very good description of the components, fuel system and how the compression ignition engine works is given in the World Bank publication "Coconut Oil Power Generation – a how-to guide for small stationary engines" (World Bank, 2009).

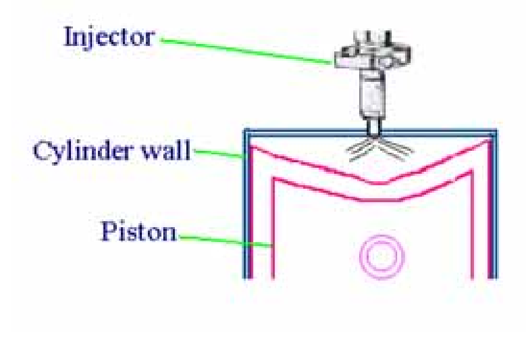
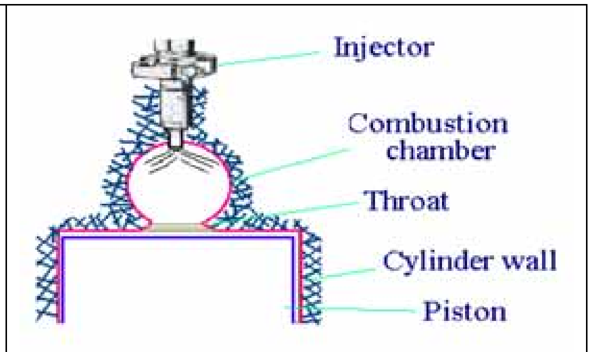
5.1.2 Fuel Injection

While using pure coconut oil in CI engines, it is very important to understand the difference between direct injection and indirect injection engines, and the advantages that an Indirect injection engine has over Direct injection so that the engine is not damaged.

- ***Direct Injection*** *engine*:   the fuel is directly injected into the combustion chamber.

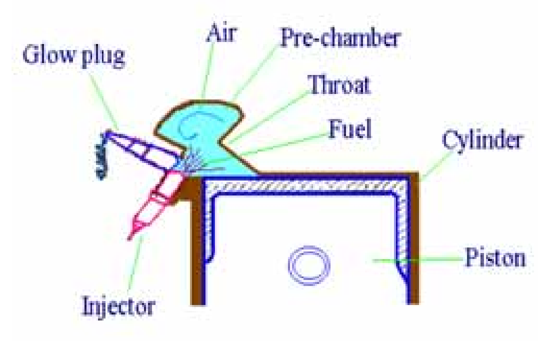
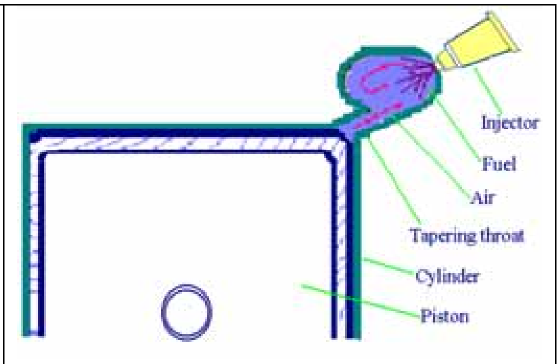
- ***Indirect Injection*** *engine*:   the fuel is injected into a prechamber which is connected with the cylinder through a narrow passage. Rapid air transfer from the main cylinder into the prechamber promotes a very high degree of air motion in the prechamber which is particularly conducive to rapid fuel air mixing. Combustion beginning in the prechamber produces high pressure and the fuels are subjected to high shear forces.

Figure 6   Direct Ignition engine

	
(a) Piston Head Cavity Combustion Chamber	(b) Cylinder Head Combustion Chamber

Source: Kopial, 2005

Figure 7   Indirect Ignition engine

	
(a) Pre - Combustion Chamber	(b) Rotational Swirl Combustion Chamber

Source: Kopial, 2005

In order to avoid engine damage proper combustion of coconut oil in the combustion chamber has to be ensured. Improper combustion can result in carbon deposits on the nozzles and valves (Photo a) and mechanical damage to the piston rings and cylinder (Photo b).

Proper combustion of coconut oil in the chamber is ensured by:

a) Decreasing the viscosity of the oil by heating it to around 70^{o}C.
b) Ensuring good atomisation of the fuel by increasing injection pressure to 180 – 200 bars

c) Ensuring that the temperature in the combustion chamber is high enough (above 500°C).

Photo 6 Effects of improper combustion of coconut oil in engine

	
a) Carbon deposits on the nozzle and valves	b) Mechanical damage on piston rings and cylinder

Source: Vaitilingom, 2009

<u>Decreasing Viscosity of Coconut Oil</u>

The viscosity of coconut oil can be decreased by using a simple shell-and-tube type heat exchanger that takes hot radiator water to warm up the coconut oil. The inner coiled pipe is made of copper to facilitate good heat transfer while the outer cylindrical shell is made of steel. Photo shows the components of the heat exchanger and when it is fitted in a car. (Deamer, 2005)

Viscocity of coconut oil can also be decreased by blending it with kerosene. Tony Deamer of Vanuatu has found that a blend of 85% coconut oil and 15% kerosene works very well with diesel engines. With this blend which he calls Island Fuel, the heat exchanger is not required, but he still recommends it. The Island Fuel blend also makes sure that coconut oil does not freeze in the fuel tank at around 20°C. See Section 5.3.1 for more details.

Photo 7 Heat exchanger used for conversion of cars to run on coconut oil

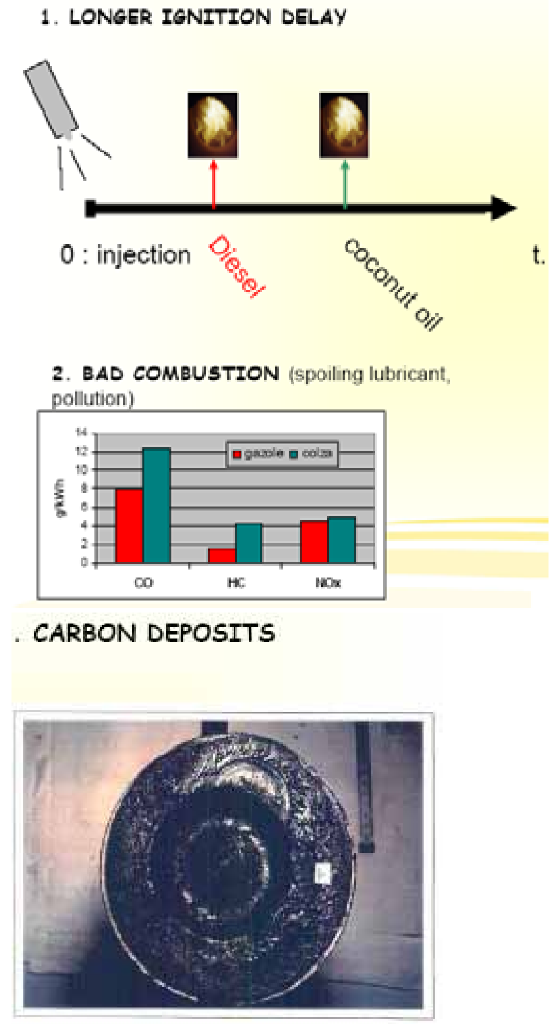
	
(a) Components of the Heat Exchanger	(b) Heat Exchanger fitted in a car

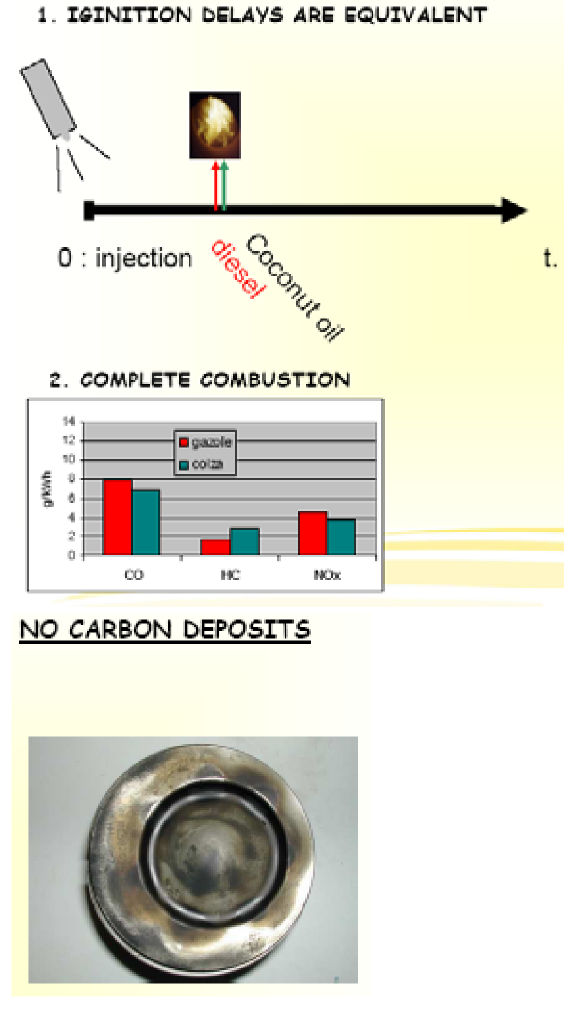
Source: Tony Deamer

Combustion Temperature

The temperature in the Combustion Chamber has to be high enough (above 500°C) for the coconut oil to burn fully. Indirect injection engines have temperatures above 500°C irrespective of the load, and so coconut oil can be used safely in these engines even at low loads.

Figure 8 Effect of chamber temperature on combustion of coconut oil





If Temperature in Combustion Chamber is low (< 300°C), e.g. Direct injection engine at low loads < 50%	If Temperature in Combustion Chamber is high enough (>500°C) e.g. Direct injection engine at high loads > 50%; Indirect injection engines at any load

Source: Vaitilingom, 2009

2-tank system for a Direct injection engine

Since Direct injection engines have temperatures above 500°C only at high loads, to ensure complete combustion of the fuel a 2-tank system must be used so that the engine is run on diesel fuel whenever the load is below 50%. Figure9 shows one way of doing this using a solenoid valve for fuel switching.

Figure 9 A 2-tank system for using Coconut Oil in a Direct injection engine

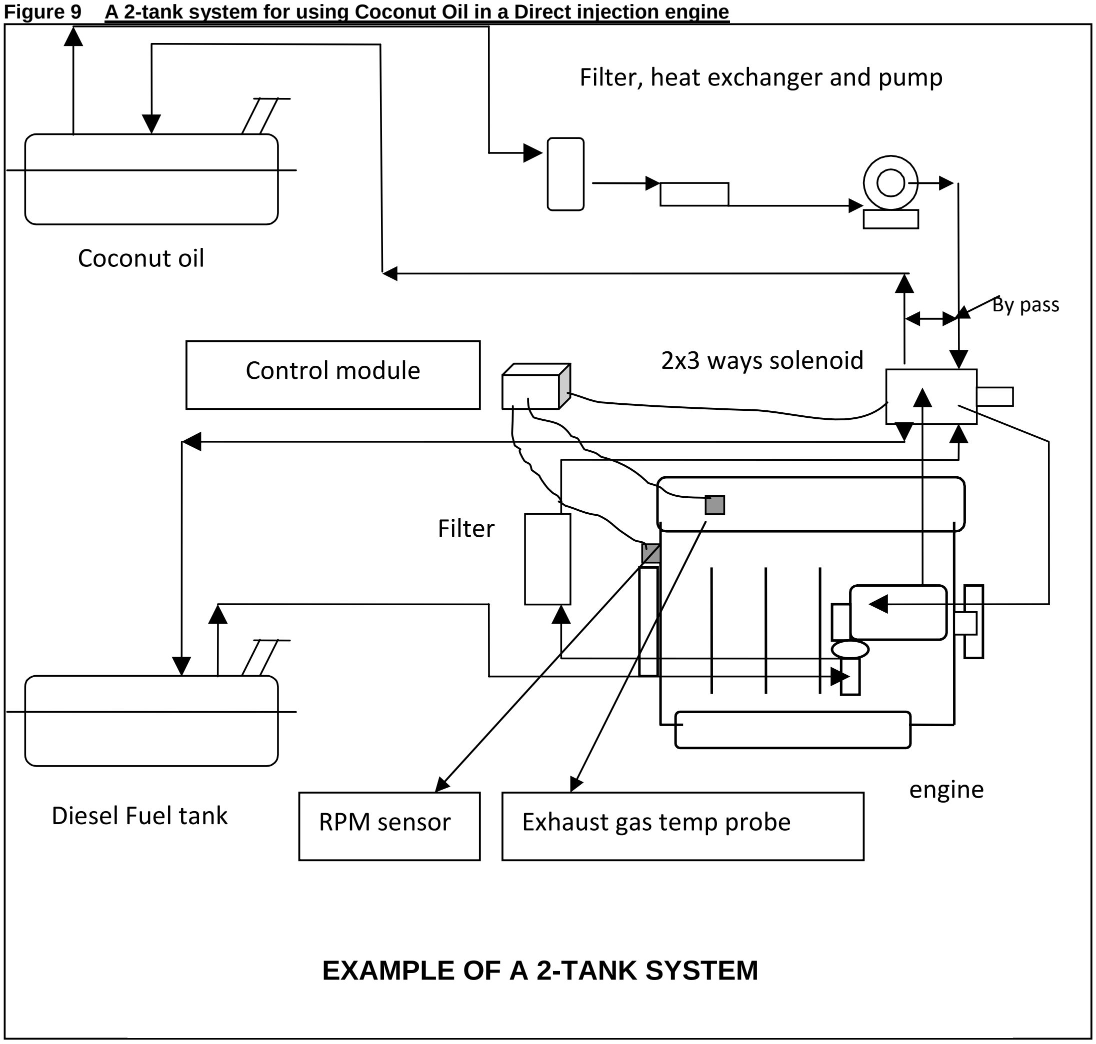


Photo 8 Auxiliary equipment used with a 2-tank system

		
Solenoid Valve	Heat Exchangers	
		
Control Module	Coconut oil Pump	Coconut Oil Filter

Source: Gilles Vaitilingom

Applications of Diesel engines

Diesel engines are used mainly for two applications:

1. **Stationery** diesel engines coupled with generators for power generation – refer to the World Bank Coconut Guide for details (World Bank, 2009).
2. **Automotive** diesel engines for trucks, buses, cars and ships – refer to Section 5.3.1 for details.

5.1.3 Quality Standards for Coconut oil

The three most important parameters of coconut oil that need to be controlled for use in diesel engines are:

1) Free fatty acids,
2) Water,
3) Particulate matter.

Free Fatty Acids (FFA) and Water:

Normal factory produced coconut oil contains around 4% water and 2 to 3% Free Fatty Acids (FFAs). These contaminants cause the oil to solidify when the temperature of the oil drops below 22^{o}C, which is quite common during winter in the South Pacific. One way around this problem is to blend the oil with some diesel fuel to prevent solidification. The presence of the diesel fuel also aids cold starting when the ambient temperature is below 20^{o}C.

The other problem with FFA s is that they block the fuel filter when the fuel system is cold. This can be overcome by fitting a small heat exchanger in the fuel line to warm the fuel prior to the fuel filter. FFAs can also be neutralized with an alkali such as sodium hydroxide (NaOH). The removal of water and FFAs eliminates the solidification of the fuel at 20^{o}C and gives the fuel greater calorific value. Moreover, after the water and FFA have been removed from the oil, it has been found that the fuel preheater is not required. (Deamer, 2005)

Particulate Matter

Particulates choke up the fuel filters. Even though a second fuel filter with a bypass valve is normally added onto a diesel engine that runs on coconut oil, particulates have to be reduced to a manageable level. Since diesel fuel filters normally filter upto 10 microns, a 10 micron filter for coconut oil will prevent the fuel filter on the genset or automobile from clogging rapidly. This can be done by a Bag Filter as shown in Photo (Vaitilingom,). It can also be done by using a ultra-high speed centrifuge (Deamer, 2005).

At present there are no internationally accepted Quality Standards for Coconut Oil as a Fuel in engines. Some standards proposed by Dr. Gilles Vaitilingom of the French research center CIRAD based on his experience is given in Table . The Fiji Department of Energy and the Fiji Institute of Technology are carrying out some tests to verify these Draft Standards.

Table 10 Draft Quality Standards for Coconut Oil as a Fuel in engines

Quality standard for Coconut oil as fuel (proposal)				
Properties/content	Unit	Min.	Max.	Test method
Characteristic properties				
Density at 25°C	Kg/m^3	0,915	-	ASTM D1298
Flash Point	°C	210	-	ASTM D93
Calorific value	MJ/kg	37	-	
Viscosity (Kin. @ 40°C)	mm^2/s	-	30	ASTM D445
Carbon residue	Mass %	-	0,40	ASTM 4530
Sulphur content	mg/kg	-	20	ASTM D5453
Cetane Index		40	-	ASTM D4737
Variable properties				
Total contamination	mg/kg	-	25	ASTM 5452
Acid value	mg KOH/g	-	10	ISO 660
Oxidation stability (110°C)	h	4		ASTM D2274
Phosphorous content	mg/kg	-	15	ASTM D323
Ash content	Mass %	-	0,02	ISO 6245
Water content	Mass %	-	0,075	ISO 12937

Source: Vaitilingom, 2008

5.2 Biodiesel

A high cetane number and a low iodine number makes coconut oil well suited for CI engines, but it has two main drawbacks: a high melting point and high viscosity, both of which can be corrected by esterifying the oil into biodiesel. Biodiesel made from coconut oil by transesterification, which is also called Coconut Methyl Ester (CME), has a melting point that is below zero degree C and its cetane and iodine numbers are nearly the same as coconut oil. CME has other advantages over coconut oil - its viscosity and other physical properties are similar to petroleum diesel so it can be easily mixed, transported and distributed with diesel, and diesel engines do not need any modification for using blends of biodiesel. For more details about biodiesel refer "Biodiesel Handling and Use Guide" (NREL, 2006)

Philippines has a government supported program to produce Coconut Methyl Ester (CME) from coconut oil and blend it with diesel fuel. The physico-chemical properties of CME produced in the Philippines and its blends with diesel have been measured . Results are compared in Table11 with Philippine National Standard for diesel fuel quality (PNS2020:2003) and biodiesel produced from Soyabean oil.

Table 11 Physico-Chemical properties of Coconut Methyl Ester (CME)

Property	Method	CME Results	PNS2020:2003	Soy Biodiesel[1]
Flash Point, ºC	ASTM D93	107	100.0, min	157
Water & Sediment, vol%	ASTM D2709	0.0	0.050, max	<0.05
Kinematic Viscosity, mm^2/s @ 40ºC	ASTM D445	2.656	2.0-4.5	4.2
Sulfated Ash, mass%	ASTM D874	0.002	0.020	0.002
Sulfur, ppm	ASTM D5453	3	50, max	9
Copper Corrosion, 3hr @50ºC	ASTM D130	1A	No. 3, max	1A
Cetane Number	ASTM D613	70	42, min	55
Cloud Point, ºC	ASTM D2500	-5	Report	0.4
Carbon Residue, mass%	ASTM D4530	N/A**	0.050, max	Not Performed
	ASTM D524	<0.010	N/A	0.02
Acid Number, mg KOH/g	ASTM D664	0.17	0.50, max	0.35
Free Glycerin, mass%	ASTM D6584	N/A	No Standard	0.006
Monoglyceride, mass%	ASTM D6584	N/A	N/A	0.40
Diglyceride, mass%	ASTM D6584	N/A	N/A	0.21
Triglyceride, mass%	ASTM D6584	N/A	N/A	0.18
Total Glycerin, mass%	ASTM D6584	0.043	N/A	0.16
Free Glycerin, mass%	AOCS Ea6-94*	0.02	0.02, max	Not Used
Total Glycerin, mass%	AOCS Ca14-56	0.145	0.24, max	Not Used
Phosphorus, mass%	ASTM D4951	0.000	0.001, max	0.0006
Distillation, AET 90% recovered, ºC	ASTM D1160	327	360, max	352

Source: Alleman and McCormick, 2006

The main findings of these tests were:

- CME as well as CME blends (1% and 5% by volume) met the current Philippine National Standard for diesel fuel quality.
- The 5% blend of CME in diesel fuel increased the cetane number slightly for each blend.
- The diesel fuels and the CME-diesel blends did not take up significant amounts of water, nor were stable emulsions formed for any of the fuels or fuel blends tested.
- The CME sample, the diesel fuel samples, and the 5% CME-diesel blends exhibited a similar level of stability. The test results showed few insolubles were generated during the tests, which under storage conditions, may contribute to poor engine performance due to plugged fuel filters or clogged injectors.

- Sixteen indicators of microbial degradation were measured. The results showed that the CME sample and the neat diesel fuel samples have similar resistance to microbial degradation, although the mechanisms for degradation may vary.
- A Fourier Transform infrared technique was found to be highly linear and can be used to quantitatively determine the percentage of CME in a diesel fuel sample.

(Alleman and McCormick, 2006).

5.3 Case studies in Pacific and lessons learned

5.3.1 Island fuel, Vanuatu

One of the pioneers in using coconut oil in diesel vehicles is Tony Deamer, an Australian who lives in Vanuatu in the south Pacific. For nearly ten years he has been experimenting with usage of coconut oil to run diesel automobiles and has now arrived at a mix that he sells under the name of "Island Fuel" which can be used in diesel engines without any modifications (Deamer et al, 2005). He started by using normal factory produced coconut oil that contains around 4% water and 2% to 3% FFAs (Free Fatty Acids). He found that these contaminants cause the oil to solidify when the temperature of the oil drops below 22^{o}C, which is quite common during winter in the South Pacific. One way around this problem is to blend the oil with some diesel fuel to prevent solidification. The presence of the diesel fuel also aids cold starting when the ambient temperature is below 20^{o}C. The other problem was that the FFA' s blocked the fuel filter when the fuel system was cold. This was overcome by fitting a small heat exchanger in the fuel line to warm the fuel prior to the fuel filter. The water for the heat exchanger was taken from the thermostat bypass circuit so that it was warm within a minute or so of the engine starting. This eliminated the fuel filter blockages.

Tony Deamer now uses a proprietary process that removes both the water and the FFAs from the coconut oil. The fuel is then filtered through a 3 micron filter. The removal of water and FFAs lowers the solidification temperature of the fuel and raises the calorific value of the fuel. Moreover, after the water and FFAs have been removed from the oil, it has been found that the fuel preheater is not required.

Photo 9 Island Fuel Filling Station

Source: Tony Deamer

Deamer has been operating his fleet of vehicles on various blends of coconut oil and diesel in several ratios, and also on a coconut oil and kerosene mix. He even tried 5% methanol for a time but found it evaporated out too quickly, so in the end he decided to stick with the proven 15% kerosene blend. Tony Deamer's "Island Fuel" made in Vanuatu contains 85% of the purified and filtered coconut oil blended with 15% kerosene. No modifications are required in the diesel engines that use Island Fuel; however, engine pre-heaters are recommended for colder areas.

Tony Deamer says that this fuel has been tried and tested over many years and is now ready for retail sale. Unfortunately, the laws of Vanuatu do not allow the sale of Island Fuel, so he sells only the coconut oil to interested car owners. The minibus fleet owners in Porta Vila have been blending their own Island Fuel since 1995. The bus operators are completely satisfied with using it and they are reporting an increase in *kilometers per litre* when operating with the Island Fuel.

Based on his experience with producing fuel-grade coconut oil and blends, and in using them as fuels in all his vehicles, Tony Deamer has found that:

a) Coconut oil has better lubricating qualities than other fuels for diesel engines so it causes less wear on internal engine parts and prolongs engine life.
b) Coconut oil burns slower than other diesel fuels so it pushes the piston all the way down the cylinder instead of a rapid explosion at the top of the stroke, resulting in an even power release, less fuel use, less engine wear and a quieter running engine.
c) Coconut oil fuelled diesel engines run cooler due to less internal friction and the slower burn rate.
d) Coconut oil is not an ideal sub tropical fuel as it will solidify overnight if temperatures drop below 24 degrees Celsius. However, the gel point (the point at which it becomes solid) can be greatly reduced by mixing the coconut oil with kerosene or by keeping the fuel heated using heating accessories commonly found on generators, boats and transport vehicles.
e) Coconut oil based fuels yield over 10% more kilometers per litre (km/l) used than petroleum diesel. Data collected over a 20,000 km, 6 month test on an Isuzu Direct injection 2.5ltr 4JAI diesel motor in a pickup that was giving less than 12 km/l diesel, showed that it had improved to approx 13.5 km/I on "Island Fuel 60".
f) A noticeable torque increase is felt with Island Fuel. It was noticed that, while driving uphill, a change down to the next gear was often not required as the engine keep pulling at the lower RPM. This is easily explained by the fact that the coconut oil burns slower than diesel.
g) The exhaust fumes from coconut oil are less harmful than mineral based fuels. When burnt in a diesel engine, coco diesel emits 50% less particle matter (black smoke) and less sulfur dioxide (SO_2). Exhaust from coconut oil contains no poly acrylic hydrocarbons (PAH's) -- the main cancer- causing component of mineral diesel fuel exhaust.
h) Coconut oil is non toxic and fully biodegradable. It is safe to store and to transport. Oil spills on land or water are harmless and there is a reduced risk of fire. No chemicals are required to produce the fuel so there are no harmful by-products.

i) The entire process of making coconut based fuel for diesel engines can be done in the islands creating jobs and stimulating the economy. All the income from the production and sale of coconut oil stays in the islands instead of going overseas. A high percentage of the income from coconut based fuels will go to the local farmers in rural areas.

j) All the steps in the production of coconut oil can be fuelled by coconut oil or coconut residues so there is no addition to green house gases during the production of the fuel product.

k) On the negative side, some drivers and passengers of the coconut oil blend powered vehicles have reported headaches if the exhaust gas leaks into the passenger compartment. The Motor Traders fleet have made changes to the exhaust system to clear the exhaust gases from the vehicle. The nature of the headache causing agent needs to be determined and if a greater number of vehicles are operating in an urban area it will need to be determined if this agent will cause problems for the general public.

[Deamer et al, 2005]

Photo 10 Range Rover and Toyota Running on Vanuatu Coconut Oil

Source: Tony Deamer

Some of the advantages of Island Fuel are:

Environmental Advantages

1) Coconut oil does not contribute to the greenhouse effect. When burned in a diesel engine, coconut oil releases the same amount of carbon dioxide (CO_2) that will be consumed by the next batch of coconuts. In this way, the coco diesel cycles carbon through the atmosphere from plant to the air and back to the plant.
2) When burnt in a Diesel engine, coco diesel emits less sulfur dioxide SO_2 (the primary contributor to tropical plant and rainforest depletion).
3) Coconut oil emits 50% less particle matter (black smoke) than conventional diesel.
4) No chemicals are required to produce the fuel so there are no harmful by-products.
5) All the steps in the production of coconut oil can be fuelled by coconut oil fuel so there is no addition to green house gases during the production of the fuel product.
6) Coconut oil is biodegradable.

Economic Advantages

1) Coconut oil based fuels yield more Km per litre used than other fuels for diesel engines.
2) The cost of coconut oil is presently lower on than the cost of other fuels for diesel engines in Vanuatu.
3) The entire process of making coconut based fuel for diesel engines can be done in Vanuatu creating jobs and stimulating the economy.
4) All the income from the production and sale of coconut oil stays in Vanuatu, instead of going overseas. So the tax received from VAT each time the money is spent locally will exceed the income derived from the duty on the imported product.
5) A high percentage of the income from coconut based fuels will go to the local farmers in rural areas.

Mechanical Advantages

1) Coconut oil has better lubricating qualities than other fuels for diesel engines so it causes less wear on internal engine parts and prolongs engine life.
2) Coconut oil burns slower than other diesel fuels so it pushes the piston all the way down the cylinder instead of a rapid explosion at the top of the stroke resulting in an even power release, less fuel use, less engine wear and a quieter running engine.
3) Coconut oil fuelled Diesels run cooler due to less internal friction and the slower burn rate.

Safety Advantages

1) The exhaust fumes from coconut are less harmful than mineral based fuels. Exhaust from coconut oil contains no Poly Acrylic Hydrocarbons (PAH's) -- the main cancer-causing component of mineral diesel fuel exhaust.
2) Coconut oil is safe to store and to transport. Oil spills on land or water are harmless and there is a reduced risk of fire.
3) Coconut oil is non toxic and fully biodegradable. After all, what other fuel can you both cook your fish and chips in and run your truck on ??

Disadvantages

Coconut oil is not an ideal sub tropical fuel as it will solidify overnight if temperatures drop below 14 degrees Celsius . However, the gel point (the point at which it becomes solid) can be greatly reduced by mixing the coconut oil with Kerosene or by keeping the fuel heated using heating accessories commonly found on generators, boats and transport vehicles.

Comments on motor performance

- Data collected on the Isuzu Direct injection 2.5 ltr 4JAI diesel motor in a pickup over a 20,000km 6 month test showed an average of 12.75 km per litre on "Coco-Diesel". This has improved on "Island Fuel 60" to approx 13.5 Km/l. On Diesel the vehicle was achieving less than 12Km/l. (A Full sheet of all fuel used and Km driven with coments is available.)
- The Two Toyota "L" and "2L" 2.2 and 2.4 ltr engines only averaged 7.5 Km/l. on Coco-diesel and about 8 Km/l on "Island Fuel 60". Top end horse power was slightly down.

i.e. acceleration was not so brisk on "Coco-Diesel 60/70 but almost normal on "Island Fuel 60". A noticeable torque increase was felt. It was noticed that a change down to the next gear was often not required as the engine keep pulling at the lower RPM. This is easily explained by the fact that the Coconut oil burns slower than the Diesel (i.e. more or a "Whoosh and less of a Bang").

- After 12 months of use on Unprocessed Coco-Diesel (Not Island Fuel) a Nissan LD28 2.8 ltr naturally aspirated diesel engine operating within a Range Rover was stripped. The pistons, rings, bearings, valves and injectors were removed for examination. All were in much cleaner and better shape than expected from a diesel engine. The bore marks still showed the cross hatch hone marks, the valves and cam gear was all clean and in perfect order. The only problem was that the engine was purchased some 10 years ago second hand so Tony does not know how it was used in the past. But he guesses that it had at least 100,000Km before he got it and approx 30,000Km from the time he had it to the time he started using Coco-Diesel in it. The motor was put back together with new pistons, rings bearings and injectors nozzles and a new timing belt. It is now using "Island Fuel 60" in winter and "Island Fuel 70" during warmer weather in the summer months.

At the start of 2003 Deamer ordered his own Processing Equipment and continued to make and supply processed coconut oil only, to anyone wanting it, and left it to them to mix their own petroleum product with it.

- In his own Units he tried mixing Methanol at 5% for a time but found it evaporated out too quickly. So in the end he decided to stick with the proven 15% kero and so since 2003 the Range Rover and all our other Units have been running on this mix as was the Volvo from the start of the experiment in 2001.
- In 2005 Cold pressed Crude coconut oil was selling in Santo for 65 Vatu a litre (approx US$0.59 per ltr). Diesel was 132 Vatu at the pumps CNO refined sold for about 90 Vatu a ltr. and the Kero was at 120 Vatu so a Blended fuel cost approx 95 Vatu per ltr.
- Deamer's vehicles have not experienced any CNO related problems in the past few years. They did replace a Head Gasket on the Volvo due to an over-heating problem that resulted in the engine running dry of water for a long period, but it did not seize up .
- Both Volvo and Range Rover are running an LD28 Nissan engine with Per-combustion chambers and they are not Direct injection.
- The Isuzu with Direct injection engine 2/5 ltr is now on the 15% kero mix and they are no longer having the bore glazing problems they were having when driven lightly on the 60/40 CNO/Diesel mix in the first year of the experiments.

5.3.2 Cocogen, Samoa

The Samoan Electric Power Corporation (EPC) has been looking into alternatives for diesel fuel electricity generation including bio-fuels, solar and wind. In the early 1980s, EPC had carried out trials on using coconut oil for diesel engine operation over a period of six months, but no records or results of these tests are available today. Because of the technical risks associated with using fuels that are not recommended by the manufacturer of the generating units, these trials were not continued.

From 2002-2005 EPC has generated a little over 120 GWh/yr of which roughly half is from hydropower and the other half from diesel power plants. The current base load delivered by the diesel power station is approximately 8 MW, with a morning peak of 13 and an evening peak of 17 MW.

Through a combination of cost savings and environmental considerations, EPC aims to utilise alternative fuels from diesel will be a part. In addition, the increasing dependence on imported fossil fuels is another main reason to carry out a feasibility study into the use of alternative fuels in the EPC generators. By aiming for a partial displacement of diesel fuel, EPC can gain valuable experience based on which further substitution can be considered. The price volatility on both the coconut oil market and the fossil fuel market do not support the complete switch to coconut oil fuel.

Dr. Gilles Vaitilingom, the Biofuel Specialist in the COCOGEN team found that none of the gensets currently running at Tanugamanono or Salelologa Power Stations could use straight coconut oil as fuel without chemical transformations of the oil or mechanical modifications of engines. However, based on his experience with running diesel gensets with pure plant oils including coconut oil, he predicted that there were high chances of success for using a 10 % blend of coconut oil with diesel fuel, if the load on the genset is kept over 50 % of its rated load. In case bad combustion occurs (misfiring or cyclical dispersion) the amount of unburnt fuel (blend of coconut oil and diesel) would be higher than 1/1000. That means, out of the 10,000 litres of the blend used in the test, 10 litres would remain unburnt, and this 10 litres would contain 1 litre of coconut oil. In a sump of around than 100 litres of lubricant capacity, this will lead to a *pollution* of the lube by triglycerides and fatty acids of 1%, and this level of contamination is easy to detect accurately. If the analysis of the lube samples reveal that the level of contamination by unburnt coconut oil is less than 1%, it can be concluded that the combustion was good and, that for this genset, under the current operating conditions, a 10 % blend of coconut oil can be used safely.

Photo 11 Cummins Direct Injection 400 kW Diesel Engine tested with 10% coconut oil

Source: SOPAC, 2005

Specifications of the Diesel Generating Set

Usage (Feb ’05)	179 hrs
Percent of Production	4%
Engine Maker	Cummins
Engine Model	KTTA 19-G2
Engine Serial #	37155000
SO No	62222
CPL	1170
HP/RPM	1500 rpm
Manufacturing Date	8/11/94
Rated Speed	1500
Idle Speed	800 (low)
# of Cylinders	6
Bore [mm]	158.75
Stroke [mm]	158.75
Type	4 cycle vertical in line cylinder
Cooling System	Water Radiator
Compression Ratio	13:8:1
Aspiration	Turbo / cooled
Displacement [l]	18.7
Rotation (flywheel)	CCW
Injection Method	Common Rail HVT
Type of Nozzle	Direct Injection Hole Type
Type of Fuel	BS 2869 A1
Governor	Electric
Starting Method	Electric 24 V
Maker	ONAN

Generator Model	450 DFFB
Serial Number	A92A001721
Rating	Standby
Spec	5673G
KVA	563
Amps	783
KW	400
KW (de-rated)	250
Volts	415

After consultation with the General Manager, it was agreed that tests with 10,000 litres of a 10% blend pilot would be carried out with engine #2A, comprising of 1,000 litres of coconut oil blended with 9,000 litres of diesel fuel. For the pilot, the following risks (and risk reduction strategies) were identified:

- **No Coconut oil available;** Contacted and visited COPS to request the delivery of oil from current production.
- **Bad Quality COPS oil;** Pre-filtering of oil with existing fuel filters to avoid particles in the fuel tank.
- **Carbon Deposits;** The machines have to be run above 50% of their rated capacity to avoid excessive carbon deposits. With the de-rating of the machines, this means they should run at maximum power.
- **Filter clogging;** If coconut oil is mixed with water by accident, the resulting mixture can lead to clogging of filters, therefore, good working hygiene is required.
- **Blend percentage not right;** As the pilot is designed to minimise the risk for the machines, it is imperative that the operator sticks to the 10% blend of coconut oil and 90% regular diesel. For higher percentages of coconut oil in the fuel, engine adaptations may be required.
- **Lube oil sample not right;** It is imperative that the sample of the lube oil after the test is taken according to instructions so that the analysis can be carried out correctly.

In order to reduce these risks, the technical consultant was present to instruct the operators on the first day of the pilot test. Secondly, clear working instructions for the pilot test were provided:

<u>Working Instructions for the Coconut Oil Pilot Test</u>

- ***Engine***: Lubricant and oil filters must be new or having less than 250 running hours.

- ***Fuel***: A total volume of 10,000 litres will feed engine 2A. It is composed of 1,000 litres of coconut oil and 9,000 litres of diesel fuel. The mixture will then be prepared as 1 volume of coconut oil plus 9 volumes of diesel. This will require the following steps:
  1) Pour 1 volume of coconut oil in the daily tank;
  2) Pour 9 volumes of diesel fuel in the daily tank;
  3) Stir the daily tank for 2 minutes with a stick.

- ***Lubricant:***
  1) The same lubricant will be used during the duration of the test.
  2) Added volume of lubricant must be logged exactly.
  3) Two samples of lube oil will be collected in the sump of the test engine and sent to SOPAC/Fiji: (a) one sample before starting the test, and (b) the second sample after completion of the test.

- ***Operation of the test genset:*** The Generator Set being tested *must not be used under 50% of its original rating*, i.e. 200 kW. The genset can only be allowed to run for upto one hour on a load below 200 kW, after which it must be shut down.

- ***Mechanical:*** In case of a mechanical intervention on the engine, *collect a sample of lube oil* before starting again. This sample will be joined with the sample taken at the end of the test.

- ***Data required –The Log book must contain:***

  At the Start of the test:
  1) Type of lubricant;
  2) Grade of lubricant;
  3) # of running hours of the lubricant in the sump;
  4) Collect of the sample of lube oil.

  Daily:
  1) Date;
  2) # of kWh;
  3) # of running hours;
  4) Volume of blend used;
  5) Volume of added lubricant;
  6) # of starts during the day;
  7) Observation/trouble shooting.

  At the End of the test:
  1) Collect of the sample of lube oil;
  2) Indicate the number of running hours;
  3) Complete the daily logbook;
  4) Send the sample and the log data sheet to SOPAC in Fiji.

Immediately after the fieldwork, lube-oil samples before and after the pilot were sent through to the laboratory of the University of the South Pacific in Fiji and to a specialised laboratory in France. The lube-oil analyses pointed that no harmful level of contamination of (unburnt) coconut oil could be detected in the lubricant. Therefore, the test can be described as successful and the recommendations of the Saleloga Power Station manager can be followed to continue the pilot. The Cocogen team proposes continuation of lube oil analysis at regular operation intervals.

Photo 12   Filtering of Coconut Oil with a Sheet Before mixing in the day-tank

Source: SOPAC, 2005

<u>Testing of a 10,000 litres Blend of 10 % Coconut Oil + 90 % Diesel Fuel in Genset 2A</u>

Test:

The test started on Saturday 2nd of April 2005 in the presence of Dr Vaitilingom. He recommended strongly that the load of the engine should not be below 80% of normal load. For this engine, the normal load is 200kW and therefore the load should be above 150kW at any time. If the load is below 150kW, then the engine must be shut down to avoid any sign of unforeseen failure. The test took about 3 weeks to complete 6 x 44 gallons of coconut oil that is on April 23, 2005.

Results of the Tests

Between April 2 and April 23 2005, a total of 1,018 litres of coconut oil was blended with 9,167 litres of diesel in the day tank of engine # 2 in Saleloga Power Station. The overall fuel usage for the trial engine for the whole month of April was 17,162 litres. Totally 10,185 litres of blend was used during the test.

The lube-oil samples after the test were sent to labs in Fiji and to France for analysis. The level of contamination of the lube-oil by unburnt coconut oil indicated that it was advisable to continue using a coconut oil blend in machine #2.

Statistics:

Duration of test (days):	22
Amount of coconut fuel used:	1,000 Litres approximately
Amount of hours during test:	245

Average hour per day:	11
Top up Oil during test:	26 litres
Total kWh:	46,278 kWh

Comments:

The successful completion of the test reveals positive direction of coconut oil as an alternative fuel, provided that it is less expensive that diesel fuel. Mechanically speaking, there was no sign of any defect during the test.

Recommendations:

1) The test is not long enough to find out the impact of the test to engine components. It is suggested of at least 1,000 hrs of running is appropriate.
2) After 1000 hrs of test, the engine should be inspected with thorough checks on its cylinder heads, injectors, liners, pistons, piston rings, and fuel pump etc for any abnormal signs or defects.
3) The exhaust gas during this test was not satisfactory and therefore suggested strongly that the recommended sulphur content of the fuel should be between 0.25 and 0.50 percentage by weight.

The financial, economic and environmental impacts of the Cocogen project are given in the Final Report (SOPAC, 2005). This report also contains details of the GIS study (Geographical Information System) used to assess the Coconut Resources of Samoa.

5.3.3 Coconut oil for power generation in Fiji

Coconuts are grown on all the Fijian islands. Coconut oil is a local resource that is abundantly available especially in the rural coastal communities. A project to use coconut oil for village electrification was planned in 1998-99 jointly by Fiji Department of Energy, the Secretariat of the Pacific Community (SPC) and CIRAD. The technical expertise and technology were provided by CIRAD France through French Government funding. The Ministry of Agriculture (Taveuni Coconut Centre) and Public Works Department (Electrical) were vital partners in the project implementation which covered four villages.

The project involved the modification of two diesel gensets of capacities 45 kVA and 90 kVA so that they could run on pure coconut oil. Two sites were chosen for the project:

1) Lomaloma, Naqara and Sawana villages in Vanua Balavu and
2) Welagi village in Tauveni.

CIRAD had already successfully installed three diesel gensets modified for coconut oil on the island of Ouvéa in New Caledonia:

1. In 1995 – a 90 KVA genset to provide electricity for a copra mill with a capacity of 350 kg copra per hour.
2. In 1999 – one 180 KVA and one 45 KVA genset to provide electricity for a desalination plant.

The coconut oil gensets that CIRAD provided for Fiji were identical to the ones that CIRAD installed in New Caledonia:

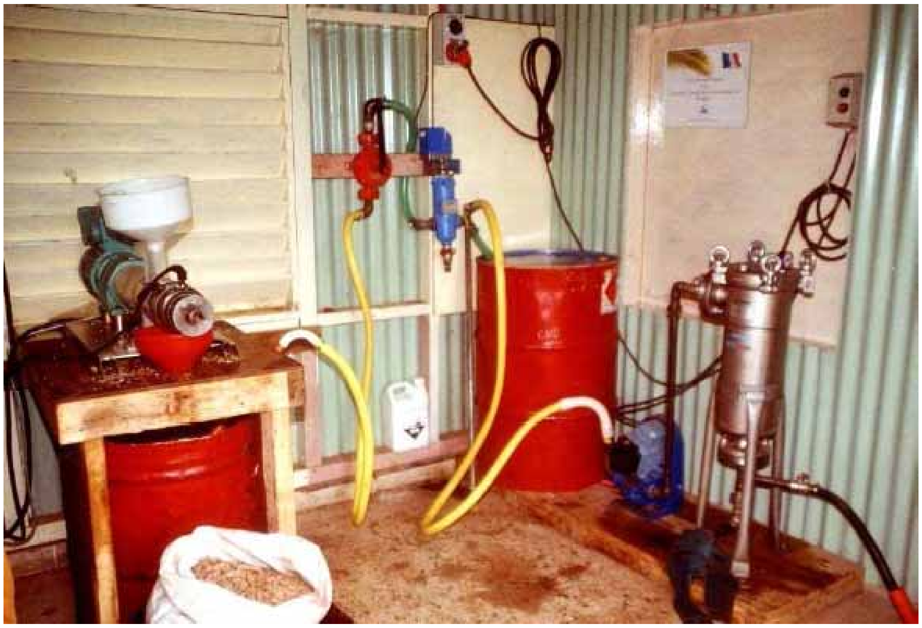
- These gensets were designed for fully automatic operation after a push button start even at temperatures below 24°C when the coconut oil is frozen.
- There were two fuel tanks – one for diesel and the other for coconut oil.
- The genset is started and stopped on diesel fuel for 10 to 15 minutes.
- The coconut oil tank had electric heaters below the tank to melt the coconut oil and also an electric heater in the well of the tank where the outlet pipe emerged. Once the coconut oil had been heated to the required temperature the control system switches the fuel supply to coconut oil by means of a solenoid valve.
- Coconut oil is utilized as the primary fuel source for 90% - 95% of the total running time of the generator.
- A second extra fuel filter is fitted with a by-pass valve.
- A larger fuel pump is fitted.
- Yearly inspections are carried out on the project sites for repairs and training of technicians to run the generators.

Welagi

The 45kVA Welagi Copra Biofuel Project was commisisioned in July 2001, and it ran trouble free for a few years after its implementation. This project serves a village with 58 households and oil production is through a small oil mill that was build as part of the project. The village has a special committee that looks after the affairs of the copra production and subsequent oil production that are used to generate electricity in the biofuel generator.

Photo9 shows the equipment installed in Welangi for producing fuel grade coconut oil. Copra cut into small pieces byt the copra cutter (not in picture) is fed into the oil expeller on the left of the photo. The pre-filtered coconut oil (drum on the left) is pumped by an electrical driven-pump (between drum and filter) and pushed through a flow line bag-filter (on the right). The hose at the bottom right is connected to the coconut oil main tank of the generator.

Photo 13 Coconut Oil production equipment at Welangi



Source: Gilles Vaitilingom

Photo 14 **45 kVA diesel genset at Welagi**

Source: Gilles Vaitilingom

<u>Vanua Balavu</u>

The Lomaloma Copra Biofuel Project was commissioned in April 2000. The 90kVA Lomaloma Copra Biofuel Project serves three villages (Naqara, Sawana and Lomaloma). Since this is the administrative heart of Vanua Balavu, electricity is also supplied to two government schools, the Lomaloma Hospital and the Post Office along with 200 customers.

An Electricity Committee formed by the three villages and other consumers in the projects oversees the project management. A power house operator and his assistant are being paid to maintain the generator while a meter reader has the task of billing consumers through readings of individual kWh meters and another person collects these bills. Thus four villagers are employed by the Electricity Committee and their wages are paid through the bills collected monthly.

The coconut oil mill on Vanua Balavu closed down shortly before this project was commissioned and all copra produced was sent outside the island for processing. Leftover coconut oil from the oil mill lasted about 8 months after which oil for the genset was purchased from the Savusavu oil mill on Vanua Levu.

Photo 15 The 90 kVA diesel genset at Vanuabalavu

Source: Gilles Vaitilingom

In March 2005 the 90 kVA community genset faced serious mechanical problems and was shutdown. Subsequently this genset was sent to Suva for repairs but nothing was done about it for several years. It was rusting away at the Walu Bay workshop till 2008 when the Biofuel Advisor at the Dept of Energy, Krishna Raghavan, arranged for the French engineer Gilles Vaitilingom to come to Fiji and help repair this genset. Since this is heavy duty Deutz indirect injection genset it can be operated at even low loads on coconut oil. So the operating procedure was changed to a much simpler, manual operation with only one fuel tank containing coconut oil. The heaters below the fuel tank to melt coconut oil in winter can still be used if required by manually operating an on-off switch. Meanwhile the three villages on Vanua Balavu have got their own separate gensets, so the repaired 90 kVA coconut oil genset will be installed at another location where coconut oil is available.

A SOPAC study team visited the two sites in 2005 to evaluate these two projects for the Fiji Department of Energy. Their conclusions are given below:

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

- *Even though thorough feasibility studies on technology, socio-economics and have been carried out before the implementation of the projects, the expectations of the villagers and the results of the projects have not been in line with each other.*
- *If the automatic fuel switch on the Taveuni generator is repaired, the villagers have the option on whether to use (commercially produced) coconut oil or diesel as fuel. For Vanuabalavu to utilise coconut oil as a fuel, an oil mill would have to be bought and oil milling organised as it does not appear to be economically attractive to import coconut oil from other islands.*
- *The evaluation findings and social survey conducted by PCDF clearly outlines the social constraints and non-cooperativeness between the 3 villages particularly, that of Lomaloma and Sawana. The idea of having an electricity committee comprising of members from the 3 villages is not practical. Thus, it is unlikely that a common generator for the villages is suitable.*
- *The current tariff structure is not sustainable as real costs are neither covered, nor equitable because all households pay the same amount irrespective of their usage.*
- *Generally, new technology can survive and operate as designed provided it is used according to its specifications. The absence of technology in a community will only hinder (wo)men's efforts to develop socially, economically and sustainably;*

(SOPAC, 2006)

<u>Fiji's coconut industry revival program</u>

Fiji's coconut industry has been declining over the last 40 years because of low productivity, low prices and competition from other edible oils sold on the world market. Although there have been some efforts in the last four decades to revive the industry, the lack of a sustained long term national policy for development of the coconut sector has made it difficult to reverse the decline. In the early 1960s copra production was over 40,000 tons/yr; now it is less than 15,000 tons/yr. Moreover, about two-thirds of the trees will go out of production over the next 20 years. The older trees need to be replaced soon otherwise the industry will decline further and the rural people dependent on the industry will migrate to urban areas looking for alternative livelihoods adding more pressure on the limited resources of the urban centers. In response to this problem, the Fijian Government created the Coconut Industry Development Authority (CIDA) under an Act of parliament in November 1998, with a mandate to revitalize the industry. However, CIDA has not been able to takeover the entire administration of the industry from the Ministry of Agriculture because of the lack of budgetary support. From 2005 onwards, the Government has agreed to handover to CIDA the full responsibility to administer all aspects of the industry with adequate funding to enable CIDA to perform its full role as required under the Act.

CIDA has drawn up a 25 year Coconut Industry Master Development Plan that includes a Nationwide Coconut Industry Promotions Program (NCIPP). CIDA aims to restructure the coconut industry, register 20,000 coconut growers and establish a network of Coconut Planters Associations throughout the coconut growing areas. This will assist the Extension and Research & Development Divisions to achieve their targets for the planting of 6 million trees and the rehabilitation of another 2 million trees. The Taveuni Coconut Center with its four seed gardens will be provided financial, manpower and logistical support to play a key role in this campaign. A manpower development plan and raising of public awareness through posters in schools, restaurants, hotels, public markets and government offices, etc. are also being planned.

CIDA aims to increase the production of copra to 50,000 tons /yr, of coconut oil to 24,000 tons /yr and of tender nuts for the local and export market to 40 million nuts /yr. Product diversification, intercropping practices, wholenut purchase centers and a centralized copra drying facility are envisaged together with a large number of mini-mills and two big coconut oil (CNO) mills. CIDA wants to improve the lifestyle of 100,000 rural people involved in the coconut sector, empower women, reduce poverty and improve the education of rural children. Other ambitious targets of CIDA include earnings of F$15m /yr in foreign exchange through sales of coconut timber, over $100m /yr from sale of CNO, tender coconuts and products made from CNO, $10m /yr from biodiesel to replace 10% of imported diesel, and $3-4m annually from sales of coconut meal. [CIDA, 2004]

6 UTILIZATION OF SOLID BIOFUELS - SHELLS & HUSK

6.1 Characteristics

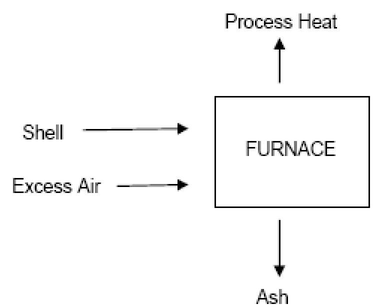
The husk of the mature coconut consists of numerous fibers embedded in a soft cork-like ground tissue usually referred to as pith. The fibres are 15 to 35 cm. Long, have a high tensile strength unaffected by moisture, and consist mainly of lignin and cellulose with about 10 per cent pectins, tannins and other water soluble and insoluble substances. The pith on the other hand is mostly made up of pectins, tannins and other water soluble substances and hemicelluloses. The energy content of coconut husk is 16.7 GigaJoules/Tonne.

The shell of the mature coconut is a uniformly dense material like hardwood that consists mainly of lignin and cellulose. The energy content of coconut shell is 18.2 GigaJoules/Tonne.

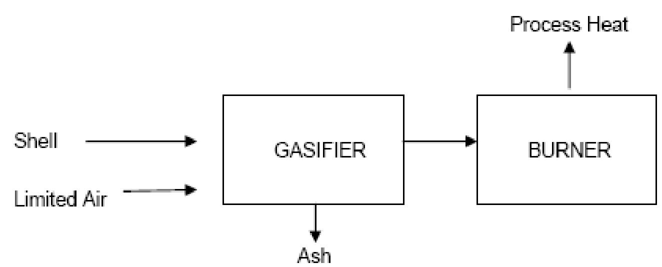
6.2 Basic Principles of Combustion

There are 4 different ways of burning coconut shells:

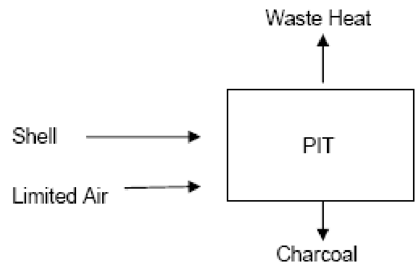
1) Combustion - Coconut Shells are burnt completely with excess air in a furnace to provide process heat. Discharge of char and tar is moderate if properly controlled.



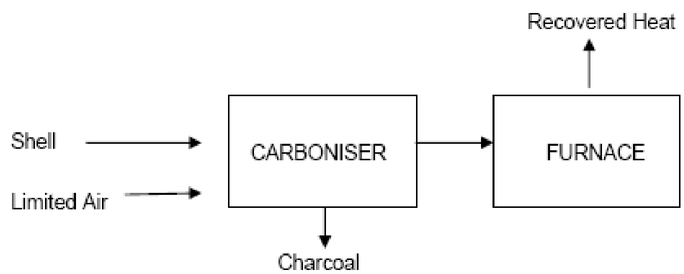
2) Gasification – Coconut Shells are completely burnt with limited air in a gasifier to give producer gas which is then burnt for process heat. Discharge of char and tar to the atmosphere is very light if properly controlled.



3) Carbonisation (Traditional) – Coconut shells are partially burnt with limited air in a pit to produce charcoal. Discharge of char and tar to the atmosphere is very heavy.



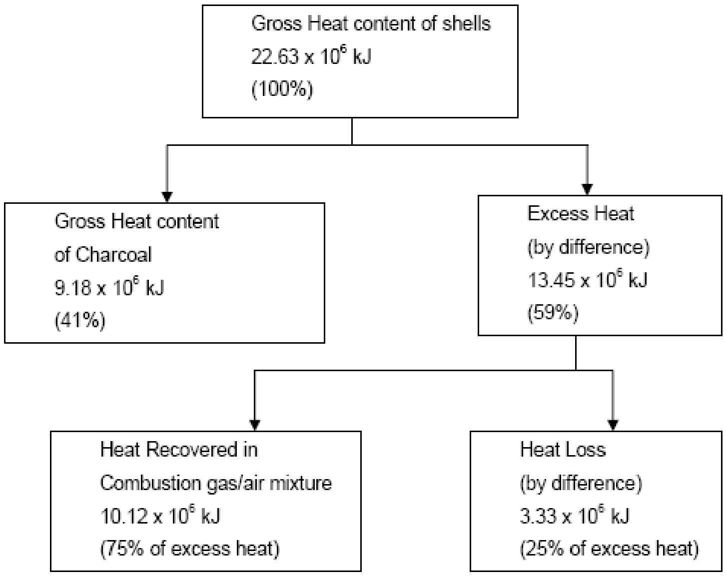
4) Carbonisation with Waste Heat Recovery – Coconut shells are partially burnt with limited air in a Carboniser to give charcoal. All the emitted gases are collected and burnt in a Furnace to recover the waste heat. Discharge of char and tar to the atmosphere is very light.



Coconut shell typically contains about 21,000 kJ/kg (kilo-Joule per kilogram) of dry matter. During carbonization by the traditional method, approximately 60% of this energy is lost to the surroundings. By use of the waste heat recovery technology developed by NRI this heat is recovered as useful energy for use by the industry.

During the carbonization process using the WHU, approximately 59% of the heat in the shell is evolved and the remaining 41 % is retained in the charcoal produced. Of the 59% of the heat generated, 75% is recovered in the combusted gas/ air mixture which can then be used to provide heat for drying applications in the coconut and other industries. (Figure)

Figure 10   Heat contents in the conversion of shells to charcoal



Source: Breag et al, 1984

6.3 Current Uses

Presently the two main uses of coconut shells and husk as a fuel are for

1) Small holder domestic use such as cooking, etc.
2) Copra drying

Besides being used as a fuel, shells and husk have numerous other uses that provide additional income to farmers. One of these other uses of the coconut shell is to produce shell charcoal that is one of the best raw materials for production of activate carbon. One method of using coconut shells to produce both a fuel gas and also shell charcoal is by means of the Waste Heat Unit that is described in the next section.

6.4 Waste Heat Unit (WHU)

Traditionally, charcoal is produced from coconut shell using the drum or pit methods (Photo16). These methods are quite inefficient and result in a lot of noxious smoke emissions to the atmosphere. Because these operations pollute the surrounding areas, charcoal-making is banned in urban areas and near to villages. Moreover, the traditional methods produce charcoal of variable quality which is charcoal often contaminated with extraneous matter such as earth, leaves and twigs.

To address these problems and also to recover the substantial amount of energy that is lost in the smoke emissions (about 60% of the energy in the shell), the Natural Resources Institute (NRI) which is funded by the British Government's Overseas Development Administration, began the development of coconut shell carbonization with waste heat recovery unit (WHU) in the early 1980s. The first prototype was built and tested by NRI in the UK (Photo 17). Pilot demonstration units were installed at the coconut industry in Sri Lanka, and NRI also imparted training in operation and maintenance and closely monitored its performance. Local workshops were provided with detailed technical know-how to manufacture the units. Twenty WHU units were installed between 1983 and 1989 – fifteen at Dessicated Coconut processing plants, two for copra drying, two for drying coconut parings, and one for a oil mill / sterilizer unit. All units except one were standard capacity of 1.5 tonnes of coconut shell; one unit used a scaled-up waste heat recovery unit (SWHU) that could process 3.5 tonnes of coconut shell. (Adair, 1989; Breag and Joseph, 1989; Tillekaratne, 1989)

Photo 16 Traditional method of burning coconut shells in a pit

Source: Breag et al, 1994

The development of the WHU, the Sri Lanka pilot and the transfer of technology was a success, and all users were very satisfied with the performance of the WHUs. Financial appraisal of the standard WHU and the scaled-up SWHU indicated very good return on investment for both units. Capital recovery period for the WHU was 7 months and for the SWHU 15 months. Break-even capacity was 13% of the capacity for the WHU and 22% of the capacity for the SWHU. For both units, Internal Rate of Return (IRR) was calculated to be over 500% (Tillekaratne, 1989).

In the 1990s, NRI began transferring the WHU technology to the coconut processing industry in Indonesia under a Project part-funded by the Common Fund for Commodities (CFC) of the United Nations in Amsterdam and the Institute for Research and Development of Agro-Based Industry (IRDABI) in Bogor. Unlike Sri Lanka where the dessicated coconut industry was the major user of WHU, the Indonesian coconut industry was more interested in using the waste heat for drying copra. One of the outputs of this project was the publication of a comprehensive Project/Country Manual for Indonesia on "WHU Technology for Copra Production" (Setiawan et al, 1997)

Photo 17 Prototype Waste Heat Recovery Unit tested by NRI, Culham, UK.

Source: Breag et al, 1994

The Waste Heat Unit (WHU)

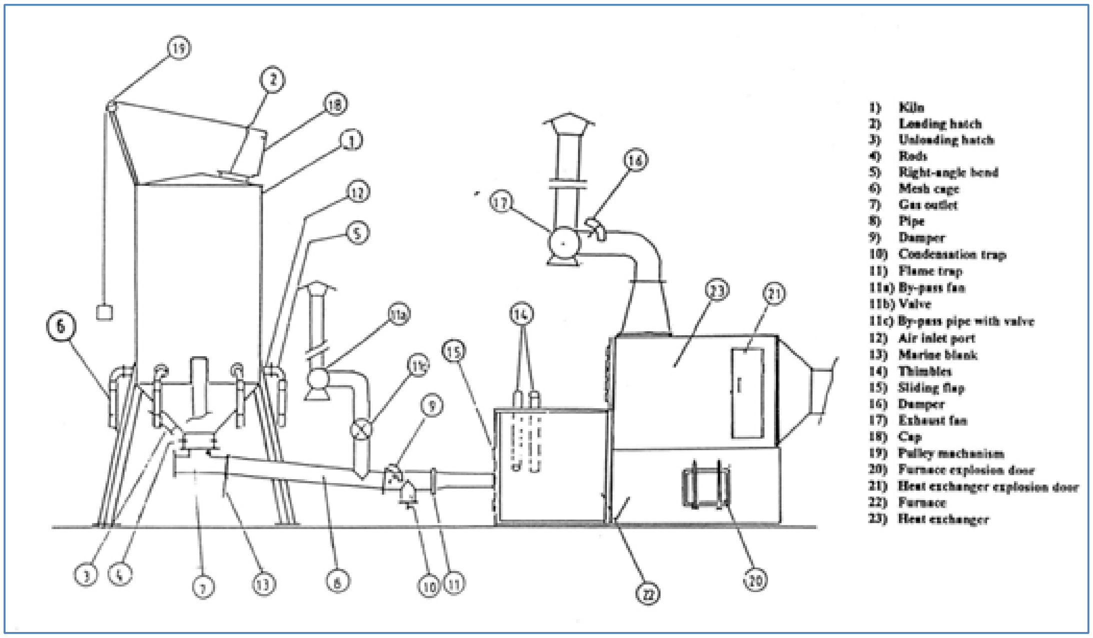
The WHU consists of a vertical kiln connected to a burner and furnace system (Figure11). The kiln (1) is cylindrical and is approximately 8 m^3 capacity. Two hatches, (2) and (3), are provided: one on top of the kiln loading the coconut shell charge, and the other near the base of the kiln for discharging the charcoal. The charcoal is supported by removable rods (4) that form a grid over the gas outlet port. Six ports (12) are equally spaced around the circumference of the kiln for lighting the charge.

These flanged ports are hinged so that right-angled bends (5), fitted with dampers to control finely the flow of air into the kiln, can be swung into position after lighting. Metal mesh cages (6) are also fitted at the inlet of the bends. The bends direct any "blowbacks" downwards and the mesh cages contain the flame or hot char which may be ejected.

The gas outlet (7) is located at the base of the kiln connected by a pipe (8) to the burner via a damper (9), a condensation trap (10) and flame trap (11). The damper's function (9) is to control the flow of kiln gas into the furnace. The kiln gas is ignited by the thimbles (14) of burning charcoal inserted through the roof of the furnace.

Combustion air is drawn into the furnace through the slots (15) on the front of the furnace. Each slot is fitted with sliding plates to control the increase of air. The draw of the combusted gases is adjusted by means of the damper (16) located in the outlet of the exhaust gas pipe-line from the furnace. This gas pipe-line is connected to a centrifugal exhaust fan (17) which provides an induced draught through the kiln/furnace system. (Breag et al, 1994)

Figure 11 Schematic of the Waste Heat Unit



Source: Breag et al, 1994

<u>Safety Features</u>

The following special safety features have been incorporated into the design of the WHU's to ensure the safe operation of the unit.

- A flame-trap (11) is fitted in the gas pipe-line extending from the base of the kiln, and is to help prevent the passage of a flame back from the furnace.
- A spring relief valve is housed on the top of the kiln and is designed to vent gases should the pressure inside the kiln exceed a predetermined limit 14 kg/m^2.
- A vent (2) is situated adjacent to the relief valve and is designed to burst and safely release the contents of the kiln in the event of an explosion. Two other vents are incorporated, one in the furnace and the other at the heat exchanger to provide explosion protection.

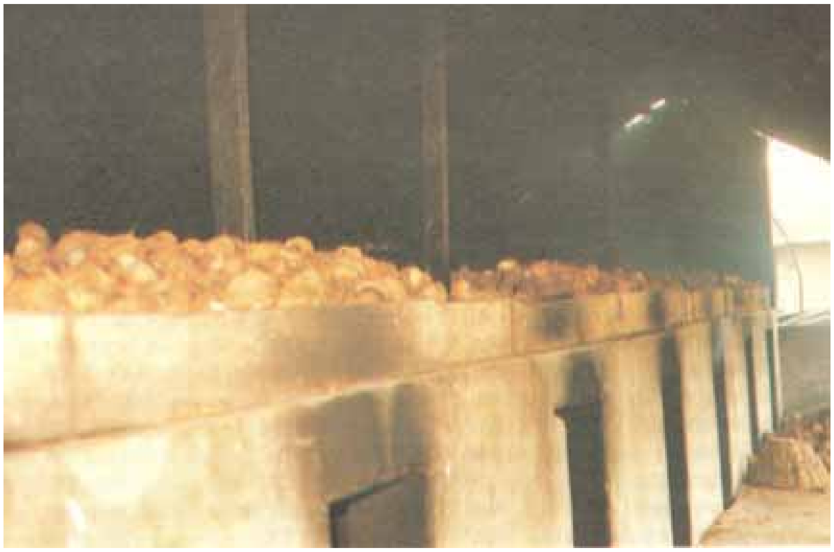
6.4.1 WHU for Copra Production

The main equipment required for using a WHU for copra drying are:

1. Kiln, 8 m^3
2. Kiln gas fan, 0.75 Hp
3. Induce draught fan, 11 Ho
4. Furnace
5. Heat exchanger, 80 tube, diameter 2"
6. Blower, 20 HP
7. Tunnel dryer
8. Trolley, 12 units
9. Genset 50 kW

10. Thermometer

Photo 18   Traditional Copra Drying



Source: Breag et al, 1994

The coconut shell carbonization with waste heat recovery unit (WHU) is produced in two sizes: 8 m^3 and 16 m^3. A standard kiln with a capacity of 8 m^3 is designed to produce approximately 0.45 - 0.5 tonnes of charcoal from 1.5 tonnes of shell per 10 to 12 hour operation. The WHU system for copra drying consists of two WHUs kilns operated alternately on a semi-continuous basis, a heat exchanger/furnace system, a dryer fan and tunnel copra dryer - it is capable of a producing approximately 0.9 tonnes of good quality charcoal and 3 tonnes of copra per day. (Figure12)

Even though the system described below is for copra production, the WHU system can be adapted and used for providing process heat for other operations such as dual-firing (kiln gas plus solid fuel) boilers for raising steam, for providing heat for hot oil immersion drying (fry-drying kernels), or for drying other products and crops.

The twin WHUs used for copra production requires a total electrical load of 25 kW, consisting of 0.50 kW for running the kiln gas fan, 8.25 kW for the induced draught fan and 15 kW for driving the dryer fan. The remainder is for lighting and minor power points.

To operate the copra factory with twin WHUs for 250 days operation with a throughput of 3 tonnes copra per day requires approximately 750 ha of coconut area. It is assumed that I ha coconut plantation can produce 5,000 nuts/year. The capacity of twin kiln WHU is 15,000 whole coconut shells/day.

The coconut shell carbonization with waste heat recovery system virtually eliminates the smoke problem and simultaneously enables the heat generated in the processing to be used in copra drying. The gas evolved during the carbonization of the coconut shells consists of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen. This gas has a calorific value of approximately 3.5 MJ/m^3 and is readily combustible. Since the technology involves burning of combustible gases, care must be exercised and safe operation procedures must be followed.

Tunnel Drier

The system consists of a forced convection tunnel dryer (size. 2.5 x 2.5 x 18 m) equipped with 12 trolleys (Figure12). The dryer, constructed of wood, is connected to two waste heat recovery units each with a shell capacity of approximately 1.5 tonnes. The WHUs provide heat to a tubular heat exchanger which indirectly heats drying air to around 65 to 80°C. The WHUs are operated alternately to enable semi-continuous operation of the dryer. The copra should be dried down to at least 8 to 10% moisture content; it will then dry down further when it is stored in dry conditions.

The operation of this system requires semi-skilled workers who are trained in the safe operation of the unit. The operation requires a total of 10 persons for:

- Loading and preparation of WHU kiln and copra dryer.
- Start-up and operation of the kiln and in tandem with the copra drying process.
- Shutting down the WHU kiln.
- Unloading the charcoal, and storage and bagging of copra.

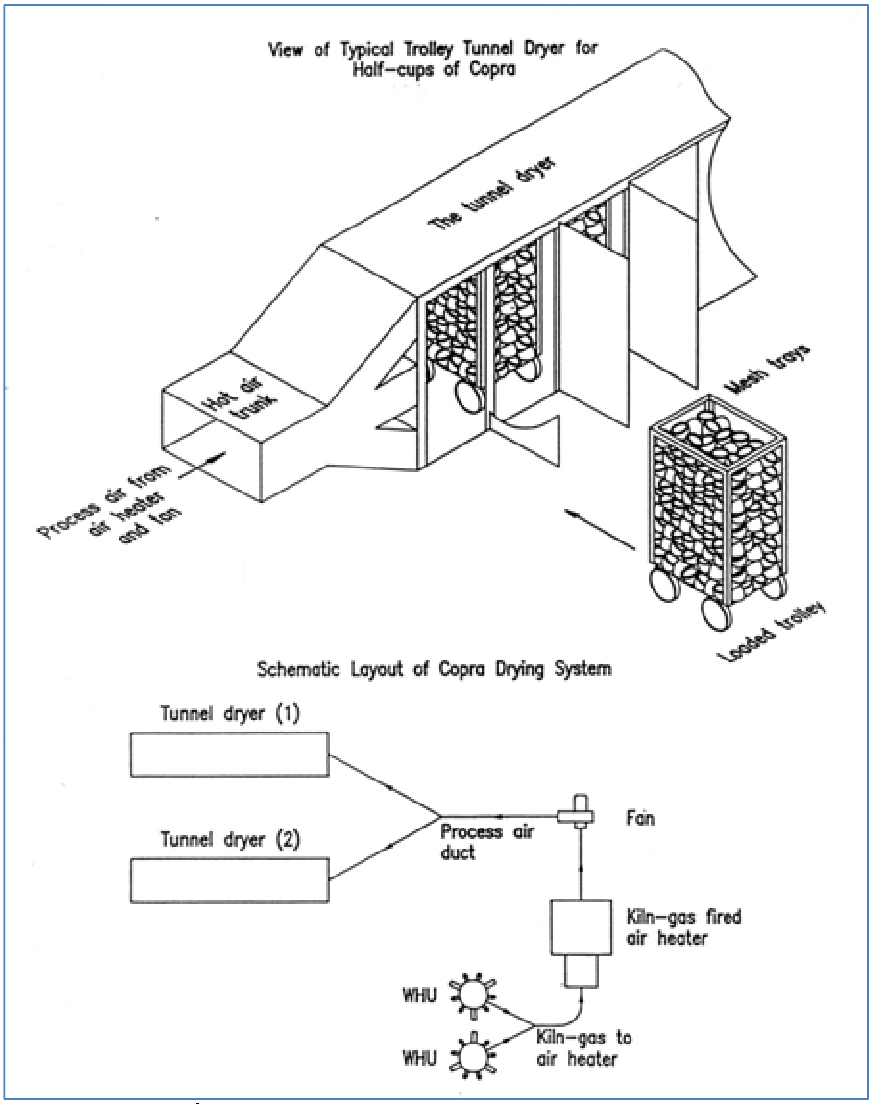
Copra Drying

1) 5 tonnes (equivalent copra in half-shells) are loaded in the first six trolleys of the dryer. After approximately 8 hours of drying the half-coconuts are unloaded from the first section of the dryers one trolley at a time - thus maximizing' the time of drying of the freshly loaded nuts.
2) The kernel is scooped out of the shell and loaded into three trolleys. The trolleys are then wheeled into the front section of the second half of the copra dryer replacing three of the six trolleys housed therein.
3) The first stage of the dryer therefore always contains 1. 5 tonnes of freshly loaded kernels in shell; and the second half of the dryer holds a total of 3 tonnes of kernels - half of which has been dried for one WHU heating cycle and the other half for two drying cycles.
4) The copra removed from the dryer for subsequent storage and bagging therefore is subjected to three WHU firing cycles which can vary from 8 to 10 hours. The cycle thus continues producing approximately 3 tonnes of copra every twenty four hours.

The WHU kiln requires approximately 1.5 tonnes of dry· shell per batch. This shell must be dry for the unit to work effectively. Half-cups of coconut shell and broken shell from copra kiln may be used. Copra shell needs no further drying. However it should be stored under cover in sacks. A coconut shell storage area of at least 100 m^2 is recommended with each WHU installed.

Fresh coconuts which have been dehusked and split into half-cups are used. To make good quality of copra it is important to use mature nuts. Dehusked fresh coconuts should not be split unless drying can proceed shortly thereafter. If there is more than four hours between splitting the nuts and applying the heat, the quality will deteriorate.

Figure 12 Typical Tunnel Drier and Layout of WHU based copra drying system



Source: Breag et al, 1994

The total land area needed to establish a copra factory using the WHU technology is approximately 450 m^2. Approximately 150 m^2 is required for an area where the workers prepare the raw material which is fresh split coconuts and separation of dry shell from the kernel for carbonization. The remainder of the land (300 m^2) is for processing, product storage, by-product storage and an office.

6.4.2 Product Recovery

Copra

Approximately 4800 - 5100 nuts will produce 1 tonne of copra. The quality of copra produced compared with traditional copra is shown in Figures (a) and (b). Tthe copra produced by the WHU system is superior to traditional copra in colour, aroma and appearance. In contrast it is important to note that traditionally prepared copra tends to be a smoky brown in colour, often mouldy, with variable moisture content and high free fatty acid content. The quality of copra is affected by several factor such as maturity coconut (oil content), efficiency of dryer and variety of coconut.

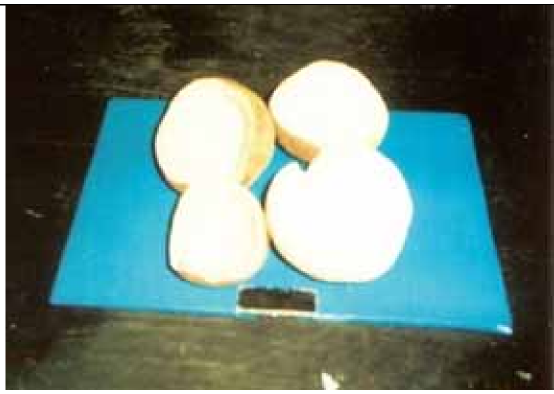
Photo 19 A Waste Heat Unit in Sri Lanka

Source: Breag et al, 1994

Copra when removed from the dryer should have a moisture content below 8 % if it is to be stored without becoming mouldy. Copra must be well-dried before it is bagged. A copra dryer in itself is not sufficient to maintain good copra quality according to the best grade standard: Once copra has left the dryer it must be allowed to cool in bulk in a well-roofed and ventilated storage shed with either a raised concrete or wooden floor.

The copra produced is of good quality and much superior to that produced locally. In the Palembang area samples of the copra were taken to several companies. The survey revealed that only 1 to 1.5% premium could be obtain for the copra. In West Java traders and producers, in spite of the much improved quality did not offer a price premIUm.

Photo 20 Copra from Traditional smoke driers and from the WHU process



(a) Copra from Smoke Drier (b) Copra using WHU

Source: Breag et al, 1994

If large premiums are to be realized, copra would need to be made available in sufficiently large quantities to have significant impact on the oil mill outputs. This raises the question of whether copra production by the WHU would ever realize a premiums unless large quantities were sold, except in site specific case where market for edible copra were established.

Table 12 Comparison of Moisture and Oil Content from WHU with other methods

Criteria	Copra			
	WHU	Traditional indirect-fired	Traditional direct-fired	WHU & Traditional indirect-fired
Moisture(%)	4.5	6.01	7.5	5.6
Oil content (%)	70.85	66.03	59.5	66.1

Source: Setiawan et al, 1997

Charcoal

Two kilns (about 3 tonnes of shell for carbonization) can be used to produce approximately 2.8 - 3 tonnes of copra. The WHU charcoal kilns typically yielded 380 to 400 kg of charcoal per 1.4 tonnes shell.

Two carbonization cycles are conducted every 24 hours allowing time for the charcoal within the kiln from the previous carbonization cycle to ·cool down and· be unloaded. The charcoal-making cycle should therefore be started every 12 hours alternating between the kilns. The bulk density of hybrid shells are lower and have thinner shells than that of the tall variety of coconut and give a charcoal yield of 26 to 28%.

Charcoal produced will typically have a fixed carbon content of 68.5% and a calorific value of 30 MJ/kg. Approximately 400 kg of charcoal is produced per batch. When first unloaded the charcoal may ie-ignite and it should be held for at least 24 hours in sealed airtight drums. Thereafter, the charcoal may be sieved and bagged. Dust masks should be used for these operations. It should also be noted that at high concentrations of charcoal dust in the air there is a potential explosion hazard. Therefore, for both health and safety reasons, operating procedures should be planned to minimize dust levels and work should only be carried out in well ventilated areas. A covered storage area for charcoal of 40 m^2 is recommended with each WHU installed. Fire precautions should be taken including the provision of water-type fire extinguishers.

Charcoal made from the process is particularly good feedstock for the manufacture of activated carbon. In Indonesia prices for charcoal vary considerably from. region to region. In addition, with the increasing price of firewood and demand for charcoal in the more densely populated area, the price of charcoal is higher than in the outer islands.
(Breag et al, 1994)

Photo 21 Charcoal produced by the Waste Heat Unit

Source: Breag et al, 1994

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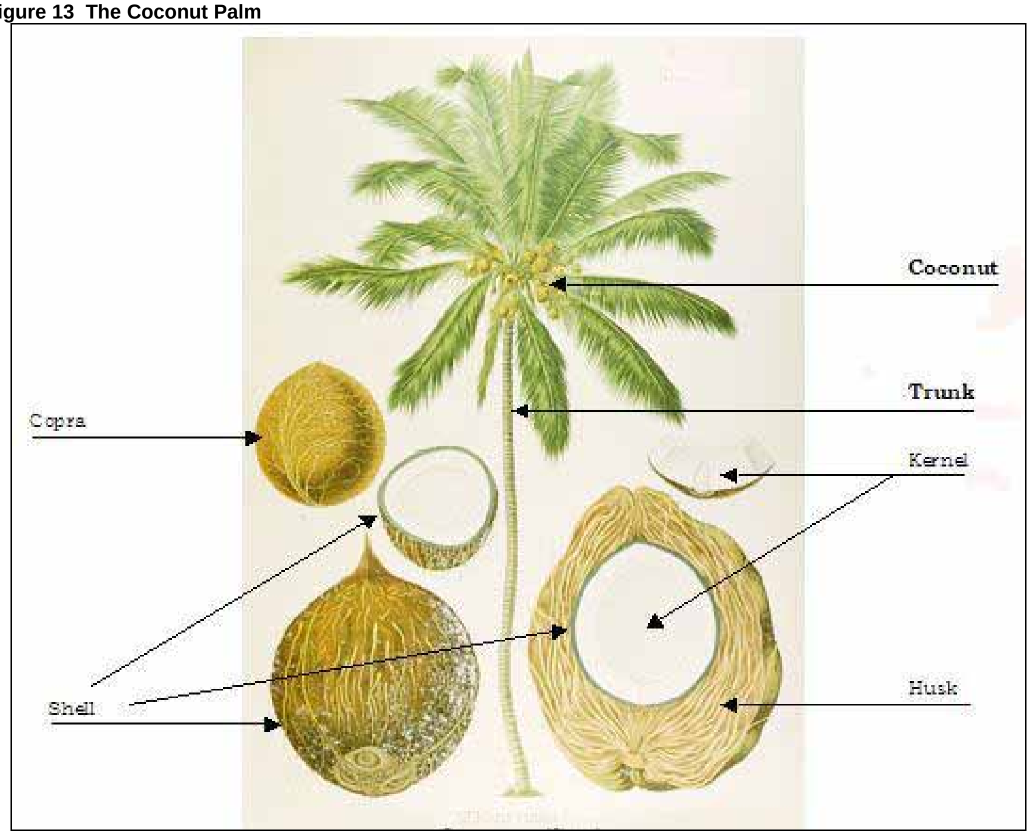
8 ANNEXES

8.1 The Coconut Palm

8.1.1 Parts and Uses

The coconut palm (*Cocos nucifera*) has been called “Kalpa Vriksha” which means “Tree of Life” in the ancient Indian language of Sanscrit, “Tree of Heaven”, "Tree of Abundance" and "Nature's Supermarket.". It is the most important palm and the most extensively grown nut in the world. The main parts of the coconut palm are shown in Fig . The coconut palm has a single trunk, 20-30 metres tall, its bark is smooth and grey, marked by ringed scars left by fallen leaf bases. The leaves and flowers that turn into coconuts grow at the top of the palm; The fronds in a mature healthy palm describe a sphere with the fronds evenly distributed in all directions from the growing tip. Fruits mature in about 12 months and a normal healthy tall coconut palm produces one mature bunch of coconuts per month on average. The length of a leaf can be up to 7 metres in tall palms, with a leaf area of up to about 10 m^2, and weighing up to 20 kg when green. Mean annual leaf production is about 14-16 for mature tall palms and 21 for dwarf palms.

Figure 13 The Coconut Palm



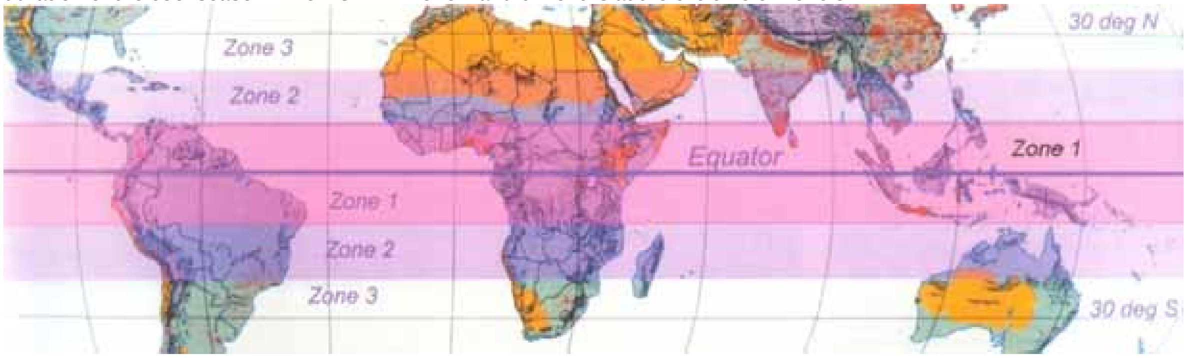
Source: Kohler's Medicinal Plants

The coconut palm is unsurpassable in its beauty and its utility because, on small islands where land-based natural resources are scarce, it provides almost all the necessities of life - food, drink, fuel, cooking and cosmetic oil, domestic utensils, medicine, timber and thatch for building houses, coir fiber for making ropes and mats, and others. In many tropical countries, coconut is an important part of the daily diet. Its main product is the oil extracted from the kernel. The residue is an important animal feed. The coconut water from the young nuts is a popular beverage. The jelly-like kernel of the young coconut is considered a delicacy. The shredded kernel is sold as desiccated coconut used in food and confectionary. The husk of the nut provides coir which is an important fiber that can be used for ropes, carpets, brushes, etc. The shell of the nut is used for household utensils and the charcoal made from it is an excellent basic material for activated carbon. Instead of being used for nut production, the inflorescences can be tapped, yielding sap with high sugar content, from which sugar, alcoholic beverages and vinegar can be made. The leaves are used for roof thatching. The midribs of the leaves are used for brooms. Coconut wood is more and more being used for house building and other uses such as furniture or tool handles. All the parts of the coconut palm, except the roots, are used in a peasant's household, so it is no wonder that this tree has also been called 'Tree of life'.

8.1.2 Origin and Distribution

The major coconut areas lie between 20^{o}N and 20^{o}S on both sides of the equator. Though it is found beyond this region as far as 27^{o}N and 27^{o}S, cultivation in these extreme regions has not been successful and the palm does not fruit in cooler climates (refer Figure).

Figure 14   Zones of latitude in which moist coastal regions support the growth of coconuts. Zones 1, 2 and 3 support high, medium and low potential productivity, respectively. Productivity falls with an increase in the duration of the cool season which is nil in Zone 1 and 6 months at the extreme of Zone 3.



Source: Mike Foale, 2003.

It is now widely accepted that, millions of years ago, the wild coconut probably reached most of the South-East Asian coastal areas and Pacific islands though its floating seeds carried by ocean currents. The coconut “heartland” is the three great archipelagos of Indonesia, the Philippines and Melanesia. Around 4000 years ago, Polynesian mariners moved eastwards from the coast of South East Asia to the islands of the South Pacific extending 10,000 kilometers from New Guinea to Tahiti, carrying with them coconut fruits for food and drink on the voyage, and for planting in their new homes. More than 2000 years ago, the coconut spread westwards from its heartland to the Indian sub-continent carried by traders returning home from the Indonesian islands. Perhaps around the same time, people from Borneo (according to linguistic evidence), took the coconut across the Indian Ocean to Madagascar, from where it was taken onto East Africa. In the 15th century, Portuguese mariners took the coconut from India and East Africa to the Cape Verde Islands in the eastern Atlantic. From here the coconut was taken westwards on slave trading ships to the Caribbean and eastwards to the West African coast all the way from Senegal to Angola. The coconut had already reached the western shores of South America much earlier over the Pacific from Polynesia. So, when the coconut palm spread from the Caribbean to the coasts of Mexico, Central and South America in the 16th century, it had completed its encirclement of the globe. (Foale, 2003)

8.1.3 World Production

Total world coconut area in 2005 was estimated at 12.2 million hectares, of which over 89 percent is found in the Asia and Pacific regions. 75% of coconut areas are in the three largest producing countries: Indonesia (3.9 million ha), Philippines (3.2 million ha) and India (1.9 million ha). Amongst the South Pacific countries, Papua New Guinea (0.26 million ha) is the leading producer. In Africa, Tanzania (0.31 million ha) is the largest producer and in Latin America nearly 43% of the coconut area is in Brazil (0.28 million ha) (refer Table and Figure).

Table also gives the production of coconuts in the major producing countries for 2005 in both nut equivalent and copra equivalent[2], and the productivity per hectare. During 2005 an estimated total of 59.6 billion nuts or 11.9 million tonnes copra equivalent were produced worldwide on 12.2 million hectares at a world average productivity of 0.98 tonnes copra equivalent per hectare.

73% of the production comes from the three major producing countries: Indonesia produces 27.7%, Phillipines produces 23.6% and India produces 21.5% (refer Figure). While productivity in both Indonesia and the Phillipines is around 0.85 tonnes copra equivalent per hectare, productivities in some other Asian countries are higher with India at 1.33, Sri Lanka at 1.12 and Vietnam at 1.03. In the Americas Brazil at 2.70 and Mexico at 1.58 tonnes copra equivalent per hectare have the highest productivities not only in their region, but also in the world (refer Figure).

Table 13 World Production of Coconuts, Area and Productivity in 2005

COUNTRY	Production Nut Equivalent (billion nuts)	Production Copra Equivalent (million tonnes)	% of Total World Production	Area under Coconuts (million ha)	Productivity (tonnes copra equiv /ha)
Indonesia	16.49	3.30	27.7%	3.89	0.85
Philippines	14.06	2.81	23.6%	3.24	0.87
India	12.83	2.57	21.5%	1.94	1.33
Brazil	3.79	0.76	6.4%	0.28	2.70
Sri Lanka	2.22	0.44	3.7%	0.40	1.12
Thailand	1.20	0.24	2.0%	0.34	0.70
Mexico	1.19	0.24	2.0%	0.15	1.58
Papua New Guinea	0.81	0.16	1.4%	0.26	0.63
Vietnam	0.68	0.14	1.1%	0.13	1.03
Malaysia	0.39	0.08	0.7%	0.13	0.60
80 Other Countries	5.91	1.18	9.9%	1.40	0.84
TOTAL / AVERAGE	59.57	11.91	100%	12.17	0.98

Note: Data refer to total production of coconut, whether consumed fresh, processed into copra or desiccated coconut.

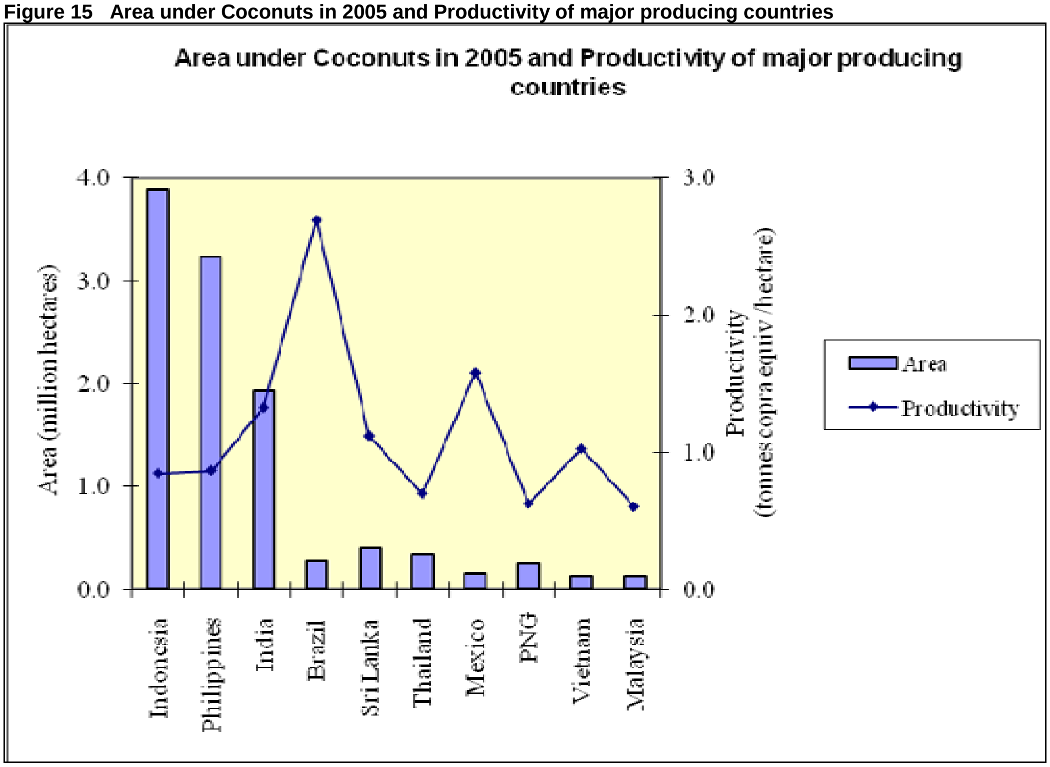
Source: APCC Coconut Statistical Yearbook 2005 (Compiled from information provided by APCC member countries and FAO Production Yearbooks; Estimate for non-APCC Countries was calculated by converting the nut weight into

[2] 5 Nuts are required to produce 1 kg of Copra

whole nuts given in the FAO Production Yearbooks, by using a conversion factor of one ton of husked nuts = 1,250 whole nuts.)

Coconut production has increased steadily in Indonesia, India and Brazil whereas in the Phillipines, severe cyclones in some years has caused a dip in the production.

Figure 15 Area under Coconuts in 2005 and Productivity of major producing countries



8.1.4 Planting material, Selection and Breeding

The coconut palm (*Cocos nucifera* L.) is a monotypic species in which there are only two varieties[3]:

1. the Tall variety: *Cocos nucifera* L. var. *typica*, and
2. the Dwarf variety: *Cocos nucifera* L. var. *nana*.

Both Tall and the Dwarf palms are found in all the coconut growing countries, although the dwarf palms account for only around 5% of the coconut population worldwide.

Tall Variety

Tall palms are characterised by a rapid growth in height and strong stems. They are cross-pollinated and are slow to mature. Tall palms include:

- trees that bear many nuts which are of medium size and with a low copra yield. Examples are the West African Tall and the Vanuatu Tall;
- trees that bear an average number of large nuts with a high copra yield. Examples are the Rennell Tall, Thailand Tall and the Polynesia Tall.

[3] Variety is a group within the species that posseses certain distinguishing features within the group but distinctly differing from other groups.

A young, good tall plant produces 5 to 7 bunches and 25 to 45 fruits per tree annually. The bunch and fruit production of young talls is a little less than half of that of dwarfs, on average. Under research station (best) conditions, a mature, well performing tall plant annually produces 13 or 14 bunches and 80 to 100 fruits per tree. On average, the fruit production of mature talls is about nine-tenths that of dwarfs. The effect of the environment can make fruit production of the same ecotype at maturity vary by 50-80%.

Photo 22 A Tall cultivar and Tall nuts

Source: Coconut Varieties and Cultivars

Ecotypes producing the highest number of fruits are those that produce the smallest fruits: Solomon Tall, Vanuatu Tall, Lacadives Micro Tall, etc. Ecotypes producing the lowest number of fruits are those that produce the biggest, round fruits: Panama Tall, Malayan Tall, Cambodia Battambang Tall. No ecotype monitored until 18 years of age has shown a decline in yield.

Dwarf Variety

Dwarf palms have shorter and thinner stems. They are normally self pollinated, are early bearing and have a high annual bunch yield. Dwarf palms are therefore important in breeding programs. Inflorescence and fruit colours such as Green, Yellow, Red, Orange and Brown are used for classification purposes.

A Dwarf cultivar and Dwarf nuts

Source: Coconut Varieties and Cultivars

For the period of 3-8 years of age, a dwarf plantation of a good genotype grown under favourable environmental conditions annually produces 10 or 11 bunches and 50 to 70 fruits. The least productive ecotypes are Niu Leka Dwarf, Tahiti Red, Kinabalan Green and Aromatic Green, with less than 25 fruits per year. On the other hand, Pumilla Green Dwarf and Pilipog Green Dwarf are classified as producing the greatest number of fruits per tree, followed by Ghana Yellow Dwarf and MYD. When mature, a well performing plantation of dwarfs annually produces 14 to 16 bunches and 80 to 130 fruits per tree. Classification according to production of bunches and fruits is more or less the same as at a young age, with higher numbers for the Madang Brown Dwarf. The ecotypes followed until 17 years of age have not shown any production decline due to age.

The main differences between the tall and dwarf varieties are summarized in the Table below.

Table 14 Comparison of the Tall and Dwarf varieties

Traits	Tall	Dwarf
Geographical distribution	Widely distributed and commercially grown	Less widely distributed and generally of non-commercially value
Stem circumference	Enlarged and with a bulbous base (bole)	Thin. with a cylindrical or tapering base
Mode of pollination	Mostly cross-pollinated i.e. allogamous	Mostly self-pollinated i.e. autogamous
Pigmentation of nuts and petiole of leaves	Most are mixtures of greens and browns	Either pure greens, or browns. yellows and reds
Height increment per year	Greater than 50 cm	Less than 50 cm
Years to beginning of reproductive maturity	Late (5-7 years)	Early (3-4 years)
Useful life span	60 - 80 years	40 - 50 years
Nut size (whole)	Very small to large	Very small to medium·
Phenotypic variation - within cultivar - between cultivar	 High High	 Low High
Root distribution	Generally more dense and plentiful	Less dense and few
Reaction to adverse conditions	Generally less sensitive	Sensitive to hypersensitive
Cultural requirements	Average	High inputs required
Leaf and bunch attachment	Very strong	Fragile

Source: Taffin, 1998 Coconut, The Tropical Agriculturist

<u>Terminology</u>

A “cultivar” is a botanical variety characteristic of a particular region where it has been planted and cultivated by man. . However, to distinguish traditional cultivars from more recent ones, the terms “ecotype” and “hybrid” are also used. The ecotype is defined by a group of individuals from the same environment showing morphologic similarities. The terms cultivar and ecotype therefore mean essentially the same. The hybrid, in its widest sense is defined as a cross between two structures belonging to different ecotypes. The term “structure” here means a population, a family, or an individual.

Within the two main groups (tall and dwarf) there are a large number of ecotypes / cultivars. The most widely known cultivars amongst the Talls are West Coast Tall and East Coast Tall in India, Ceylon Tall, Malayan Tall, Fiji Tall, Jamaica Tall, West African Tall, and amongst the Dwarfs we find Chowghat Dwarf in India, Malayan Dwarf, Fiji Dwarf, etc. Within a cultivar certain members can differ from others in a single character (as in the case of Laccadive Tall in which the Laccadive Micro differs only in nut size from the Laccadive Ordinary) or members could differ from others in a constellation of characters (as in the Chowghat Dwarf cultivar the Chowghat Orange Dwarf differs from the Chowghat Green Dwarf in a whole range of characters). These cultivars are referred to as “forms”. “Types” refer to those which exhibit some special characteristics like the sweet husked ones, Kelapa wangi in which the water and kernel emit a pleasant smell etc. These types occur in very limited numbers and are not under regular cultivation.

Selection Criteria

To increase yields and maintain them at an economic level, coconut planting material needs some form of regular selection. All small coconut growers practise selection by collecting germinated nuts from under high-yielding trees and by choosing the most vigorous seedlings for planting. The commercial grower may, however, prefer to use planting material that has been selected and is recommended by research institutes, who can also advise on the choice of planting material for specific soil and climatic conditions.

If the main aim is to sell copra, then in addition to maximum yield of copra/hectare, the selection criteria will also include adaptability to the environment, sturdiness and resistance to pests and diseases. On the other hand, if the nuts are to be sold for eating, then market preferences are an important consideration particularly the nut size. In either case, the use of early bearing, high-yielding hybrids that meet the above criteria is the best way of maximising the returns from a coconut grove.

For larger plantations, it is best to protect against pests or diseases by using several different hybrids. For smallholders, local cultivars are likely to be more important since they are often preferred either for their taste or for their traditional uses, but hybrids should also be considered. Local cultivars are often used in garden plots, alongside small commercial plantations in which the production of copra is the main objective.

8.1.5 Planting practices

Planting Holes

1) Dig the planting holes after the preparation of the drainage system and the roads, preferably a few months before planting, except in sandy soils where the holes may cave in.
2) The dimensions of the planting holes depend on soil conditions and the depth of the water table, and also on the farm type.
3) On large estates where large numbers of seedlings will be planted especially on light soils, the holes may be only slightly bigger than the polybag containing the seedling, for economic reasons.

4) In heavy soils, and especially in soils with a high content of lateritic gravel, large holes, subsequently filled with light soil are an advantage for palm development. Results of trials have shown that planting at 60 and 90 cm depths resulted in 10 months earlier bearing and increased annual yields by 10 and 7 nuts per palm respectively. It also increased the root numbers by 100% and 104% respectively, as compared to the control. Deep planting also provides resistance to cyclones.
5) On Kiritimati (Christmas Island) it has been found that coconuts under conditions of low and irregular rainfall can be successfully established by digging planting holes down to the water-table (up to 2.5 m deep), refilling to 30 cm above the water-table with topsoil and planting 3-6 month old seedlings.
6) In India, coconuts are sometimes planted in holes as deep as 1.5 m, particularly in areas with a long dry season and in soils with a deep water-table. As the coconut stems grow, these holes are gradually filled with organic waste and soil. Care should be taken to keep the soil level below the growing point, otherwise the palm may be killed. Therefore, the planting hole should be wide enough to permit keeping the soil away from the seedling collar. In this way, the bole is nearer to the water-table where the soil will not dry out so quickly, and the rooting surface of the palm is much larger than that of palms planted at shallow depths.
7) Usually, seedlings are transplanted to the field when they have about 3 or 4 leaves. Planting at a later stage increases the transplanting shock, with the exception of seedlings raised in polybags.
8) Seedlings selected for planting should be taken out of the nursery bed with the use of a shovel, cutting all the roots before lifting them. All further handling should be done carefully to avoid damage. Seedlings should not be lifted by the sprout. This is particularly important for dwarf seedlings, as the sprout can become easily detached from the nut.
9) Only seedlings than can be planted within one day should be lifted. The transplanting age should be determined beforehand to allow effective planning of the planting schedule in the nursery and in the field. The lifted-out seedlings should be kept in the shade as much as possible until planted.
10) The best time for planting seedlings in the field is at the beginning of the rainy season, after the rains have started to fall regularly. Seedlings planted late in the rainy season may not be able to develop a root system large enough to survive the dry season.
11) Seedlings in polybags should be watered the day before transplanting, to keep the soil firm at transplanting. Handling of the seedling should be done by means of the plastic bag. Holding the seedling by the collar when attached to the bag heavy with wet soil is dangerous, as the plant may break away from the nut.
12) Before placing the bag in the hole, the two lower corners of the bag are cut with a sharp knife and the bottom is slit. After planting the bag in the hole, the hole is partly filled with soil and the sides of the bag are cut and the bag is removed.
13) Including the digging of the plant holes, one man can plant 60-80 seedlings per day. Having dug the holes earlier, one man should be able to plant about 150 seedlings per day.
14) Where termites may be expected to cause damage, the planting hole should be treated with an appropriate insecticide (BHC, Endrin) before the seedling is planted.
15) The planting hole may be filled with topsoil from the surrounding area, mixed with the recommended quantity of fertilizer or manure. Organic manuring is very beneficial to the seedlings, due to its great waterholding capacity and the micro-nutrients that will become available with its decomposition.
16) Two layers of coconut husks may be placed, concave side up, at the bottom of the planting hole, as they contain a fair amount of nutrients and of water. Husks can also be used for mulching around the young palm to keep the soil moist and reduce weed growth.

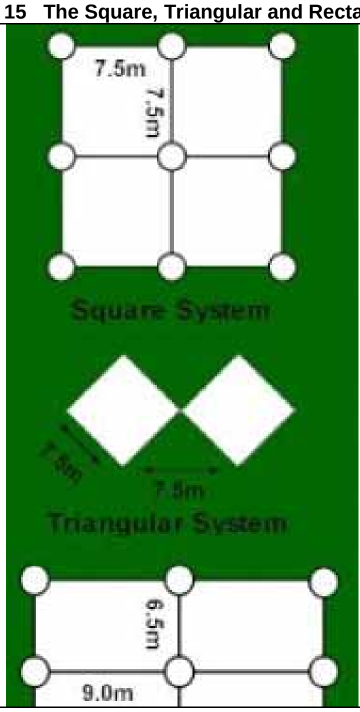
17) Optimal treatment of seedlings will pay dividends throughout the long life of the coconut palm. Adequate fertilizing and weeding and irrigation where needed may accelerate the onset of flowering by one or more years.
18) Weeding the area around the seedling is very important to avoid competition for water and smothering of seedlings by weeds. The circle to be kept free of weeds should be about 1.50 m in diameter. These circles should be widened with the development of the seedling.

Planting Density

The three planting layout systems used are Square, Triangular and Rectangular. These are shown in Table with the number of palms per ha for the generally used spacings. Several factors come into play when the planting density is changed:

- Planting density influences individual palm development and yield as well as yield, per hectare, maintenance and harvesting costs.
- Generally, planting density has little influence on stem girth, number of leaves produced or the age of first flowering.
- By low density planting, a larger soil volume is available to each palm, which is one of the reasons for high yields per palm.
- Fewer palms/ha also means less production/ha of total biomass, and less fertilizer may be needed to increase nut production because less nutritious elements will be used for the production of biomass.
- Fewer palms to be climbed for harvesting also reduces the harvesting cost.
- Wider spacing favours weed growth, increasing weeding cost.
- Factors such as fungus disease may be a reason for adopting a spacing below optimum, especially in very humid areas.

Table 15 The Square, Triangular and Rectagular planting systems



Method	Palms per ha
Square:	
7.5 m x 7.5 m	177
8.0m x 8.0m	156
8.5m x 8.5m	138
9.0m x 9.0m	134
10m x 10m	100
Triangular:	
8mx8m	180
8.5 m x 8.5 m	160
9mx9m	143
10mx10m	115
Rectangular:	
6.5m x 9.0m	170

Optimum planting density for coconut monoculture differs for different ecological conditions, and depends primarily on the farming system and the coconut variety / hybrid selected. A review of various coconut growing countries indicates that:

- Most coconuts in commercial plantings have been planted at spacings varying between 8 x 8 m to 9 x 9 m, either in a triangular, a rectangular or a square system. Dwarfs are planted at closer spacings of 6.5 x 6.5 m or 7 x 7 m.
- Planting on the triangle is done mostly in coconut monocropping with the objective of maximum copra yield per ha.
- Planting on the square or rectangle is sometimes used in monocropping, but mostly when coconut is intercropped or undergrazed, especially where cultivation has been mechanized.
- For intercropping, planting in avenues is even better, as it will provide space and light for intercrops throughout the entire coconut growing period. Where wide inter-rows are preferred, such as in mixed farming systems, single or double hedge planting systems have sometimes been used, in which the spacing within the row is narrow and between the rows wide.
- In Ivory Coast, optimum density for MAWA hybrid was found to be around 150 palms per ha, the limiting factor mainly being water deficit.
- Research in Jamaica found that the optimum spacings for talls, hybrids and dwarfs were 7.9, 6.7, and 5.5 m, corresponding with densities of 185, 257 and 381 palms/ha, respectively. The curve representing the yields/ha with increasing density is flat topped, indicating that under the conditions in Jamaica there is a rather wide range where increasing densities produce almost equal yields.
- Results of large-scale research programmes in the Philippines and Indonesia have shown that there are no significant differences in production per hectare within a range of 115-180 trees per ha. This is because with increasing planting density: (a) nut production per palm decreases; (b) nut production per ha increases because of the higher number of palms per ha; (c) the size of the nuts decreases due to competition for the same nutrients; therefore (d) the total yield of copra per ha increases initially and then levels off.
- Where coconuts are grown as a monocrop, planting can be carried out at densities at the higher limit of this curve. The heavy shade would reduce weeding costs considerably. Losses of palms due to lightning, etc. would not reduce yields as long as the number of palms correspond with the flat top of the curve. High densities will also produce high initial yields.
- Lower planting densities gives more space for intercrops and multi-cropping systems without decreasing the coconut yields.

(Nuce de Lamothe, 1990; Ohler, 1993)

<u>Low density planting:</u>
Between planting densities of 100-180 palms per ha, the yield curve for different densities is rather flat. Therefore, a wider spacing is preferred where multiple cropping is planned because it will provide more land, light and water for intercrops. Planting in a square or rectangular system will facilitate mechanized cultivation and crop management. In climates with long dry seasons, spacing at 9 x 9 in a triangular system, or 10 x 10 in a square system will not give very different yields, but the latter may improve light conditions for the intercrop considerably. The selection of the coconut variety to be planted is also of importance when intercropping is considered. When high-yielding hybrids are preferred, tall x tall hybrids may

be selected instead of dwarf x tall hybrids.

Hedge row or double hedge row planting:
The hedge row system is based on narrow spacing between palms in the row, and large spacing between rows. The double hedge row system is based on alternation of a narrow spacing between two rows with a very wide spacing. All dead leaves and other organic debris can be collected within the row, and the inter-row be kept clean for cultivation. The narrower the spacing in the row, the more the palms will tend to bend outwards, reducing the effect of wide inter-row spacing. With a hedge system, intercropping is possible during the entire life-time of the palms, with a reduction of space when the palms are young, and low leaves may hamper cultivation of other crops close to the palm. The system to be chosen depends very much on the crop(s) planned for intercropping.

8.1.6 Green manuring, Organic Manuring & Chemical Fertilizer application

There are 3 different ways of improving nutrient availability in the soil:

1. Green Manuring;
2. Application of Organic Manures; and
3. Application of Chemical Fertilizers.

Organic fertilizing has some advantages over chemical fertilizing, because of several reasons all of which are very important for the regulation of mineral supply to the plant:

- it involves macro- as well as micro-elements;
- it improves soil texture;
- it improves soil moisture-holding capacity;
- it improves conditions for soil micro-biological life; and
- it improves the soil's cation exchange capacity.

Therefore, the use of manure and/or compost, or just green leaves cut off from some source outside the coconut grove, should always be given preference.

Green Manuring

The same crops are frequently used for cover crops and green manuring. Cover crops are a cultural practice to reduce weed growth and evaporation from the soil. Green manures, which have the ability to fix nitrogen in symbiosis with soil micro-organisms will mainly add nitrogen to the soil in addition to the organic matter.

- In an experiment conducted in Ivory Coast by in soil where nitrogen was the essential production factor, yields in all plots declined after N fertilizer treatments were discontinued, except in plots covered with legume cover crops. The N-content of the soils where leguminous cover crops were planted was much higher than in other plots.
- In some soils, *Rhizobium*-inoculation and seed pelleting can enhance the nodulation and N fixation of green manures.
- When pelleting was done on *Rhizobium* inoculated seeds sown in an acidic coconut soil, significantly more response in nodulation behaviour, dry matter yield and nitrogen concentration was observed. The difference in response due to the use of different pelleting materials (rock phosphate, calcium carbonate, charcoal, and dolomite) was not significant.
- If the legumes produce edible products, such as beans and pods, harvesting these products will also remove that part of the nitrogen used by the plant to produce these beans and pods.

- Legumes have very deep roots by which they can take up minerals that have already leached to depths below the dense root zone of coconut palms. These minerals will be returned to the topsoil when the green manure is incorporated into the soil. However, this cannot be regarded as additional fertilizer. It is rather a recycling of minerals that otherwise would have been leached out and lost.
- Often, soils are so poor that green manures also grow very slowly, and are barely beneficial. In such a case, the growth of the green manure crops could be improved by applying chemical fertilizers. The coconuts would benefit from the fertilizers.
- In plantations with poor soils it can often be observed that green manure crops grow much better in places where some organic debris has been burned before planting the legume.
- Alternate growing of green manures and annual intercrops, using chemical fertilizers, may be an effective system of maintaining soil fertility.
- The dense mass of vegetation, especially where a mixture with winding cover crops are planted can hinder movement in the plantation and hamper nut collection. A simple device to manage this vegetation is a low-cost roller that can be made at village level. It consists of a rounded tree trunk of 50 cm diameter and 1 m in length, in which six lengthwise saw cuts have been made at regular spacing. Steel blades are inserted into these cuts. The roller can be drawn by a pair of oxen. The capacity of the rolling equipment is about 0.8-0.9 ha per day, without exhausting the animals or the operator. Such a roller crushes the cover crop without cutting and uprooting it; the cover crop is not incorporated into the soil but functions as a mulch on top of the soil. The use of disk harrows could affect the re-growth of the cover crop. A similar roller without the steel blades has been found to be equally effective.

(Fernando, 1989; Pomier and Taffin, 1982)

Organic Manuring

When fertilizing with organic material, recycling of plantation material is the most obvious choice. This includes husk, coir pith, leaves and stem.

Recycling Husk

- The husks have a high mineral content, 50 husks contain about 0.5 kg potash equal to about 1 kg muriate of potash. Husks may represent the equivalent of 200 to 300 kg KCl per ha per yr. This should be taken into consideration when calculating the profitability of alternative industrial uses of husks (fibres, energy).
- Husks can absorb and retain about six times their own dry weight of water.
- It takes about 3-4 years for husks to decompose.
- Dehusking the coconuts and leaving the husks in the field are generally recommended practices.
- Husks can be placed around the palm as a mulch, but they can also be buried. When buried, they will improve soil conditions, and the soil water holding capacity will be increased. Husks should be placed with their convex side upwards, in circles around the stem of the palm.
- Inoculation with the cellulolytic fungus *Trichoderma* has been found to accelerate the decomposition of husks. Two months after treated and untreated husks were buried in the soil, distinct areas of decomposition in the treated husks were noted where fibres were reduced to tiny pieces. The original soil K content was 190 ppm. After two months, soil with untreated husks and soil with treated husks contained 517-593 ppm and 700-747 ppm extractable K respectively.
- Leaving the husks in the field may attract termites.

(Liyanage, 1987; Nunez et al, 1991)

Coir Pith or Coir Dust

- Coir pith is an excellent product to be returned to the soil, either as a mulch or as an organic fertilizer. Due to its fibrous and loose nature, incorporation of coir pith into the soil improves the physical properties and water- holding capacity of the soil considerably.
- The word 'coir' is derived from 'kayar' in the Malayan language.
- Coir Pith represents about 45% of the coconut husk. It contains about 25-30% lignin and 33% cellulose.
- Coir Pith can absorb and retain about ten times its own dry weight of water.
- A great variation of C:N ratios have been reported, ranging from 58:1 to 112:1.
- The quality of coir pith depends on the fibre extraction process. Coir pith obtained after mechanical fibre extraction is richer in nutrients compared to coir pith obtained after retting, as it loses much of its original mineral content during this wet process.
- The coir pith obtained from the fully mature and older nuts contains a higher amount of lignin and cellulose and fewer water-soluble salts compared to younger nuts.
- Use of coir pith as mulch or organic fertilizer will solve an environmental problem near processing centres where large numbers of coconut are husked. The huge amounts of coir pith dumped as waste ooze tannins during the rainy season. Sometimes the pith is set on fire, but it burns very slowly, due to its high moisture content.
- Coir pith can be applied as a mulch, used as litter (after drying) in stables or poultry pens before applying it to the soil, or applied directly to the soil. Using coir pith as a litter will enrich the material with minerals and reduce the C:N ratio, improving its quality as a manure.
- In a trial conducted in India, a coir pith mulch, 10 cm thick around seedlings resulted in a higher seedling survival and higher soil moisture content than other treatments, such as mulching with rice husk or black polythene, and earthen pitch and pot watering at a rate of 10 per week.
- Decomposition of coir pith uses soil nitrogen, and this may result in temporary nitrogen deficiency of the palm. Reduction of the C:N ratio (e.g. by using as litter) before applying the coir pith to the soil is recommended. Results of laboratory experiments on the effect of blending retted coir dust with fertilizers suggest a nitrification inhibition property of coir dust, and indicate the usefulness of blending urea with coir dust for controlled and gradual release of urea nitrogen. This finding is important for soils prone to heavy leaching losses, where controlled release of N can be achieved in the root zone of perennial crops.
- After treating 1 ton of coir pith with an edible basidiomycetous fungus (*Pleurotus sajor-caju*) and 5 kg urea, and keeping the mixture as a heap to decompose in an open yard for 30 days, it was observed that: (a) lignin content dropped from 30% to 4.8%; (b) cellulose content reduced from 26.5% to 10.1%; and (c) C:N ratio went down from 112:1 to 24:1, which is comparable to farmyard manure and compost when applied to the soil.
- For composting coir pith, an area of 3x5 m is required in a shady place. About 100 kg of coir pith is spread out in a 2 cm thick layer over which one bottle of spawn (300 g) of *Pleurotus sajor-caju* is uniformly spread. Then the layer is covered with another 2 cm thick layer of coir pith, over which 1 kg of urea is uniformly spread. This process can be repeated until the heap reaches a height of about 1 metre. For each ton of coir, 5 kg of urea and 5 spawn bottles are required. The moisture content in the heap is maintained at about 200% by sprinkling.
- In a trial conducted in the Philippines with several fungi, including *Pleurotus sajor-caju*, it was observed that *Phanerochaete chrysosporium* UPCC 4003 was the most effective fungus for degrading the lignocellulose components of coir dust at optimum conditions. However, the degradation process was carried on with minimal nitrogen concentration.

- *Trichoderma sp* is among the native microflora observed in the raw coir pith. An additional advantage associated with *Trichoderma sp.* is its ability as a biocontrol agent of soil borne fungal diseases, such as *Ganoderma*, the causal agent of Basal Stem Rot.
- Stable manure adds nutrients to the soil, but if it is produced from vegetation growing under the coconut palms only, it does not add anything new to the soil; rather it is a system of recycling nutrient elements in an organic form. Minerals taken up by animal bodies are lost to the land; nitrogen that may evaporate during production and application of stable manure is also lost to the land.
- Waste materials can sometimes be obtained from agro-industries, such as rice bran, straw, or the residue from beer breweries. Such materials, if available at a reasonable price, can be composted in the plantation, or spread out in stables, to be mixed with the animal excrement.

(Savithri and Khan, 1994; Uthaiah *et al*., 1989; Uyenco and Ochoa, 1984)

CPCRI recommends a slightly different method for composting coir pith to Indian farmers:

- Large scale composting of coir pith can be done either by the heap method in a shaded place or in cement tanks.
- Coir pith obtained from coir processing units are treated with lime (0.5%), urea (0.5%), rock phosphate (0.5%) and legume biomass *(Glyricidia* leaves) or cowdung or compost from previous batch (10%) and moistened.
- The treated coir pith is sprayed with 1 % jaggery solution and mixed with fungal inoculum at 0.2% level, 15 days after the amendment.
- Regular watering is done to keep the heap moist.
- The raw coir pith with a C:N ratio of 108: 1 would turn into compost having a C:N ratio 15:1 and high microbial population within a period of 40-50 days.
- *Marasmiellus troyanus,* an efficient producer of Iigninolytic and cellulolytic enzymes, isolated from decomposing coconut waste has been found to be effective in composting of coir pith. A local isolate of *Tn'choderma* species was also effective to compost coir pith.
- Microbial enrichment with nitrogen fixing bacteria and phosphate solubilisers enables production of good quality compost with better manurial value.

For composting coir pith using earthworms, the CPCRI recommendations are:

- Coir pith is treated with lime and rock phosphate @ 0.5% each and incubated for three weeks.
- It is then mixed with cow dung @10%, fresh vermicompost @10%.
- This mixture is layered with uncut coconut leaves @20% to facilitate aeration in the bed.
- The earthworm *Eudrilus* spp. is introduced at the rate of 1000 numbers/ tonne of organic materials.
- The bed should be mulched and protected from direct sun light.
- Moisture level is to be maintained at 50% by regular irrigation.
- Earthworms form burrows in the bed and vermicastings appear as surface casts.
- A granular vermicompost with 1.2% nitrogen and C:N ratio of 16.7:1 can be obtained in two months.

In an experiment carried out by CPCRI on substitution of chemical fertilizers by composted coir pith in coconut, the treatment NPK (50%) + composted coir pith (50%) gave the highest yield of 104 nuts /palm /year followed by the treatment 100% NPK as inorganic fertilizer (82 nuts/palm/year). The lowest yield of 66 nuts/palm/year was recorded in the control. Foliar analysis for N, P and K did not show significant differences. Organic carbon content of soil at 0-25 cm depth was found to be the highest in the treatment, 50% composted coir pith + 50%

NPK. Available K content in the soil at 0-25 cm depth differed significantly and chemical fertilizer recorded significantly higher average K. The highest net returns of Rs. 18,124 /ha was obtained in the treatment NPK (50%) + composted coir pith (50%).
(Rajagopal and Arulraj, 2003)

Vermicomposting of Coconut Palm Wastes

Ligno-cellulosic materials like coconut palm wastes decompose rather slowly, and vermicomposting is a good technique to convert them to a form that can be utilized by the coconut palm more quickly. Vermicomposting is a process of composting organic matter using earthworms, and the end product is known as vermicompost. The main steps involved in vermicomposting are:

1) multiplication of earthworms,
2) preparation of base materials for vermicomposting,
3) introduction of earthworm to the base material,
4) management of vermicomposting bed,
5) separation of vermicompost from undecomposed materials.

Waste materials from coconut plantation can be converted into brown, non-odourous, granular vermicompost using earthworms. CPCRI in India has isolated a local earthworm closely related to the African night crawler (*Eudrilus* sp.) that has been found to be effective in vermicomposting of coconut palm wastes.

- *Eudrilus* sp. can be multiplied in a mixture of cow dung and decayed leaves in 1:1 ratio taken in cement tub, wooden box or plastic bucket with drainage facilities.
- Worms should be introduced at the rate of 50 numbers per 10 kg of organic wastes.
- Within 2-3 months, the earthworm multiplies 300 times, which can be used for large scale composting.

Organic wastes weathered in rains for 3-4 months can be directly used for vermicomposting.

- Composting can be done in pits of convenient size, with depth less than 1 metre dug in coconut plantation or in cement tanks.
- Cow dung may be added to the wastes at the rate of 10% by weight and the heap should be watered and allowed to undergo preliminary decomposition for 1-2 weeks.
- Then earthworms may be added at the rate of 1 kg per tonne of organic wastes.
- The bed should be mulched and watered regularly to maintain sufficient moisture and the composting will be over in about 70 days.
- Watering should be avoided for one week before the removal of compost. Worms will move to deeper moist area and compost can be collected, sieved and dried.
- The recovery of compost could be as high as 70%. The waste material can be converted into brown, non-odourous, granular vermicastings.
- From one hectare coconut garden, one could get 4,000 kg of vermicompost from leaves alone.
- The final product will contain 1.2-1.8% Nitrogen, 0.1-0.2% Phosphorous and 0.20.4% Potassium.
- The management of vermicomposting requires regular watering to keep the bed moist. Direct sunlight is harmful to worms and the bed should be mulched with dry grasses or moist gunny bags.
- It takes nearly 60 days to compost most of the materials. Harvesting of vermicompost requires separation of worms (adult and juveniles) and cocoons by sieving from the compost. The granular vermicastings so obtained can be dried and stored for field application.

(Rajagopal and Arulraj, 2003)

Other Organic Materials

Organic material for the manuring of coconut can also be obtained by interplanting coconut with other trees or shrubs that can be pruned regularly.

- In a mixed cropping trial in Sri Lanka, *Gliricidia sepium* and *Leucaena leucocephala* were planted in double rows in the coconut avenues at a spacing of 2 x 0.9 m. They yielded 7-10 tons and 12-16 tons of green matter per ha respectively and 14-20 t per ha of fresh firewood during the first and second years Harvesting started one year after planting the trees by lopping the plants at one metre above the ground at 3-month-intervals.
- In some countries, coconuts are manured with leaves and branches of other trees growing outside the plantation. This is possible only on very small holdings, as the practice is labour intensive. For large plantations it may be very difficult to obtain sufficient quantities of such material from outside the plantation.
- Experiments in India investigated organic material fertilizing in combination with a system of root rejuvenation. A trench was opened 30 cm from the bole, forming one-quarter of a circle. This trench was filled with organic material and covered with soil to prevent the breeding of rhinoceros beetles. After two years another quarter of the circle was filled, etc. This method induces new root formation from the bole. In these experiments using 30 kg of *Gliricidia* or *Leucaena* leaves to fill the trenches, after two years of treatment nut yield increases of 15-20 nuts per palm per year to 50-60 nuts per palm per year were observed after 2 years of treatment.

(Gunasekera, 1989; Liyange and Wijeratne, 1987)

Chemical Fertilisers

- Most cultivated lands need regular supplies of mineral nutrients, especially after having been cultivated for some time.
- When planting or replanting coconut on land previously cultivated, fertilizer application to the seedlings is very important to guarantee good development of the bole, which is very important for the productivity of the tree, as it increases the rooting surface.
- With good nutrition, the stem will also attain its maximum width. Nutrient deficiencies at a later stage may cause a narrowing of the stem, which may decrease the palm's productivity. Fertilizing after such a period may again allow the stem to attain its original width, but not in the narrow section, as the stem has no cambium. Such narrow stem sections may also be caused by drought and other unfavourable growing conditions, and show something of the palm's history.
- Adequate fertilizing of young palms lowers the pre-bearing age. Depending on soil conditions, adequately fertilized young palms may start bearing one or more years earlier than palms growing without fertilizers.
- High-yielding cultivars need more mineral nutrients for the production of a greater number of nuts than low-yielding palms. On the other hand, high-yielding varieties can also respond much more strongly to fertilizer application. Results of a fertilizer experiment in Thailand suggested that, in the absence of fertilizer, hybrids did as badly as local varieties, but no worse.
- When recommending fertilizer application, it should be verified whether the planting material is of adequate quality and not too old and senile to respond economically to fertilizer application. Where this is doubtful, improvement might better be achieved through renovation of the plantation and building up soil fertility with fertilizers and green manures.

- When deficiency symptoms become visible, the palms may have suffered from a shortage for a long time and the plantation has been producing at sub-optimal level. Monitoring of mineral contents in the palm is therefore imperative for good management.

The three main systems used to determine fertilizer needs are leaf analysis, soil analysis and fertilizer experiments.

- Leaf analysis is a rather accurate system to determine the nutritional situation of the plant.
- Soil analysis not only determines the soil availability of certain nutrients, but it also provides information on other chemical soil characteristics, such as pH and nutrient fixation. Also other soil characteristics, such as cation exchange capacity, texture and depth, may all be important to determine the system of fertilizer application and the doses to be used.
- Fertilizer experiments provide the final answer of plant reaction to certain fertilizer applications, the influence on the nutrient levels in leaves, the interactions between the various nutrients, and the potential yield responses within local ecological conditions. Fertilizer experiments also give information on costs and on the most economic level of fertilizer use.

The most widely used system for leaf analysis is the one developed by IRHO:

- The best time for sampling is at the start of the dry season. After rainfall, at least 36 hours should pass before sampling, as nutrients may have leached from the leaves.
- Sampled trees may be marked, to be sampled again later to investigate the results of treatments applied on the basis of sampling results.
- As leaves of different ages have varying mineral contents, only one leaf position is used. For young seedlings, leaf no. 4 is used; as soon as it is available, leaf no. 9 is used for somewhat older palms and for fully grown palms leaf no 14 is used.
- The position of the corresponding spathe indicates the turning direction of the leaf spiral. If its position is slightly to the left of the leaf, the spiral turns left, if it is on the right, the spiral turns right. Leaf no. 1 is the youngest leaf just detached from the central spear. Usually, leaf no. 9 supports the largest unopened spathe and leaf no. 14 generally supports an inflorescence with nuts the size of a fist.
- Without cutting the leaf, 6 leaflets are cut, 3 on either side, from the central part of the lamina. Of each leaflet, only the central 10 cm portion is used. The edges of each leaflet (about 2 mm) and the central vein are removed. Of each leaflet fragment, one side is used for analysis, the other is kept as a duplicate.
- The leaflets are cleaned with cotton wool and distilled water, then carefully dried. Duplicates are wrapped and stored in a dry place.
- Samples should be adequately labelled, giving all necessary information on date, site, and conditions, as well as on the condition of the plot at the time of sampling.
- After labelling, the samples are dried in an oven at 70-80°C for about 10 hours. Where no oven is available, a 250 W electric bulb can be used for drying. The sample batches can be sent in sealed plastic bags to the laboratory for analysis.
- The sample covers 25-30 trees. For large areas, one sample is used for every 50 or 100 ha, and a system is often used to facilitate follow-up work. In smallholder areas, one sample is taken per holding, and the trees are randomly selected. Abnormal trees should be excluded.

CPCRI recommendations

For the west coast of India where planting is done just before the monsoon rains which fall mainly during July and August, CPCRI recommendations to farmers for fertilizer application are:

- One-tenth of the adult palm dosage of nutrients should be applied after three months, one third after two years of growth, two thirds after three years and full dosage from fourth year onwards (Table).

Table 16 CPCRI recommendations for Chemical Fertiliser application

Fertilizer application is	May-June			September-October		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
First year	–	–	–	50	40	135
Second year	50	40	135	110	80	270
Third year	110	80	270	220	160	540
Fourth year onwards	170	120	400	330	200	800

- General requirement of fertilizer elements for palms yielding an average of 50 nuts/ palm/ year is 500 g N, 320 g PP5 and 1200 g Kp palm/year.
- In acid soils the nutrients should be applied in the form of urea, rock phosphate and muriate of potash, whereas in alkaline soils urea, single super phosphate and muriate of potash should be applied.
- Adequate quantity of bulky organic manures (50 kg/ palm/year) should also be applied. It provides some of the micronutrients needed by the palms and also improves the soil physical conditions including water holding capacity.
- Boron deficiency causes characteristic malformation of leaves like hook leaves, nut cracking, drying of the female flowers etc. Soil application of Borax @ 50 g/palm twice at monthly intervals after the appearance of the first symptom corrects the deficiency. In root (wilt) disease affected areas, apply Borax @ 300 g /seedling and Borax @ 500 g /adult palm.
- Application of Magnesium @ 500 g MgO per palm is advantageous for the management of root (wilt) diseased palms to restore palm vigour and sustain the productivity.
- Hybrid palms do not require higher N, P and K inputs for higher productivity as compared to Tall cultivars.
- Soils with 1 % organic carbon status is ideal for coconut cultivation.
- 70 to 80 ppm of mineralizable nitrogen in soil and 10 to 12 ppm Bray extractable 'P' can sustain sufficient levels in coconut.
- If soil available P is less than 10 ppm, full recommended dose of 320 g P_2O_5 /palm/ year may be applied and for a soil test value of 10 to 20 ppm, 50 per cent of the same may be applied. For soil test values of more than 20 ppm, P application can be skipped.
- The content of a certain element in Leaf 14, below which the application of this element as a fertilizer may result in an economical yield improvement, is called the critical level of this element. Critical levels for coconut are:

  N - 1 .7 - 1 .8 %
  P - 0.11-0.12 %
  K - 0.8 - 1 .0 %
  Ca - 0.3 %
  Mg - 0.2 %

- The results of the experiments under taken in the All India Coordinated Research Project on Palms indicated that high yielding coconut varieties and hybrids have responded well to the integrated nutrient management practices.

Higher pressure on land might become beneficial to coconut production when intercrops are incorporated into the Coconut Based Farming System (CBFS) and when these intercrops are fertilized. In an intercropping trial conducted in the Philippines, coconut production increased more than twofold within a period of 7 years. A substantial increase was observed in coconut production, especially in the last years of the experiment, which was attributed to the impact of improved cultivation and more absorption of nutrients from the soil. (Ditablan and Astete, 1986)

8.2 Drying methods of copra & storage

8.2.1 Basic Principles of Coconut Drying

Drying is a process for reducing the moisture content of materials by bringing the water to the surface and evaporating it. Even under ambient conditions, evaporation will take place as long as the actual moisture content of the product is above its equilibrium moisture content (EMC). The EMC depends on the properties of the product and ambient air characteristics such as temperature, humidity and pressure. Once the moisture content of the product reaches the EMC, it will not lose any more moisture to the ambient air and its weight will not change anymore. Products whose moisture content is lower than the EMC will absorb moisture from the ambient air till it has attained a moisture content equal to its EMC. Under prevailing weather conditions in the coconut growing areas in the tropics EMC for copra is generally around 6% to 7%. This means that drying down to a lower moisture content is wasting time and money, since copra will absorb water until the EMC is reached.

The rate of drying depends mainly on the temperature and humidity of the drying air. Drying starts with the evaporation of surface water followed by the diffusion of moisture from inner layers towards the surface. As long as the moisture migration is higher than the evaporation on the surface, the rate of drying will remain constant. Higher drying air temperatures will increase the rate of drying, but the highest drying air temperature that can be used is restricted by the quality requirements on the product. Humidity, temperature and ambient pressure define the water holding capacity of air. Table 1 shows the effect of changes in temperature and humidity on the water holding capacity of air in a tropical country. The drying air pressure can be considered constant at 1 bar for the drying of coconuts in natural draught driers.

Table 17 Water holding capacity of air in a tropical country

Temperature (°C)	Relative Humidity (%)	Maximum Water Absorbtion (g /kg dry air)	Δx (g /kg dry air)
30	80	22.9	1.0
40	46	26.4	4.5
50	29	29.6	7.7
60	17.5	32.9	11.0
70	10.9	36.2	14.3
80	6.5	39.6	17.7
90	4.1	43.6	21.7
100	3.0	46.4	24.5

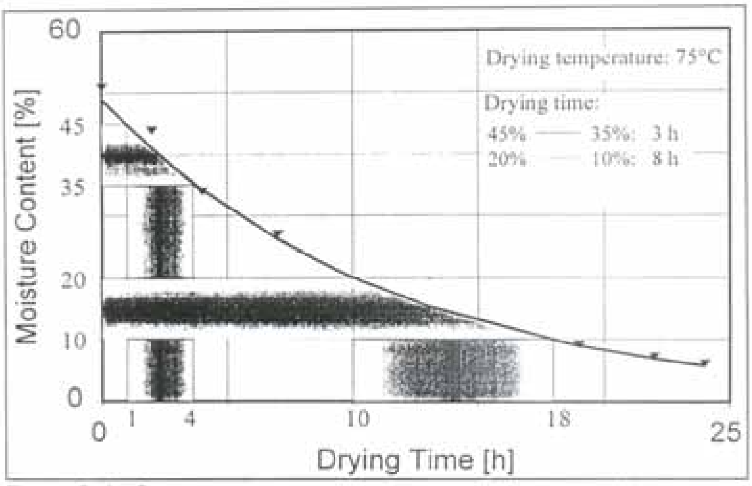
Note: For tropical country x = 21.9 g /kg dry air at 30°C and 80% RH

Source: Dippon and Villaruel, 1996

The rate of drying at a given temperature and humidity is fastest immediately after splitting the coconuts. The lower the moisture content the more difficult it gets to further dry down.

Figure 18 shows a drying curve (time is plotted against moisture content) for coconut meat at a drying temperature of 95°C. In this case 2.5 hours are needed to bring down the moisture content from 45% to 35% (a decrease in moisture content of 10%). On the other hand, to dry the coconut meat from 20% moisture down to 10% (again a decrease of 10%), 8.5 hours are needed which is more than three times longer. Coconut growers therefore prefer to dry down to a moisture content that is acceptable to the buyer even if a price deduction is applied for high moisture content.

Figure 16 Drying Curve



Source: Dippon and Villaruel, 1996

Evaporation has to be followed by the removal of the moisture from the coconut kernel. This requires a certain air velocity to transport the evaporated water to the outside. The most important factors affecting the performance of a coconut dryer are:

- properties of the product (size. age. initial moisture content. etc.)
- drying management (nuts arrangement. pile height. time lag from splitting to start of drying)
- physical properties of the drying air (humidity. temperature and velocity)

Size. age and initial moisture content all vary. The average diameter of nuts of different varieties may vary from 10 to 20 cm. The higher the difference in diameter in a batch, the higher the percentage of overlapped nuts, which results in a higher percentage of wet copra. Young nuts (less than 11 months old) are more difficult to dry than older mature nuts (13 to 14 months old). If the nuts are not properly drained after splitting and/or if splitting and loading are done on a rainy day, more water has to be evaporated. In this case the drying time has to *be extended and this results in a lower efficiency.

The general practice is to arrange the nuts in a dryer with the first (lowest) layer facing up and all other layers facing down. However, drying trials in the Phillipines have shown that the arrangement of the nuts does not significantly affect the quality of copra produced. Arranging nuts requires an additional four hours per 2000 nuts.

Loading should be done immediately after splitting the nuts and draining the water off. Drying trials have shown a slight discoloration of nuts loaded more than four hours after splitting. The more drying is delayed the higher the percentage of discoloration.

The higher the pile of coconuts loaded, the more difficult it is for the drying air to pass through the nuts. This will be result in the bottom layer getting over-dried while the top layer still has a high moisture content. This is usually taken care of by shuffling the layers once during the drying process – the top layer is placed at the bottom, and the bottom layer is taken to the top. Recommendations for the optimum bed height vary from 20 - 50 cm.

Similarly, a wide range of temperatures have been recommended by various researchers, from 35°C to over 90°C. Quite often, a two stage drying process is recommended. A high temperature initial stage is followed by a period of lower temperature. The first stage could be for 8 – 16 hours followed by the next phase until a final moisture content of 8 to 10 % is reached. Pile heights, temperatures and time periods for the stages of drying are given for the different types of dryers in the following sections.

Average air flow rates in natural draught dryers are below 1.0 m/s. For higher air velocities additional blowers (or ventilators) are necessary and this has been done for research experiments, but the initial and operating costs of blowers cannot be justified for copra driers used by smallholders.

8.2.2 Types of Dryers

Since copra is considered as a low value product, it is not economically viable to use sophisticated dryers, or even the use of blowers for a more constant airflow. Therefore, for making copra, natural draft dryers are used. Common methods of drying can be classified as:

3) Using Heat from the Sun
    c) Sun drying
    d) Solar drying

4) Using Heat from burning Biomass
    c) Kiln drying using Smoke
        - Direct drying
        - Semi-direct drying
    d) Indirect drying using Hot-air

The sun is the source of energy for both sun drying and solar drying. The drying methods vary from that which is considered primitive and traditional to one that adheres to certain scientific principles of drying. A Solar dryer is a structure (very simple to highly sophisticated) that is used to trap the sun's heat and thereby enhance the effect of solar radiation.

Heated dryers usually burn coconut shells and husk:

- *Direct Dryers*: Fuel is burnt under the copra and combustion gases come in contact with the coconut meat by rising up through the copra bed.
- *Semi-direct Dryers:* Fuel is burnt to the side of the pile of coconut meat and the combustion gases are sent through a tunnel to the space below the drying chamber to rise up through the copra.
- *Indirect Dryers*: Combustion gases are sent through a heat exchanger that heats up ambient air, and the hot air dries the coconut meat.

Sun Drying

When copra is spread out under direct sunlight for drying, it is called *Sun Drying*. If the weather is right then sun drying can produce good quality copra.

- This method is used only during the dry season and when drying only small quantities of nuts.
- Sun drying copra is the simplest and cheapest method available. Overall drying cost is very low compared to other copra drying methods that use biomass fuelled dryers.
- It requires up to 5 consecutive days of sunshine and a moderately humid atmosphere (60 - 80% relative humidity) to facilitate evaporation of moisture.
- Excellent quality copra is made under good conditions which exist in certain parts of the world, such as Allepey in Kerala State in India, and Cebu in the Philippines.
- Sun drying is capable of producing clean, white and edible copra, and such copra usually commands a premium price locally and is a superior quality export product.
- Unfortunately, most sun-dried copra is produced under unfavourable conditions, where intermittent rains or very humid air produce badly deteriorated copra.
- Fuel saved is additional farm income when it is sold or transformed into high value products like coconut shell charcoal, activated carbon, coir, etc.

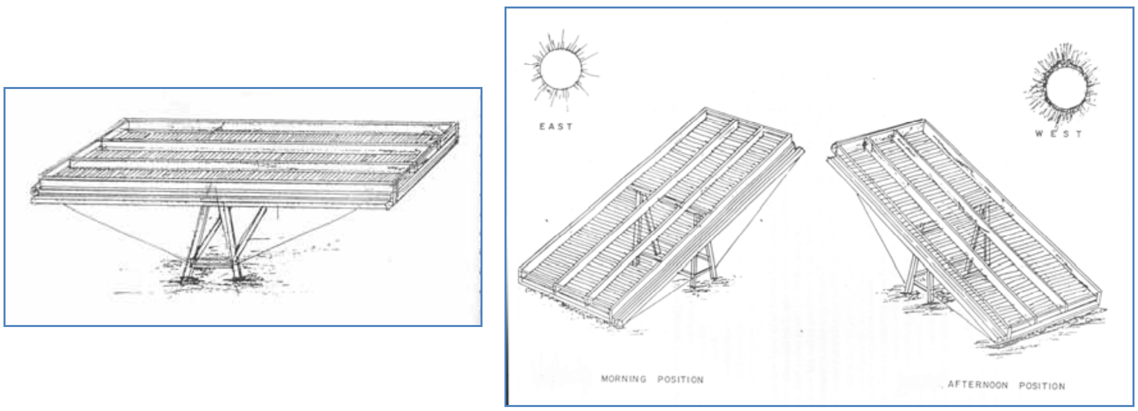
Photo 23 **Sun drying copra**

Source: Foale, 2003

See Saw Drier

The see-saw drier is an improved method of sun drying that was conceptualized at the Institute for Tropical Agricultural Products Technology and Industrialization of Abidjan, Ivory Coast. The design was further improved in Ghana where it was introduced to dry leafy vegetables, root crops, fruits and spices. In 1975-76, this dryer was tested to dry coconut meat at the Philippine Coconut Authority - Davao Research Center, Bago-Oshiro, Davao City. Tests showed that see-saw produced copra has no significant difference on the duration of drying time as well as in the level of moisture content compared to traditional sundrying. Nonetheless, advantages in the use of the dryer are the labor requirement reduction in copra handling during the drying process and the production of clean copra which is free from dust and dirt contamination. Since the copra is covered with a plastic sheet, it is much better than open sun drying on days when it is partly clear and sunny, but with intermittent showers.

Figure 17 The See-Saw Drier



(a) Horizontal Loading Position	(b) Morning and Afternoon Positions

Source: Castro and Thampan, 1996

The frame of the see-saw drier is mounted freely on the trestle on its transverse centerline, to give a "seesaw" action.

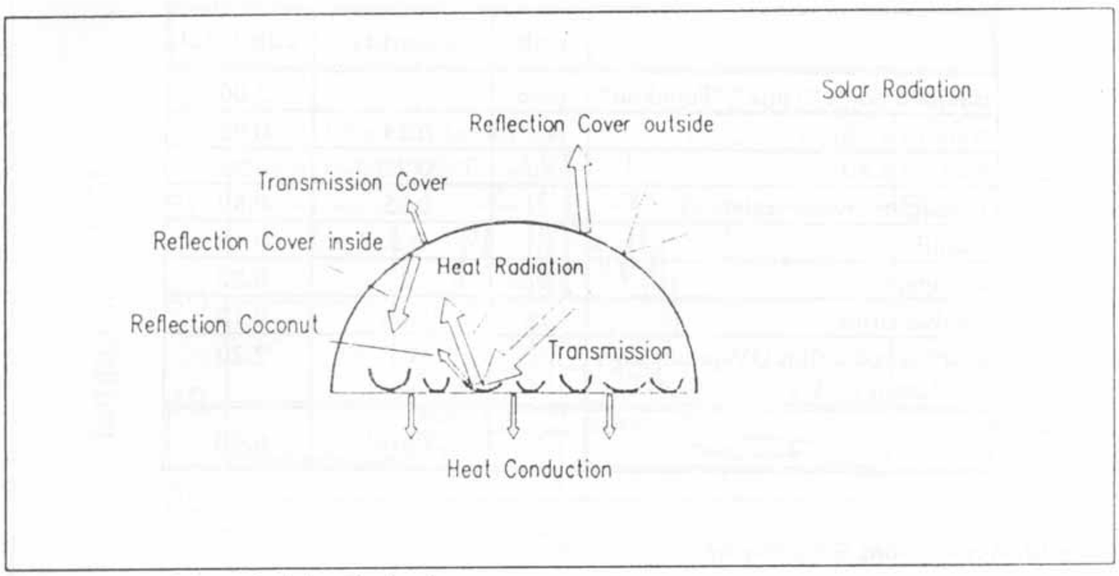
- Heat absorbing bands are provided at each and across the center of the frame, transverse retaining bars demarcating the areas between them. These bands and all other internal parts are coated with a durable matt black paint.
- Produce to be dried is loaded up to the retaining bars on each channel of the rack, between the bands, leaving clearance under the blind to permit air flow.
- The loading is done in the horizontal position shown in Figure 20a.
- The cover is stretched over the top of the frame. It consists of a transparent sheet of plastic materials in the form of a blind, which provides a substantial screening effect against ultra-violet light thus, reducing photo-oxidation.
- Air flows from one end to the other through gap at each end of the frame.
- The loaded frame is fixed in a position to face the sun on the East in the morning and in the West in the afternoon (Figure 20b). To maximise the collection of sunlight for drying, the frame position can be adjusted once every 3 hours to follow the sun.

Solar Drying

Principle of Solar dryers

Solar dryers make use of the "*greenhouse effect*" in which solar heat is trapped inside a transparent enclosure. The energy flows in a solar dryer is shown in Figure 21. Solar dryers can generate higher air temperatures at a lower relative humidity, than sundrying, thereby improving the drying rates and enabling lower final moisture contents. In addition, the negative effects of rainfall, insects, dust and molds on the quality of copra produced by sun drying can be minimized.

Figure 18 Energy Flows in a Solar Dryer



Source: Dippon and Villaruel, 1996

Development of a Solar Dryer

In the early 1990s, the "Philippine German Coconut Project" studied and tested the existing coconut dryers and came up with several innovative dryer designs for small-scale and medium-scale coconut farms. Based on the output of about 80 drying trials on different dryers as well as additional information from farmers meetings, visits of farmers to the project and personal experience, the project drew up the main criteria for what an ideal coconut dryer should be:

1. Durability: lifespan of the essential dryer components should be at least five years;
2. Ease of Operation;
3. Costs: the total costs should not be higher than any alternative indirect dryer;
4. Ease of Construction: construction should not require any special tools;
5. Working Performance: minimum requirements were:
    - not more than two drying days
    - less than 10% final moisture content and uniform dried
    - less than 20 ppb aflatoxin content
    - fuel usage lower than 90% of the husks of nuts loaded

To meet these criteria and performance requirements, two dryers were designed, developed and tested:

(a) A Solar Dryer to cater to the drying needs of individual coconut farmers owning 2 to 5 ha of land producing 10,000 to 25,000 nuts/year;

(b) An Indirect Dryer called the "COCOPUGON" for coconut growing cooperatives and/or bigger plantations having around 40 ha of coconuts producing around 200,000 coconuts/year. The indirect dryer type was chosen because of the disadvantages of direct dryers like soot (PAH) contamination and scorched copra.

In the development of a solar dryer the main aims were to:

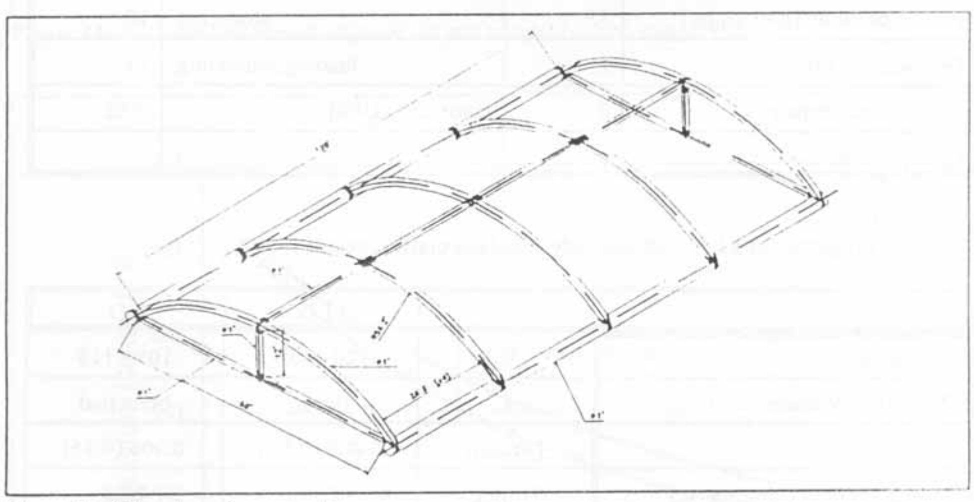
1. Provide the small coconut farmer an alternative to sun drying at the lowest cost possible;
2. Utilise locally available materials;
3. Keep the labor requirement for coconut drying lesser than sun drying; and
4. Make the dryer small and transportable, preferably operable by one man.

At the start of the project the effectiveness of solar dryers was established. Based on the findings of these initial trials, several designs using different materials were built, tested and analyzed. The prices of the designs based on different materials were:

1.	Bamboo	0.75 US$ per square meter
2.	Rattan / Bamboo	1.8 US$ /square meter
3.	Rattan	2.3 US$ /square meter
4.	Water pipe	6.9 US$ /square meter

Since the results were quite similar, the main criterion for selecting the best dryer was minimum cost, and therefore the bamboo based design was chosen. The bamboo type solar dryer is shown in Figure22 , and a complete list of materials is given in Table14. The main parts are the bamboo frame and the plastic sheet. At a length of 3 m and a width of 1.75 m, an area of about 5.25 m^2 is covered, and this is enough to dry 200 - 250 nuts per batch.

Figure 19 Solar Dryer designed by the Philippine German Coconut Project



Source: Dippon and Villaruel, 1996

Farmers can easily make their own dryers since bamboo poles are available in most tropical areas where coconuts are grown. The only other materials required are a hand saw, nails or wood glue, and the plastic sheet for the construction.

Table 18 Materials required for construction of a Solar Dryer

Material	Unit	Quantity	Cost (US$)
Bamboo poles "Tinik","Tunukon"	pole	2	2.00
Nails (3 x 65)	kg	0.25	0.25
Nails (3 x 80)	kg	0.25	0.25
Wood glue (water resistant)	litre	0.25	0.80
Gasoline	litre	0.5	0.18
Sandpaper	piece	2	0.80
Canvas strips	m^2	0.04	0.12
LDPE-plastic film UV-protected (0.125mm x 55")	m^2	5.7	2.20
		Total	6.60

Source: Dippon and Villaruel, 1996

The plastic sheet is the most essential part of the dryer, so it requires careful selection. In general the following standards for plastic sheets used as cover in solar dryers should be followed:

1. Life span: minimum two years (UV-protection needed)
2. Gauge: min. 0.004 (0.10 mm)
3. Width: min. 50" (tube type)
4. Transparency: min. 80 %
5. Price: less than 1 US S per m^2.
6. Ecologically friendly

Since PVC (Poly Vinyl Chloride) is expensive and not environment friendly (softing agents and dioxin are emitted when disposed), PE (Poly-Ethylene) was chosen because of its low price and availability throughout the country. Others like PTFE (Poly-Tetra-Flouro-Ethylene) would give the best optical and mechanical properties, but were not produced in the Philippines.

In order to get a life span of at least two years, the plastic sheet has to be UV-stabilized, meaning light stabilizers are added to prevent photo-oxidative damage. Unprotected plastic sheets will be destroyed within weeks depending on the region and level of solar radiation.

For the solar dryer a blend of LLOPE (linear low density PS) and LOPE (low density PS) at a ratio of 40: 60 was used. Mixing these two materials will result in a higher tensile strength and tear dilation. Table contains the most important properties of these two materials. The sheet was extruded in Oavao, Philippines, with the specification of a life span not less than two years.

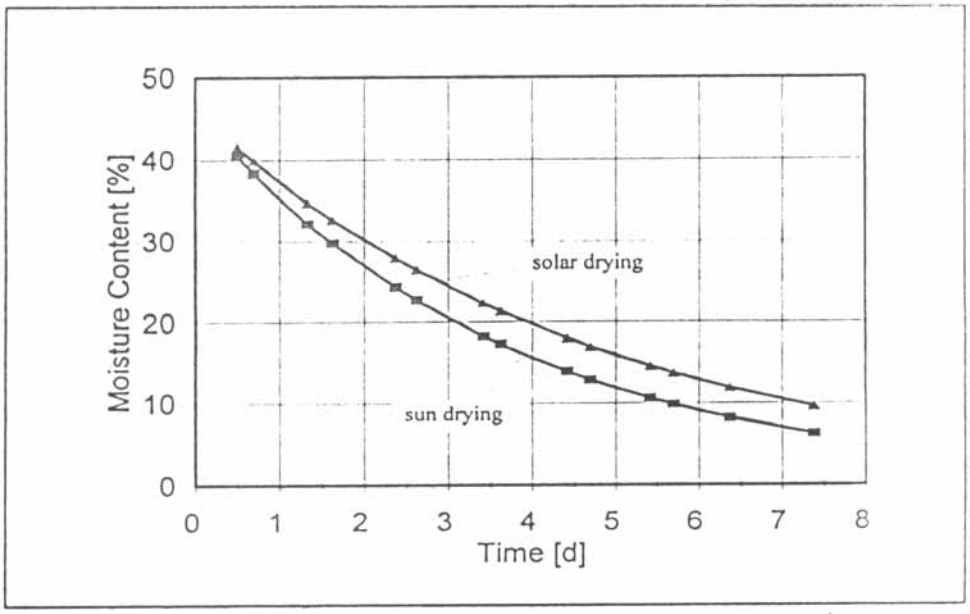
Table 19 Properties of LLD- and LD- Poly-Ethylene plastic sheets

PE-type		LLD	LD
Melting point	[^{0}C]	120 - 130	105 - I 15
Molecular structure	-	linear	branched
Gauge	[- (mm)]	0.006 (0.15)	0.006 (0.15)
Tensile strength (lengthwise)	[N/mm^2]	33. 1	22.3
Tensile strength (crosswise)	[[N/mm^2]	34.7	19.7
Tear dilation (lengthwise)	[%]	1360	510
Tear dilation (crosswise)	[%]	760	1480

Source: Dippon and Villaruel, 1996

Comparison of Sun Drying and Solar Drying

Figure 20 Drying Curves for Sun Drying and Solar Drier



Source: Dippon and Villaruel, 1996

Table 20 Assumptions for Solar Drying

Drying cycles/year	52	Working time (per 1000 nuts)	
Drying capacity [nuts/sq.m.]	33	arranging	10
Depreciation time	2	loading/unloading	15
Maintenance/repair	0	Labor cost [US$]	0.32
kg copra/nut	0.2		

Source: Dippon and Villaruel, 1996

With this sheet attached to different designs, a series of drying trials were conducted to compare sun and solar drying. Weather data (rainfall, temperature, humidity, wind speed and radiation), temperatures and humidities inside the solar dryers as well as copra quality related parameters were recorded and analyzed. The dryer is operated in such a way that after splitting. the nuts are spread on the ground and covered with the dryer. Since the dryer weighs less than 20 kgs, one worker can do the job. Once the nuts are covered. the next work that has to be done are unloading and scooping. The results are as follows:

- Compared to sun drying, a maximum temperature of up to 65 °C can be reached in the solar dryer during noon time, about 30 Kelvin more than the ambient temperature.
- However, drying time for sun dried coconuts under optimum weather conditions is slightly longer, because the uncovered coconut meat also absorbs the solar radiation, thus increasing meat temperature which in turn accelerates drying. The results show, that the difference in average meat temperature between solar and sun dried coconuts on sunny days was in the range of only 3 to 6 Kelvin.

- On average, drying time is cut down by about 2 days to 4.5 days when using solar dryers. This is the result of comparative drying trials done for about half a year. However, having three to four straight sunny days without rainfall, sun drying could be finished in almost the same time.
- The average radiation per day was measured at 5.1 kWh/m^2. Based on an average drying time of 4.5 days about 23.4 kWh/m^2 are needed to bring the moisture content down to 10%.
- Drying trials done throughout the year showed that the color of almost 50% of the solar dried coconuts were white after reaching the final moisture content of less than 10% compared to 18% of simultaneously sun dried coconuts while about 71 % were moldy.
- To obtain good quality copra, the first drying day should be sunny. This is a major disadvantage especially in the wet season.
- Under weather conditions favorable for the growth of aflatoxin producing molds, the average aflatoxin content in solar dried coconuts was 1/10th of sun dried coconuts. Former was about 10 ppb while the later resulted in aflatoxin content of more than 100 ppb.
- Solar drying will reduce the red color and TFA content by 28% and 32%, respectively.

<u>Construction and Usage of the Solar Dryer</u>

- Rattan is not as durable as bamboo. That is why only good bamboo should be used as material for the frame.
- The attachment of the plastic sheet is done with nails cushioned with canvas (tarpaulin). So far no problems were noticed except the attachment with double seamed loops where the plastic was torn apart along the seams after five to six months.
- After less than a year some of the joints made of splice rattan were broken. If bamboo is used, holes can be drilled in the poles to fit in the ends of the arc. The joints should be sealed with wood glue.
- Except grass, any surface can be used as long as the underground is slightly tilted to prevent water accumulation inside the dryer.
- Animals should be kept away from the dryers, since the plastic sheet can be easily destroyed by stepping on it.
- Front and back side have to be kept open to allow a steady air flow to remove the moisture from inside.
- The dryer should be aligned to the main wind direction to maximize air flow.
- Under the existing weather conditions at the Davao Research Center (Southern Mindanao) the theoretical water absorption capacity of this dryer is about 100 kg per day.
- Assuming a drying time of 4.5 days and a load of 100 kg coconuts (meat-shell ratio: 1.8) to be dried down from a moisture content of 50 to 10%, about 6.6 kg water has to be evaporated per day. This indicates, that even in areas with a lower air velocity the dryer can be used.

- Since the half cups are usually turned upside down in the evening or when rain is anticipated, more labor is required for sun drying.
- When placed on a clean surface or paved area, the cost for drying (Bamboo type) were determined to be US $ 0.014 per kilogram copra (as of 5/95). The assumption for this calculation are listed in table II.
- The average farm size of three hectares needs two solar dryers to dry the coconut produce annually.
- This will cost the farmer less than US$ 30.
- To maintain a good performance the plastic sheet should be cleaned occasionally and replaced every two years.
- A new sheet will cost about US$ 3 per dryer. Replacement can be easily done by the farmers themselves.
- Aside from coconuts, the dryer can also be utilized for drying other products like mango, rice etc.

Kiln Drying

There are two types of smoke dryers commonly used by coconut farmers: the direct and semidirect types. Primarily, both types have the same heating principle but differ only in design and manner of firing or charging fuel.

- The direct dryer is designed in such a way that the fire bed is directly located below the copra bed.
- On the other hand, the design of semidirect dryer is superior to the direct type. The hearth where fuel charging/feeding is done is located on one side of the dryer, connected to the drying bed by a tunnel-like flue.

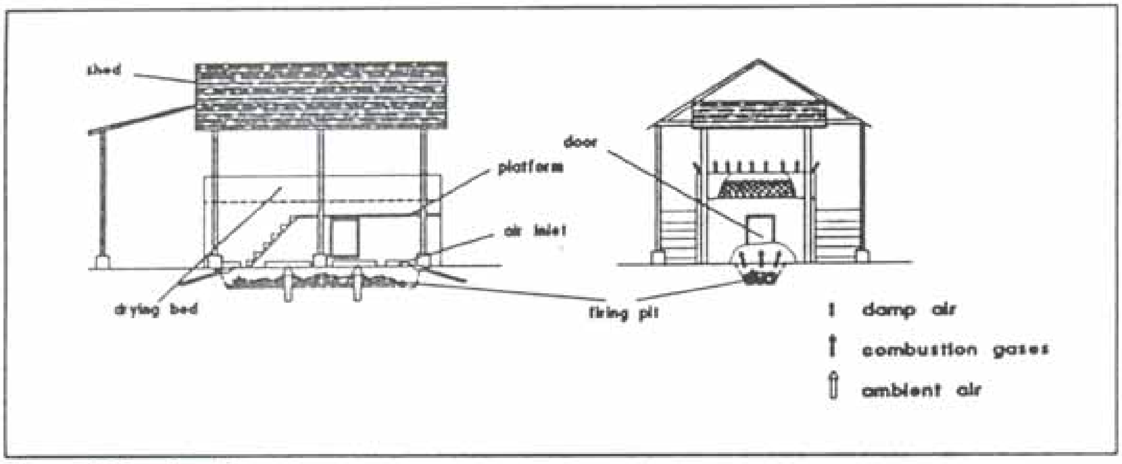
Direct Smoke Copra Dryer

The direct smoke dryer is a commonly used by coconut farmers in many coconut producing countries in the world. The smoke dryer has a grill-platform usually of split bamboo which constitutes the drying area. Halved nuts in the shell are placed on this grill. Underneath the platform is a fire hearth where coconut shells and husks are burned slowly to provide the heat for vaporising the water from the coconut meat. Generally, there is no chimney. The coconut meat shrinks upon drying and may be removed or scooped out from the shell. The meat is then further dried in the smoke dryer.

Tapahan Dryer

This direct smoke dryer is one of the commonly used direct dryers in the Philippines. It comes in different versions. starting with an open pit filled with husks and covered by a bamboo flooring up to more advanced dryers where the drying platform is provided with a wall (hollow blocks. plywood, etc.) The capacity of a standard Tapahan dryer is 2000 nuts and the volume of the drying bed is 2.69 m^3. The main components and the air / heat flow are shown in Figure24.

Figure 21 Schematic of Tapahan dryer



Source: Dippon and Villaruel, 1996

Tests carried out with the Tapahan dryer by the "Phillipines German Coconut Project" found:

- A fairly distributed temperature within the drying bed.
- Average temperatures of 86, 95 and 88°C were measured from front, middle and back sections respectively.
- Higher temperatures in the middle section are caused by the fuel concentration at the middle, and this leads to a lower moisture content in this area.
- Quite often scorched copra was found in the bottom layer, the middle layer was better in color, and parts of the top layer still had wet nuts, especially at the front and back.
- The fuel feed rate used was:
    - first firing: 40 husks
    - after 35 minutes another 25 husks
    - followed by 15 husks every 15 minutes until drying was finished.
- There is no way to control temperature except to change the fuel feed rate, and temperatures were found to fluctuate. A higher fuel feed rate is not recommended because of the high risk of burning the dryer and copra.
- On average, about 20 hours firing are needed to reach a final moisture content of about 10 %. Since the fuel (husks) is burned inside a pit underneath the drying bed, the dryer has to be attended to when in operation to prevent the dryer from burning. This means, that in most cases drying has to be done on two days.
- Based on a firing time of 20 hours, the amount of energy consumed (input) was found to be 94 kWh.
- The thermal efficiency, that is the ratio between output (evaporated water) and input (fuel used), is between 12 and 13%.
- Smoke drying is also known as a source of PAHs (polycyclic aromatic hydrocarbons). Results of Tapahan dried copra showed PAH figures as high as 79.8 μg/kg.
- However, because of the preservative properties of smoke, less aflatoxin producing molds will grow, and this is one big advantage of smoke drying on the storage quality.

Photo 24 Direct Smoke Copra Dryer

Source: FAO

The basic features which make the direct smoke dryer preferred by farmers are:

- High thermal efficiency of the dryer (the coconut meat is directly heated),
- Low cost of construction (the component parts are available on the farm),
- Simplicity of the design,
- Low cost of fuel.

However, the direct smoke dryer has two disadvantages:

- Copra produced from this dryer is usually dark, sooty with smoke and at times scorched.
- Since the fuel is burned inside a pit underneath the drying bed, the dryer has to be attended when it is in operation to prevent the dryer including copra from burning.

Direct Heat Dryers Using Only Shells for Fuel

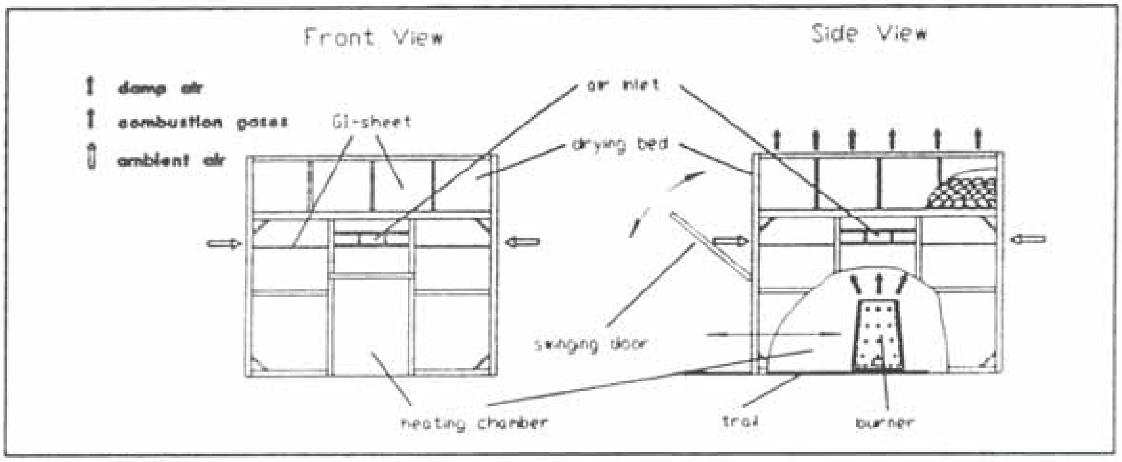
In Sri Lanka, India, Malaysia and Papua New Guinea (large plantations), direct heat dryers using only coconut shells as a fuel, providing great heat and little smoke, produce excellent quality copra. These kilns are operated centrally, either by specialized copra manufacturers or by plantation owners with high levels of management. Drying takes about 4 or 5 days with about 6 or 7 fires, reducing the moisture content to the desired level of about 6%. Two driers of this type are described below:

- UPLB drier used in the Philippines
- Sri Lanka copra kiln also called the Ceylon Drier.

UPLB Dryer

This dryer was developed at the University of Philippines at Los Banos (UPLB). The UPLB dryer has a capacity of about 1.000 nuts. The body of the UPLB Dryer is cubical in form (length = 1.91 m, width = 1.83 m, height = 1.77 m) and the volume of drying bed = 1.47 m^3. Lumber measuring 1.5" x 2" and 1.5" x 1" is used for the basic structure. The wooden structure is lined with GI-sheet to form the drying bed and heating chamber. At the front side a swinging door and two trails allow the placement of one burner inside at a time (see Figure25). A heat dissipator (made of GI-sheet) between burner and drying bed helps provide a uniform temperature distribution. Four air inlets (18 x 8 cm) located at each side between drying bed and GI-Sheet give a steady air flow that is essential for convectional drying.

Figure 22 Schematic of UPLB dryer



Source: Dippon and Villaruel, 1996

- Tests on the UPLB dryer found the temperature in the bottom layer was fluctuating and uneven. In some locations a maximum temperature of more than 180°C was recorded, but the center showed a relatively low temperature. Even after seven burners (more than 20 hours drying), the center portion in the drying bed was still wet, while the nuts in the bottom layer in other locations of the drying bed were scorched.
- The average fuel capacity (cracked coconut shells) per burner is 15 kgs. It takes 2.5 to 3.3 hours to consume one burner.
- For this dryer the working time (including dehusking and splitting) to produce one kilo copra was computed at 5.44 minutes. About 24% of this time is needed to break the shells used as fuel.
- The thermal efficiency was measured to be 24.5% at a specific energy consumption of less than 10 MJ per kg evaporated water.
- The average PAH content was measured at 60.7 micro g/kg
- Since the dryer is collapsible it can easily be moved to another location

Sri Lanka Copra Kiln (Ceylon Drier)

In Sri Lanka, the opened nuts are sun dried on the first day for a few hours on a cemented barbeque (weather permitting) as this improves the copra colour. They are then dried further down to 6% moisture content using the Ceylon drier which burns coconut shells directly under the copra drying platform. The design of a Ceylon drier is simple. The frying platform is a wire mesh placed about 2.5-2.7 metres above a dirt floor. Concrete blocks or galvainsed iron walls enclose the firing pit and the drying platform. A roof is placed over the platform and the roof may be sliding to enable sundrying. Air vents are placed near ground level to allow oxygen to enter the firing pit.

Husked and split nuts are loaded onto the drying platform to a depth of about 30 cms. In the firing pit, empty shells are nested against each other in single rows on the ground. One end of each row is lit and it burns slowly to the end. After the fire has burned out, new rows are laid out and set afire. Firing is continuous for about four days after which the copra has dried and can be easily separated from the shell.

Ceylon driers are widely used because:

- capital costs are relatively low,
- construction is simple,
- there are no fuel costs because it burns empty shells,
- copra produced is of a much higher quality than the smoke driers because shells produce very little smoke,
- there are empty shells left over which can be used to dry other crops such as cocoa (in a kiln drier),
- the shells burn at a fairly constant rate so it is easy to time the firing by counting the shells.

The only disadvantage of Ceylon driers is that they can burn down easily if left unattended because the highly flammable copra is directly over the fire.

<u>Semi-Direct Copra Dryer</u>

The design of semi-direct dryer is superior to the direct type because it retains the best features of the direct drier (simple structural design and operation, low cost, easy to build with materials locally available) while producing copra of a much better quality. This is because the hearth where fuel charging/feeding is done is located on one side of the dryer, connected to the drying bed by a tunnel-like flue. It is socially and economically ideal for small coconut farmers.

The combustion pit is located about 1 metre away from the drying bed. The hot combustion product is channelled to the drying bed via an underground tunnel that can be made using empty oil drums. The excavation pit is roughly 4m long, 2m wide and 1m deep. The pit floor of the firing chamber is slightly inclined upward toward the end portion, which is designed to direct the flow of heated air. Dry coconut husks are used for fuel. It has a capacity of 2,000 nuts which are dried after 20 to 25 drying hours with resultant moisture of 6 percent. (Photo25).

Photo 25   Semi-Direct Smoke Copra Dryer

Source: FAO

The VISCA copra drier

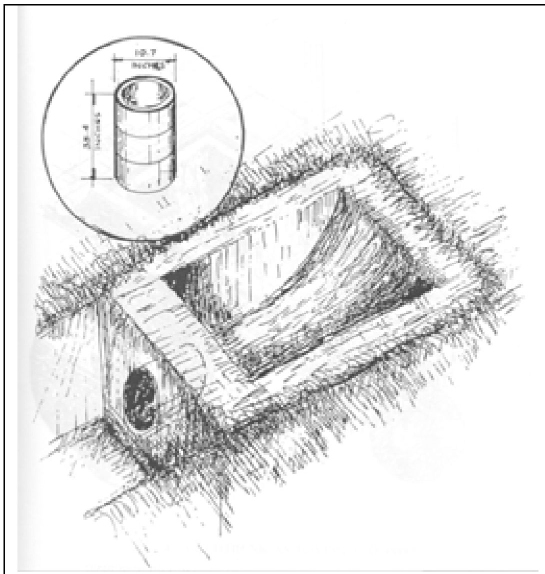
The VISCA dryer (Figure 26) is a semi-direct, excavated type with dimensions and design as described above. The design of this drier originated from the Visayas State College of Agriculture (VISCA) in Leyte - one of the Visayan islands of the Philippines. The copra produced by this drier is similar in quality to copra from smoke dryers, and it is used primarily for oil milling purpose. The VISCA dryer uses mainly cheap and locally available construction materials such as coconut trunk and lumber, bamboo and nipa shingles, and it is simple in structural design, cheap and easy to build. Moreover, the drier needs only 50% of the husk, so the remaining 50% husk and the shells can provide additional income to the farmer.

Dry coconut husks are used for fuel. It has a capacity of 2,000 nuts which are dried after 20 to 24 drying hours with a resultant moisture content of 10 %. To ensure production of good quality copra using the VISCA Copra dryer, the following operating procedure should be followed:

1) Harvest only matured nuts (12-13 months old).
2) Do the dehusking in a shady area and prevent the dehusked nuts from being exposed to the heat of the sun to avoid cracking.
3) Split the nuts early in the morning and immediately load them into the dryer.
4) Arrange the half-nuts in the dryer in a brick-like formation with the first bottom layer having the kernels facing-up and all succeeding layers with kernels facing down.
5) Start the drying process within four (4) hours after splitting so as to avoid deterioration of the fresh meat. Do the first drying stage for ten (10) continuous hours.
6) Carry out the drying process over two (2) days with an in-between cooling period during nighttime.

7) In the second day, rearrange the half nuts by interchanging the nuts in the upper layers with the nuts in the lower layers. This ensures even drying for the whole batch of copra. Continue the drying process for another fourteen (14) hours.
8) It is very important that only dry husks are used as fuel.
9) Control and regulate the dryer temperature by using the right fuel feed rate. Listed below is the recommended fuel feed rate using dry coconut husks as fuel.
    - 1st day drying period (10 hrs) : 7-8 husks / 10 min
    - 2nd day drying period (14 hrs) : 6-7 husks / 10 min
10) Remove the copra from the shell, separate half dried copra and redry. Air dry the copra and store it in clean and well ventilated bodega.

Figure 23 VISCA Copra Drier



(a) Empty oil drum used as Tunnel

(b) The completed VISCA drier

Source: Castro and Thampan, 1996

<u>Hot-Air Dryers</u>

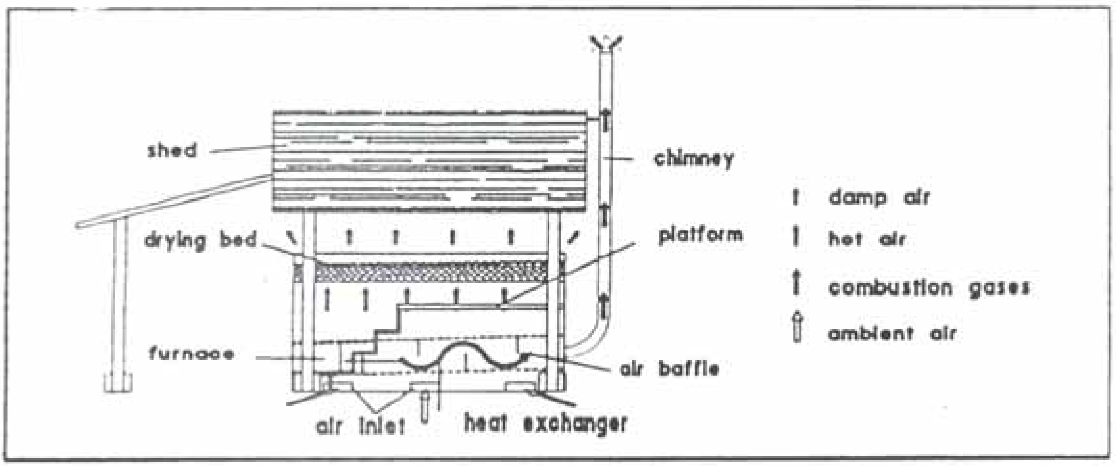
The main advantage of hot-air dryers is that high quality, clean and white copra with 6% moisture can be produced. This is because the smoke does not come in contact with the kernel. The smoke heats air in a heat exchanger and the uncontaminated hot air passes through the copra bed. Two designs of hot-air driers will be described:

- Modified Kukum Hot-Air Dryer
- Cocopugon Brick Hot Air Dryer.

<u>Modified Kukum Dryer</u>

The modified Kukum Dryer is an indirect natural draught dryer that can dry around 2000 nuts of average size at a time (volume of drying bed = 2.8 m^3). The measurements of the dryer are: length = 3.66 m, width = 1.83 m, and height = 2.13 m. Its heat exchanger is made up of three standard 200 litre oil drums welded together with five semi-circular baffles installed alternately inside the drums at distance of 0.46 m. The furnace measures 90 cms in length and 60 cms in width, and is made of steel plastered with 6 cm thick cement-ash mixture inside. The furnace is provided with a slanting grate and door to regulate air entry. A butterfly valve is also provided at the chimney to control the temperature.

Figure 24 Schematic of Modified Kukum dryer



Source: Dippon and Villaruel, 1996

Tests conducted by the "Phillipines German Coconut Project" found that:

- The temperature is quite even between left, middle and right side. The lengthwise distribution is more uneven.
- Highest temperatures were measured at the front section, while lowest at the back. The difference in temperature between front and back section of the drying bed is about 20 to 25 ^{o}C.
- Cold spots were observed at the back section within the top layer.
- The fuel feed rate used in operating the Kukum dryer was between 6 and 10 husks per 10 minutes. However, a higher fuel feed rate was used for the initial stage (first drying day).
- About 30 hours are needed to dry one batch down to less than 10%. Based on a 10 hours operation time per day, drying will take three days.
- About 8.7 minutes are needed to produce one kilo copra with the modified Kukum dryer.
- Quality of copra from the Kukum dryer is very good, as can be expected from a well designed and operated indirect fired dryer.
- However, maintenance and repair costs are high because the metal parts of the dryer start to corrode soon after construction due to exposure to high temperatures, aggressive fumes and water. Frequent use of the dryer will reduce corrosion, but will

never stop it. Since copra is a low value product, stainless steel is too expensive to consider.

- Similar to the Tapahan dryer. a thermal efficiency of 12.7% was computed.

Photo 26 Modified Kukum hot air dryer

Photo: FAO

COCOPUGON Dryer

This dryer was developed in the early 1990s under the "Philippine German Coconut Project" which studied and tested the existing coconut dryers and came up with several innovative dryer designs for small-scale and medium-scale coconut farms. The main criteria for what an ideal coconut dryer were identified to be:

6. Durability: lifespan of the essential dryer components should be at least five years;
7. Ease of Operation;
8. Costs: the total costs should not be higher than any alternative indirect dryer;
9. Ease of Construction: construction should not require any special tools;
10. Working Performance: minimum requirements were:
    - not more than two drying days
    - less than 10% final moisture content and uniform dried
    - less than 20 ppb aflatoxin content
    - fuel usage lower than 90% of the husks of nuts loaded

To meet these criteria and performance requirements, an Indirect Dryer called the "COCOPUGON" was designed and tested for coconut growing cooperatives and/or bigger plantations having around 40 ha of coconuts producing around 200,000 coconuts/year.

- The indirect dryer type was chosen because of the disadvantages of direct dryers like soot (PAH) contamination and scorched copra.

- Because Heat Exchangers made of metal tend to corrode at the high temperatures in which they operate the project explored the use of bricks instead, since bricks are known for their high strength (fire and weather resistance), durability (long service life) and dimensional stability. During preliminary trials, bricks were found to be a very promising replacement for metal. Standard fire bricks were used for the chimney and 2.5" crown bricks for the heat exchanger.

Photo 27 Cocopugon Hot-Air Brick Copra Dryer

Source: FAO

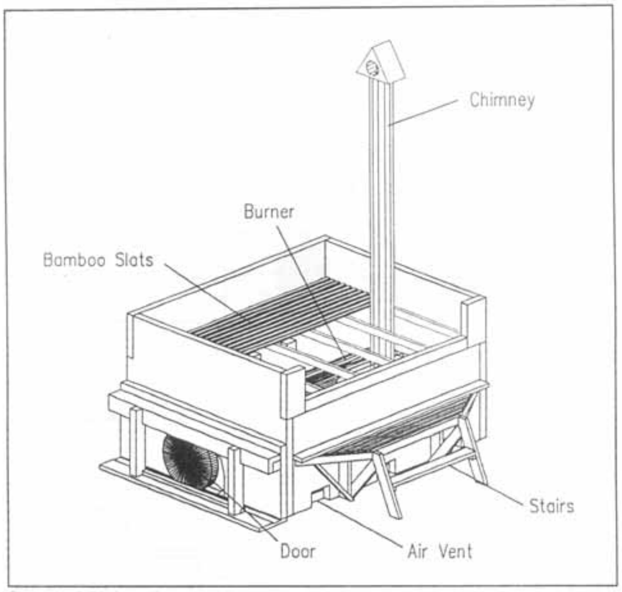
- Several prototypes were constructed to optimize shape and size of the burner and to determine the appropriate thickness of the bricks. The final version of this brick dryer was called COCOPUGON (Figure and Photo).
- The dimensions of the dryer are: length = 360 cm, width = 260 cm, and height = 200 cm, giving a drying bed volume = 3.33 m^3.
- The dryer can accommodate 2500 average sized nuts per batch.
- To make loading and unloading easy, the right side of the drying bed wall is removable and a one step stair and platform is provided.

Operation of Dryer:

- Firing should be done first before loading the splitted nuts. Unlike dryers with metal heat exchangers, preheating is needed for this dryer because bricks get heated more slowly that metal. .
- The burner can accommodate about 200 to 300 husks.
- Husks have to be added every 3 to 5 hours. The heat stored in the bricks will be released slowly after the last firing on the first drying day because bricks also retain heat and release it more slowly than metal. Drying will therefore continue for several hours without adding more husks to the burner.
- After a preheating time of 3.5 hours and a loading time of two hours, the average temperature in the bottom layer is 66.3°C.

- The burner then has to be fed five to seven times for the whole drying period. Unloading could be done after the dryer has cooled down on the second day.
- If operated on a two-day schedule, five firings are needed on the first day and another two to three firings on the second day. Unloading will be done the next morning to utilize the heat stored in the bricks.
- If the baffle in the chimney is closed during night time, hot embers can still be found inside the burner on the following morning making it easy to continue firing.

Figure 25 Schematic of Cocopugon Dryer



Source: Dippon and Villaruel, 1996

- The dryer has an almost constant drying temperature, even though the temperature curve for the burner has several small peaks indicating the maximum temperature per feeding interval. Since the heat exchanger or the burner cover almost the whole area inside the dryer body, the temperature distribution is very uniform. The difference in temperature between the highest and lowest value is less than 5 Kelvin. A standard deviation of 3 Kelvin indicates a very constant temperature.
- Even if the burner is fully loaded, the resulting temperature in the drying bed wont exceed 90 to 95°C. thus eliminating the risk of producing scorched copra.
- During operation, the dryer operator spends two hours per batch at the dryer, meaning the labor requirements were cut down by more than 50 % to 4.1 minutes per kilogram copra compared with the modified Kukum dryer. The operator can leave the dryer in between fuel feedings and use his time for other activities.
- The thermal efficiency was very constant with an average of about 15%.
- The drying cost per kg of copra (see table 8) was determined to be 2.6 Cents (pesos: 0.66).
- The copra quality was found to be far better than the minimum requirements set for good quality copra for domestic use, i.e., 14% moisture content. 5% free fatty acid content of oil (as lauric); 10% mold infection; and 20 ppb aflatoxin content. The culm

of oil is not much of concern. however, a 9 red and 50 yellow color is required for export or merchantable quality.

- The quality of copra produced also met the criteria set for the dryer. Good quality copra production was attributed to the appropriate procedure of drying, i.e., fast; smoke-free, and proper temperatures. Brownish copra was produced from the bottom layer. This is due to higher temperature exposure for a longer period. Due to delayed drying some brown colored copra was also produced from the top layer. On average, about 80% per batch was white. About 1 % of the total copra produced was wet at optimum drying set up. The average ffa content of more than 20 drying trials stood at 0.21.
- Average fuel consumption is about 80% of the husks from the total nuts loaded.

Samoan Drier

This is an indirectly heated drier commonly used in the Pacific to dry finger cut copra and also cocoa which cannot be dried on the direct and semi-direct driers because of the likely transfer of odors to the cocoa. The drying platform of a Samoan drier is a wire mesh which is placed on top of four walls which are about 1.5-2.0 meters high. A roof or sliding roof is placed over the drying bed. The walls are made of galvanized iron or concrete blocks. Inside the walls and under the platform on the ground is a flue running from one end of the platform to the other. One end of the flue is open for stoking with coconut shells and husk or fire wood. The other end is connected to a chimney with a small cowl over it. The opening at the firing end of the flue may be partially closed to manage air flow and temperature. Samoan driers usually dry copra filled to about 20 cms deep on the platform. The copra is indirectly heated and drying time is about two to three days.

8.2.3 Copra Storage

The main objective of copra storage is to provide a buffer stock to take care of differences of receipts and issues to the mill. Technically, storage performs two important functions for oil extraction:

- to dry any excess moisture in the copra, and
- to equalize the moisture content in the entire copra stock prior to processing.

During storage, copra must be protected from the elements and pests. Proper ventilation, and proper rotation of stocks when issues are made, should be practised.

Proper storage of copra after manufacture and during shipment is important, as even good copra will deteriorate if badly stored. Copra warehouses should have:

- cemented floors elevated about 0.5 m above the outside ground level to minimize dampness during rainy weather;
- good ventilation at roof level to breathe out evaporated moisture; and

- an air gap between the floor and bagged copra with the use of pallets or wooden logs. The air gap provides ventilation for removing moisture 'sweating' on the floor during rainy weather.

Good copra, when stored under poor conditions, and bad copra even under good storage conditions, deteriorate with consequent losses in both quality and quantity. Loss of quantity through drying of excess moisture is desirable, as the copra quality improves. Losses to be avoided are those due to decomposition and attack by fungi, bacteria, insect pests and rats. In case of insect pests, it is important to fumigate warehouses and returnable empty bags.

The Aflatoxin Problem

Poorly dried copra has occasionally been found to be contaminated with aflatoxins, which are a group of toxic chemicals produced by the *Aspergillus* mould, particularly *Aspergillus flavus* and *Aspergillus parasiticus*. Although groundnut and maize are most susceptible to aflatoxin contamination, copra, cottonseed and cassava are contaminated at lower levels. Aflatoxins found in these have been named B1, B2, and G1 and G2. Aflatoxin B1, which is the most abundant, is extremely poisonous and is a very powerful carcinogenic chemical. It caused liver cancer in all test animals and is almost certainly one of the causes of cancer in humans. Animals vary in their susceptibility to the effects of aflatoxins, but the young and males are at greater risk. Aflatoxins cause death when present in high concentration. Investigations revealed that in 1880, 100,000 young turkeys died in the UK due to the presence of 10 ppm of aflatoxin in the feed. At lower levels, it causes stunted growth and poor feed efficiency.

Recent work undertaken in the Philippines by the Natural Resources Institute of the UK found that the safe moisture level for hot-air dried copra is below 8%, and for smoke dried copra it is below 11%. The higher level of moisture tolerable for smoke dried copra is due to smoke particles inhibiting mould growth, as in smoked meat or fish. When contaminated copra is milled for oil, the aflatoxin passes into the oil. Edible coconut oil is usually chemically refined, which removes all contamination. However, the aflatoxin remaining in the copra cake has caused problems for its use as an ingredient in blending animal feeds. Copra cake is valued for its effect in enhancing butterfat content and increasing yields of milk in lactating cows. If contaminated cake is used for feeding lactating cows, the aflatoxin reappears in the milk as aflatoxin M1, which is also unacceptable.

The European Union introduced regulations on limits of aflatoxin levels in feed ingredients and feeding stuffs in 1976. These regulations were further tightened by the EC Commission directive of 13 February 1991, which for copra cake is 50 ppm. Prevention of aflatoxin contamination is best carried out by drying copra rapidly down to safe levels. Proper storage, handling, packing and transport of well-dried copra is equally important to prevent growth of mould spores during condensation of moisture, etc. Although experiments has been conducted in detoxification, none have been commercially acceptable to date.

Copra Quality, Grade and Standards

Most copra-producing countries have quality specifications. General requirements (non-technical) for good quality mill copra stipulate white coloured cups, excluding wrinkled (immature), germinated, mouldy, charred (black) or broken cups. Technical specifications limit moisture content to 6% (sometimes up to 10%), minimum oil content of 68% on a dry basis, and a maximum free fatty acid content of 1% for the expelled oil. Only copra manufactured by the direct heat of coconut shells or indirect heat 'hot air' dryers under proper conditions could conform to these specifications.

Generally, copra produced in Sri Lanka, India, Malaysia, Papua New Guinea and Pacific countries with hot air dryers conform to these specifications. In these countries grading practices exist, with a price premium for good quality. In the Philippines, Indonesia and other areas where copra is smoke dried, good white coloured copra cannot be produced, and the moisture content ranges between 8 and 15%, and the free fatty acid content of the expelled oil varies between 1 and 5%. The oil content, the colour and appearance, and the moisture content are variable. These characteristics are demonstrated in the grades and standards used for copra.

Philippines

In the Philippines there are four recognised classes of copra designated A, B, C and D. The classification is based on the method of drying. Under each class are seven grades, from 1 to 7, based on moisture content. The classes are given in Table and the grades in Table . These tables show the 3 types of copra drying in existence: sun drying, smoked tapahan drying and hot air drying. It is also indicates among the grades, as high as 22 percent moisture content (Corriente) is traded. The best grade copra contains no more than 6 percent moisture.

Table 21 Quality Standard for Copra in the Philippines

Class	Name/Designation	Requirement (Appearance)
A.	Hot air, kiln or mechanically dried	Clean, whitish or pale; free of smoke, moulds and dirt
B.	Sun dried	Dull white; low in dirt, mould and decay; free of smoke
C.	Smoked or tapahan	Tinged with soot; low in mould, dirt and decay; not unduly charred or burned
D.	Mixed	Low in mould, dirt, soot and decay

Source: FAO

It must be noted however, that trading of copra is essentially based on moisture content. In the Philippines where roughly 90-95 % of total production is sold to the village trader, copra with 20-25 percent moisture content are bought at a discounted price. This is referred to as the "pasa system" of copra buying where a discount on the copra price is based on moisture. Thus, copra is classified according to its moisture content even at the first point of sale. (See

Table 4). Since moisture meters are not readily available in the villages, moisture content determination is done visually or by cracking or splitting the copra by hand and feeling. Experienced and highly skilled copra buyers do this.

Table 22 Grades of Copra Used in the Philippines

Grade	Name/Designation	Moisture Content	Requirements
1	Resecada Bodega	6.0 %	Free from noticeable mixture of copra from unripened nuts
2	Resecada	7.5 %	Free from noticeable mixture of foreign materials
3	Semi-Resecada	9.0 %	Free from noticeable mixture of foreign matter
4	Buen Corriente Mejorado	12.0 %	Reasonably free of vermin
5	Buen Corriente	15.0 %	Reasonably free of weevils and other insects
6	Corriente Mejorado	20.0 %	No objectionable odour or putrefaction
7	Corriente	22.0 %	No objectionable odour or putrefaction

Source: FAO

India

In India standard contract terms for milling copra were specified in as early as 1949. Since then, these form the basis of transactions in the domestic market. The terms apply to sundried and smoke dried copra, but the smoked copra cannot be tendered against a contract for sundried copra. The following are the details of contract terms for milling copra.

Table 23 Contract Terms for trading Copra in India

1. Moisture	Basis 6 percent	- with mutual allowance	
	Below 6 to 5 percent	-allowance to seller equal to 1.5 times less moisture	
	Below 5 percent	-allowance to seller at the rate of 1.25 percent for every 1 percent less of moisture	
	Over 6 to 8 percent	-rebate to buyer equal to 1.25 times the excess	
	Over 10 percent	-rejection at buyer's option	
2. Dirt and Foreign Matter	Basis 0.5 percent	- with mutual allowance	
	Below 0.5 percent	- proportionate allowance to seller	

	Over 0.5 to 2.0 percent	- rebate to buyer equal to 1.25 times the excess
	Over 2.0 percent	- rejection at buyer's option
3. Mouldy	5 percent free	

Source: FAO

Papua New Guinea

Table 24 Classification of Copra for export in Papua New Guinea

Grade	General Appearance
A. (Hot-Air Dried Copra)	Clean; of good colour; free from smoke, excess mould or insect infestation, charred pieces or foreign matter; free from an unreasonable admixture of copra from germinated nuts; not exceeding 6 percent moisture content (MC) ; not exceeding 3 percent free fatty acid (FFA) content.
C. (Smoke Dried Copra)	Clean and of uniform colour, not burned or tarry; free from excess mould or insect infestation, charred pieces or foreign matter; free from an unreasonable admixture of copra from germinated nuts; not exceeding 6 percent MC; not exceeding 3 percent FFA.
D. (Mixed Copra)	Copra of exportable quality which cannot be reconditioned to a higher grade; not exceeding 7 percent MC and not exceeding 4 percent FFA.

Source: FAO

Measuring Moisture Content

A copra moisture meter has been developed by CPCRI that can determine the moisture content of copra quickly and accurately. The meter works on the principle of electrical conductivity, and can read moisture contents between 5% and 40%. The instrument is handy and useful to copra processors, buyers and marketing societies.

Photo 28 Copra Moisture Meter

Source: Rajagopal and Arulraj, 2003