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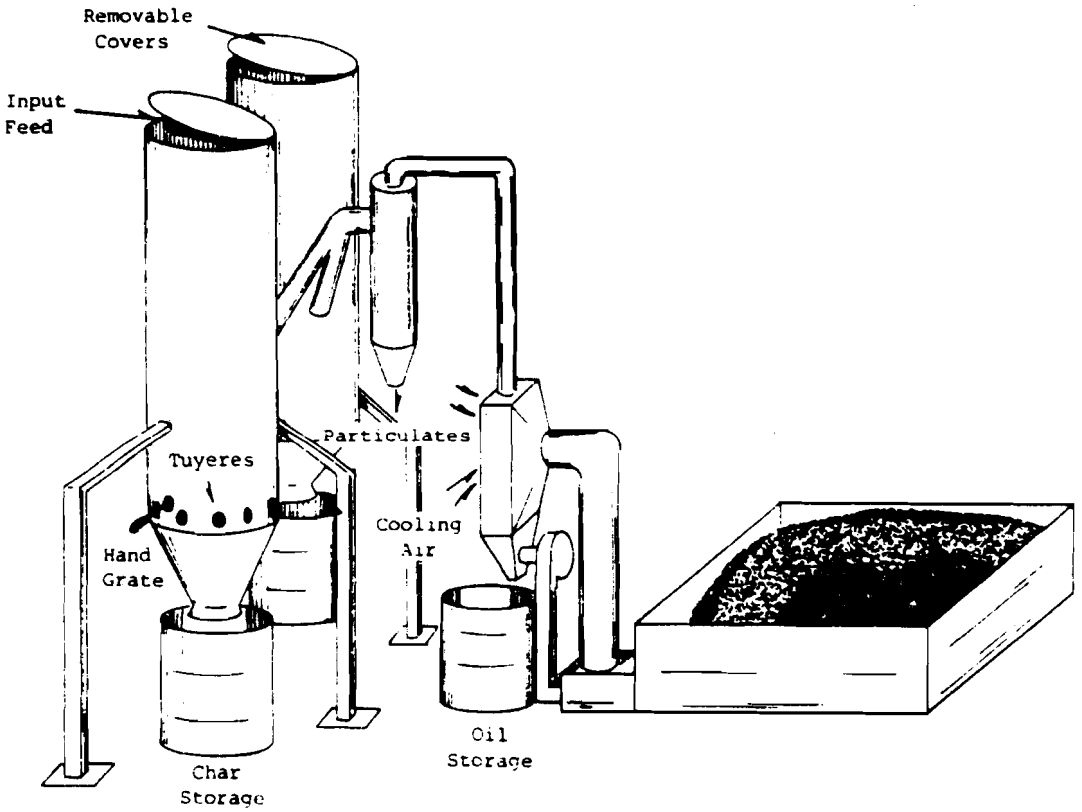
PYROLYTIC CONVERSION OF AGRICULTURAL AND FORESTRY WASTES TO ALTERNATE ENERGY SOURCES IN INDONESIA

A Feasibility Study

PREPARED FOR THE
AGENCY FOR INTERNATIONAL DEVELOPMENT



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Summary

This report describes the results of a short feasibility study of the application of pyrolytic conversion techniques to agricultural and forestry wastes in Indonesia. The study was conducted in Indonesia in a joint effort by personnel from the Engineering Experiment Station at the Georgia Institute of Technology and the Development Technology Center at the Institute of Technology Bandung. The principal circumstance that led to the study is the severe firewood cutting of the forests, especially in Java, which has resulted in damage to soil, water, and mangrove resources, with the resulting need for an alternate source of fuel for cooking. Agricultural and forestry wastes appear as a possible fuel source, but in their initial form are largely unusable for this purpose. However, through the use of pyrolysis, these wastes can be converted into clean-burning char and oil which can be easily stored and transported and a gas which can be used on site.

The study involved (1) an investigation of the production of agricultural and forestry wastes in Indonesia; (2) an evaluation of the market for the char, oil, and gas which are products of the pyrolytic conversion process; (3) the development of a preliminary pyrolytic conversion system design; and (4) an approximate economic evaluation of the system.

The primary results of the waste survey indicate that at least 17 million tons of wastes are produced in Indonesia each year, with rice hulls comprising a third of the total and sawmill, coconut, logging, rubber, oil palm wastes and bagasse comprising the remainder. From the available wastes it is estimated that about 1.5 million tons of charcoal and .9 million tons of pyrolytic oils could be produced. To put these numbers in perspective, this represents something like 15% of the total 1974 Indonesian energy consumption. The market survey reveals that domestic consumption of charcoal is declining because of increased home use of imported and heavily subsidized kerosene. However, it may be expected that this domestic familiarity with liquid fuels should facilitate the use of the pyrolytic oils for cooking and lighting. There does appear to be a great potential export market for the charcoal, however, and with anticipated increasing fuel prices, the use of charcoal as a home cooking fuel should likely increase.

The preliminary design study has produced three different appropriate technology one-ton-per-day systems using rice hulls as the fuel and for use at typical rice mills. All three systems could be easily fabricated in Indonesia. They are assumed to operate 150 days per year. The three systems include (1) a three-shift-per-day design with a drier, (2) a three-shift-per-day design without a drier, and (3) a larger, single-shift design without a drier. All the systems appear economically favorable, having an estimated return on investment of 16%, 15.7%, and 18.5%, respectively. The estimated total capital requirements are 1.4 million rupiahs, 1 million rupiahs, and 1.25 million rupiahs, respectively.[1/]

In addition to the above, the need for a follow-on demonstration program is discussed and a program plan devised.

1/ One U. S. dollar equals approximately 414 rupiahs at current (1976) exchange rates.

INTRODUCTION

Current Indonesian development plans (1)[1/] assume an average annual increase of about 7% in energy consumption throughout the last quarter of this century, with the result that by the year 2000 the energy required will have increased almost six times above today's needs. While Indonesia is fortunate to have abundant supplies of oil and coal, it currently depends heavily, and will continue to do so in the future, upon these fossil fuels, especially the oil, to provide it with the foreign exchange required for the planned development. Thus, since the needs of the country for energy are increasing and the need for foreign exchange is unabated, the obviously finite limit to Indonesia's fossil fuel reserves is a subject which cannot long be ignored (witness the crises of the Developed World). Clearly, a program to develop an alternate energy supply appropriate to Indonesia's needs should be of high priority. While there are a number of alternate energy sources, such as nuclear, geothermal, and solar, that show considerable promise, there is another that has not received the attention it deserves and which offers many advantages to Indonesia and other LDCs: energy from agricultural wastes and/or biomass (2), as it is often called.

An attractive means of converting biomass into high-energy fuels that can be stored, transported, and used much more efficiently and conveniently than the original agricultural waste is low-temperature pyrolysis. Low-temperature pyrolysis produces charcoal and oil, which are fuels that can be used by the people and thereby relieve the current heavy burden on Java's forests caused by the need for firewood. But before any program concerning the use of low-temperature pyrolysis can be implemented, however, a preliminary technical and economic feasibility study should be made to insure that an adequate supply of wastes is available, that a market exists for the products of pyrolytic conversion, and that the means for producing the necessary equipment is at hand.

Additionally it must be recognized that to practically utilize energy from wastes, especially in the homes, some changes in habit may be necessary and the development of auxiliary equipment, such as cooking stoves and lamps, that can burn the pyrolytic oils must be made. Further, the need for appropriate charcoal briquetting equipment should be noted.

1/ Numbers in parentheses refer to citations in the References section at the end of this report.

The present study, then, addresses this need and is a companion to an earlier investigation in Ghana (3), which complements the work presented herein. The study is divided into six parts: The first section introduces the technology of pyrolytic conversion of agricultural wastes into fuels. The second section identifies agricultural and forestry wastes in Indonesia. The third section points out markets for charcoal, oil, and gas and their competing products. The fourth section offers a preliminary design of a simplified pyrolytic conversion system. The fifth section illustrates the economics of the selected systems. Finally, the sixth section describes the steps necessary to implement a pilot project based on the study findings.

The study was limited to a four-week field trip and thus is necessarily limited in scope. Considerable data obtained for this study came from direct field interviews. Without the cooperation and assistance of various institutions and individuals in Indonesia, the study would have been impossible to complete.

The Development Technology Center at Bandung, under a subcontract, provided outstanding technical and logistical support throughout the study, including the construction and successful test operation of a small, laboratory-scale pyrolytic convertor.

AGRICULTURAL WASTE CONVERSION TECHNOLOGY

Advantages of Energy from Agricultural Wastes

Agricultural wastes represent a major potential alternate energy source in Indonesia which could provide an effective means to relieve the current strain on the forests in Java from firewood cutting. The development of a program to recover energy from wastes also would prolong the life of Indonesia's oil reserves and help generate badly needed foreign exchange required for its continued development. Since energy conversion from wastes is a relatively labor-intensive process, a program for using these materials as fuels could create substantial new employment opportunities in Indonesia.[1/] Additionally, it should be recognized that since these wastes are often a nuisance and are continuously produced, they represent an especially interesting means for supplementing Indonesia's energy needs because in their use the environment would be cleaned and the energy sypply would be renewable. Further, since the fuels derivable from these wastes can be produced in an ecologically clean manner, without the presence of any hazards such as nuclear accidents and oil spills associated with other energy sources, the public acceptance of such a program would be increased. Moreover, because the fuels produced from these wastes would contain essentially zero sulfur, they could be burned with no increase in atmospheric sulfur dioxide concentration.

Much of the waste produced is concentrated at process plants and offers the additional advantage of requiring minimum effort in collection. These process wastes are typically of a small individual particle size and could be readily used where required as fuels at the process plants themselves. Thus, such materials as rice hulls, sawdust, coconut shells, and oil palm wastes offer a convenient opportunity to produce significant quantities of high-energy fuels from a previously unusable source.

Not all the wastes are gathered; in fact, major amounts of logging residues in the outlying islands are left to rot in the forests and massive

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1/ The November 2, 1976, issue of the Indonesia Observer reported that on Java alone there are about 20 million unemployed.

amounts of rice straw[1/] are burned in the fields, thus polluting the rural air. Clearly not all the wastes can be practically used as fuel sources. However, wastes can be used to supply a major fraction of Indonesia's future energy needs.

Problems with Recovering Energy from Wastes

The use of agricultural wastes as an energy source has been considered frequently in the past but has not been widely practiced because of the following factors:

1. Agricultural wastes, even process wastes, are widely scattered, often far from potential energy users.

2. The wastes frequently contain significant amounts of water which, combined with the great distance involved, make transportation costs excessive.

3. The moisture content makes it difficult to efficiently employ conventional energy conversion techniques such as direct burning, and expensive boilers must be constructed to burn the wastes.

4. The wastes are usually produced seasonally and thus do not offer a steady supply of fuel.

Any successful system to utilize agricultural wastes as fuel must overcome these problems.

Pyrolytic Conversion of Wastes to Higher-Quality Fuels

Pyrolysis, which is the thermal degradation of lignocellulosic materials, is one promising means for converting wastes into higher-value fuels which can be transported, stored, and used more efficiently and economically than the original materials. The products of pyrolysis are a char, an oil, and a combustible gas. The char is a familiar product; however, the oil and gas are not so widely utilized at present. The applications of the char for home

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1/ It must be recognized that not all of the rice straw should ever be used for energy production since the organic content of the soil would be depleted. Likewise it is clear that some means to return to the soil nutrients such as potassium found in the stalk would have to be devised. However, since the residue from the conversion of these wastes to energy contains all these nutrients, it is not hard to imagine a soil conditioning program using the ashes from the wastes. It might be noted that the fertilizers used in the "miracle rice" production already include potassium and could be further enriched with this element if need be.

cooking or as an industrial or metallurgical fuel are also well known, but the uses of the gas and especially the oil are not generally appreciated.

A number of factors govern the relative amounts of char, oil, and gas produced through pyrolytic conversion; among them are the operating pressure, the time required for pyrolysis, and the temperature of the process. In the more commercially successful pyrolytic conversion systems developed to date, carbonization has occurred at near ambient pressure and at a relatively moderate rate. Thus the conversion temperature is, for practical purposes, the most important controlling variable. At higher temperatures, greater amounts of gas and oil are produced and the char yields are small; at lower temperatures, the char yields are large and the oil yields moderate. Since the oil and char are storable and more easily transported, they are of greater interest than the gas as the products of pyrolytic conversion of agricultural wastes. Thus low-temperature pyrolysis has a definite advantage in rural applications. This is convenient, since the materials problems associated with the higher temperature processes can create serious design difficulties.

Pyrolytic conversion can occur in batch processes, such as those historically used for making charcoal, or in continuous processes. Batch processes are simpler and allow carbonization of relatively large pieces; continuous processes are generally more mechanized and require the feed to be in smaller sizes, such as the wastes produced at agricultural processing plants. Continuous processes also allow the recovery of the pyrolytic oils, while this is not so easily accomplished with batch processes.

While pyrolysis is actually an exothermic reaction, once the feed reaches a temperature of several hundred degrees, the rate of this reaction without any external heat addition is usually too slow, especially for continuous processes, for commercial utilization. Thus most continuous flow systems require the addition of external heat.[1/] This heat can be added in many ways, i.e., directly through the walls of the containing vessel or retort, in a rotary-type kiln where combusion of some fuel is made within the kiln, or perhaps in a vertical shaft furnace where a small part of the charcoal produced is oxidized using

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1/ An important exception is the Stafford retort, which is designed to utilize the exothermic heat of decomposition in well-insulated kilns. Usually the kilns are very large and, even though the feed residence time is long, the charcoal production is substantial.

controlled air addition and the hot gases generated transfer the necessary heat to the feed. Combinations of these techniques also can be found.

Because of the simplicity and efficiency of the shaft furnace design, because it can be made to be self-sustaining, and because it provides greater flexibility in the type of feed that can be used, it has been developed over the last century in a variety of forms. While there have been some differences in the source of the energy, i.e., either by external combustion of the pyrolysis gas with subsequent introduction into the bed or by the simple addition of air and combustion of the char, almost all the designs have involved the introduction of the feed at the top of the retort, the removal of the char from the bottom, and the passage of the hot gases upward through the downward-moving feed. The gases are subsequently removed at the top of the unit, scrubbed, and passed through a condensing unit, from which the liquid fraction is recovered. Frequently the feed is dried externally, rather than in the bed itself, thereby allowing the utilization of the chemical rather than the sensible energy of the gas for drying. This results in another advantage, which is that less gas need be produced, thus allowing greater char and oil yields -- an important consideration for agricultural wastes.

In these systems involving partial burning of the char, the amount of air introduced can be used to control the reaction temperature, thus allowing variation in the product yields. One important consideration in the operation of these systems is to maintain the off-gas temperature well above the dew point of the mixture and even above the condensation temperature of all but the highest boiling point fraction of the pyrolytic oils. This is usually satisfied if the off-gas temperature is in the range of 350°F-400°F.

Several examples of this general type of pyrolytic conversion system, utilizing all or some of the above characteristics, include:

- the basic Stafford retort (4) used widely over the past 50 years in the U. S. and elsewhere for production of charcoal and liquid by-products
- the Mellman retort (5)
- the Lambiotte retort (6)
- the de Bartolomeis design (7)
- the Barneby process (8)
- the Georgia Tech design (9)

Obviously, the technology of low-temperature pyrolysis is well advanced and can be applied to Indonesia's needs with confidence.

While continuous conversion systems are suitable for process wastes, and do allow oil recovery, they generally are more complex and more expensive than simple kilns, which provide charcoal production only, but can readily process logging residues. Likewise, continuous processes are more vulnerable to shut-downs in LDCs because of reduced spare part availability. Thus, since the character of the wastes in Indonesia varies widely, a process that would accept all kinds of materials in various sizes and shapes and still allow oil recovery would be most desirable. However, it is important that such a system should work efficiently using rice hulls, since they represent the predominant waste. In a later section, a preliminary description of a system which has many of these desirable characteristics is presented.

In reviewing the previously mentioned problems of using agricultural wastes for energy production, it is useful to note that low-temperature pyrolysis systems produce dense, dry, high-energy fuels that can be easily stored and transported and used in existing facilities with little or no modification. By making the system transportable, the seasonal nature of these wastes can be dealt with. Thus, the problems characteristic of using these wastes can be materially reduced or resolved through the use of low-temperature pyrolytic conversion.

POTENTIAL SOURCES OF AGRICULTURAL AND FORESTRY WASTES FOR ENERGY CONVERSION IN INDONESIA

Agriculture is the principal economic activity in Indonesia. About 64% of the population is directly employed on farms during the major part of the year. If employment in forestry and in the manufacturing and selling of agricultural and forestry products is included, the percentage may reach over 80%. The quantity of waste materials associated with farming and manufacturing of agricultural and forestry products is enormous. This section, then, presents a discussion of the types of these wastes found in Indonesia along with a description of the quantities involved and the general locations where the wastes are produced.

In any discussion of wastes, there is an immediate difficulty which must be faced regarding the important distinction that should be made between the terms "wastes" and "available wastes." This is because there are many present commercial uses for "wastes," and while it is not too difficult to determine the quantities of wastes produced in most cases, it is often extremely difficult to identify what portion of those wastes is presently being used and what portion is actually "available." Conveniently, the predominant sources of waste in Indonesia, i.e., rice hulls and logging and sawmill residues, are generally used to a relatively minor extent. However, such materials as coconut, oil palm, and rubber tree wastes and bagasse, which are produced in prodigious quantities, are used to a significant but unknown degree. Therefore, some inaccuracies are likely present in the results shown in this study, since estimates of the available fraction of the wastes have been made of necessity.

In addition, there are likely problems of omission -- no doubt some waste types have been ignored due to lack of information regarding their existence and/or amounts. For example, peanut hulls and maize stalks, because of poor knowledge regarding their production rates and uses, are not included. Further, there is a semantic difficulty regarding the definition of what a waste actually is. For example, rice straw, which has historically been burned in the fields and used as a fertilizer -- by and large -- and is therefore not a waste, to a large extent could be replaced by chemical fertilizers and thus become a waste. However, for present purposes this straw has not been considered a waste even though its total dry weight could easily approach an order of magnitude greater than that of the rice hulls; hence, the energy potentially recoverable from this source is enormous.

A summary of the agricultural and forestry wastes in Indonesia which, based on the results of this field study, have a high potential for energy conversion is given below,[1/] along with the estimated available percentages:

	Annual Waste Production (in metric tons)	Estimated Percentage Available
Rice hulls	5.7×10^6	90
Logging wastes	1.4×10^6	50
Sawmill wastes	1.1×10^6	70
Coconut wastes	2.4×10^6	30
Oil palm wastes	1.5×10^6	30
Rubber wastes	1.9×10^6	30
Bagasse	3.1×10^6	10
Total	17.1×10^6	

The weight of these materials is in green tons.[2/] If all the estimated available wastes were converted into charcoal and oil, 1.5×10^6 tons of charcoal and $.90 \times 10^6$ tons of oil would be produced. The market value[3/] of these products would be about 28 billion rupiahs.[4/] To put this number in perspective, Indonesia consumed an amount of energy equivalent to 16 million tons of coal in 1974. Thus, charcoal and oil produced by pyrolytic conversion would be equivalent to about 15% of the total energy consumed in the nation in that year.[5/] If the energy potentially available from rice straw also were included, this percentage might be increased by a factor of three or more. Clearly, the potential impact of agricultural and forestry wastes as an energy source in Indonesia is highly significant.

It should be noted that in the event a pyrolytic convertor, based on a specific waste material, is to be built, a survey of available wastes to confirm

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1/ All weights given in this report are metric, except where otherwise indicated.

2/ The rice hull moisture content is taken at 14%. The remaining wastes are assumed to have a 50% moisture content.

3/ The producer's price for loose charcoal is taken as 12,000 rupiahs per ton; pyrolytic oil is valued at 10,560 rupiahs per ton.

4/ At current (1976) exchange rates, one U. S. dollar is worth 414 rupiahs.

5/ The energy content of the char and oil is approximately equal to that of coal.

the results of this study should be conducted. More importantly, a long-term supply of material should be assured before actual construction of a pyrolytic conversion plant is begun.

In the following sections the seven major types of waste identified above as potential raw materials for pyrolytic conversion are discussed in terms of production rates and location.

Rice Hulls

The production and marketing of rice constitute the dominant economic pursuit in Indonesia. The varied occupations associated with rice production and marketing include paddy cultivation in the wide tracts of rural land, thousands of rice mills scattered among farms, and numerous wholesalers and retailers of rice in villages and cities. Since rice is the major food staple of the land and 129 million people consume it daily, the importance of rice to Indonesia can only be imagined. About 62% of the rice production is centered in Java, which contains a comparable fraction of the national population.

After the rice is harvested, the separation of stalk and rice grains is typically done at the farm by simple foot-pedaled or hand-operated threshers. Rice stalks, which contain potassium, are presently being left on the farms and are typically burned, thereby returning the potassium to the soil. Only about 10% of the stalk from the local rice variety goes through the rice mills and is used for papermaking or for mushroom cultivation. The stalk of the local rice variety has a value of 15-20 rupiahs per kilogram for these purposes, but the stalk and leaves of the miracle rice currently have no value. In sum, rice stalks in Indonesia cannot currently be considered as waste because they play an important function in maintaining soil fertility. However, in the future, chemical fertilizers could be used to replace the rice stalks if the economics were favorable.

Today, the rice is generally sent for grinding to mills rather than using the older manual methods. However, in the outlying areas, the older methods are still practiced to some extent. Two kinds of wastes are generated in the milling and polishing processes -- rice hulls and fines, or bran. These wastes constitute about one third of the weight of rice grains input. The balance is the output of milled and polished rice. Of the total grain, rice hulls constitute about 25% and fines make up about 8%. Fines, or bran, are

Table 1

THE DISTRIBUTION OF RICE MILLS BY PROVINCE, PRODUCTION, RICE HULLS GENERATED, INDONESIA, 1975

Province	Number of Rice Mills		Milled Rice Production (metric tons)	Hulls Generated (metric tons)
	Large	Small		
West Java	273	5,994	3,675,375	1,357,683
DKI Jakarta	1	26	14,692	5,427
Central Java	145	3,855	2,671,376	986,806
D.I. Yogyakarta	8	872	284,485	105,088
East Java	245	4,022	2,801,172	1,034,753
D.I. Aceh	70	1,071	456,859	168,764
North Sumatra	269	2,044	981,846	362,694
West Sumatra	1	841	479,224	177,025
Riau	2	198	146,903	54,266
Jambi	2	406	212,171	78,376
Bengkulu	-	141	110,503	40,820
South Sumatra	11	2,072	477,433	176,364
Rampung	63	1,080	356,793	131,799
West Kalimantan	3	403	282,567	104,380
Central Kalimantan	-	257	112,933	41,717
South Kalimantan	19	683	322,638	119,182
East Kalimantan	-	209	70,175	25,923
North Sulawesi	-	121	127,467	47,086
Central Sulawesi	-	88	119,993	44,325
South Sulawesi	13	2,761	788,568	291,297
Southeast Sulawesi	-	64	29,238	10,800
Maluku	-	39	5,975	2,207
Irian Jaya	-	19	670	247
Bali	-	705	323,925	119,658
N.T.B.	17	55	359,512	132,804
N.T.T.	2	33	129,829	47,959
Total	1,144	28,059	15,342,322	5,667,450

Note: Large mill = One metric ton or more per hour.
Small mill = Less than one metric ton per hour.

Source: Directorate for Food Crops Promotion, Sub-Directorate for License, Ministry of Agriculture, Jakarta.

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Published data giving potential or maximum allowable cut of logs and potential logging and sawmill wastes by province in Indonesia for 1974-1975 are presented in Table 2. Based on the potential production data, estimated logging and sawmill wastes were derived on the basis of actual log and sawmill outputs in 1974. The quantity of logging wastes in 1974 was estimated at 1,426,573 tons in Indonesia, while sawmill wastes were estimated at 1,103,897 tons. East Kalimantan, Central Kalimantan, and Riau are the major logging and sawmilling centers of Indonesia.

Coconut Wastes

Indonesia has slightly over 2 million hectares in coconut plantations. Over 99% of this acreage is operated by small holders and only slightly less than 1% is operated by "estates." An "estate" is a government institution organized to own and operate the plantations for the production of various crops.

Coconut production is centered in North Sulawesi, West Java, East Java, and North Sumatra. The nation produced 1,365,000 tons of copra in 1974.

The average weight contents of a coconut are given as follows:

Components	Percent
Husk	40
Copra	33
Shell	17
Water	10
Total	100

Waste volume estimates are as follows:

Husk	1,654,000 tons
Shell	703,000 tons
Total	2,357,000 tons

A portion of the husks and shells is used by farmers for drying the copra. The remainder is burned; however, the amount burned is unknown. These wastes are at the sites of coconut plantations.

Oil Palm Wastes

The nation had 164,300 hectares of oil palm plantations in 1974, nearly all of which are state-run estates. The distribution of oil palm estates is given in Table 3.

Table 2

POTENTIAL LOGGING AND SAWMILL WASTES IN INDONESIA, 1974

Province	Logging Wastes		Sawmill Wastes	
	Potential Volume 1/ (cubic meters)	Estimated Actual Volume (metric tons) 2/	Potential Volume 1/ (cubic meters)	Estimated Actual Volume (metric tons) 2/
West Java	65,957	11,872	51,172	9,211
Central Java and Yogyakarta	63,214	11,379	49,044	7,357
East Java	111,557	20,080	86,450	15,561
Aceh	323,850	58,293	251,253	45,225
North Sumatra	210,600	37,908	156,390	28,150
West Sumatra	135,600	24,408	105,203	18,936
South Sumatra	231,300	41,634	179,450	32,301
Riau	652,350	117,423	506,115	91,101
Jambi	471,450	84,861	365,766	65,721
Bengkulu	117,750	21,195	91,354	16,444
Rampung	45,900	8,262	35,611	6,410
West Kalimantan	422,925	76,126	328,119	59,061
Central Kalimantan	1,671,075	300,794	1,296,476	233,366
South Kalimantan	135,300	24,354	104,854	18,874
East Kalimantan	2,253,600	405,648	1,748,418	314,715
North Sulawesi	77,550	13,959	60,166	10,830
Central Sulawesi	214,500	38,610	166,417	29,955
Southeast Sulawesi	46,650	8,397	36,193	6,515
South Sulawesi	150,300	27,054	116,608	20,989
West Nusa Tenggara	13,050	2,349	10,125	1,823
Maluku	404,730	72,851	314,003	56,521
Irian Jaya	106,200	19,116	82,394	14,831
Total	7,925,408	1,426,573	6,144,581	1,103,897

1/ Derived from published potential volume for logging and sawmilling wastes by province in 1974-1975.

2/ The conversion into actual wastes volume in metric tons is based on the following equation:

MT = PW x .6 ÷ SV x D, where

MT = Metric Tons of estimated actual waste volume

PW = Potential Waste volume given in the table as M^3. Actual Waste volume estimated based on 1974 log production is 60% of PW

SV = Solid Volume, which equals Actual Waste volume divided by 2.

D = Wood Density of .6 ton/M^3 to arrive at metric tons

Source: Evaluation of Forest Utilization for Wood Processing Plants in Indonesia, 1975, Directorate General of Forestry, Ministry of Agriculture, Jakarta, 1976.

Table 3

NUMBER OF OIL PALM ESTATES BY PROVINCE IN 1973

Province	Number of Estates
Aceh	9
North Sumatra	48
Riau	1
West Sumatra	1
Rampung	6
West Java	3
Total	68

Source: Statistical Pocketbook, Indonesia, 1974-1975, Central Bureau of Statistics, Jakarta, 1975.

From the tables, it is obvious that North Sumatra is the oil palm plantation center in Indonesia. The area exported 385,020 tons of palm oil in 1975 and the volume is expected to increase 8.84% per year. According to Asjari Darus, Head of the North Sumatra Trade Service, the export in the area is projected to reach 732,740 tons by 1985.[1/]

The average yield of oil palm fruits and bunches is estimated at 9.4 tons per hectare. The weight distribution between the fruit and the bunch of oil palms is given below:

Bunch stem	40%
Fruit	60%
Husk	60% of the fruit
Shell	32% of the fruit
Kernel	8% of the fruit

Waste volume estimates are as follows:

164,300 hectares x 9.4 tons fruits and bunches	= 1,544,420 tons
Bunch stem wastes	= 617,768 tons
Fruits	= 926,652 tons
Husks	= 555,991 tons
Shells	= 296,529 tons
Kernels	= 74,132 tons

1/ Indonesia Times, October 26, 1976.

Thus the total waste volume, which includes bunch stems, husks, and shells of the oil palm production, is estimated at 1,470,288 tons in 1974.

It is interesting to note that coconut shell and oil palm shell are two excellent materials for pyrolytic conversion, and these two materials deserve special attention. Dimensionally they are the right size for pyrolytic conversion using continuous processes without additional chopping or hogging. Physically they have high density and are excellent materials for making activated charcoal, which commands a much higher value in the world market than ordinary charcoal. These two sources of shells, based on currently estimated data, have a total weight of 995,500 tons per year in Indonesia. Assuming a yield of 6% activated carbon, this would produce 59,730 tons of activated carbon per year. Assuming the world price of activated carbon is $500 per ton, $29,965,000 worth of commodities would be created out of these shell wastes in Indonesia.

Rubber Wastes

Indonesia had 2,303,400 hectares in rubber plantations in 1974. Of the total acreage, small holders constituted 81%, while estates made up the balance. West Java and North Sumatra are the major provinces for rubber plantations. The distribution of estates of rubber plantations is given in Table 4.

The productivity of a rubber tree depends greatly on cutting practices. In general, after 25 to 30 years' cuttings, a plantation of rubber trees should be removed for replanting because of the declining yields of the trees. It is estimated that 3% to 5% of the total acreage of rubber plantations in Indonesia is being replanted each year. In 1973, 12,628 hectares were replanted; each hectare had an average of 500 trees. However, 300 trees per hectare are used here for waste-volume estimates because of mortalities during the years after planting. It is further estimated that each cut-down tree weighs about one-half ton. The quantity of old rubber trees being cut down for replanting purposes is estimated as given below:

12,628 hectares x 300 trees = 3,788,400 trees

3,788,400 trees x ½ ton = 1,894,200 tons

At present, the primary use for old cut-down trees is as a fuel for smoking rubber. Only a small portion is currently being sold as firewood or being

Table 4

NUMBER OF RUBBER ESTATES BY PROVINCE, 1974

Province	Number of Estates
Aceh	35
North Sumatra	160
Riau	53
West Sumatra	4
Jambi	5
South Sumatra	7
Rampung	15
West Java	246
Central Java	49
East Java	85
Bali	1
West Kalimantan	10
South Kalimantan	17
North Sulawesi	2
South Sulawesi	4
Southeast Sulawesi	1
Total	694

Source: Statistical Pocketbook, Indonesia, Central Bureau of Statistics, Jakarta, 1975.

converted into charcoal for export. However, the percentage of the total available wood that is actually wasted is uncertain.

Bagasse

Indonesia has 57 sugar processing plants (in 1976). Fifty-five of them are in Java. Sugarcane cultivation and sugar refining are largely done in East Java and Central Java. The distribution of sugar plants by province, cane processed in 1975, and bagasse generated are presented in Table 5.

Nearly all the bagasse is or soon will be burned as boiler fuel in sugar refining. Only an insignificant amount is used in papermaking or as pressboard material. Because of the high moisture content of bagasse, burning it directly

Table 5

THE DISTRIBUTION OF SUGAR PLANTS BY PROVINCE, CANE PROCESSED, SUGAR PRODUCED, AND BAGASSE GENERATED IN INDONESIA, 1975

Province	Number of Plants	Cane Processed (in tons)	Sugar Produced (in tons)	Bagasse Generated
East Java	33	5,964,242	596,424	1,816,112
Central Java	16	2,891,972	289,197	880,605
West Java	6	1,084,876	108,488	330,345
Outside Java	2	361,627	36,163	110,115
Total	57	10,302,717	1,030,272	3,137,177

Source: Indonesian Sugar Experiment Station, Pasuruan, Indonesia.

as a boiler fuel entails a loss in thermal conversion efficiency of about 40%. Through pyrolytic conversion into a char and oil mixture, bagasse would become a higher-quality fuel with a much smaller loss in thermal conversion efficiency when it is used in a properly designed, lower-cost boiler. The replacement of an old boiler with a new one requires the consideration of capital costs. However, when a worn-out boiler in a sugar plant needs a replacement, it would be appropriate to consider pyrolytic conversion of bagasse because of the substantial savings in the boiler cost and significant improvements in conversion efficiency that could be realized.

MARKETS FOR PRODUCTS OF PYROLYTIC CONVERSION IN INDONESIA AND THEIR COMPETING PRODUCTS

Charcoal, oil, and gas are the three end products from pyrolytic conversion. The gas is most practically used on site for such purposes as drying; however, the other two end products, charcoal and oil, must compete in the market with cheaply available kerosene, diesel and fuel oils, and with firewood. In order to understand the situation in which the charcoal and pyrolytic oil have to compete, the current market for the major domestic fuels is described separately.

Kerosene

Kerosene is a petroleum-based derivative. It has clean burning characteristics and is easily handled. In Indonesia, the processing of kerosene is heavily subsidized by the government in order to provide a cheap fuel for domestic uses and to relieve the burden on the forests resulting from firewood cutting. The production cost of a liter of kerosene is estimated at about 26 rupiahs and the net sale price (f.o.b.) of a liter of kerosene is 16 rupiahs; the result is a loss to the government of approximately 10 rupiahs. The consumption of kerosene in Indonesia was reported at 4,868,663,000 liters in 1975, which meant that the government subsidies were at 48,686,630,000 rupiahs for the kerosene production in that year. By 1977, the domestic consumption of kerosene is projected to reach 6,150,000,000 liters. If the production costs remain the same, the government will have to pay 61,500,000,000 rupiahs for subsidies.

Kerosene is used largely by city dwellers for cooking and lighting purposes. However, in rural areas, kerosene is used more for lighting. Retail prices of kerosene may be 25 to 30 rupiahs per liter because of markups in the various middleman transactions.

Indonesia is one of a few oil exporting countries in the world.[1/] However, the known proven oil reserves may be exhausted in 20 years if no new discoveries

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1/ Indonesia is importing lower-value Arab oils (higher sulphur content) for domestic consumption. On the other hand, it is exporting higher-value domestic oils to Japan and the U.S.A. Pyrolytic conversion of agricultural wastes into charcoal and oil to replace some portion of kerosene consumption would save the nation a considerable amount of foreign exchange from importing Arab oil.

are made. Further exploration for new oil is likely to depend upon the world price of oil and the costs of exploration.

Diesel Oil and Fuel Oil

Diesel oil and fuel oil are both industrial fuels which would compete directly with the charcoal and the pyrolytic oil. The processing of both oils is subsidized by the government for the same reason as kerosene. The domestic consumption of the oils and government subsidies are given in Table 6.

Table 6

DOMESTIC CONSUMPTION OF DIESEL AND FUEL OILS IN 1975 AND PROJECTED CONSUMPTION IN 1977, WITH GOVERNMENT SUBSIDIES, INDONESIA

	1975		Projected 1977	
Kind	Consumption (kiloliters)	Government Subsidies (rupiahs)	Consumption (kiloliters)	Government Subsidies (rupiahs)
Diesel Oil	708,758	4,252,548,000	1,130,000	6,780,000,000
Fuel Oil	1,085,360	6,512,160,000	1,660,000	9,960,000,000
Total	1,794,118	10,764,708,000	2,790,000	16,740,000,000

Source: Directorate General of Oil and Gas, Department of Mining, Jakarta.

The consumption of diesel and fuel oils was reported at 1,794,118 kiloliters in 1975 and was projected to reach 2,790,000 kiloliters by 1977. The government subsidies for the production of these two fuels would increase from 10,764,708,000 rupiahs in 1975 to 16,740,000,000 rupiahs by 1977. The enormous costs to the government to maintain cheap fuels for domestic consumption are obvious.

Firewood

Firewood of various kinds and species is the dominant fuel for domestic cooking despite the low cost of kerosene. The sources of firewood come largely from the forests, mangrove trees on the beaches, cut-down rubber trees, coconut trees, oil palms, logging wastes, sawmill wastes, etc. No reliable statistics are available on the production and consumption of firewood. However, it is estimated that the uses of firewood are equal to twice the commercial energy

consumption in Indonesia.[1/] The rapid disappearance of trees and forests as a result of the demand for firewood has alarmed many authorities in the world. A recent article in the Indonesia Times aptly described the situation.

> A century ago tropical forests provided an inexhaustible supply of energy in the form of firewood for the poor of the world. Today the forests are disappearing at the rate of 15 hectares a minute. In the developing world the shortage of firewood is becoming critical. The increasing rate of destruction of trees in the developing world shows no sign of abating, as between one and two thirds of the rural population burn up these forest products. . . . Exhortation not to chop down bushes or trees can have little effect, if people have no other means of cooking. The third world's energy crisis could become much worse unless some alternative to firewood as fuel becomes available.[2/]

To find alternatives to firewood is one of the major objectives in conducting this field study in Indonesia. Pyrolytic conversion of agricultural and forestry wastes into charcoal and oils may make them important alternative sources of fuel energy to the population in the years to come because these wastes are self-generating as long as farming and forestry activities are conducted in Indonesia.

Firewood is sold at about 1,500 rupiahs per cubic meter in rural areas and about 3,000 rupiahs in cities. A large percentage of the firewood consumed in the nation is obtained simply by foraging into nearby forests by the rural population. The loss of trees and bushes causes erosion and depletion of the fertility. How to stop the practice of chopping down trees and bushes in rural areas is a delicate problem. Firewood is used not only for domestic cooking, but also as industrial fuel for drying roof tiles, bricks, etc.

Potential Market Outlets for Pyrolytic Oil

The weight of oils produced by pyrolytic conversion is equal approximately to 75% to 80% of the weight of charcoal produced. Although the oils presently cannot be used directly as fuels for combustion engines, they could be used as fuels for cooking, drying, steam and electrical power generation, and for

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1/ Filino Harahap, "The Prospect of Solar Utilization, the Indonesian Case," paper presented to the Symposium on Energy, Resources and the Environment, February 25 to 28, 1975, Jakarta.

2/ Alastair Matheson, "Third World Faces a Firewood Crisis," Indonesia Times, November 3, 1976.

lamps. Pyrolytic oils could be used as fuel in the place of firewood in thousands of kilns throughout Indonesia used for making roof tile. They also could be used in the same way in making bricks, which is another large industry within Indonesia. A mixture of pyrolytic oils and charcoal could be used as boiler fuel in factories, in steamships, in trains, and in power stations.

Pyrolytic oil, because of its convenient form, should be a suitable fuel for domestic cooking purposes. It would appear that a simple cooking stove based on the oil could be designed and manufactured in Indonesia. The domestic cooking and heating market may well be a good potential outlet for the oil because of its instant generation of heat, because of the cleanliness of its burning, and because of the ease of control in using it. A good cooking stove design is essential to the success of promoting the oil for domestic cooking purposes. In addition, the stove itself would become a manufacturing opportunity in Indonesia. If it is accepted in the market, it could become an export item together with the oil.

Pyrolytic oil also can be used for lamplight.[1/] Kerosene-type lamps are already commonly used in Indonesia. With some modification of the lamp, pyrolytic oil could replace kerosene if it were produced in large quantities. Modified kerosene lamps could become another manufacturing opportunity in Indonesia.

The heating value of pyrolytic oil is approximately equal to two thirds that of kerosene. As a result, the market value of pyrolytic oil is given at two thirds of the current market price of kerosene, which is sold at 16 rupiahs per kilogram (net sale price f.o.b. refinery). Pyrolytic oil should be valued at 10.56 rupiahs per kilogram or 10,560 rupiahs per ton.

It should be noted that the pyrolytic oils, in their initially produced form, have a pungent odor, are mildly corrosive at room temperature, and upon exposure to air do tend to polymerize. Thus further work to stabilize the oils needs to be done before the applications of lighting and cooking are immediately pursued. There is no reason to expect, however, that the necessary

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1/ Very preliminary tests of the burning characteristics of pyrolytic oil in a standard kerosene lamp have indicated that while the oil burns cleanly, with no odor with a standard cotton wick, there is insufficient wicking action because of its relatively high viscosity. Thus a modification to the standard kerosene lamp design or a different wick will be required.

modifications to the oil characteristics cannot be made. Experience with these oils at Georgia Tech's Engineering Experiment Station indicates that the corrosion problem, even with untreated oils, is not excessive, 55-gallon steel drums of these oils having been stored routinely for two or more years without leakage. Furthermore, in LDCs such as Indonesia, wood or ceramic storage containers might be more readily available than metal ones and would have essentially no corrosion problems.

Potential Market Outlets for Charcoal

Because cheap kerosene and firewood are available as domestic fuels, the charcoal production in Indonesia is declining. Unfortunately there are no reliable statistics concerning the production and consumption of charcoal. This is because a large amount of charcoal is produced and sold without being reported by small holders using wood obtained from the forests. Foraging forests for charcoal making is illegal; however, the practice goes on.

Forest Service published data on charcoal production and exports are given in Table 7. According to the table, exports are increasing and production is declining. However, a contradiction exists because the export volume exceeds the production volume. It is believed that the production refers to domestic consumption excluding the export volume. Generally there is some question about the validity of the data for the reasons previously cited; however, it is the only published source of information available..

Table 7

CHARCOAL PRODUCTION AND EXPORTS IN INDONESIA, 1968 TO 1975
(in tons)

Year	Production	Exports
1968	646,000	-
1969	120,000	-
1970	6,517	-
1971	15,436	18,983
1972	30,992	25,826
1973	38,702	34,345
1974	-	51,686
1975	30,566	47,029

Sources: Production - Statistical Pocketbook, Indonesia, 1974/1975, Central Bureau of Statistics, Jakarta, Indonesia; Exports - Indonesia Forests, 1975, Directorate General of Forestry, Jakarta, Indonesia.

There are three kinds of charcoal producers in Java -- Forest Service (government), estates (semigovernment), and small holders (privates). Based on one estimate, the government supplies about 70% of the charcoal market in Java, estates 20%, and privates 10%. The total volume of charcoal consumed in Java is insignificant compared with the total energy needs for domestic cooking.

The charcoal export business in Indonesia appears to be a growing enterprise. According to one report, a number of charcoal producers in Sumatra export about 1,000 tons of charcoal to Singapore, Hongkong, and Japan daily. (Clearly such amounts of charcoal production are totally inconsistent with the data presented in Table 7 and caution must be advised in the use of these results.)

Charcoal production in Java is accomplished by earth mounds. Mound charcoal is produced by piling pieces of timber or wood together in mounds and setting the pile afire. Then the pile is covered with earth and allowed to smolder for a week or so. After the fire goes out, the charcoal is removed. The method is primitive and wasteful, producing barely half the quantity of charcoal which might be obtained from the same amount of wood by a more efficient method such as pyrolytic conversion.

The charcoal produced by the Forest Service in legal operations is sold at 14,000 rupiahs per ton to wholesalers. Labor costs constitute the largest single outlay in production, about 9,500 rupiahs per ton. Wholesalers pay about 3.5 rupiahs per kilogram for the charcoal to be shipped to a city about 60 kilometers away. Wholesalers' prices are 45 to 50 rupiahs per kilogram on chunk charcoal and about 33 rupiahs per kilogram for loose charcoal. The retail value of charcoal may reach as high as 75 rupiahs per kilogram, depending upon the quality and distance from the sources of supply.

A wholesaler in Bandung sells only about 200 kilograms of charcoal a day with a profit margin of 15 to 16 rupiahs per kilogram. The sales of a retailer average only about 30 to 50 kilograms a day.

Because of the declining use of charcoal, it appears that the market for pyrolytic-conversion charcoal in Java may be limited. However, successful pilot plants could be introduced to sell a moderate amount of charcoal for domestic uses. If pyrolytic conversion is to be introduced in Indonesia on a large scale, exports to Singapore, Hongkong, and Japan should be explored thoroughly.

It should be noted that charcoal produced by pyrolytic conversion may be in a loose and pulverized condition, while mound and kiln charcoal are in lump form. Lump charcoal is more suitable for domestic cooking and heating purposes, while loose charcoal, until it is briquetted, is more suitable for industrial applications such as boiler fuels. As an industrial fuel, loose charcoal has to compete with coal and raw-grade oils such as Bunker C. Coal production in Indonesia has suffered the same fate as charcoal, a declining trend, because it cannot compete with the government's subsidized fuel oils.

PRELIMINARY DESIGN OF A PYROLYTIC CONVERSION SYSTEM

General

This section presents a preliminary description of a pyrolytic conversion system appropriate to the Indonesian situation. The rationale for the selection of the waste to be processed and the size of the plant are discussed, and the design philosophy is described. In addition, a brief description of the selected design(s), together with comments regarding its working operation, is offered.

Waste Selection

While a variety of agricultural wastes are produced in Indonesia, the survey demonstrates the overwhelming preponderance of rice residues, especially rice hulls, compared with any other. Thus rice hulls appear to provide the greatest opportunity for waste conversion at present, although wood residues in some outlying areas of Indonesia, but not in Java, offer an attractive alternative.

Since rice is collected at mills for processing, the logical location for a pyrolytic conversion system is there. Because the new "miracle rice" allows the harvesting in many locales of three crops each year -- two occurring during the monsoon season -- the need for a mechanical drying system at the mills to augment or perhaps replace sun drying is indicated.[1/] (Conveniently, with the new rice, significantly more hulls are produced than with conventional rice, thus making the potential energy recovered from rice hulls much greater than in the past.) A fortunate occurrence is the fact that in using the low-temperature pyrolysis system previously discussed, drying of the feed material also is required. Consequently, the opportunity for integrating the pyrolytic conversion system into the milling operation by drying the "paddy" with energy supplied from the convertor itself is provided. This would be a happy marriage, since a portion of the production costs of milled rice (the drying costs) thereby could

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1/ Even though sun drying is usually less expensive than mechanical drying, the production of an extra crop during the monsoon may force the rice miller to convert to mechanical drying. Thus, unless some auxiliary heat source is available, this may further increase the energy required in the production and cultivation of "miracle rice" -- an ironic circumstance in these days of energy shortages.

be substituted for the costs of producing an additional product, the result being a considerable profit increase to the miller and a reduced demand on Indonesia's fossil fuel reserves. Since a number of personnel would be required to operate the conversion system, there need not be any loss of jobs from the cessation of sun drying; indeed there likely would be a substantial increase in the employment requirements. If a charcoal briquetting plant were operated in conjunction with the conversion system, a further advantage could be gained since the briquetting could be done during the slack season, thus providing a stabilizing influence on mill employment.

The above considerations provide a convincing argument to design the conversion system for use at a rice mill. While the conversion of wood residues does offer an attractive alternative, the selection of a system design primarily applicable to rice hulls is believed to be more appropriate at present in Indonesia, especially since an intermediate technology system for wood wastes is described in (3). Thus, in the sections to follow, a system primarily suitable for rice hull conversion and located at a rice mill is discussed and a design philosophy appropriate to Indonesia is developed.

System Capacity

Examination of the data concerning rice production indicates that the overwhelming majority of the rice in Indonesia is processed in mills having capacities in the range of two to four tons of rice per day. Thus a mill producing about three tons per day appears to be representative. Such a mill would typically produce about one ton of hulls (14% moisture) and about one-third ton of bran each day, additionally. Therefore, a one-ton-per-day pyrolytic conversion system would be an appropriate size. This is a convenient choice since it allows for the use of a single International Rice Research Institute (IRRI) drier (18) operating on a three-shift basis to dry the paddy. Additionally a one-ton-per-day conversion system, if need be, could be readily disassembled and transported to another site during the slack season.

Design Philosophy

The crucial element in the design philosophy is the requirement that the system be appropriate to the needs of Indonesia. The technology utilized and the level of labor intensity must be chosen to best suit the local Indonesian situation. Ideally, the system should be designed as simply as possible,

possess reliable, rugged operating features, have only a few moving parts, require negligible maintenance, have a minimum number of imported components and/or materials, and operate as flexibly as possible. In addition, commonality of motors, bearings, etc., as much as practicable, should be sought. Moreover, while labor-intensive methods generally should be applied, care must be taken not to compromise system performance by replacing critical components by manual operators who can occasionally be distracted from their duties. Additionally, the system design should allow for operator inattention and be designed, where possible, to be fail safe. Finally, the system components should be readily available in Indonesia, insofar as possible, and be off-the-shelf, where practical.

The results of a survey of a number of large, medium-size, and small metal fabrication shops in Bandung, Surabaya, and Jakarta indicate that in Indonesia the general availability of materials -- including iron, aluminum, copper, steel, stainless steel, sheet metal, and tubing -- is adequate and that the people's ability to work with these materials is excellent. Even in the smallest shops, surprising but simple techniques allow fabrication of relatively complex components. Indonesian ingenuity and the relatively low labor cost make techniques practical that would be out of the question elsewhere; but these methods are effective and economical. Thus there appears to be no difficulty in fabricating and assembling components for any practical pyrolytic conversion system. Moreover, the availability of components such as electric motors, gasoline engines, blowers, and other manufactured items is quite adequate for the needs of any conversion system contemplated.

Alternative Designs

While mechanical drying of the paddy, using heat available from combustion of the pyrolytic gases, is an attractive approach for many rice mills, there likely will be numerous situations where sun drying is still preferred. Moreover, although it is desirable to reduce initial capital requirements and maximize labor needs by full utilization of the conversion system, the difficulty of obtaining crews for three-shift operation and the convenience of processing only during the times when the mill itself is running make necessary the consideration of systems operating on both a single shift and on three shifts. In all cases, because the convertor is assumed to be located at a rice mill, where either electrical or mechanical power is available, there seems to be no need

to consider completely manually operated systems (although in unusual circumstances such systems may be required and could readily be devised). Thus there appear to be three general classes of pyrolytic convertors applicable to Indonesian needs:

(1) A relatively mechanized system, operating on three shifts with one-ton-per-day capacity and including a drier. The system probably would be at a rice mill in a locale where three crops of rice are harvested each year.

(2) A more simplified system, without a drier,[1/] and operating on three shifts with one-ton-per-day capacity which would probably be located at a rice mill in an area where only two annual crops are harvested and where sun drying is practical.[2/]

(3) A more capital-intensive system, with one-ton-per-day capacity but requiring only a single-shift operation.

Obviously a mixture of these cases is possible. However, in all systems, the design of the basic pyrolytic conversion unit or kiln would be the same.

The technical approach to the development of these systems is also an important consideration. One approach might be to use existing practices; another might involve the development of more advanced, inexpensive, and maintenance-free components. The first designs could be made with relative confidence immediately; the latter would require some development. Both approaches have merit and together would provide for both today's and tomorrow's needs. The presence at the Institute of Technology Bandung (ITB) of the Development Technology Center (DTC), together with its skilled and experienced personnel, offers an especially promising opportunity to pursue both paths.

Thus the system for pyrolytic conversion of waste in Indonesia to be described in the next section involves four different design approaches:

1/ Thus flaring of the off-gas would be necessary. While this would initially be a wasteful practice, it is likely that this gas would be quickly utilized once its potential and presence were recognized since it represents an ideal source of clean energy for other commercial applications.

2/ It appears that the need for drying the first rice crop is reduced because the supplies of stored rice from the previous season have been depleted by the time this rice has been harvested and the rice produced can be quickly sold. Thus only the second crop must be dried for storage; however, this can be done after the monsoon season has ended and the dry season returns.

(1) A mechanized system, with a drier, using existing practices, and based on a three-shift operation.

(2) A more labor-intensive system, without a drier, using existing practices, and based on a three-shift operation.

(3) A mechanized system, without a drier, using existing practices, and based on a one-shift operation.

(4) A mechanized system, with a drier, using more advanced practices.

In a later chapter, an economic analysis of the first three systems is presented. The economics of the latter system, since it represents a future design, has not been investigated.

System Description

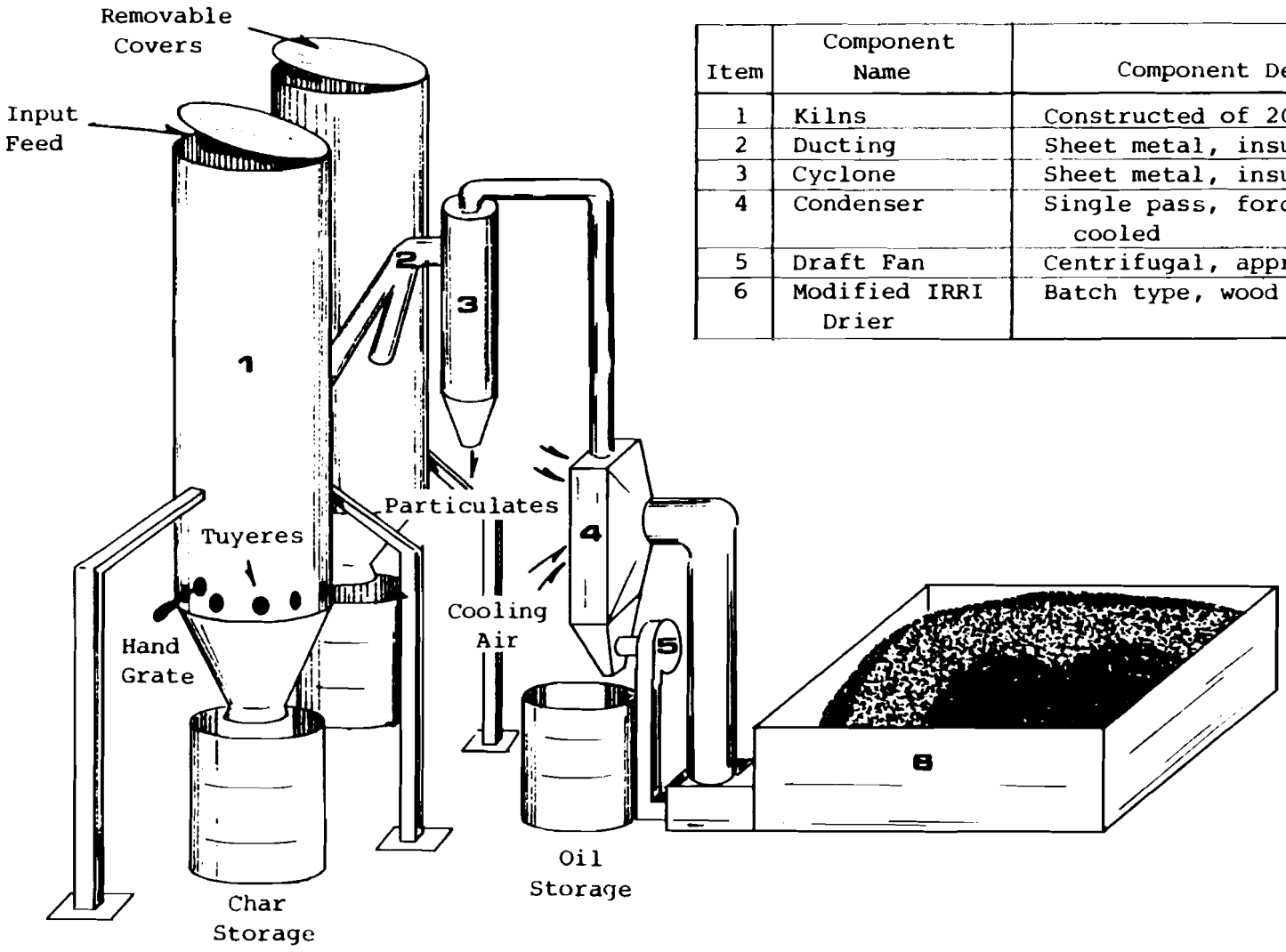
The first three selected system designs are shown schematically in Figures 1, 2, and 3. In the figures, the various components for each system are numbered and a brief description of each is presented in a table insert. In the fourth design (not shown), typical improvements such as the integration of the cyclone (scrubber) and the condenser[1/] and the use of a pumping ejector (rather than a mechanical blower) would be investigated. It is likely that other component simplifications also can be found; however, these two appear presently to offer the most promise since they should result in considerably reduced cost and lower maintenance.

In all the designs presented, a basic characteristic is the use of the same kiln or pyrolytic conversion unit design. The differences all lie in the off-gas systems and in the presence or absence of a drier. For example, designs 1 and 3 are basically the same except that the convertor in design 3 is larger and no drier is used.

1/ Using a conventional condenser design approach, a recurring problem is blockage of the condenser tubes by particulates not removed by the scrubber. In the proposed approach, the condensation process would not involve a solid boundary, and thus clogging would be much less of a problem. Additionally the particulates could be removed from the oil using a disposable oil filter, perhaps composed of the rice hulls themselves. It would not be expected that the fine fraction of the feed would be a problem since microscopic examination of the hulls indicates only a very minor portion of the waste to be in the fine particle range.

Figure 1

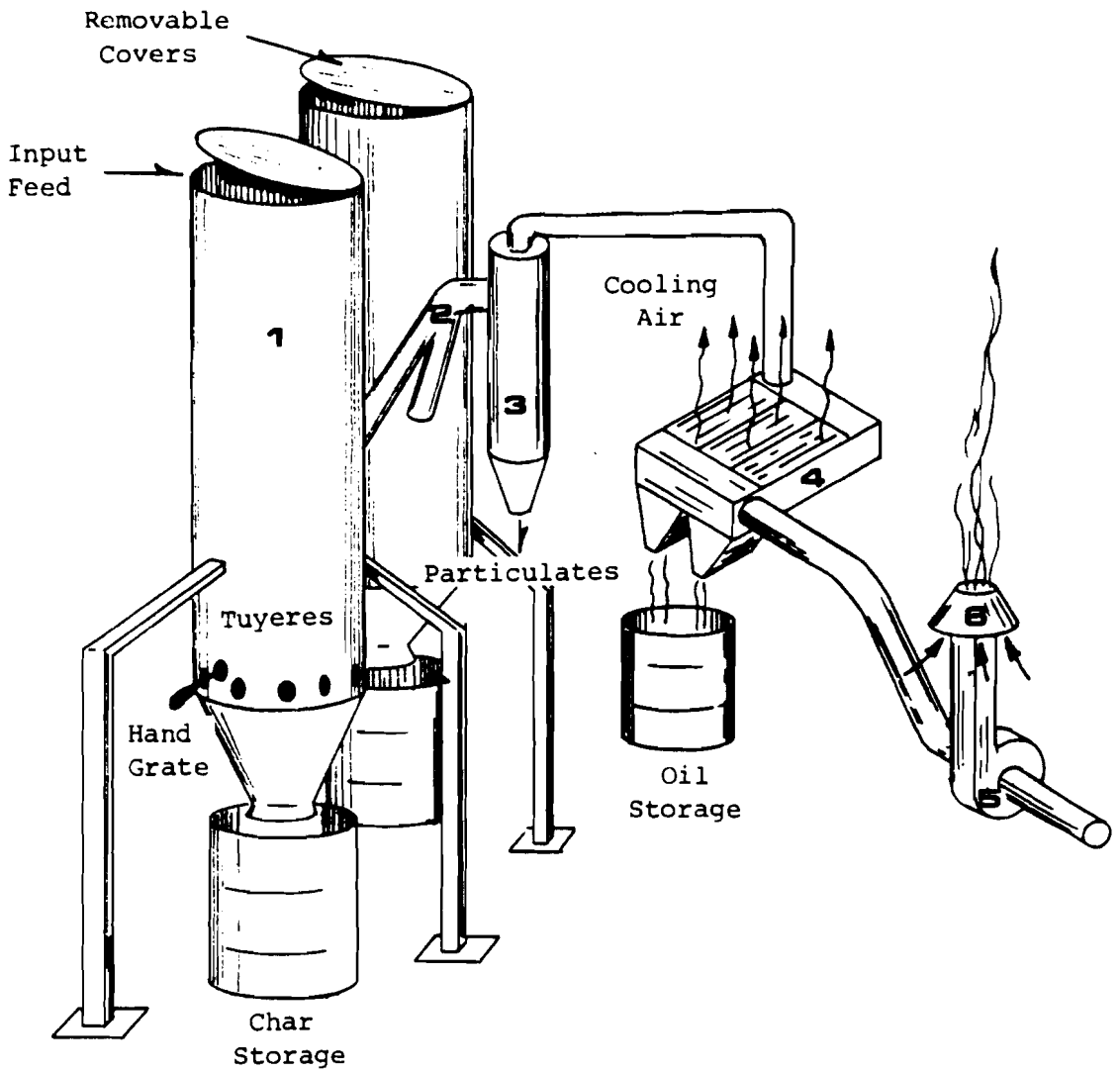
ONE-TON-PER-DAY PYROLYTIC CONVERTOR FOR INDONESIA - MODEL 1



Item	Component Name	Component Description
1	Kilns	Constructed of 200-liter oil drums
2	Ducting	Sheet metal, insulated
3	Cyclone	Sheet metal, insulated
4	Condenser	Single pass, forced convection cooled
5	Draft Fan	Centrifugal, approximately 20 cfm
6	Modified IRRI Drier	Batch type, wood construction

Figure 2

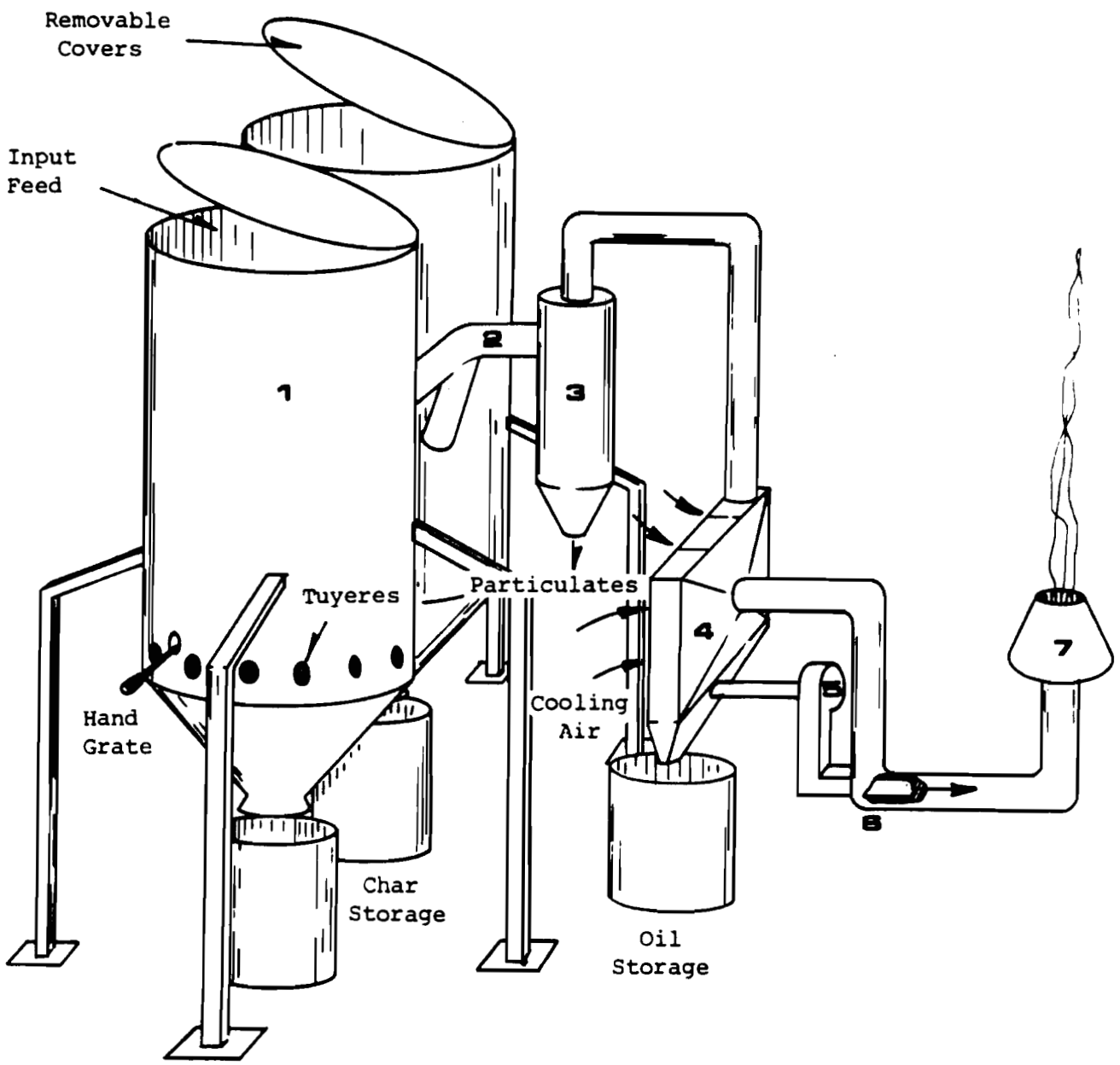
ONE-TON-PER-DAY PYROLYTIC CONVERTOR FOR INDONESIA - MODEL 2



Item	Component Name	Component Description
1	Kilns	Constructed of 200-liter drums
2	Ducting	Sheet metal, insulated
3	Cyclone	Sheet metal, insulated
4	Condenser	3 pass, natural convection cooled
5	Draft Fan	Centrifugal, approximately 30 cfm
6	Burner	Diffusion

Figure 3

ONE-TON-PER-DAY PYROLYTIC CONVERTOR FOR INDONESIA - MODEL 3



Item	Component Name	Component Description
1	Kilns	Sheet metal construction
2	Ducting	Sheet metal, insulated
3	Cyclone	Sheet metal, insulated
4	Condenser	3-pass, forced convection cooled
5	Draft Fan	Centrifugal, approximately 60 cfm
6	Ejector	Pumping - secondary to primary flow ratio - 2
7	Burner	Diffusion

While all the systems are capable to some degree of recovering oil while processing large pieces of wood waste using a batch mode and the sequenced firing technique described in (3), the preferred operating practice is a batch-continuous mode with rice hulls as the feed. This is because the number of conversion units is only two (as opposed to four in (3)), and it is uncertain if truly significant amounts of oil could be recovered in the pure batch mode, sequenced operation. Therefore, only the batch-continuous mode with rice hulls will be discussed further. Moreover, only a description of the more mechanized system, No. 1, will be presented in detail, since an understanding of the other systems should follow from this discussion.

Referring to Figure 1, it is seen that the basic system involves several components:

(1) The cylindrical kilns, including a feed storage plenum at the top, a manually operated shaker-grate char output system, several adjustable air tuyeres, and a char holding container at the bottom.

(2) The off-gas ducting system.

(3) The cyclone scrubber for removing particulates from the off-gas.

(4) The single-pass condenser to separate the high-temperature oily fraction from the off-gas stream.

(5) The draft fan.

(6) The modified IRRI drier for drying the paddy.

In practice, the paddy is introduced into the drier, the dry grain later milled and the dry hulls separated from the remainder. Then, periodically the hulls are introduced into the kiln. After entering the kiln, the hulls pass down into a hot zone and are there converted to charcoal. The char is removed from the holding container into steel drums for cooling and storage. The air induced by the draft fan into the kiln passes through the tuyeres and combusts a small fraction of the charcoal to produce hot upward-flowing gases which, in turn, supply heat to carbonize the downward-moving feed. The resulting smoke or pyrolytic gas from the feed leaves the kiln, passes through the cyclone to remove the particulates, passes through the condenser where the oily fraction is recovered, and then is incinerated in the drier.

The system operates at several inches of water negative pressure. The pressure is controlled by the speed of the draft fan, the process rate, and the tuyere opening. The combustion air for the modified IRRI drier passes across the condenser tubes to provide the required cooling of the off-gas. To allow ease of maintenance, the off-gas passes through the tubes rather than across the tube bank, as is normal condenser design practice. Easily removable access plates allow the tubes to be cleaned with a minimum of disruption to operation. During this cleaning, the condenser would be bypassed.

Insulation of the kiln walls in the hot zone above the tuyeres may be provided by means of "char shelves" as described in (9), which would use the feed/char itself as a lightweight, expendable insulator.[1/] The kilns are basically cylindrical and constructed of two welded 200-liter oil drums with a single 100-liter drum inside at the top for feed storage. The kiln would stand about 10 to 11 feet above the ground and be approximately two feet in diameter. Because of the danger of corrosion, especially in the upper volume, the 100-liter drum should be constructed so that it can be easily removed from the overall kiln.

Blowout ports would be located on the kilns, the cyclone, and the condenser to insure that any over-pressure would be easily vented. The entire system would be located underneath a shed to protect it from the rain and direct sunshine.

The overall system would process, on a three-shift, 24-hour basis, one ton of dry hulls per day. It is estimated that the system would produce about 250 kilograms of charcoal and about 150 kilograms of oil each day.

It should be recognized that the system described is only preliminary. The limitations of time and budget have allowed only a brief span in which to actually consider the design within the constraints previously noted. Thus some oversights have likely occurred and some oversimplifications have no doubt been made. No attempt has been made to optimize the design. However, the system design presented should be useful in making cost estimates. Hopefully, a future program will allow the opportunity for a more detailed investigation of the system.

1/ The use of the feed as an insulator is a well-established practice in producer gas technology.

System Operation

To start up the system, a fire would be built in each kiln at a level slightly below the tuyeres. After the fire has reached a stable condition and the unit heated up, additional feed would be added to cover the combustion zone until the hulls fill the kiln. Then, after a pause to allow a thermally stable condition to be reached, the shaker grates would be manually activated and the system slowly brought up to the operating mode. Depending on the process rate desired and the feed moisture characteristics, the tuyeres could be completely closed or partially open.

To check the char quality, a sample could be taken through one of the tuyeres. If the char contains brown, uncharred material, the process rate is too high; if the char contains much ash, the process rate is too low; if the char is dark black, the process rate is just right.

Periodically the char holding container would need to be emptied. The char level could be monitored by striking the sides of this container at different heights with a stick and listening for the difference in the sound below and above the char zone. Typically the charcoal has about 50% of the volume of the hulls; thus, by designing the char storage to be one half the hull storage volume, the need to fill the kiln with hulls would occur at the same time the char storage needs to be emptied.

Also, the oil storage container would need to be emptied periodically and the cyclone checked to be certain that the off-gas particulates were not blocking the flow. Finally, daily inspection of the condenser would need to be made to insure that particulates passing through the cyclone do not foul the tubes.

While the above discussions are not complete, they should provide a reasonable picture of the basic system design and operation. In the next section a discussion of the economics of the first three systems is presented.

PROJECTED COSTS AND RETURNS

The analysis of costs and returns, based on the design shown in the previous chapter, requires the assumption of several essential working conditions in order to arrive at quantitative results. These conditions, based on past experience and the best knowledge of the local situation, were used as the basis for the cost and return estimates:

a. Plant location: Adjacent to the source of waste material supply; i.e., a rice mill, in this case.

b. Plant sizes and models: Three models are given.
   (1) One ton of dry feed material per day with three shifts and with a drier
   (2) One ton of dry feed material per day with three shifts and without a drier
   (3) One ton of dry feed material per day with one shift and without a drier

c. The system would be in a fixed position, but it is designed to be easily dismantled for moving purposes.

d. The system is designed for labor-intensive purposes. All major components would be manufactured locally.

e. For the first two models, the plants would be operated on a three-shift basis (24 hours per day). For the third model, the plant would be operated on a one-shift basis (eight hours per day). There would be 150 working days a year to allow for a six-month season of rice mill operation in Java.

f. In all the analyses, the assumption is made that the rice hulls are free. (More than likely this will require participation of the rice mill owner in any commercial enterprise involving pyrolytic conversion of these materials.)

Estimated Capital Costs

The three plant models require different capital inputs. The estimated capital costs for each model are presented in Table 8.

Table 8

ESTIMATED CAPITAL COST REQUIREMENTS FOR DIFFERENT MODELS
(in rupiahs)

	Model 1	Model 2	Model 3
Production Components	800,000	510,000	760,000
Building and Hull Storage	250,000	250,000	250,000
Contingency	100,000	40,000	40,000
Total	1,150,000	800,000	1,050,000
Working Capital	250,000	200,000	200,000
Total Capital Requirements	1,400,000	1,000,000	1,250,000

Note: 1 = One ton per day with an IRRI drier (three shifts)
2 = One ton per day without a drier (three shifts)
3 = One ton per day without a drier (one shift)

Operating Costs

Several elements in the operating cost estimates have to be predetermined. Labor represents the largest cost outlay in the operation. The assumed number of workers needed per shift and costs involved are given in Table 9.

Table 9

ESTIMATED LABOR REQUIREMENTS AND COSTS PER DAY

	Model 1		Model 2		Model 3	
Shift Number	No. of Workers	Wages (rupiahs)	No. of Workers	Wages (rupiahs)	No. of Workers	Wages (rupiahs)
1	2	800	1	400	2	800
2	2	1,000	1	600	-	-
3	2	1,000	1	600	-	-
Total	6	2,800	3	1,600	2	800

Total operating costs based on a 150-day operation per year are given in Table 10. Operating costs include labor, management overhead and maintenance, and debt service on borrowed capital. The debt service includes both interest and principal for the total capital requirements, based on a 10-year loan at 12.5% annual interest rate.

Table 10

ESTIMATED OPERATING COSTS PER YEAR
(in rupiahs)

	Model 1*	Model 2*	Model 3**
Labor	420,000	240,000	120,000
Management Overhead and Maintenance	150,000	110,000	110,000
Debt Service	253,400	181,000	226,250
Total	823,400	531,000	456,250

* Based on three-shift operation per day, 150 days a year.

** Based on one-shift operation per day, 150 days a year.

Projected Returns

Returns would vary according to the quantity of products produced, service performed, and the number of shifts operated per day. Models 1 and 2 are based on three shifts per day and 150 days a year, while Model 3 is based on one shift per day and 150 days a year. Besides the products produced, Model 1, which is equipped with an IRRI drier, would dry the wet paddy brought in by the farmers. For this drying service, a credit of 600 rupiahs per ton of grain is assumed to be received from the mill. The drier would dry four tons of grain per 24 hours and would be operated 150 days a year. The total income from the drying service would be 360,000 rupiahs per year.

For all three models, the charcoal yield would be 0.25 ton per day and the oil yield would be 0.15 ton per day. Loose charcoal is priced at 12,000 rupiahs per ton, while oil is priced at 10,500 rupiahs per ton.

Projected returns for the three models are presented in Table 11. The profit margins vary according to the model. The return on investment is 16.0% for Model 1, 15.7% for Model 2, and 18.5% for Model 3. Payout time would be 6.25 years for Model 1, 6.4 years for Model 2, and 5.4 years for Model 3.

In passing, it is of interest to note that even though Model 3 requires more capital and does not use a drier, its return on investment is higher than for Models 1 and 2. This is largely due to major reductions in labor costs which override the increased capital. Considering the added convenience of

Table 11

PROJECTED RETURNS PER YEAR
(in rupiahs)

	Model 1	Model 2	Model 3
Charcoal	450,000	450,000	450,000
Oils	237,600	237,600	237,600
Drying Service	360,000	-	-
Total	1,047,600	687,600	687,600
Operating Costs	823,400	531,000	456,250
Profit before Taxes	224,200	156,600	231,350

one-shift operation, Model 3 appears to offer the most attractive option of the three considered.

In addition, it might be noted that the income from milling operations alone for rice mills in the size category chosen is typically in the range of 400,000 to 600,000 rupiahs per year and the return on investment is approximately 15% to 20%. Thus the income derivable from pyrolytic conversion of the wastes could substantially augment the present mill revenues and the capital required would be invested at a rate of return compatible with the mill operation itself. Therefore, such a system should be of considerable interest to the mill operators as a means of increasing their income.

Finally, it must be observed that the above economic analysis is based on prototype models. Further improvements made to the models and a larger scale of operation would naturally lead to the reduction of production cost per unit of product output.

DEMONSTRATION PROJECT

Background

During a part of the time this feasibility study was being conducted, efforts were made at the Development Technology Center (DTC), in consultation with EES personnel, to develop a laboratory-scale pyrolytic conversion system not unlike that shown in Figure 2. The system has a small capacity and should be able to produce no more than two to three kilograms of char per hour. At the time of the project's end, the convertor, filter, and condenser had all been fabricated and successful tests of the system were conducted, producing char, oil, and gas. Extensive further testing of this unit is planned by DTC. In addition, charcoal from the rice hulls was produced in an oven, and simple briquettes were made with it using cassava starch as a binder to establish the feasibility of larger-scale briquetting equipment. This work was done to familiarize personnel at DTC with the technology involved and to provide a preliminary understanding of the processes at work.

While the results of this effort are incomplete at this writing, there is little doubt that the initiative shown at DTC will provide a powerful push to overcome any problems in the system operation and prepare EES and DTC to develop the larger-scale field demonstration system as described in previous sections. All the principals in this undertaking are enthusiastic about the need for a hardware development program and in numerous discussions have formulated a plan to develop the necessary system. This plan is described in the next paragraphs.

Project Definition

A program to further investigate the practicality of pyrolytic conversion of agricultural and forestry wastes in Indonesia not only would involve the construction and field test of several conversion systems, but it would also include the development of various household components, such as a stove and lamp, to burn the pyrolytic oils. A small briquetting machine to convert the char into briquettes also should be devised. Moreover, since the ultimate aim of this effort would be widespread replication and utilization of pyrolytic convertors for agricultural wastes, this will require a massive educational and demonstration program, the development of promotional materials, and a push by the government and numerous manufacturers.

Additionally, a development program to improve and simplify this present-day pyrolysis technology should be pursued with the goal of making the system less expensive, more reliable, and more maintenance free. Hence a demonstration project would include two major phases.

System Demonstration. This phase itself would include a number of steps:

- o Identification of several specific locales where field surveys of the available wastes and the market for the fuels produced indicate that the concept shows promise.
- o Detailed design of a system appropriate to the needs of the specific locales selected, using currently available technology.
- o Manufacture and assembly of the system.
- o Check-out testing.
- o Long-term operation to investigate the operating characteristics and economics of the system.
- o Training of staff and technicians to operate the system.
- o Development, testing, and fabrication of various items, such as a cooking stove, a lamp, and a charcoal briquetting machine suitable for use with the char and pyrolytic oil.
- o A major effort to disseminate information forthcoming from the study, including participation by the Indonesian Government itself.

Technology Development. In this phase, improvements in the system, such as the combination scrubber/condenser described previously, would be made. Simplications in system operation and in maintenance requirements would be sought. The potential for alternate energy conversion techniques would be considered and the feasibility, for example, of combining a low-temperature pyrolytic convertor with a producer-gas generator would be studied. Additionally, a program for upgrading the present-day technology systems would be pursued with the goal of improving their operating performance.

Conclusion

When the potential impact of the use of wastes and the concurrent reduction in the firewood crisis in Java are considered, when the resultant increased employment is recognized, and when the quality of life of future

Indonesian generations is regarded, there can be no conclusion but that an urgent program to develop energy from wastes should be pursued. The approach offered in this document is believed to be practically realizable and is directed toward a goal which will benefit the people of Indonesia -- not just the wealthy. The technical and economic questions appear to be answered. What remains is the will to proceed.

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