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OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: April 6, 1976

Project Title: Pyrolytic Conversion of Agricultural Wastes

Project No: A-1823

Project Director: Drs. Tze I. Chiang and John W. Tatom

Sponsor: Agency for International Development - Washington, D. C. 20523

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(thru OCA)

Agency for International Development
Central Operations Division
Office of Contract Management
Washington, D. C. 20523

Defense Priority Rating:

Assigned to: Economic Development (~~School~~/Laboratory)

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- Other ____________

CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: June 9, 1977

Project Title: Pyrolytic Conversion of Agricultural Wastes

Project No: A-1823

Project Director: Drs. Tze I. Chiang and John W. Tatom

Sponsor: Agency for International Development - Washington, DC

Effective Termination Date: 7/31/76

Clearance of Accounting Charges: 1/31/77

Grant/Contract Closeout Actions Remaining:

NONE

- _ Final Invoice and Closing Documents
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______

Assigned to: Economic Development Laboratory (School/Laboratory)

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CA—4 (3/76)

Project A-1823
AID/ta-C-1290

PYROLYTIC CONVERSION OF AGRICULTURAL AND FORESTRY WASTES IN GHANA

-A FEASIBILITY STUDY-

Prepared for

Agency for International Development
Office of Science and Technology
Washington, D. C. 20523, U. S. A.

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Summary

As in many other developing countries, agricultural and forestry activities in Ghana are accompanied by large amounts of waste. These waste materials become valuable fuels if proper conversion methods are adopted. This study demonstrates that pyrolytic conversion of the waste to high-energy fuels offers a promising solution to the waste utilization problem, and a simple, self-sustaining, continuous/batch process appears to be especially applicable to the situation in Ghana. A system based on this process could be constructed using many "off-the-shelf" items, along with components readily fabricated in Ghana. The system could be used to carbonize either large pieces of wood from forestry and/or reforestation wastes or smaller materials such as sawdust, groundnut shells or rice straw available at processing plants.

This report describes the results of a field study to determine the quantities and characteristics of waste in Ghana and the feasibility of using pyrolytic conversion of these wastes. The study shows that Ghana is generating 2,735,100 tons of agricultural and forestry waste materials each year that are suitable for pyrolytic conversion. Using pyrolytic conversion of all these waste materials, approximately 342,000 tons of charcoal and perhaps 273,000 tons of oil could be produced. The market value of the end products would be about ¢48,396,000 each year. The amount of energy generated by the conversion would exceed the total energy produced in Ghana in 1973.

The demand for domestic charcoal in Ghana was estimated at 250,000 tons in 1975, with an annual growth rate of 2.7%. Over 99% of this demand was met by locally produced charcoal in earth mounds which are primitive and wasteful. The char yield of modern pyrolytic convertors is more than double that of the earth mound method and, additionally, they produce both oil and gas. Thus the opportunity for introduction of more efficient methods of charcoal production in Ghana is obvious.

The pyrolytic oil produced with continuous pyrolytic processes may be used as fuel for boilers, furnaces, and other industrial uses. Any surplus of the oil can be exported. The char and oil mixed together also can be used in place of coal in running trains and ferries. Gas generated by pyrolytic convertors is most practically used on site in drying feed materials or in utility boilers.

A preliminary description of an appropriate technology version of a continuous/batch pyrolytic conversion system is also presented in this report. This specific design is based on six dry-tons of sawdust input per day, a crew of 11 workers per shift, and major components to be made locally, except for a few critical parts. The unit would be run at three shifts per day and 300 days a year. (While this work schedule may seem excessive for less-developed countries in general, it is believed to be practical for the Ghanaian situation and this opinion has been verified in field consultation.) Four hundred and fifty tons of charcoal and 350 tons of pyrolytic oils would be produced a year.

Fixed capital requirements for such a unit were estimated at ¢30,000. On a three-shift operation, gross returns were estimated at ¢63,720 a year. Production costs per year were estimated at ¢49,419. Net profit before taxes would be ¢14,301. The payout time would be two years if no taxes were assessed. On a two-shift operation, gross returns were estimated at ¢42,480 a year and production costs at ¢36,419, yielding a net profit before taxes of ¢6,061. The payout time would be five years if no taxes were assessed. A one-shift operation does not appear to be profitable.

INTRODUCTION

The quantity of waste materials generated by agricultural and forestry activities in developing countries such as Ghana is huge. The overwhelming majority of these wastes lie rotting in the fields while the nation spends millions of cedis[1/] for importing oil and coal each year. Converting these wasted materials into fuels can save the nation a substantial amount of foreign exchange for other uses. One especially attractive means of converting ligno-cellulosic materials into high-quality solid and liquid fuels is by means of pyrolysis or "destructive distillation."

This report describes the results of a field study that was conducted at the suggestion of the Building and Road Research Institute of the Ghana Council for Scientific and Industrial Research and was funded by the Agency for International Development, U. S. Department of State. The purpose of the field study was to find out whether pyrolytic conversion is appropriate to and can be adapted successfully in Ghana. Specific objectives of the field study are given below:

1. To determine agricultural and forestry wastes by kind, volume, and location in Ghana.
2. To find out potential markets for the products of an intermediate technology pyrolytic convertor, namely, the charcoal, oil, and gas.
3. To make a preliminary design of a pyrolytic unit that can be manufactured in Ghana.
4. To project costs and returns based on the adapted design.

The study is presented in six sections. The first section introduces the technology of converting agricultural wastes. The second section identifies agricultural and forestry wastes in Ghana. The third section points out markets for charcoal, oil, and gas in the nation. The fourth section offers a preliminary design of a simplified pyrolytic convertor. The fifth section illustrates the economics of a prototype model. The sixth section describes the steps necessary to implement a pilot project based on the study findings. Finally, an "energy-food plantation" concept is described in the appendix.

1/ Based on the current exchange rate, one cedi is equal to $0.87.

While the results of the study are directly applicable to Ghana, they also should be pertinent to other developing countries where agricultural and forestry wastes are available in abundance. Although the study emphasizes waste materials, deliberately grown materials could become a permanent source for energy conversion. Since many of the developing nations are located in the tropical zone where sunshine is abundant and the growing season is year-round, large-scale energy production based on the "energy-food plantation" concept could become a major income-producing activity. Ghana could become a test country for this concept.

The study was limited to a three-week field trip in Ghana and thus is necessarily limited in scope. However, essential elements of a feasibility study are included.

Data obtained for this study came largely from direct field interviews. Without the cooperation and assistance of various institutions and individuals in Ghana, the study would have been impossible to complete within the given time limit.

ENERGY CONVERSION TECHNOLOGY

In Ghana, agricultural and forestry wastes represent a major potential energy source and, by their substitution for expensive imported fuels, provide a means for improving the severe national balance-of-payments problem. Clearly some attention must be given to alternate energy sources such as wastes since the present rate of economic development is already limited by the hydroelectric potential in Ghana and conversion to thermoelectric power production will soon become a necessity. Since energy conversion from wastes is a relatively labor-intensive process, a program for using these materials as fuels could produce many new jobs in Ghana.

Many of the wastes produced are concentrated in fixed locations and thus offer the additional advantage of requiring minimum effort in collection. A characteristic of these wastes is the small size of the individual particles. Such materials as sawdust, rice husks, coconut shells, and oil palm wastes are produced in very large quantities at processing plants, which themselves offer a potential market for the fuels derived. Not only is the annual production of these wastes available, but that produced from preceding years' operations also could be converted. Indeed, there are mountainous piles of sawdust at many sites throughout Ghana. These mountains could be "mined" as coal and thus represent a significant national energy resource.

Other wastes are not currently gathered, but are produced in very large quantities. They could be collected if a value were given them. Typical types of wastes in this category include, besides rice straw, timber slash, reforestation cuttings, cull trees, and cocoa pods and husks. While the agricultural wastes are mainly of small physical size, the major part of the reforestation wastes would be tree trunks and branches of substantial lengths and diameters.

Clearly, not all the wastes in Ghana can be practically used as fuel sources. Some of these wastes are already being used for other purposes. However, these wastes can be used to supply a significant portion of Ghana's future energy needs. In addition, it should be recognized that since these wastes are often a nuisance and are continuously produced, they represent an especially interesting means for supplementing Ghana's energy needs because in their use the environment would be cleaned and the energy supply 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, public acceptance would be enhanced. Moreover, because the fuels produced from the wastes would contain essentially zero sulfur, they could be burned with no increase in atmospheric sulfur dioxide concentration.

It should be noted that agricultural and forestry wastes have several problems that have somewhat limited their use as fuels in the past. These problems include the facts that:

1. These wastes are widely scattered, often far from potential energy users;

2. The wastes contain significant quantities of moisture which, combined with the great distances involved, make transportation costs excessive;

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

4. The wastes are often produced seasonally and thus do not offer a steady supply of fuels (it is clearly uneconomical to invest in waste energy conversion systems which would stand idle during much of the year).

Any successful system to utilize waste material as fuels must overcome these problems.

There are at least three general processes by which these wastes can be converted into energy:

1. Direct burning

2. Fermentation

3. Pyrolysis

Direct burning is no doubt the best understood and the most widely used energy conversion process today. Almost everyone, at some time or another, has used wood to cook by. Many sawmills use their waste to drive boilers that power their equipment. Farmers routinely use corn stalks and groundnut shells as fuels for their home energy needs. However, direct burning has several problems, especially for general large-scale uses:

1. There is a need for large, expensive, but inefficient boilers. Perhaps only 60% of the available energy in wastes can be realized through direct burning.

2. There is a serious air pollution problem associated with direct burning since large quantities of particulates are produced.

3. There is a significant added cost associated with the transportation of the wet fuels.

While there will doubtless continue to be practical uses for direct burning, the above problems will force consideration of alternative energy conversion technologies.

<u>Fermentation</u> of certain types of wastes is also a means for producing fuels. Anaerobic fermentation has been applied to animal wastes -- manures -- as a means of producing methane gas, a fuel gas similar to natural gas. The amount of gas thus produced is limited, and its quality is such that it is, at best, sufficient to support the energy requirements of the fermentation process. The principal value lies in the sludge, which is useful as a fertilizer or animal feed supplement. This process is not applicable to wastes which are high in lignocellulosic materials, since such materials are low in volatile fatty acids, the principal microbial feed materials, and since lignin is toxic to anaerobic microbes responsible for the fermentation reactions.

Of aerobic fermentation processes, composting is probably the most familiar. The cellulosic material is mixed with animal manure, lime and soil and is periodically "turned" for aeration purposes and to prevent excessive heat buildup. It is a relatively slow process, requiring eight to ten weeks for completion. The process is labor intensive, and capital investment is very low. No usable form of energy is produced in this process. Other aerobic processes, such as acetic fermentation in a silo-type structure, are faster and sufficiently exothermic to produce usable heat energy, transferable over short distances through insulated heat transfer media.

A third type of fermentation utilizes cellulosic materials and converts them into liquid fuels containing ethyl and butyl alcohols, acetone and water.

This process is the subject of several patents and patent applications and might be considered as an alternate to the pyrolysis process. However, it suffers from the requirement of long-term biological schedules. Fuels produced may be sufficient only to meet energy requirements of the process. In view of these restrictions, fermentation does not presently seem to offer an attractive means for energy conversion from agricultural and forestry wastes in Ghana.

Pyrolysis is a process ancient as civilization itself. Charcoal production in almost every culture has been a mark of the beginnings of organized society. However, pyrolytic conversion of wood into charcoal by means of the traditional batch-type "earth mound" processes is very inefficient and does not permit recovery of another, almost equally valuable product of pyrolytic conversion -- the pyrolytic oils. These oils cannot be ignored, especially today, since they represent a potential source of energy for industrial and utility boilers. The corrosive nature and odor inherent in the oils requires special handling and storage procedures.

In addition to the charcoal and oil, another by-product of pyrolysis is a clean-burning but relatively low-energy gas which could be used in many situations where a gaseous fuel is required.

While earth mound kilns are not very efficient, several types of inexpensive, easily constructed kilns are available today that can produce large amounts of charcoal with relatively minor labor requirements. Although these kilns do not presently allow oil recovery, they do provide a low-cost means for charcoal production and are especially well suited for reforestation wastes -- the larger pieces in particular. Since the major waste production in Ghana is currently from the reforestation project sponsored by the Ghana government to promote oil palm production, the use of simple low-cost kilns, such as the Missouri kiln (1),[1/] as a major means for energy conversion should not be overlooked. The charcoal thus produced would be well suited for domestic consumption and also could be used as a fuel in coal-fired boilers such as locomotives, which presently require expensive imported coals.

1/ Numbers in parentheses refer to publications listed in the References section at the end of the report.

While the potential for charcoal production using the kilns is large, there are still problems associated with the collection of the wastes. This is especially significant so far as the reforestation project is concerned. In situations where the wastes are already collected, a promising means of pyrolytic conversion involves continuous, rather than batch (kiln)-type, processes. Since very large quantities of these process wastes suitable for continuous processing presently are available in Ghana, it appears that continuous processes operating on these type wastes offer an attractive alternative to kilns, especially since oil recovery is then feasible.

Various types of modern continuous-flow pyrolysis processes have been developed recently in the United States and elsewhere to emphasize the production of one or more of the products of pyrolysis. Characteristically, these processes require the wastes to be shredded into relatively small pieces which can be handled easily. Primarily, these processes tend to maximize the production of gas, with the oil a secondary by-product and the char reduced essentially to ash. This is because most of these processes have been developed to deal with municipal wastes and have assumed the proximity of a large, gaseous-fueled industrial or utility type boiler. Clearly emphasis on gas production for a system to convert agricultural and forestry wastes would be a serious mistake because of the problem of storing and/or transporting the gas to a user. There is a system, i.e., the Garrett process, that emphasizes the production of oil, but it is very complex and requires significant preprocessing of the wastes. Its feasibility when applied to agricultural and forestry wastes and when operated in a rural environment is doubtful.

Typically, high-temperature processes emphasize gas production, while low-temperature processes emphasize char and oil production. Conveniently, low-temperature processes can be made of cheaper materials and can be made to operate in a simpler manner than the higher-temperature processes. This favors their use in a rural environment, especially in a developing nation such as Ghana, where spare parts are not always conveniently available.

A number of continuous low-temperature pyrolysis processes also have been developed throughout the world in recent history; perhaps the simplest and most promising involve vertical retorts through which the feed passes. In almost every case these processes are self-sustaining, with the heat required to dry and carbonize the as-received wet wastes being supplied through combustion of either a small part of the feed itself or the products of the pyrolytic conversion. All these processes possess basic similarities and differ mainly in the manner in which the auxiliary heat to facilitate the drying and pyrolytic conversion is applied.

Several examples of this type of retort include: the basic Stafford retort (2) used very widely over the past 50 years in the U. S. and elsewhere for production of charcoal and liquid by-products; the Mellman retort (3); the Lambiotte retort (4); the de Bartolomeis design (5); the Barneby process (6); the Georgia Tech design (7).

While continuous processes allow oil recovery, they generally are more complex and more expensive than simple kilns. Likewise, they are more vulnerable to shutdowns in LDC's because of reduced spare part availability. Moreover, they require some or extensive preprocessing of the waste feed.

Since the character of the wastes in Ghana varies widely, a process that would accept all kinds of materials in various sizes and shapes and yet still allow oil recovery would be most desirable. Clearly it also should maximize labor utilization, be of a rugged, simple design, and be as inexpensive to manufacture within Ghana as possible. A preliminary description of a system having these properties is presented in a later section.

In reviewing the previously mentioned problems of using agricultural and forestry 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 modifications. By making the system portable, the seasonal character of the wastes can be dealt with. Thus the problems characteristic of using these wastes can be significantly reduced or resolved using low-temperature pyrolytic conversion.

POTENTIAL SOURCES OF AGRICULTURAL WASTES
FOR ENERGY CONVERSION IN GHANA

Forestry and agriculture are two major segments of Ghanaian economic life. Wastes generated in these two segments are voluminous. However, only those sources which can easily be identified and have no practical uses at the present time are considered here. Data presented on these wastes are the best estimates based on the information provided by authoritative sources in Ghana. In the event a pyrolytic convertor based on a specific waste material is to be built, a survey of available waste to confirm the results of this study should be carried out. More importantly, a long-term supply of the material should be assured before actual construction of a pyrolytic converting plant is begun.

A summary of agricultural and forestry wastes in Ghana which have high potential for collection for energy conversion purposes, based on the results of this field study, is given below:

Kind	Tons per Year
Sawdust	25,500
Rice straw and husks	517,700
Logging wastes	403,000
Reforestation wastes	1,079,700
Coconut wastes	686,400
Oil palm wastes	22,800
Total	2,735,100

The weight of these waste materials is in green tons, assuming a moisture content of 50%. If all these materials were converted into charcoal and oils, 342,000 tons of charcoal and 273,000 tons of oil would be produced. The market value of these end products would be ¢48,396,000. To put this number in perspective, Ghana consumed an amount of energy equivalent to 1.45 million metric tons of coal in 1973, but it produced only 0.42 million metric tons of coal-equivalent energy that year (8). Thus, charcoal and oil produced by pyrolytic conversion in Ghana would exceed the total energy produced in the nation in 1973. Clearly, the potential impact of wastes as an energy source in Ghana is very significant.

Other agricultural wastes, such as maize stalks, peanut hulls, cocoa pods, etc., are not included because of their importance as domestic fuels to farmers and the problem of collection. Also, the importance of returning cocoa pods, which contain calcium, to the soil as fertilizer should not be overlooked.

Six major kinds of agricultural and forestry wastes which are considered as potential raw materials for pyrolytic conversion are discussed in terms of volume, location, and methods of estimates in the following sections.

Sawmill Wastes

Sawmills generate two kinds of wastes. One is sawdust which is thrown away or dumped as a landfill at the present time. Another kind is off-cuts such as trims, short ends, and defects. Most of the off-cuts are presently used for boiler fuel at the mill, for low-grade furniture material, or as a giveaway fuel for neighbors. Most sawmills would be willing to give away sawdust free if a receiver could provide his own means of transportation. Because of its fineness and pulverized condition, sawdust is especially adapted to continuous pyrolytic conversion processes.

The volume of sawdust generated by sawmills in eight major locations is estimated below.1/

1. Kumasi

No. of Sawmills	Bags of Sawdust Generated Each Mill per Month	Total Bags per Month
4 large	1,500	6,000
10 medium	1,000	10,000
14 small	500	7,000
28		23,000

23,000 bags x 12 months = 276,000 bags per year

276,000 bags x 105 lbs.2/ = 28,980,000 lbs. or

14,490 tons a year

1/ Based on basic data provided by the Forest Products Research Institute, University of Science and Technology, Kumasi, Ghana.

2/ Each bag contains 105 lbs. of sawdust.

2. Takoradi has one large and three medium-sized sawmills:

1 x 1,500 bags x 12 months	=	18,000 bags per year
3 x 1,000 bags x 12 months	=	36,000 bags per year
Total		54,000 bags per year
54,000 bags x 105 lbs.	=	5,670,000 lbs. per year or 2,835 tons per year

3. Mim has one large sawmill:

1 x 1,500 bags x 12 months	=	18,000 bags per year
18,000 bags x 105 lbs.	=	1,890,000 lbs. per year or 945 tons per year

4. Samreboi has one large sawmill:

945 tons per year

5. Sefwi-Wiawso has one large sawmill:

945 tons per year

6. Oda has one medium and four small sawmills:

1 x 1,000 bags x 12 months	=	12,000 bags per year
4 x 500 bags x 12 months	=	24,000 bags per year
Total		36,000 bags per year
36,000 x 105 lbs.	=	3,780,000 lbs. per year or 1,890 tons per year

7. Sunyani, Berekum, and Tepa have five small sawmills:

5 x 500 bags x 12 months	=	30,000 bags per year
30,000 bags x 105 lbs.	=	3,150,000 lbs. per year or 1,575 tons per year

8. Nkawkaw has six small sawmills:

6 x 500 bags x 12 months	=	36,000 bags per year
36,000 bags x 105 lbs.	=	3,780,000 lbs. per year or 1,890 tons per year

Total sawdust generated by sawmills in these eight areas is estimated at 25,500 tons per year.

Transportation cost for sawdust is estimated at ¢5.00 per 1.5 tons of sawdust in a three-ton truck within a ten-mile radius. It is estimated at 33 pesewas per ton-mile.

Rice Straw and Husk

Within a 50-mile radius of Tamale, there are 165,000 acres of rice in cultivation. The average yield is about one-half of a ton per acre per year. However, the range of yields may be from one-third of a ton to one ton per acre a year, depending upon weather and other conditions.

The rice is harvested by combines. After threshing, the rice straw could be baled up and made ready for hauling to a pyrolytic conversion plant. Currently, rice straw is left in the field after harvesting.

Two major rice varieties are planted in the area -- IR5 and IR20. IR5 has a tall stalk, while IR20 has a shorter stalk. In order to estimate the volume of rice straw generated in the area, several basic factors are given:1/

Ratio of rice straw to yield by weight:

IR5	7.5:1
IR20	5.5:1

IR5 constitutes one third of the total acreage

IR20 constitutes two thirds of the total acreage

Rice straw volume generated per year:

IR5	165,000 acres x 1/3 x 7.5 x 1/2 ton	=	206,250 tons
IR20	165,000 acres x 2/3 x 5.5 x 1/2 ton	=	302,500 tons
Total rice straw in the radius		=	508,750 tons

If it is assumed that 80% of the rice straw volume generated in the 50-mile radius can be collected, then 407,000 tons can be made available for energy conversion. The use of rice straw as feed material for a continuous pyrolytic convertor might require chopping before feeding into the convertor. However, this does not present a particularly difficult problem for the system.

There are three rice mills in the Northern Region. Two of them are in Tamale and one is located at Yendi, which is 70 miles from Tamale. Each mill processes 72,000 bags of rice per year. Each bag contains 82 kilograms. The rice husk constitutes from 22% to 25% of the weight.

1/ Based on basic data provided by the Agricultural Research Station, Nyankpala, Ghana.

Rice husk estimates:

Tamale: 2 x 72,000 bags x 82 kilograms x 2.2 lbs. x 23% = 5,974,848 lbs. or 2,987 tons per year

Yendi: 1 x 72,000 bags x 82 kilograms x 2.2 lbs. x 23% = 1,493 tons per year

There are three rice mills in the Upper Region with the same capacities as in the Northern Region. Total rice husk generated in those three mills is estimated at 4,480 tons.

Summary:	Rice Straw	-	508,750 tons
	Rice Husk	-	8,960 tons
	Total	=	517,710 tons

Logging Wastes

Logging is carried out in the high forest zone. The waste is made up of branches, off-cuts, butt trimmings, and defective trees. The waste volume is estimated by the Forestry Department, Accra, Ghana, as follows:

Year	Million Cubic Meters
1970	0.51
1971	0.53
1972	0.62
1973	0.68
1974	0.47
Five-year average	0.562

In order to convert volume into weight, the wood density must be known. Wood density in the high forest zone ranges from 20 pounds per cubic foot to 62 pounds per cubic foot, with an average of 41 pounds. A density of 41 pounds per cubic foot would correspond to about 652 kilograms per cubic meter.

Logging wastes are estimated as follows:

562,000 cubic meters x 652 kgs. = 366,424,000 kgs.

366,424,000 kgs. x 2.2 lbs. = 806,132,800 lbs. or 403,000 tons

Reforestation Wastes

Ghana has carried out a reforestation program since 1971. Under the program, land has been cleared for planting desirable tree species. All bushes and noncommercial species have been cut and cleared. Since 1971, an average of about six to seven thousand hectares of land was cleared each year. It may take 20 years, according to an estimate, to complete the program. Available wood volume in cubic feet for clear-cutting under the program is given below:[1]

Region	Cubic Feet	
	Available to 1975	Average per Year
Ashanti and Brong-Ahafo	545,473,000	27,273,650
Eastern and Volta	76,366,000	3,818,300
Western and Central	327,284,000	16,364,200
Northern and Upper	54,547,000	2,727,350
Total	1,003,670,000	50,183,000

Annual wood waste under the reforestation program:

50,183,500 cubic feet x 0.03 = 1,505,505 cubic meters

1,505,505 cubic meters x 652 kgs./cubic meter =

981,589,260 kgs. x 2.2 lbs. = 2,159,496,372 lbs. or 1,079,700 tons

The magnitude of forest wastes in Ghana is large. How much of these wastes can be collected economically for energy conversion remains to be seen. The design of a convertor, the plant location, and the road conditions are factors to be considered.

It should be pointed out that tree trunks and large branches represent the major portion of the forest wastes. Since continuous pyrolytic convertors may require the feed material in small-size pieces, tree trunks may have to be split and hogged before they can be used. For economical reasons, other charcoal conversion methods such as the Missouri kiln may be better adapted to trunks than conventional continuous pyrolytic processes. However, small branches, twigs, and bushes, which can be easily chopped or hogged, also constitute a significant portion of forest wastes. These materials can be converted not only into charcoal, but also into oil and gas.

1/ Estimates based on data supplied by the Forestry Department, Accra, Ghana, and the Forest Products Research Institute, University of Science and Technology, Kumasi, Ghana.

Since the quantity of forest wastes is so large in Ghana, it is clear that continuous pyrolytic processes and other methods all have a place in converting forest wastes into fuels.

Coconut Wastes

The land under coconut cultivation in Ghana is estimated at between 80,000 acres and 84,000 acres. Each acre contains approximately 60 to 70 trees, and each tree bears 50 nuts per year on the average. The average weight of a nut is 6.82 pounds. The average weight contents of a nut are given as follows:

Components	Kilograms	Pounds
Husk	2.5	5.50
Shell	.1	.22
Copra (meat)	.2	.44
Water	.3	.66
Total	3.1	6.82

The waste components of a coconut (husk and shell) average approximately 5.72 pounds.

Waste volume estimates are as follows:

80,000 acres x 60 trees x 50 nuts	=	240,000,000 nuts per year
240,000,000 nuts x 5.72 lbs.	=	1,372,800,000 lbs. per year
		or 686,400 tons per year

The Asiama-Nzima and Winneba areas are the major coconut-producing areas. Coconut shells are currently being exported to Yugoslavia for making activated charcoal.

Oil Palm Wastes

The oil palm plantations at Prestea and Sese presently represent the two major locations for which production data are available. The distance between the two locations is about 12 miles.

Prestea	-	10,974 acres
Sese	-	8,228 acres
Total	=	19,202 acres

Oil palm yield on the average is estimated at two tons of bunches per acre in the area. The distribution of these components is given below:

Bunch waste	-	40%
Fruit	-	60%
Shell	-	25% of the fruit

Waste estimates on per acre basis:

Bunch	-	2.0 tons
Bunch waste	-	0.8 ton
Fruit	-	1.2 tons
Shell	-	0.3 ton
Bunch and shell wastes	-	1.1 tons

19,202 acres x 1.1 tons = 21,122 tons per year

Kusi-Kade, where the Oil Palm Research Center is located, has 500 acres under cultivation for experimental purposes. The yield is six tons per acre per year.

Wastes estimate:

500 acres x 6	=	3,000 tons of bunches
40% x 3,000 tons	=	1,200 tons of bunch wastes
60% x 3,000 tons	=	1,800 tons of fruit
25% x 1,800 tons	=	450 tons of shells

Total oil palm wastes in Kusi-Kade:

1,200 tons of bunch waste and 450 tons of shell =

1,650 tons per year

Total known oil palm wastes are estimated at 22,772 tons.

One palm oil processing plant is located at Prestea. The plant processes nine tons of bunches per hour. It is operated on an eight-hour day and a five-day week. Estimated processing volume at the plant is 18,000 tons per year, with bunch and shell wastes estimated at 9,900 tons per year.

It is reported that a project is under way to plant 100,000 acres of oil palms in the next ten years under the joint efforts of a Ghana-FAO/UN program. The outlook for oil palm production is bright in Ghana.

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 continuous processes without additional chopping or hogging. Physically they have high density and are excellent materials for making activated carbon, which commands a much higher value in the world market than ordinary charcoal. These two sources of shells, based on currently known data, have a total weight of 32,610 tons per year in Ghana. Assuming a yield of 6% activated carbon, this would produce 2,038 tons of activated carbon per year. Assuming the world price of activated carbon is $500 per ton, over $1 million worth of commodities would be created out of these shell wastes in Ghana.

MARKETS FOR PRODUCTS OF PYROLYTIC CONVERSION IN GHANA

Charcoal, oils, and gas are the three end products from pyrolytic conversion. Markets and utilization of these products are presented separately in the sections that follow.

Charcoal

Charcoal has a long history associated with the life of human beings, extending back several thousand years. Charcoal was the dominant fuel material a century ago before the development of the petroleum industry and electrical power. It is still a major fuel material in developing nations and in some developed countries. Charcoal in various forms is a versatile material and has applications for both domestic uses and industrial uses.

Domestic Uses. Charcoal is commonly used for cooking and heating purposes in homes and shops throughout the nation. The consumption of charcoal in Ghana was estimated to be between 250,000 and 300,000 tons in 1975 at an annual growth rate of 2.7%.1/ This estimate is very close to a separate estimate made by a different source.2/ The second estimate on the charcoal consumption by region in Ghana is given below:

Region	1975 Million Cubic Meters	1975 Tons*
Eastern - Volta Regions	0.34	98,000
Western - Central Regions	0.57	162,400
Ashanti - Brong-Ahafo Regions	0.05	14,000
Northern - Upper Regions	0.02	5,600
Total	0.98	280,000

* The estimates were given in million cubic meters which were converted into tons by assuming charcoal density at 261 kilograms or 574 pounds per cubic meter.

1/ Estimated by the Forest Products Research Institute, University of Science and Technology, Kumasi, Ghana.

2/ The Forestry Department, Accra, Ghana.

The estimated volume of charcoal consumption in Ghana is largely used for domestic cooking and heating purposes. Only a small portion of the estimated volume is used for industrial purposes.

Industrial Applications. Charcoal can be used for various industrial applications (1) such as fuel for boilers and brick kilns, drying of agricultural products such as tobacco and grain, and as a fuel in lime and cement manufacture. It can also be used for metal extraction of copper and iron. Some charcoal can be made into activated carbon, which commands a much higher price in the world market than ordinary charcoal. It can also be used as feed in the manufacture of fertilizer. All of these industrial opportunities can become realities if the charcoal production in the nation can be improved and increased. Because of the high costs of petroleum fuels, charcoal's place in industrial applications has become increasingly important in the world.

Supply Conditions. Traditionally, charcoal has been produced by earth mounds in Ghana. Mound charcoal is produced by piling pieces of timber or wood together and setting the pile afire. Then the pile is covered with earth and allowed to smoulder for a week or so. After the fire goes out the charcoal is removed. The method is primitive and wasteful, producing barely half of the volume of charcoal which might be obtained from the same volume of wood by more efficient methods (9). However, mound charcoal supplies over 99% of the demand for charcoal in Ghana at the present time. No statistics are available on the number of mounds and locations.

The savannah woodland zone, which is north of Kumasi, is the major charcoal-producing area. The density of wood in the region is higher than other regions and, as a result, a good quality of charcoal is produced which is preferred by housewives. Charcoal produced in the region is shipped to neighboring areas.

The more recent method of charcoal production is by kiln. There are about 33 kilns engaged in making charcoal in Ghana. Ownership, location, number of kilns, and volume produced per week are given as follows:[1/]

1/ Forest Products Research Institute, University of Science and Technology (FPRI, UST), Kumasi, Ghana.

Ownership	Location	No. of Kilns	Pounds per Week
Ashanti Regional Corporation	Kumasi	5	4,200
Central Regional Corporation	Cape Coast	5	4,200
Individuals	Scattered	20	8,400
Forestry Department	-	2	1,680
FPRI, UST	Kumasi	1	1,400
Total		33	19,880

This volume of 19,880 pounds per week is equivalent to 517 tons per year -- a negligible amount when compared with the national demand of 280,000 tons a year. Thus the need for more efficiently produced charcoal in Ghana is obvious. The yield of a typical modern pyrolytic convertor is more than double that of the earth mound method, and it will produce nearly an equal amount of oil as well. With the demand for charcoal in the nation growing at 2.7% each year and with some large industrial complexes such as a steel mill, fertilizer plant, calcium carbide plant, etc., under private and governmental planning, the need for charcoal as a source of fuel or material for industrial purposes is destined to grow in the years to come. Thus pyrolytic conversion can clearly be a major contributor to the future supply of charcoal in Ghana.

The current market prices of charcoal vary according to locations and quality. On the average, ¢4.5 per bag of 72 pounds is prevailing in Kumasi and ¢6 to ¢6.5 per bag is common in Accra. Mound charcoal and kiln charcoal command about the same market price. However, kiln charcoal is generally sold at the kiln, while mound charcoal is generally hauled to marketplaces. When mound charcoal is sold at the site of production, the price is lowered to ¢2 or ¢3 per bag.

It should be noted, however, that charcoal produced by continuous pyrolytic convertors may be in a loose and pulverized condition, while mound and kiln charcoals 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. Coal-burning boilers are commonly used in factories, trains, and ferries. All coals used in Ghana have to be imported. Ghana imported 24,000 metric tons of coal from Nigeria in 1975. The use of loose charcoal in the place of coal would save a considerable amount of Ghana foreign exchange for other purposes.

Loose charcoal, when it is briquetted, would require additional process cost. However, charcoal briquettes are more convenient in handling, can be bagged more easily, and can be shipped greater distances for marketing purposes than lump charcoal. As a result, they could become an export item and should command a higher price in the marketplace.

Transportation costs for charcoal are estimated at 23p[1/] per ton mile by truck for a distance of 250 miles and 28p per ton mile by truck for a distance of 100 miles.

There is no import or export of charcoal in Ghana at the present time. With large-scale production of charcoal, it could become an export item if the production cost could be significantly reduced.

Pyrolytic Oils

The weight of oils produced by continuous pyrolytic convertors is approximately equal 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 lamps. The present economic planning in Ghana requires substantial buildup of both agricultural and industrial bases in the years to come. More boilers, kilns and furnaces will be required. All fuel oils used for these power and heat generating purposes in Ghana are currently originating from foreign sources. Because of the skyrocketing oil prices in the world in the last three years, Ghana has had to cut back its oil import volume. A tight supply of gasoline and fuel oil in the nation and higher prices of these petroleum-based products are thus inevitable. The production of pyrolytic oils in the nation would reduce the reliance on the foreign imports. Any surplus of pyrolytic oils beyond the domestic needs can be exported for earning foreign exchange.

The costs of residual fuel oil (Bunker C or #6 containing 37 million Btu per ton) from refineries are reported at ¢77 per ton or about ¢2.08 per million Btu. Each ton of pyrolytic oil, containing about 25 million Btu, should be worth about ¢52. This compares very favorably with ¢5.34 per million Btu for charcoal, based on the calculation of ¢5 per bag of 72 pounds of charcoal.

1/ One cedi (¢) is equal to 100 pesewas (p).

This further reinforces the idea that the pyrolytic oils could become a good fuel source for lighting and cooking in Ghana.1/

Gas

Gas generated by a pyrolytic convertor is most practically used on site. Since most agricultural and forestry wastes have a high degree of moisture content, the gas generated would be largely consumed for drying these materials at the plant site. Any leftover gas could be flared. However, if a pyrolytic convertor were located next to a brick kiln or a sawmill, the surplus gas could be used for drying bricks or lumber. Then a market value could be attached to the gas.

1/ It should be noted that the pyrolytic oils, in their initially produced form, are mildly corrosive at room temperature and upon exposure to air do tend to polymerize. Thus further work to stabilize the oils may need to be done before the applications of lighting and cooking are immediately pursued. There is no reason to expect, however, that the necessary modifications to the oil characteristics cannot be made. Experience at the EES with these oils indicates that the corrosion problem, even with untreated oils, is not excessive, steel 55-gallon drums of these oils having been stored routinely for two or more years without leakage. Clearly, in LDC's such as Ghana, wood or ceramic storage containers might be even more available than metal ones and would have essentially no corrosion problems.

PRELIMINARY DESIGN OF PYROLYTIC CONVERSION SYSTEM

Introduction

This section describes the rationale for the selection of the prototype system size and also discusses the design philosophy appropriate to Ghana.[1/] Additionally, it defines the various system inputs and outputs and presents an artist's concept of the proposed system. Considerations important to the final design are also discussed.

System Capacity

While there are several situations in Ghana for which different capacity system would be appropriate, only one size unit could be selected for a follow-on program, prototype demonstration, and for an economic evaluation. However, since one immediate need in Ghana is for an energy supply for brick kilns to replace the oils presently used, a system that would meet the kiln energy requirements would perhaps be especially useful.

It appears, therefore, that a reasonable size for the system would be a nominal six tons per day of dry input feed. Such a system should supply sufficient oil to power the 12,000 brick per day kiln presently operated by the Building and Road Research Institute in Kumasi and allow for perhaps a 50% expansion in capacity. By using both the char and the oil in a mixture, more than three kilns of the mentioned capacity could be supplied with energy. A further advantage to this capacity is that the system would be small enough so that it could be made readily transportable. Additionally, the unit could provide the oil required to feed the slightly larger kilns planned for use by the Bank of Ghana in its brick kiln program.

1/ Note: The situation in Ghana may not be representative of LDC's generally because a fairly well-developed electric power system is available there. The design selected for Ghana was chosen to take advantage of this fact. Likewise, the capacity selected for the unit in Ghana may not be appropriate for other LDC's. It should be emphasized, however, that a more labor-intensive system is readily conceivable, and a unit of much smaller capacity could be designed. The important idea is that the process lends itself easily to the situation in LDC's and, while modifications for specific circumstances may be necessary, they could be made without compromising the system's performance.

Design Philosophy

A major consideration in the design is to incorporate technology appropriate to the Ghanaian situation, i.e., where practical, labor-intensive components should be employed and alternate manual operating models should be used as much as possible in all mechanically powered units. In addition, commonality of motors, bearings, etc., as much as practicable, should be sought. However, 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. Moreover, 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 Ghana, insofar as possible, and be "off the shelf" where practical.

In addition to these factors, the availability of materials must be considered in the design. Thus, even though serious compromises may often be necessary, with resulting requirements for frequent replacement of certain components or parts of these components, it may be necessary to use inferior, but available, materials in place of more advanced materials. This consideration also should influence individual component design, since any material problems should be anticipated, and threatened components or their parts should be designed so that they can be easily removed and/or replaced. While by some standards this may seem a doubtful practice, it may be that "inferior" materials using innovative design practices will suffice in many situations that normally require advanced materials. In addition, because of lower labor rates in Ghana and other developing countries, the occasional replacement of a part may be far more practical than the use of more expensive (and unavailable) advanced materials in the initial fabrication.

To illustrate, the available materials which can be used to fabricate components in Ghana include the following:

Mild steel sheet	- 4' x 8', 1/8" and 3/16" thickness
Galvanized steel sheet	- 4' x 8', 16-24 gage
Box tubing, steel	- 20', 2" x 2"
Flat bar, steel	- 20', 2" x 3/16" and 1-1/2" x 1/4"
Angle, steel	- 20', 2" x 2" x 1/4" and 1-1/2" x 1-1/4" x 1/4"
Galvanized pipe	- 20', 1/2", 3/4", 1", 1-1/4", 2"
Copper pipe	- 20', 1/2", 1"

Inspection reveals that indeed the available materials are limited and considerable design ingenuity will be required to construct a successfully operating system.

A final consideration in the design is the fabrication capabilities within Ghana. Information available from the Technology Consultancy Center at the University of Science and Technology at Kumasi indicates that simple welding, cutting, and rolling of the available materials can be accomplished routinely. In addition, metal machining requirements involving lathes, milling machines, and drills can be satisfied. Thus it appears that a reasonably broad range of fabrication skills is present, so far as work with the available materials is involved. Hence, the design of the unit itself does not appear to be seriously compromised by the fabrication capabilities.

System Description

At the outset, it must be emphasized that the system design 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. The system design presented should be considered only as typical, although perhaps useful in making cost estimates. No attempt has been made to optimize the design. Hopefully, a future program will allow the opportunity for that more detailed work.

The selected system has been chosen to utilize as much as practical existing techniques for pyrolytic conversion that are appropriate for LDC's, and to take maximum advantage of both kiln and continuous pyrolytic processes. The system has been designed to be constructed using concepts familiar to the Ghanaians and consisting primarily of components either already manufactured or readily fabricated in Ghana. The system, shown schematically in Figure 1, can operate in both a batch mode[1/] and/or a semicontinuous mode with, respectively, either large pieces of wood or relatively small-size materials such as rice straw, sawdust, and groundnut shells as feed. In either case, the higher

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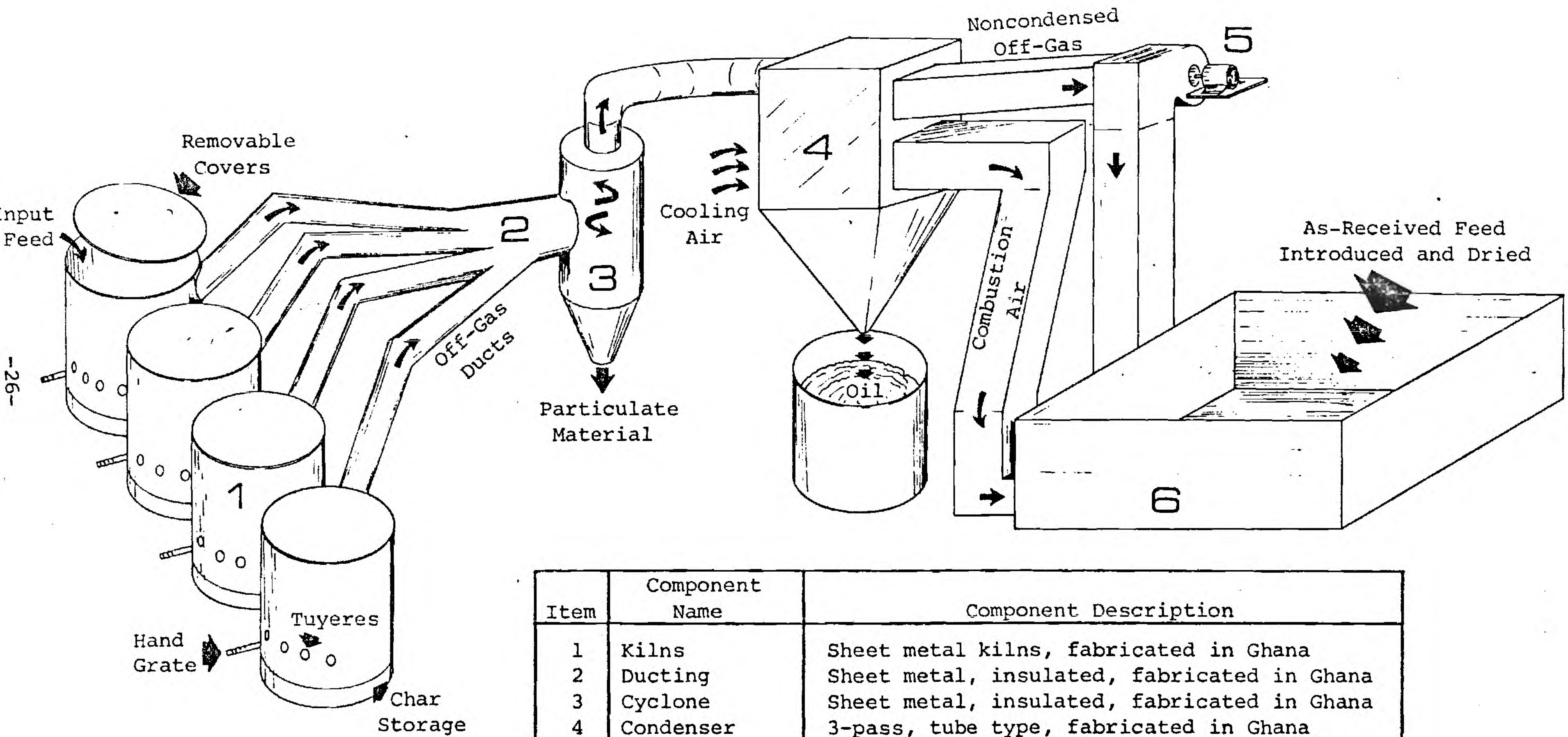
1/ It might be noted that for years oil drums have been used throughout the Caribbean in a similar manner to produce charcoal but without any oil recovery.

Figure 1

SIX TONS PER DAY PYROLYTIC CONVERSION SYSTEM FOR GHANA



Item	Component Name	Component Description
1	Kilns	Sheet metal kilns, fabricated in Ghana
2	Ducting	Sheet metal, insulated, fabricated in Ghana
3	Cyclone	Sheet metal, insulated, fabricated in Ghana
4	Condenser	3-pass, tube type, fabricated in Ghana
5	Draft Fan	Centrifugal, probably imported
6	Modified IRRI Drier	Batch drier, composed of both locally fabricated and imported parts

boiling point pyrolytic oils can be recovered and the system operates in a self-sustaining mode.

Operating with large pieces of wood, batch operation would be appropriate, with manual loading of the feed and unloading of the char using a removable grate. By proper sequencing of the kilns' firing order, a relatively constant supply of off-gases would be produced and the condenser would effectively remove the higher boiling point fraction. In this batch mode, the draft fan, besides removing the off-gases, would also induce a limited supply of combustion air into the kiln through adjustable tuyeres as with conventional kiln operation.

Operating with smaller-size feed, a modified batch/continuous operation would be used with the feed introduced and the char removed intermittently (in the latter case using a conventional shaker-type grate). In this mode, the air tuyeres could be (1) *closed*, simulating operating in a Stafford-type retort (2) and using the exothermic reaction heat to carbonize the feed, or *partially open*, simulating operation of the Barneby process (6), the De Bartolomeis retort (5), or some similar process, using the additional heat produced by combustion of a small portion of the char to accelerate the carbonization process.

Examination of Figure 1 reveals the presence of several key components; for example:

1. The four modified kilns, including the manually operated shaker grate char output system and adjustable air tuyeres.
2. The cyclone for removing particulates from the off-gas system.
3. The condenser itself, which separates out the high-temperature oily fraction from the off-gas stream.
4. The draft fan.
5. The modified IRRI drying system for preparing the feed.

The unit is assumed to have access to electric power for operation of the draft fan and also the blower in the IRRI drier.

The system would operate at perhaps one-half inch of water negative pressure. The pressure would be controlled by the speed of the draft fan, the process rate, and the tuyere opening. For continuous operation, the production of gas required to dry the feed would be controlled by the amount of air introduced. For very dry feeds, only a little gas would be needed and the tuyere openings could be reduced, while for wetter feeds, more gas would be needed and the tuyere openings increased. The off-gases, upon leaving the kiln, would pass through a cyclone to remove fine suspended material and then to a condenser where the higher boiling point oils would be recovered and stored in drums. The noncondensible off-gases would leave the condenser and be incinerated in a modified IRRI drier (10). The charcoal produced would be collected from the bottom of the kilns and stored in air-tight steel drums while it cooled.

The combustion air for the modified IRRI drier would pass through the condenser and thus provide the required cooling of the off-gases. To allow ease of maintenance, the off-gas would pass through the tubes rather than across the tube bank as is normal condenser design practice. Easily removable access plates would 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 may be provided by means of "char shelves," as described in (7), which would use the feed/char itself as a lightweight, expendable insulator. Conceivably, clay also could be used in conjunction with the char shelves. The kilns would be cylindrical and constructed of 1/8" reinforced steel sheet. Because of the danger of corrosion, especially in the off-gas plenum, it would be built in easily removable sections. The overall outside dimensions would be approximately 3' x 5'.

The entire system would be located underneath a shed to protect it from the rain and direct sunshine. Asbestos insulation supported by plywood would be used to minimize heat transfer, especially from the kilns and the cyclone. Blowout ports would be located on the kilns, the cyclone, and the condenser to ensure that any overpressures would be easily vented.

The overall system, operating on a 24-hour basis, would process six tons of dry feed per day. It is estimated that the system would produce about 3,000 pounds of char and 2,200 pounds of oil each day. The total energy available in the char and the oil would be about 70% of that in the dry feed.

System Operation

The operation of the overall system in either the batch or continuous mode would be basically similar except for the method of kiln charging and unloading. Hence, in the case of batch type operation, a small fire would be built in the bottom of a kiln and the larger pieces of wood introduced manually. The kiln would be sealed, the tuyeres would be opened, and the draft fan would induce a limited flow of air for combustion of a small fraction of the charge. This, in turn, would supply the heat needed for carbonization of the feed, as in conventional kiln operation.

Since the production of off-gas from a kiln is strongly time dependent, the successful operation of a condenser to recover the oily fraction is doubtful without complex cooling controls. However, if an array of kilns is used and fired in a sequence so that a relatively constant supply of off-gas is produced, it is anticipated that successful removal of the oils, without the recovery of excessive amounts of water, can be accomplished. This then would be the operating procedure for the system in a batch-type mode.

For continuous operation, each unit would be started up by building a fire in the partially filled bed, at a level slightly above the tuyeres. The off-gas system draft fan would provide the needed combustion air. After the fire had reached a good stable condition and the unit had heated up, additional feed would be added to cover the combustion zone until the bed depth reached that desired. Then, after a pause to allow a thermally stable condition to be reached, the shaker grates would be manually activated and the systems slowly brought up to the operating mode. Depending upon the process rate desired and the feed moisture characteristics, the tuyeres could be completely closed or partially open.

As the level of the charge in the kiln dropped, it would be periodically replaced by the manual introduction of feed at the top. A simple plate valve to isolate the kiln from the off-gas system could be used to minimize air introduction into the system during feeding.

There are a number of constraints inherent to the process which require special design, maintenance, and product handling procedures.

The final design of the unit must permit periodic disassembly and cleaning of the ducts because one of the operational problems is the clogging of ducts and pipes with solid matter and oil condensate. In addition, the pyrolytic oils are somewhat corrosive and have a strong, unattractive odor. Hence, they must be stored and sealed in adequate containers. Additional research is needed to reduce the odor of the oils, if the oils are intended for use in households for cooking or lighting.

This proposed system configuration is somewhat experimental, although the individual components have worked in a number of similar processes. Hence, testing and evaluation of a prototype unit is essential. This may lead to on-site modification to optimize the operating characteristics and to minimize "downtime" of the unit through a properly designed maintenance program.

PROJECTED COSTS AND RETURNS

The analysis of costs and returns, based on the design shown in Figure 1, 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:

1. Plant location: Adjacent to the source of waste material supply.
2. Plant size: A three-shift operation would require six tons of feed material per day in dry condition or 12 tons with a moisture content of 50%. A two-shift operation would require four tons of dry feed material per day or eight tons with a moisture content of 50%. A one-shift operation would require two tons of feed material per day in dry condition or four tons with a moisture content of 50%.
3. The system would be in a fixed position, but it is designed to be easily dismantled for moving purposes.
4. The system is designed for labor-intensive purposes. Major components would be manufactured locally, except for a few critical parts which would have to be imported.
5. The plant would be operated either on a one-shift basis (eight hours per day), a two-shift basis (16 hours per day), or on a three-shift basis (24 hours per day) for 300 working days a year, allowing 65 days for maintenance and holidays.

Capital Costs

Production components	¢12,000
Building	10,000
Contingency	5,000
Total	¢27,000
Working capital	3,000
Total capital requirements	¢30,000

Operating Costs

Several elements in the operating cost estimates have to be predetermined. The raw material (sawdust in this case) is assumed to be free and on the site of the production unit. A crew of 11 workers per shift is needed. Operating costs include labor and management overhead, transportation costs for finished products and some raw material hauling, maintenance, and debt service on borrowed capital. It is assumed that the production unit would wear itself out in ten years with no salvage value. A summary of the operating costs is presented in the following table:

	Per Year		
	One Shift	Two Shifts	Three Shifts
Labor and management overhead	¢15,000	¢28,000	¢40,000
Transportation	1,000	1,500	2,000
Maintenance	1,000	1,500	2,000
Debt service*	5,419	5,419	5,419
Total	¢22,419	¢36,419	¢49,419

* Payment includes interest and principal, based on a 10-year loan of ¢30,000 at a 12.5% annual interest rate.

Projected Returns

Returns would vary according to the number of shifts operated per day and the quantity of products produced. Loose charcoal was given a value of ¢100 per ton compared with ¢133 per ton of lump charcoal. Oil value was estimated at ¢52 per ton (2,000 pounds) and therefore is equivalent in value on a Btu basis to Bunker C fuel oil.

Based on a three-shift operation, total returns on production were estimated at ¢63,720 per year. The returns were estimated on the basis of 450 tons of charcoal and 360 tons of oil annually. Profit before taxes was estimated at ¢14,301 after deducting the production costs of ¢49,419. The payout time would be two years if no taxes were assessed.

Calculation of net income based on a three-shift operation is as follows.

	Per Year
Charcoal - 450 tons x ¢100	¢45,000
Oils - 360 tons x ¢52	18,720
Total	¢63,720
Operating costs	49,419
Profit before taxes	¢14,301

Based on a two-shift operation, total returns on the production were estimated at ¢42,480 per year. The returns were estimated on the basis of 300 tons of charcoal and 240 tons of oil per year. Profit before taxes was estimated at ¢6,061 after deducting the production costs of ¢36,419. The payout time would be five years if no taxes were assessed.

Calculation of net income based on a two-shift operation:

	Per Year
Charcoal - 300 tons x ¢100	¢30,000
Oils - 240 tons x ¢52	12,480
Total	¢42,480
Operating costs	36,419
Profit before taxes	¢ 6,061

If the plant were operated only one shift or eight hours per day, it would incur a net loss of ¢1,179 per year. Consequently, it is recommended to operate either two shifts or three shifts a day on the designated model.

Calculation of net income based on a one-shift operation:

	Per Year
Charcoal - 150 tons x ¢100	¢15,000
Oil - 120 tons x ¢52	6,240
Total	¢21,240
Operating costs	22,419
Net loss	¢ 1,179

The above economic analysis is based on a prototype model with a maximum feed input of six dry tons per day. Further improvements made on the model and a larger scale of operation would naturally lead to the reduction of production cost per unit of product output.

PILOT DEMONSTRATION PROJECT DEFINITION

The implementation of a pilot demonstration project to investigate the validity of the findings of this study would involve several steps. These include:

- Identification of a specific locale where a field survey of (1) the available wastes and (2) the market for the fuels produced indicates that the concept shows promise and where local financing is available;
- Detailed design of a system appropriate to the characteristics of the specific locale identified, with proper attention given to available materials and manufacturing practices in Ghana;
- Manufacture and assembly of the system in Ghana;
- Checkout testing of the system;
- Long-term operation to investigate the operating characteristics and economics of the system.
- Training of staff and technicians to operate the system.

Completion of these six steps should provide sufficient information to establish the feasibility of using pyrolytic conversion of wastes in Ghana.

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Appendix

ENERGY-FOOD PLANTATION FOR THE THIRD WORLD

ENERGY-FOOD PLANTATION FOR THE THIRD WORLD

It is but a small step conceptually from the recovery of energy from plant wastes to the deliberate cultivation of plants and trees (11) for the production of energy. Such a process, termed "bioconversion," is currently being examined closely in the U. S. and shows great potential as an alternate energy source. Because the concept involves a perpetually renewable supply of storable and easily transportable fuel that can be produced in an ecologically acceptable manner, it has great appeal. Basically, "bioconversion" is a means of converting solar energy into an easily used fuel at a capital cost only slightly more than the real estate required to grow the "biomass" (i.e., the organic fuel input). Contrast this with the highly capital-intensive methods of direct solar energy collection and storage that are currently being developed and the advantages are apparent. Even today in the U. S., where labor costs are high, land costs are high, and energy costs are relatively low, the use of bioconversion is practical in many situations. For example, in New England where fuel costs are extremely high, electric power is now being generated from the direct incineration of wood in utility boilers.

The technology of direct burning, pyrolysis, and gasification for energy conversion from biomass has long been available. To illustrate, in Europe in 1937, 576,000 tons of synthetic fuels produced from living plant matter were consumed in 4 million motor vehicles (12). Since that time, the conversion technology has improved significantly, and today efficient production of high-quality fuels and energy supplies from biomass is a reality. Likewise, the agronomical technology has more than kept pace. Modern methods of cultivating rapid juvenile growth, coppicing hardwoods have led to a new branch of agronomy termed "agri-silviculture" which involves planting and harvesting trees just as a row-type crop. Annual yields in the range of 10 to 20 dry tons/acre have been realized using this method. So there clearly is no technical reason why living material cannot be grown, gathered, and converted into storable fuels.

Developing countries of the Third World -- where labor and land costs are low and energy costs are high -- generally have immediate needs for food, energy, and foreign exchange. Usually, they suffer from excessive unemployment and underemployment, especially in the agricultural sector because of its seasonal nature. This results in a serious tendency for large numbers of people to leave the hard life in the country and to seek a better way in the urban centers -- a condition that undermines economic development, since a stable food supply must be assured before industrialization can be realized.

The recent excessive increases in energy costs have particularly affected the Third World economic development. The impact can be seen from the fact that in 1974 these countries paid about $15 billion for their oil imports, of which $10 billion was the additional cost above 1973 levels. In a number of these countries, the oil import bill in 1974 represented some 20% of projected imports -- a devastating blow to their ability to continue economic development. Clearly some alternative energy source must be developed.

Consider the resources that Ghana and other LDC's have. First, since they are generally located in the tropics, one resource they have in abundance is sunshine (i.e., year-round growing season). Moreover, rain in quantities to insure copious plant growth is available in immense areas which are currently unused. And finally, the idle hands available represent a vital factor in the development of any labor-intensive industry.

Thus a further step from simply recovering energy from agricultural and forestry wastes would involve the combination of direct biomass energy production with agriculture and the introduction of this combined concept into the Third World. It can be shown that the potential for this concept is outstanding and could, if properly implemented, insure the development of many LDC's to a prosperous, stable condition otherwise practically unattainable. The application of this concept, using highly organized, labor-intensive farming methods (including conventional, nontill, and "organic" practices) could produce a year-round, perpetually renewable source of biomass for energy production and food and could generate the continuous need for many, many new jobs. By proper selection of the primary energy-food crops, "energy-food plantations" could be made to yield a blend of products tailored to meet a country's needs as it develops toward a more industrialized society.

To illustrate the potential of the concept, a simple 100,000-acre plantation (that is, about a 12.6-mile by 12.6-mile tract) could produce the energy equivalent of 500,000 tons of coal per year, perhaps 54,000 tons of corn, and 60,000 tons of peanuts.

A more capital-intensive plantation of the same size but including processing plants to produce methanol, ammonia fertilizer, and also a thermoelectric plant could typically produce:

- 50,000 tons methanol/year
- 120,000 tons anhydrous ammonia/year
- 17,000 tons char/year
- 12,000 tons pyrolytic oil/year
- 80,000 kilowatt hours/year

In addition, the 54,000 tons of corn and 60,000 tons of peanuts would go a long way toward correcting the imported food deficit.

To put the above numbers in perspective, in 1973, Ghana consumed a total of 4.1×10^{13} Btu's or the energy equivalent of 1.64×10^{6} tons of coal. Of this, 2.9×10^{13} or 70% of the total was imported. Likewise, Ghana imported 15,500 tons of wheat and 267,000 tons of rice. Thus it can be seen that the production of energy and food, using the method described, could have a profound effect in stabilizing Ghana's economy and meeting its own needs in a socially beneficial way.

Not only could LDC's meet their own energy needs, but there is good reason to believe that, by the end of this century, the developing countries of the Third World could, by application of biomass conversion techniques, become major suppliers of the world's energy demands. Several recent publications (13) (14) (15) (16) have recognized the significance of bioconversion to the Third World and have called for intensive development of the concept.

Thus, in summary, it appears that the technology of bioconversion is available today. The potential for its application, combined with agriculture, in the Third World is awesome. What is needed now is the practical development of the concept and, most of all, the commitment to such an undertaking.