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Fuels from Coconut Waste*

by

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INTRODUCTION

The Philippines is a land of abundant coconut trees, which can give a large number of products that serve the people in countless ways. The production of the major products, under present day methods, involves utilization of only 35 percent of the whole nut. By and large, the rest is discarded as wastes and causes environmental problems. The amount of wastes generated every year is enormous. These waste materials from the nut together with the leaves which are shed yearly by the coconut palm represent a potential fuel source of significant magnitude. Presently, only a small portion is utilized as fuel for cooking and drying.

Petroleum prices and supply uncertainty have created a large demand for alternative fuel. Coconut wastes could meet some of the energy needs especially in areas where coconut trees abound. Unlike coal and oil, coconut is continuously replenishable.

The purpose of this presentation is to discuss the thermal processing of the solid part of the coconut into fuel. The coconut water, which is often discarded, is best utilized to produce a fuel by biological means.

ENERGY POTENTIAL OF COCONUT WASTES

The husk and the shell together constitute the largest solid components (about 48.3 percent) of the nut which are co-produced in the commercial processing of the meat. The petiole which is about 91 percent of the leaf will be the only waste from the leaf to be considered. A coconut tree can shed one leaf in one month. The estimated energy potential, as well as composition and calorific values of these components are shown in Table 1.

The fuel calories have been estimated to be 100 MJ/tree for the petiole; 4.14 MJ/nut for the shell; and 6.69 MJ/nut for the husk (Banzon, 1982). If we consider the 1981 UCAP Coconut Statistics, which show 16 billion nuts harvested and a tree population of 411 million, whether bearing or not, the energy potentially available from these materials is quite large amounting to 214×10^9 MJ/year. This is broken down into leaf petioles, 41×10^9 MJ; shell 66×10^9 MJ; and husk, 107×10^9 MJ.

Table 1. Estimated Annual Energy Potential (1981), Composition[1], Calorific Values[2] of Major Coconut By-Products

By-Product	Estimated Energy in Billion MJ	Wt/nut kg	% of Nut	Proximate Analysis, % Composition, % Dry Basis							Calorific Value, MJ/kg
				H_2O	FC	VM	Ash	Cellulose	Lignin	Pentosan	
Husk	158	0.40	33.3				6.6	21.33	45.2	19.15	14.8
Shell	66	0.18	15.0	6.07	31.3	64.4	4.3	27.31	33.3	30.28	23.0
Petiole	41	(2.17)[a]		10.57			9.6	32.7	23.3	19.71	16.7

a. Dry weight (kg) of one petiole

1. PCA, 1979
2. Banzon, 1982

In terms of barrels of oil or liters of gasoline with the calculations based on 33.68 MJ/liter of gasoline and 8368 MJ/barrel oil the equivalents are given in Table 2.

Table 2. Energy of Coconut Wastes in Terms of Barrel of Oil or Liters of Gasoline

Waste	Million Barrels of Oil equivalent	Billion Liters of gasoline
petiole	4.90	1.21
shell	7.89	1.96
husk	12.79	3.18
Total	25.58	6.35

The shell and husk from 16 billion nuts plus the petioles from 411 million trees can yield a total of 25.58 million barrels of oil equivalent or 6.35 billion liters of gasoline. A one per cent utilization of this available energy would still be substantial and is equivalent to 700 barrels of oil or 174,000 liters of gasoline a day.

DIRECT COMBUSTION

It has been shown by simple calculations (Banzon, 1984) that the husk, shell and petiole from eleven coconut palms can meet the average kitchen needs by direct burning. Direct combustion is applicable only if these materials have been previously dried to a certain moisture content. The wetter the fuel, the poorer the combustion process and the lower the heating values because heat is wasted in vaporizing the moisture.

There is no limit to direct combustion of wet biomass so long as the biomass contains sufficient thermal value to vaporize the water that is present, to raise water vapor to the temperature of the fuel gases, and to keep the combustible material sufficiently hot to keep the combustion going.

The choice between direct combustion and thermal conversion into fuel should depend upon a combination of moisture content, density, thermal value and physical form.

ENERGY CONVERSION PROCESS

The purpose of energy conversion processes is primarily to overcome the various disadvantages of biomass as a fuel. The removal of moisture, increasing the thermal content and decreasing the bulk are important objectives.

Assessment studies have identified three processes as being most appropriate for utilizing biomass wastes for energy purpose. They are:

o   combustion to provide heat.

o   thermal processing to produce gas, liquid or solid fuels.

o   anaerobic digestion to produce gas.

There are many other conversion processes which are being studied. Invariably, they would fall under anyone of the above methods.

An outline of possible routes for biomass conversion to fuels, any one or combinations of which, may be adapted to coconut waste, is shown in Figure 1. It also shows their primary and secondary products.

Pyrolysis

This process consists of heating an organic substance in the absence of air. Sometimes the process is called "thermal degradation." Yields of products depend on the pyrolysis conditions and the type of biomass used, but generally consist of gas which has various amounts of methane, carbon monoxide, hydrogen, and other low molecular weight hydrocarbons; a liquid containing high molecular weight hydrocarbons, oxygenated organic compounds and water; and a solid char.
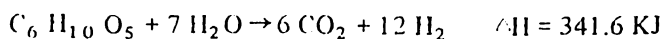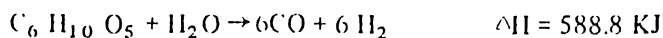
A pyrolysis optimized for the production of liquid products is often referred to also as "destructive distillation." A pyrolysis optimized for the production of char is termed "carbonization."

Gasification

This process involves heating organic compound with a less than stoichiometric amount of air or oxygen to yield mainly low molecular weight gaseous products. Both combustion and pyrolysis can occur simultaneously. Heat released by the exothermic combustion supports the endothermic pyrolysis. Gasification is often referred to as "partial oxidation." The simplified reaction, using the cellulose component of the biomass only is $C_6 H_{10} O_5 + 3O_2 \rightarrow 6\, CO + 5\, H_2O$ $\Delta H = -862$ KJ.

Steam Reforming

This process refers to the reaction of water with organic compound to give CO and H_2, as summarized by the following reactions:

$$C_6 H_{10} O_5 + H_2O \rightarrow 6CO + 6 H_2 \qquad \Delta H = 588.8 \text{ KJ}$$

$$C_6 H_{10} O_5 + 7 H_2O \rightarrow 6 CO_2 + 12 H_2 \qquad \Delta H = 341.6 \text{ KJ}$$

The process is known as "steam reforming" if CO is the main product and "steam reforming + shift reaction" if CO_2 is the main product.

Hydrogasification

This process involves the pyrolysis of organic compounds in a hydrogen-rich atmosphere to give hydrocarbon gases, mainly methane. The overall reaction may be summarized by:
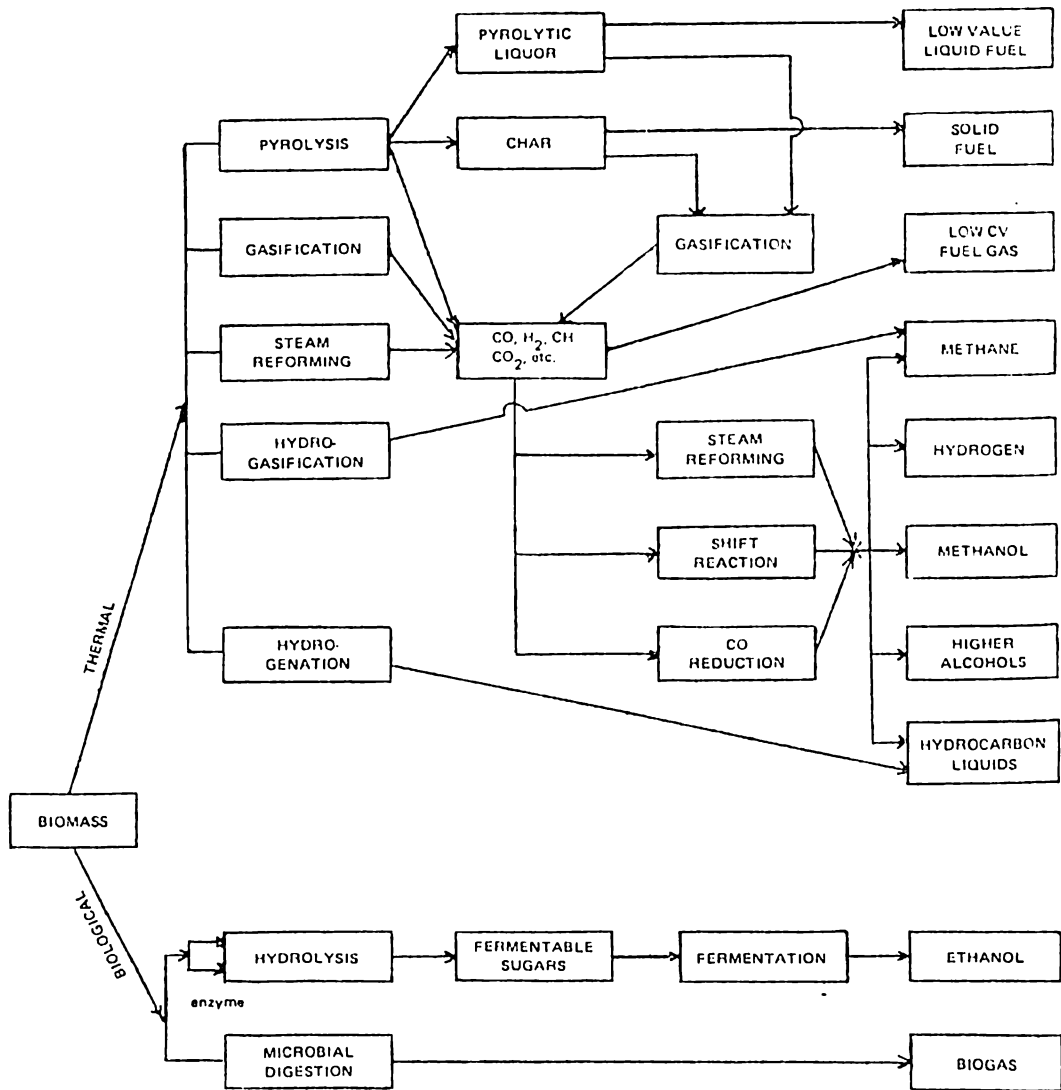
$$C_6 H_{10} O_5 + 12 H_2 \rightarrow 6 CH_4 + 5 H_2O \qquad \Delta H = -648.4 \text{ KJ}$$

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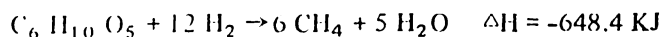
Figure 1. Outline of Possible Routes for Solid Coconut Wastes Conversion to Fuels

Hydrogenetion

In this process the pyrolysis is carried out in a hydrogen-rich atmosphere under pressure to give liquid hydrocarbons which may however contain a relatively high proportion of oxygen. A highly simplified overall reaction is:

$$C_6H_{10}O_5 + 6 H_2 \rightarrow 6 (CH_2) + 5 H_2O \quad \Delta H = -979 \text{ KJ}$$
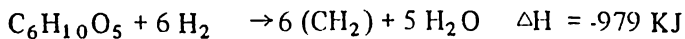
where (CH_2) represents the normal hydrocarbons.

Hydrolysis and Fermentation

In this biological process the polysaccharides of the biomass may be converted to monosaccharides by either acid hydrolysis or enzyme hydrolysis. The monosaccharides may in turn be fermented anaerobically to the liquid fuel ethanol.

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Anaerobic Digestion

The process constitutes an anaerobic degradation by bacteria of soluble solids and repartition of carbon to microbial cells, CO_2 and methane (biogas).

Thermal Processing

The behavior of biomass on heating is important in thermal processing. It is most often studied by measuring the rate of weight loss of the organic sample as a function of time and temperature. This is done by using a thermogravimetric analyzer (TGA). TGA curves for several kinds of biomass materials have been measured at the U.S. Solar Energy Research Institute, (SERI, 1979) and is shown in Figure 2.

Cellulose is stable to temperatures over 300°C, then decomposes over a narrow range of about 50°C leaving a char residue. Although some decomposition appears to start at a lower temperature than for cellulose, most lignin decomposition occurs at higher temperatures. Acid lignin appears to be more stable than other derived lignins. Hemicellulose is the least stable major component of wood. The pyrolysis reactivities of the major components of wood therefore decrease according to the following order: hemicellulose, cellulose and lignin.

Several studies have shown that thermal degradation of wood may be closely related to the degradation of the three major components, although no study has so far been reported which quantitatively demonstrates that the gaseous products of biomass are the sum of the gaseous products or its components.

REACTION SCHEMES

The chemistry of the various reactions that can occur during thermal processing is quite complex. For a better insight into the process, the many interacting alternatives
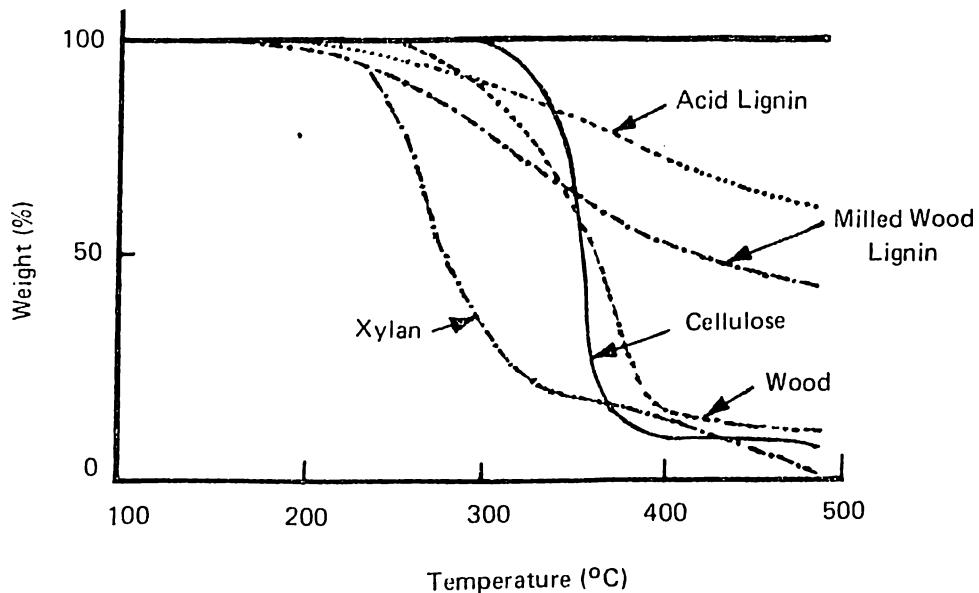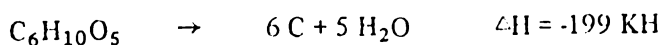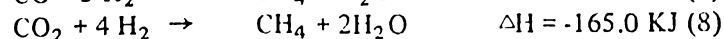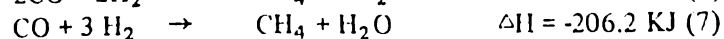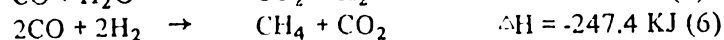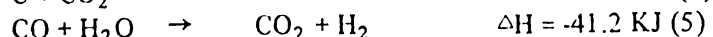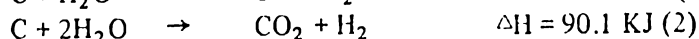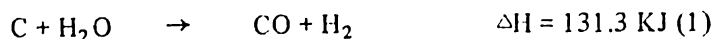
Figure 2. Examples of TGA Cottonwood and Its Components, Taken from
Shafizadeh and McGinnis (1971)

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are reduced to the following simplified reactions at $20^{\circ}C$. The cellulose component of the biomass is again being considered:
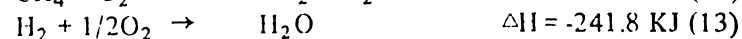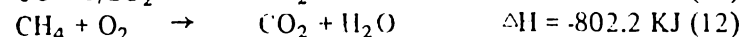
Carbonization

$$C_6H_{10}O_5 \quad \rightarrow \quad 6\,C + 5\,H_2O \qquad \Delta H = -199\ KH$$

Pyrolytic Reactions

$$C + H_2O \quad \rightarrow \quad CO + H_2 \qquad \Delta H = 131.3\ KJ\ (1)$$
$$C + 2H_2O \quad \rightarrow \quad CO_2 + H_2 \qquad \Delta H = 90.1\ KJ\ (2)$$
$$C + 2H_2 \quad \rightarrow \quad CH_4 \qquad \Delta H = -74.9\ KJ\ (3)$$
$$C + CO_2 \quad \rightarrow \quad 2CO \qquad \Delta H = 172.5\ KJ\ (4)$$
$$CO + H_2O \quad \rightarrow \quad CO_2 + H_2 \qquad \Delta H = -41.2\ KJ\ (5)$$
$$2CO + 2H_2 \quad \rightarrow \quad CH_4 + CO_2 \qquad \Delta H = -247.4\ KJ\ (6)$$
$$CO + 3H_2 \quad \rightarrow \quad CH_4 + H_2O \qquad \Delta H = -206.2\ KJ\ (7)$$
$$CO_2 + 4H_2 \quad \rightarrow \quad CH_4 + 2H_2O \qquad \Delta H = -165.0\ KJ\ (8)$$

Combustion Reactions (if oxygen is present)

$$C + O_2 \quad \rightarrow \quad CO_2 \qquad \Delta H = -393.5\ KJ\ (9)$$
$$C + 1/2\ O_2 \quad \rightarrow \quad CO \qquad \Delta H = -110.5\ KJ\ (10)$$
$$CO + 1/2O_2 \quad \rightarrow \quad CO_2 \qquad \Delta H = -283.0\ KJ\ (11)$$
$$CH_4 + O_2 \quad \rightarrow \quad CO_2 + H_2O \qquad \Delta H = -802.2\ KJ\ (12)$$
$$H_2 + 1/2O_2 \quad \rightarrow \quad H_2O \qquad \Delta H = -241.8\ KJ\ (13)$$

Drying

$$H_2O\ (liquid) \rightarrow H_2O\ (vapor) \qquad \Delta H = 43.2\ KJ\ (14)$$

The important reactions in gasification are reactions 1, 3, 4, 5, 7, 9, 13, 14. Pyrolytic reactions 1 and 2 occur in the reduction zone of the reaction. Reaction 1 is favored by high temperature and catalyzed by sodium-based compounds. Reaction 4 is a reduction reaction and also favored by high temperature. Reaction 5 is the water gas shift reaction used for the adjustment of the H_2 and CO ratio and is important in methanol synthesis. Reaction 6 is an accompanying reaction. Reactions 3, 6, 7, 8 are hydrocarbon-forming reactions and are important in the production of gaseous and liquid products. Reactions 9, 10, 11, 12, 13 occur in the oxidation zone. Reaction 14 occurs in the drying zone.

PROCESS VARIABLES

The process variables determine the yields and composition of the products.

Effect of Temperature

. At high process temperatures of $800\text{-}900^{\circ}C$, gas yield increases while the char product decreases. Liquid yield decreases slightly and is almost independent of temperature. The water content on the gas decreases significantly with increasing temperature because water reacts with char to give H_2 and CO. H_2 and CO yields increase with temperature. When the yield of $C\cap$ is low, the shift reaction is playing an important part.

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Effect of Water

Water has two main effects on thermal processes. Firstly, it represents an energy requirement as liquid water has to be heated to $100^{\circ}C$, vaporized, and finally heated to the temperature of the reaction. The second effect of water is that it can undergo various chemical reactions. It can react directly with the feed and with organic intermediates in steam reforming; with carbonaceous char to give H_2, CO and CO_2; and with CO to give H_2 in the shift reaction.

Effect of Oxygen

The main effect is the higher concentration of the CO_2 and, perhaps, of water in the gas product. If air is used, about half the volume of the gaseous product will be nitrogen, thus reducing the calorific value of the gas, and possibly precluding its use for upgrading to methanol or methane. An advantage of using air or oxygen is that the char is more likely to be totally gasified, leaving only ash or slag as the solid by-product. If the heat produced by char gasification is more than required for the pyrolysis, steam can be added to give endothermic reactions, which when balanced with the exothermic reaction will give overall autothermic operation.

Effect of Gas Flow

The course taken by pyrolytic reactions will depend to a considerable degree on the gaseous environment in the reactor. Movement of gases relative to the solids within the reactor is one of the factors that determines the reaction occurring during thermal processing. Whether the intermediate products are contacted with fresh feed, with pyrolysis products, or are removed directly from the reactor will be determined by the type of reactor used and its mode of operation. The gas velocity relative to the movement of the solids in the reactor is also important. On this will depend the period during which gases and solids are contacted and the length of-time gaseous products are held at the reaction temperature.

Effect of Particle Size

Particle size of the feed will determine 1) the rate at which the temperature of the inner region of the particle can be raised and will affect the rate at which gases can leave the particles, and 2) the ease with which feed is handled.

Effect of Pressure

Increasing pressure in the reactor will normally increase the rates of reaction when moles of reactants are greater than moles of products. Thus, the CH_4 content of the gas generally increases with pressure.

Effect of Other Variables

Catalysts can play an important role in thermal processing. Inorgant salts, present in many feedstocks, are known to have a catalytic effect on the type of reaction expected to occur.

Residence time of the solids also influences the yields in thermal processing. Long residence time results in more gas because the tars produced may be cracked.

The choice of bed depth can affect reactor performance. If bed is too deep, the temperature of the off-gas, if removed at the top, goes below the dewpoint of the liquid product resulting in its low yield.

By controlling the parameters the fuel forms can be adjusted according to specific needs. Flexibility in fuel types gives energy from thermal processing of biomass attractive characteristics.

PRODUCTS OF THERMAL PROCESSING

Solid Product

The solid residue from thermal processing of biomass will vary according to process conditions. It may take any of the following; char, a mixture of carbon with varying amounts of ash and/or metals; ash, a mixture of finally divided inorganic salts, containing also metal residue or slag, a solid mixture of inorganic salts and metals. The char from cocoshell has a good calorific value which is 30.9 MJ/kg while that from-the husk is 24.8 MJ/kg. (PCA, 1979). Charcoal chip is a good fuel for gasifiers as it produces relatively clean producer gas.

Liquid Product

The liquid product comes from the condensed fraction of the hot vapor and is referred to as pyrolytic oil. It consists of two phases: an aqueous phase referred to as crude pyroligneous acid and a tarry oil. The yield of liquid products and ratio of acid to tar depends considerably on the type of feed and processing variables. In its existing form it is unlikely that pyrolytic oil can become a usable liquid fuel because it is corrosive due to high acidity. It does not burn well. Subsequent processing may well overcome these disadvantages.

Gas Product

The primary gaseous products consist mainly of CO, CO_2, H_2 and CH_4 together with smaller concentrations of the higher hydrocarbons, such as ethylene and ethane. Nitrogen will be present if air has been used in the thermal process. The calorific value of pyrolysis gas from coirdust obtained in the pilot plant is 12.03 MJ/m. (Festin, 1979). The gas may only be economically used as it is produced or if the user is situated close to its point of production.

Thermal Processing Units

There are thermal processing units that can use coconut wastes which are already available in the market. One of these units is the "Likas Gasifier" locally manufactured by the Gasifier and Equipment Manufacturing Corporation, (GEMCOR, 1981) The units which are downdraft gas producer models, come in different sizes and capacities. They can be used in electric power generation, water supply systems, rice mills, coir fiber processing, drier operations, and other applications requiring the use of internal combustion engines.

The economics as of 1981 of different applications supplied by the company is shown in Table 3. The annual savings is substantial and the payback period ranges from 1.2 months for truck vehicles using gasoline to 2.9 years for a dryer unit.

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The economics of a 3163 MJ/hr (3M Btu/hr) model using different fuels is given in Table 4. The per cent savings for using coconut shell and coco shell charcoal are 35.6 percent and 10 percent, respectively.

A carbonization pilot plant at the Chemical Engineering Laboratory of the University of the Philippines is shown in Figure 3 (Festin, 1980). This unit processes coir dust into pyrolysis products. It can also process other kinds of granular organic materials.

The significant findings of the studies on the utilization of coconut coir dust can be summarized as follows:

1. Pyrolysis of coir dust is an exothermic process. The heat of carbonization is 121 cal/gm of dry coir dust at 30°C.

2. At about the same temperatures, the yields of char and pyrolytic liquor from the pyrolysis of wood and coir dust are about the same. The coir dust gives higher yield of gas but a lower yield of tar.

3. The coir dust yields a gas very high in hydrogen content but low in methane and carbon monoxide contents. Wood gas, on the other hand, has high methane and carbon monoxide but very little hydrogen.   -

4. Wood gas has a higher fuel value than coco gas per unit volume but the total heat available in coco gas is higher.

5. The quantity and composition of the products of coir dust pyrolysis depend upon the temperature. High temperatures yield increasing amounts of non-condensable gas but decreasing amounts of tar, pyroligneous liquor and charcoal. The composition of the gas vary widely with temperature. At about 500°C, the gas is composed mainly of CO, H_2, and CO_2 with small amounts of CH_4. Beyond 800°C the gas is essentially H_2 and CO of almost equal proportions. Furthermore, the char is activated at this temperature.

6. The char when mixed with a suitable binder could be formed into briquettes. They burn without smoke and could withstand handling.

7. Introducing a catalyst into the reaction system increases the volume and fuel value of the gas by as much as 50 percent.

8. A continuous pyrolyzer could be made self-sustaining with respect to fuel requirements. Either the gas or char, preferably the latter, could provide the indirect heat for the pyrolyzer.

9. Coir dust feed with more than 20 percent moisture does not give satisfactory performance in a continuous pyrolyzer.

Table 3. Economics of Different Applications (1981)
Annual Operating Cost

Application	HP	w/o gasifier	w/ gasifier	Annual Savings	Cost of Gasifier	Payback Period
A. Irrigation System	60	P 57,505	P 43,337	P 14,118	P18,000	1.28 yrs.
B. Ricemill	24	19,141	10,756	8,385	20,800	2.48 yrs.
C. Dryer	10	10,726	3,479	7,247	20,800	2.87 yrs.
D. Electric Power Generation	50	376,401	289,778	86,623	20,200	9 mos.
E. Vehicles						
a. Jeep (diesel)	100	29,313	21,234	8,080	15,000	1.86 yrs.
b. Jeep (gasoline)	100	96,715	30,117	66,598	15,000	2.70 mos.
c. Truck (diesel)	150	108,463	78,127	30,336	17,000	6.72 mos.
d. Truck (gasoline)	150	250,219	77,659	172,560	17,000	1.20 mos.
F. Banca	16	8,094	2,273	5,821	5,000	10.32 mos.

Source: Gasifier and Equipment Manufacturing Corporation

Table 4. Economics of 3M BTU/HR Model DHS Using Different Fuels (1981)

	BUNKER OIL	GASIFIER FUEL		
		Cocoshell	Cocoshell Charcoal	Wood Refuse
Fuel Consumption	80 li/hr.	210 kg/hr.	150 kg/hr.	230 kg/hr.
Fuel Substitution	–	100%	100%	100%
Annual Operating Cost	P960,000.00	P618,000.00	P865,000.00	P667,000.00
Annual Savings	–	P342,000.00	P 95,000.00	P293,000.00
Percent Savings	–	35.6%	10%	30.5%
Payback Period	–	1,260 hrs.	4,500 hrs.	1,485 hrs.

Source: Gasifier and Equipment Manufacturing Corporation

10. Fifty percent of the CO_2 in the coco gas could be removed by inverting the gas collector of the pyrolyzer unit over lime water instead of plain water.

The following products are obtained in a typical run of the pilot plant at $530^{\circ}C$ (per hr): coir dust (20 percent moisture), 30.75 kg; charcoal, 8.53 kg; coco gas, 7.85 kg.

The heat input to the retort is 91.15 MJ while the heat from the gas and charcoal are 117.91 MJ and 203.51 MJ per hour, respectively. It can be seen that the char (even at 50 percent utilization) is more than enough to supply the heat to the retort. The heat can be utilized for power generation or as a source of synthesis gas for methanol production.

The most promising use of the thermal unit processing coir dust is by integrating it with a coir fiber extraction unit. The by-product coir dust could be converted into fuel gas which in turn could provide the mechanical power for the decorticator.
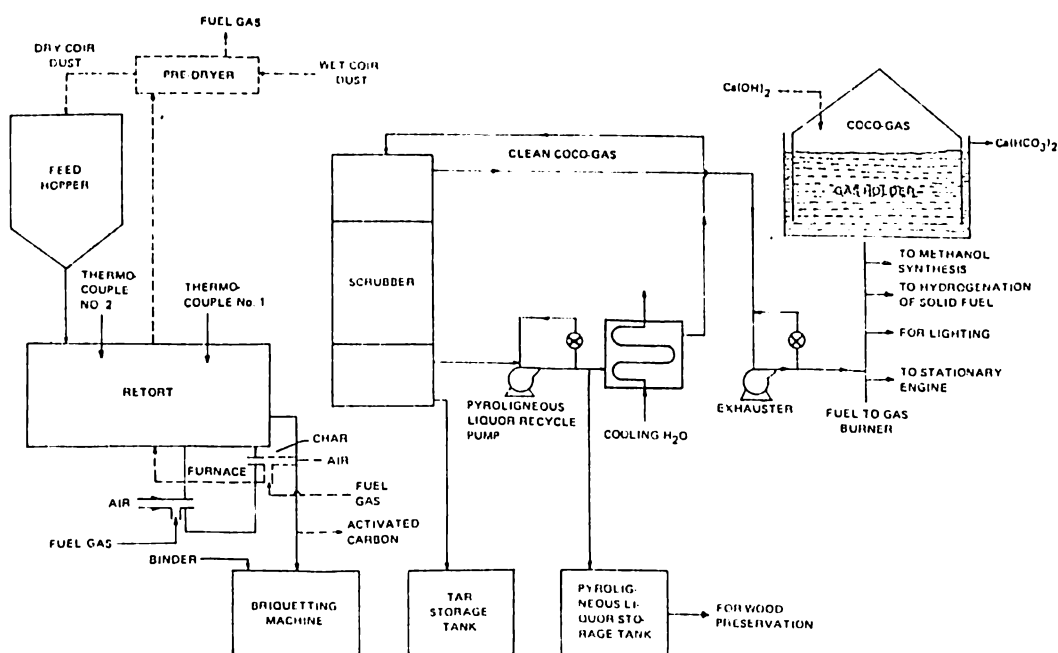

Figure 3. Carbonization Pilot Plant Lay-out at the U.P.Chemical Engineering Laboratory.

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REFERENCES

Banzon, J.A. 1984. The Coconut Palm as a Source of Firewood. Philippine Association for The Advancement of Science Seminar Proceedings, Quezon City.

Banzon, J.A. and J.R. Velasco 1982. Coconut- Production and Utilization. Philippine Coconut Research and Development Foundation.

Festin, T.F. and W.I. Jose 1980. Utilization of Waste Coconut Coir Dust as a Source of Fuel. Conservation and Recycling, vol. 3:383-388, Pergamon Press Ltd., Great Britain.

Philippine Coconut Authority (PCA) 1979. Technical Data Handbook on the Coconut — Its Products and By-Products. Research Coordination and Documentation Center.

U.S. Solar Energy Research Institute (SERI) 1979. A Survey of Biomass Gasification. Golden, Colorado, U.S.A.