Bioenergy Systems Report

DECEMBER 1983: BIOENERGY FROM CROP RESIDUES

INTRODUCTION

The Reports in this series are sponsored by the Bioenergy Systems and Technology Project of the U.S. Agency for International Development. They are designed to contribute to wider international sharing of experience with systems and technologies for the conversion of biomass to energy in developing countries.

Most of the literature on bioenergy technologies and applications has been devoted primarily to the use of wood in combustion and gasification systems and to the use of animal residues to make biogas in anaerobic digesters. However, in many areas in developing countries neither wood nor manure is available for use in new bioenergy systems. In vast areas present or potential deforestation problems preclude new bioenergy systems using wood or charcoal derived from wood. In many areas the only types of biomass which are available locally in considerable quantities are the residues generated by the production and processing of the area's primary cash crop or crops.

Many crop residues are left in the fields or elsewhere on the farm. Until now it has rarely seemed economically feasible to collect and transport such residues to a central location for use in a large bioenergy system. However, studies of the economics and technology of residue collection have been carried out in several countries.

Other biomass is transported to a mill along with the food or fiber product, but remains at the mill after processing. Such mill residues include sugarcane bagasse, rice hulls, coconut shells, cotton ginning waste, peanut hulls, nut shells, fruit pits, and residues from many other kinds of food and fiber processing.

Around the world, most of the industrial use of biomass for fuel is at biomass processing mills which are using their own residues. The most notable examples are sawmills and other wood-processing plants which burn wood residues. The most widely used crop residue is sugarcane bagasse. Most sugar mills in developing countries burn bagasse in boilers to make steam for the process heat needed in the mills. Some sugar mills produce high pressure steam which is used in turbine generators to produce electric power for the mill and perhaps for the adjacent community. However, a number of technical and economic factors have limited the use of other crop residues for fuel.

In many mills the primary need is for mechanical power rather than for process heat. The use of steam engines to provide mechanical power for milling machinery was once rather common, but this form of motive power is now rare and most mills are powered with diesel engines or electric motors. This evolution has been due to many factors including expanding rural electrification, the low price of diesel fuel for many decades prior to 1975, and the greater convenience of operation of electric motors and diesel engines. Although the high price of petroleum fuels has altered the comparative economics of these power systems and generated some renewed interest in steam engines, there seems to be little prospect of a widespread return to the use of steam engines in biomass processing

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mills. Inhibiting factors include the limited present infrastructure for manufacturing and servicing steam engines, the rather high capital cost per unit of output, and the need for well-trained operators.

Larger plants with electrically operated machinery may be able to generate their own electricity using crop residues as fuels. One option is to use the biomass as a boiler fuel to produce high-pressure steam and then use the steam in a turbine generator. The economics of power generation through a steam turbine system are much more favorable if the plant also uses steam for process heat; in such a "congeneration" system the high-pressure steam is used in the turbine for power generation and the lower pressure exhaust steam is then used for drying the incoming biomass or other process heat needs. These steam generating systems are too complex and expensive for many medium and smaller mills, especially those which do not need steam for process heat.

At present the only other way to use biomass to provide mechanical power is through thermal gasification. The biomass is converted to a low-Btu gas known as producer gas which can be used alone in spark-ignition engines or can be mixed with 10 to 20% diesel oil in diesel engines. The gas can operate an engine providing direct mechanical power for a mill or it can fuel an engine-generator providing electrical power for a mill equipped with electrical motors.

Gasification systems provided power to a considerable number of rice mills and some other biomass processing mills in developing countries in the earlier decades of this century. However, like steam engines, most of these units were supplanted in the middle part of the century by diesel engines and electric motors. Today, due to the high cost of petroleum fuels, there is renewed interest in the use of crop residues in both combustion and gasification systems.

Some crop residues, notably rice and cotton residues, contain high percentages of ash. This high ash content reduces the heating value of the biomass, requires more complex ash removal equipment in both combustion and gasification systems, and can cause slagging problems in gasifiers if the temperatures rise above the melting point of the ash.

While there has been less experience with the use of crop residues as fuels than with wood and charcoal, there has been sufficient experimentation and commercial development to provide an opportunity for more effective sharing of this experience with the production of energy from crop residues. Accordingly, this Report will focus on the thermal conversion of crop residues to energy in developing countries. Information will also be provided on thermal processes which have been used in developed countries to produce energy from the residues of crops which are also grown in some developing countries. The use of residues from the processing of agricultural corps in anaerobic digesters to produce biogas will be reviewed in a Bioenergy Systems Report to be published early in 1984.

The Bioenergy Systems and Technology (BST) Project, sponsor of these Reports, assists USAID missions and governments of developing countries with the identification and planning of bioenergy projects. Dr. Paul Weatherly is manager of the Project in the Agency for International Development's Office of Energy. Staff support for the project is provided by a team from the Tennessee Valley Authority which is coordinated by Mr. Edward Storey.

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PART ONE: LOW-ASH FUELS

The easiest crop residues to use in thermal conversion systems are those with a low ash content. This part of the Report will describe the use of the following low-ash fuels in thermal systems: coconut shells, coconut husks, corn (maize) cobs, sugarcane bagasse, coffee bean husks, and peanut hulls.

1. COCONUT SHELLS

The shell of the coconut is from 12 to 18 mm thick. Crushed shells are a relatively high density fuel with a heating value of 18 to 21 MJ/kg. Energy can be produced from the shells through direct combustion, charcoal production, and the use of the shells or charcoal made from the shells in gasifiers.

a. Direct Combustion of Coconut Shells

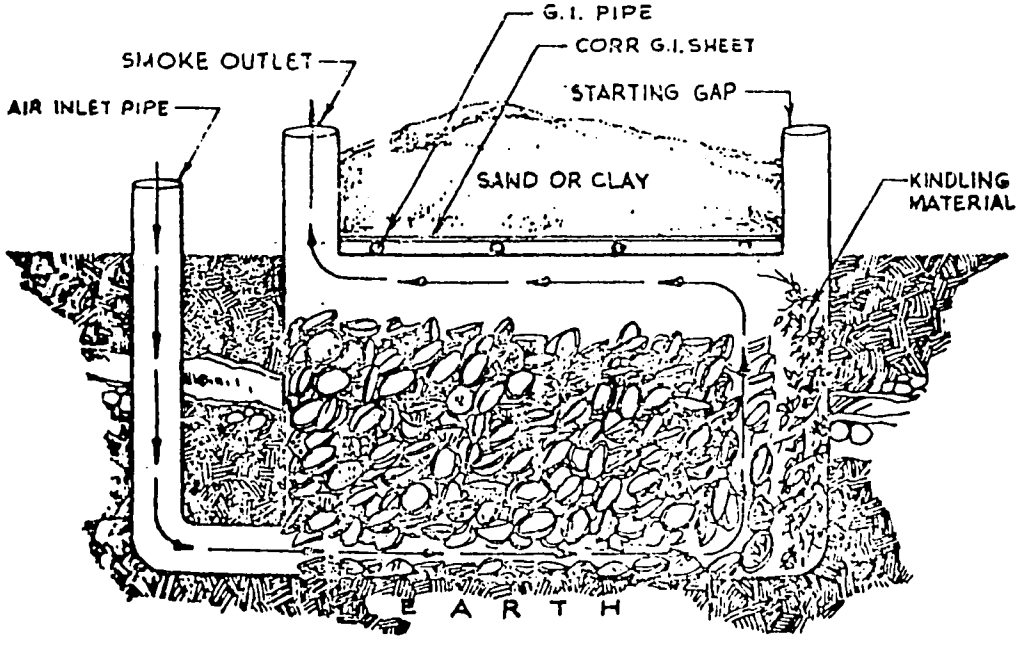
A survey by Sri Lanka's Coconut Research Institute indicated that 440 million shells, or about 40% of the total produced in Sri Lanka, are burned annually in coconut-processing plants to provide heat for the kiln drying and curing of copra. The shells can also be burned as a domestic fuel, although charcoal made from the shells is a more convenient fuel.

Coconut shells and husks would be burned along with coconut wood in a small steam turbine power plant which has been proposed for Christmas Island in Kiribati in the South Pacific. Steam would be produced in a 2000 kg/hr boiler and used in a 100 KVA turbine generator set. The development of an effective system for collecting the coconut residues for use in such plants is complicated by the land ownership and land use patterns in the South Pacific area.

b. Production of Coconut Shell Charcoal

In the Philippines, Sri Lanka, and other coconut-producing countries, coconut shell charcoal for household use in rural areas is made in primitive earth pits. Sri Lanka exports about 50,000 metric tonnes of coconut shell charcoal annually; most of this charcoal is made by the pit method. The typical Philippine pit is 1m x 2m x 3m. A few shells are ignited in the bottom of the pit, and the pit is then filled with shells. Flames are quenched by sprinkling with water. When charcoaling is completed, the pit is covered with banana stalks and leaves and left to cool.

A somewhat more complex "reverse draft" system is shown below. A larger pit (4m x 2m x 1.5m) is lined with scrap iron or pieces of oil drums to avoid contaminating of the charcoal with earth. Two 8 to 10 (20



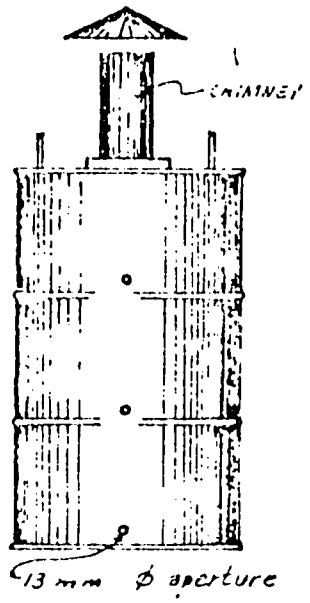
to 25cm) air inlet pipes lead from the bottom of the pit to the surface about 1m from each end of the pit; only one of these is shown in the sketch. After the pit is filled with coconut shells, it is covered with sheet iron which is then covered with sand or clay. Two gaps are left at either end; the starting gap is used to ignite the kindling material and is then closed. Burning is controlled by gradually closing the smoke gap and air inlets. The charcoal yield from this unit ranges from 20 to 25%.

The Forest Products Research and Industries Development Commission in the Philippines has developed several modifications of the widely used oil drum charcoal kiln. The top of a 55 gallon oil drum is removed. A 10 cm diameter piece of roundwood is placed at the center of the drum, when is then filled with coconut shells; the roundwood is removed, and a burning rag is dropped to the bottom of the center airspace. When the shells are well ignited, the drum is covered by a steel plate with an attached metal chimney as shown in the adjacent sketch. Air is controlled by the successive opening and closing of three sets of four 13mm diameter holes at equal distances around the circumference of the drum. At the start of charcoaling, only the lowest set of holes is open. Later these are sealed and the middle set of holes is opened. Finally, only the top set of holes is used. This design gives a charcoal yield of 32 to 35% with very few reject pieces.

In England the Tropical Development and Research Institute (formerly Tropical Products Institute) produced charcoal from coconut shells in a portable steel charcoal kiln and used the gases produced during the carbonization to dry three tons of copra. Subsequently the Institute has designed and manufactured an integrated coconut shell carbonization and waste heat recovery unit. The pilot plant produces 270kg of charcoal and 10,000 MJ of process heat during the 10-hour processing of each batch of shells.

c. Coconut Shell Charcoal in Gasifiers

Coconut shell charcoal is an excellent fuel for downdraft gasifiers. The ash content of the shell is low (0.8 to 1.5%),



and the tars have been driven out in the carbonization process. The principal advantage of using coconut shell charcoal as a gasifier fuel, compared to using uncarbonized shells, is that gas cleaning problems are greatly reduced. In experiments at the University of the Philippines the only gas cleaning device used with charcoal fuel was a cyclone; when uncarbonized coconut shells were used, it was necessary to add a wet scrubber to remove the tar and other condensibles.

The University of the Philippines tests included the use of producer gas from coconut shell charcoal in both gasoline and diesel engines. A four-cylinder Jeep engine connected to a small AC generator produced 6.71 kW with gasoline. Using producer gas from coconut shell charcoal, power output dropped only slightly to 6.14 kW; the unit used 1.485 kg of the charcoal per kilowatt hour of power produced. The gas was also dual-fueled with diesel oil in a 5 HP single-cylinder diesel engine. Diesel fuel consumption was reduced by 79%, and the engine output remained the same as with 100% diesel fuel. Charcoal consumption in the diesel engine was .45 kg per HP per hour.

The University of the Philippines also tested producer gas from coconut shell charcoal in a 65 HP, six cylinder irrigation pump; the highest diesel fuel displacement (75%) was at 1568 RPM, but more diesel

fuel was used at higher speeds up to 1800 RPM. Diesel fuel displacement reached 92% with coconut shell charcoal in a 60 HP irrigation pump at the Farm Systems Development Corporation's demonstration farm in Bulacan.

Most of the 331 gasifiers installed by the Gasifier Equipment and Manufacturing Company (GEMCOR) in the Philippines up to June 1983 are operated with coconut shell charcoal. These include units for irrigation pumping, rice milling, fishing boats, vehicles, and other applications. Since charcoal gasifiers produce a cleaner gas and do not require a very complicated gas cleaning system, they are cheaper than gasifiers designed for wood or other biomass.

Maya Farms in the Philippines has planted coconut trees and plans to make coconut shell charcoal; the charcoal will be used in gasifiers to operate trucks at the large swine-producing and meat packing enterprise.

A low-cost experimental gasifier, designed for use with small engines, was tested with coconut shell charcoal at the Ceylon Institute of Scientific and Industrial Research in Colombo, Sri Lanka. Fuel flow and gas quality improved after the original 10 cm diameter choke plate or throat was widened to 16 cm. There was some slag formation, but it did not interfere with the operation of the unit. The gas was cleaned in a cyclone, cooler, and dust filter before entering a 3 HP engine.

d. Crushed Coconut Shells in Gasifiers

Crushed but uncarbonized coconut shells also make an excellent gasifier fuel. Electric power was generated through the gasification of coconut shells in West Africa before World War II. Tahiti's capital, Papeete, was powered by the gasification of coconut wastes from 1928 to 1945. Since 1979 producer gas from coconut shells and husks has fueled a 190 kW Duvant gasifier system on the Pacific island of Bora Bora. Coconut shells are used in another large Duvant gasifier-generator system in the Ivory Coast.

Producer gas from coconut shells was dual-fueled with diesel fuel in a 5 HP diesel engine at the University of the Philippines. Diesel fuel displacement averaged 73%. When the engine was dual-fueled with producer gas the maximum output was 6.5 HP, compared to only 5.5 HP when operating on 100% diesel fuel. The thermal efficiency of the engine was significantly higher with the producer gas than with 100% diesel fuel.

Gasifier system fueled with coconut shells is providing 27 to 29 kW of electric power at a coconut processing plant in Giriulla, Sri Lanka. The plant was donated by the Government of the Netherlands, built by Biomass Energy Consultants and Engineers (BECE) of Almelo, Netherlands, and installed by Twente University of Technology of Enschede, Netherlands, in cooperation with Peradeniya University of Sri Lanka. After about 1,000 hours of operation with the gasifier the engine began to misfire; carbon deposits were found in the combustion chamber and the piston head and there were tar deposits in the inlet manifold. The addition of a wet scrubber or auxiliary filter to the present gas cleaning system is being considered. A detailed description and sketch of the Giriulla system was provided on page 7 of the Bioenergy Systems Report on "Bioenergy for Electric Power Generation" published in June 1983. (The Editor regrets that the system was incorrectly identified in that Report as a Swedish-built unit. BECE offers 7.5 and 15 kVA charcoal gasifiers and gasification systems using wood and agricultural residues in several sizes from 30 kVA to 150 kVA.)

Experiments were conducted at the University of the Philippines with the gasification of the shells to produce a boiler fuel for a small steam power plant. A gasifier with a 0.9 m^2 grate was designed to operate as either an updraft or downdraft unit by reversing the roles of the air inlets and gas outlets. The shells were fired in 5 to 10 cm pieces. The gas was burned in a horizontal-return, tubular, package boiler; steam was used in a 3-cylinder, 1200 RPM Spilling steam engine coupled to a 50 kW

generator. Heavy clinkers were formed during updraft operation, but clinker formation was negligible when the unit was converted to downdraft operation. However, 24% less carbon was gasified during downdraft operation and the caloric value of the gas was much lower (2720 to 3465 KJ/m^3) than during the updraft phase (4322 to 4471 KJ/m^3). Consequently, the steam produced during downdraft operation generated only 17 kW, compared to 33 kW when the unit was in the updraft mode.

Producer gas from coconut shells was also used for copra drying at the University of the Philippines. Unscrubbed producer gas and tars were burned together in a furnace producing a smokeless flame. A blower circulated the hot gases directly through chambers containing trays of copra. The average temperature in the chambers was 141°F (60°C); the moisture content was reduced from 52% to 4% in a drying period of 18 hours.

2. COCONUT HUSKS

The fibrous husk which covers the shell of the coconut has a lower heating value per unit of volume and a higher ash content (3.4 to 6%) than the coconut shell. The Coconut Research Institute's survey indicated no use of coconut husks for copra drying or charcoal production in Sri Lanka. However, there have been experiments with the use in gasifiers of chopped coconut husks and of the coir dust produced when the fibers are removed from the husks.

a. Chopped Coconut Husks in Gasifiers

The Economic Development Foundation in the Philippines used about 2.5 kg of coconut husks to produce 1 kW hr of electric power in a gasifier system with a 80 HP diesel engine and a 37.5 KV generator. Diesel fuel consumption was reduced by 65%. The unit produced power for 100 families. Husks are used along with coconut shells in the 190 kW Duvant gasifier on the island of Bora Bora.

Research on the gasification of coconut husks is being conducted by the research division of the Ministry of Planning and External Relations in the Seychelles, with the assistance of Swedish and German agencies. During 1982 tests were made with coconut husks in an Imbert downdraft gasifier supplied by Gotland Gengas of Sweden under the auspices of the Beijer Institute of Stockholm. The unit is 1.10 m high and .45 m in diameter with a 100 mm diameter throat. The initial system included an air cooler and a gas filter packed with wood wool or coconut coir. The gas was fed to a Volvo V-8 3.5 liter car engine, connected to 35 kW alternator.

Bridging, slagging, and gas quality problems were encountered in the initial tests. The slag had a high carbon content, was very fragile, and did not affect operation during the limited test runs. Gas quality problems were more serious. The wood wool and coconut coir filtering media allowed a substantial qualtity of carbon and grit to pass through to the engine, and operations were suspended until a new gas cleaning system could be obtained from Twente University in the Netherlands. A new series of tests are planned, in the hope of reducing bridging problems due to the rough and fibrous nature and low density of the coconut husks.

A 50 kW Swiss-built gasifier system, presented by the German Agency for Technical Cooperation, is also being tested in the Seychelles with coconut husks. Severe bridging and slagging problems have been encountered. Due to these and other problems, the unit operates only intermittently and delivers only 25 to 30 kW at present.

b. Coir Dust in Gasifiers

In some countries most of the coconut husks remaining at coconut processing plants are sold to plants which remove the fibers for use in brushes and rope. The defibering process generates a voluminous residue known as coir dust. In Sri Lanka 703 million coconut husks are used annually for fiber production; the fiber plants produce 135,000 dry tons of coir dust per year. The dust has accumulated for as long as 25 years in some plants in Sri Lanka. The production

of some of the Philippine fiber plants has been curtailed due to the lack of a suitable dumping site for the dust.

The principal limitation of the use of the coir dust as fuel in direct combustion or gasification systems is the high moisture content of the dust which often reaches 85% (wet basis). An analysis by the Coconut Research Institute in Sri Lanka indicated that drying dust with more than 60% moisture content would be very unattractive from an energy standpoint. The Ceylon Tobacco Company is experimenting with a method of pressing the dust to reduce the moisture content to 50% and then using solar and air drying. The company is also developing a plan for use of the dust in a cogeneration system; waste heat from the generation of electric power would be utilized to dry the coir dust for use as a boiler fuel.

Both loose coir dust and briquetts made from the dust were used in a small updraft gasifier at the University of the Philippines. Due to the high moisture content of the dust, the gas became incombustible for a few minutes after each charge of fresh fuel. There were also fuel feeding problems. Continuous combustion was achieved with briquetted coir dust in which the moisture content has been reduced to about 50%. However, the thermal efficiency and the caloric value of the gas were lower with the briquetted fuel. Although the coir dust contains 6% ash, no slagging problems were reported.

3. CORN (MAIZE) COBS

This section and a later section will review systems to produce energy from the residues of the crop which is known in the U.S. as corn but is called maize in most developing countries. The terminology used locally will be used in the description of each project.

The corn cob, the remainder of the ear after the husks and kernels have been removed, is an excellent fuel for combustion and gasification. Cobs contain rather low percentages of moisture (3.5 to 9%) and ash (1.5 to 4%). The heating value is 8000 to 8900 Btu/lb or 18 to 21 MJ/kg.

a. Heat for Grain Drying

Agricultural engineers at several U.S. universities have experimented with corn cob combustion and gasification, and several commercial firms are now using or marketing commercial units for the combution and/or gasification of the cobs for grain drying.

Sukup Manufacturing Co. of Sheffield, Iowa, sells a combustion system which burns corn cobs with corn husks. An auger conveys the biomass from a forage wagon to the continuous-feed stoker in the furnace. The husks serve as kindling to ignite the cobs. The feeding system can be adjusted to produce from 200,000 to 2.5 million Btu/hour. Automatic sensors maintain the desired feeding rate and the optimum air-fuel ratio. Furnace temperatures reach 1,000°F (538°C) with corn residues. Sukup officials say the combustion is so complete that the exhaust stream can be used directly for corn drying without a heat exchanger. The quantity of ash produced by the unit is reported to be very small. The Sukup unit sells for $14,160 in the U.S.

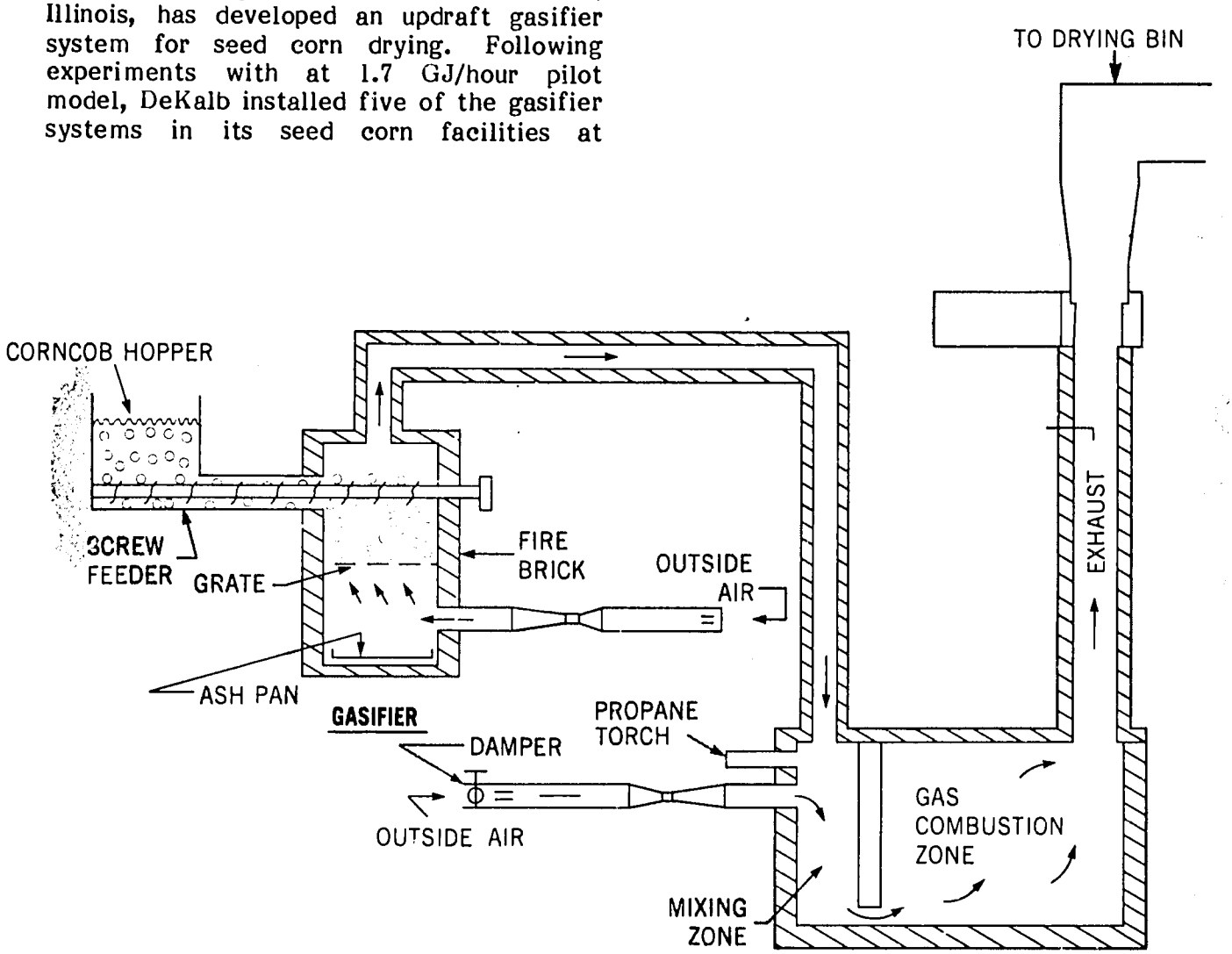
GEKA Warmetechnike of Karlsruhe, Germany, has developed a corn cob combustion system which is used for seed corn drying by firms in Germany, Austria, Hungary, and Yugoslavia. The unchopped cobs are stored in a silo with special appliances to prevent bridging; they are fed to the combustion chamber by a conveyor belt equipped with a feed screw. Combustion temperatures are kept below the ash melting point. The hot gas passes through a fuel gas boiler where the heat is transferred to oil; the heated oil circulates through heating vanes located in the suction openings of three corn dryers. The system consumes 900 to 1,000 kg of corn cobs per hour and produces 2.35 gcal of heat per hour.

A corn cob gasifier-combustor, developed at the University of Kentucky to provide heat for corn drying, is now being marketed by the Clayton and Lambert Co. of Buckner, Kentucky. The storage hopper holds a four-hour supply of cobs. A screw feeder or auger feeds the cobs from the

hopper to the updraft gasifier; a level sensor turns off the auger when the cobs reach a specified depth in the gasifier. Primary air enters below the grate and moves up through the cobs. Producer gas rich in hydrocarbons and tars passes over to the secondary combustion chamber, where it is burned with an excess of air at 1650°F (898°C). The designers and manufacturers of the system state that the carbon monoxide in the gas is totally converted to carbon dioxide and that all contaminates are removed in the combustion process. For grain drying applications the exhaust stream is passed directly into a centrifugal drying fan in a grain dryer. Ashes must be removed from the bottom of the gasifier every four hours. The unit, shown below, sells in the U.S. for $13,500 which does not include wiring or a concrete pad for the burner.

DeKalb AgResearch Inc. of DeKalb, Illinois, has developed an updraft gasifier system for seed corn drying. Following experiments with at 1.7 GJ/hour pilot model, DeKalb installed five of the gasifier systems in its seed corn facilities at Waterman, Illinois, and Boone, Iowa. The units range from 3.2 GJ/hour to 10.5 GJ/hour.

Dry cobs are fed from the hopper through alternating slide gates which keep the system sealed. An agitator keeps the bed packed and prevents bridging. When temperatures reach 1400°F (760°C) there is some slagging in the form of soft clumps of mineral and carbon. The steep incline of the perforated stainless steel grates reduces slag adhesion. The rotary powered ash removal system breaks and removes most of the slag. The gas is mixed with primary air in the burner and moves on into a cyclonic combustion chamber; the tar droplets and carbonaceous particulates are held in the system long enough to ensure complete heat release. However, some combustion products are delivered directly into the dryer, including a fine dust and



corrosive agents which accelerate corrosion of the dryer structure. Efforts are being made to reduce particulate levels.

b. Mechanical and Electrical Power

An experimental program on the use of maize cobs in downdraft gasifiers to provide fuel for village maize mills has been conducted in Tanzania by the Small Industries Development Organization and Twente University of Technology of Enschede, Netherlands. Following experiments with a prototype, a simplified 0.65 m diameter downdraft gasifier was designed and several units were tested for a total of over 2,000 hours. The cobs are fed into a conical bunker through a spring-loaded hatch which also serves as a pressure-release device. Because of concern for air leakage, the units were designed without ash removal hatches. At intervals of five to ten days operators must swing back the hinged bunker and remove the charcoal, the cast-iorn throat plate, and the welded steel grate to reach the ashes from the top.

The gas cleaning system includes an insulated fiberglass filter, a cooler of galvanized water pipe, and a water trap to collect condensate. The gas has been used in three types of diesel engines rated at 25 kW, 20 kW, and 16 kW respectively for full diesel operation. The engines were set to operate with 20% of maximum diesel fuel consumption at full load but, due to the low load factor at the corn-grinding mills, the actual diesel savings were only about 50%. Shaft power output of the three engines was 18.75 kW, 14.25 kW, and 11.85 kW respectively. Micro-dust particles, apparently of ash and carbon, formed glow points in the engine cylinders. There have also been serious problems of operator training, maintenance, social acceptance, and fuel quality.

Experiments with the gasification of corn cobs for electricity generation were conducted in the corn-growing state of Iowa under sponsorship of the American Public Power Association, Iowa municipal utilities, and Iowa State University. Although there is more than 300 MW of diesel generating capacity in 70 smaller Iowa communities, the use of this capacity is very limited due to the high price of diesel fuel.

The Iowa tests were conducted in 10" (25 cm) and 16" (40 cm) diameter downdraft gasifiers; the latter unit approaches the size which would be needed to operate a 1 MW generator. In most downdraft gasifiers the gas passes through a narrow throat in the lower hearth which is designed to provide high enough temperatures for total combustion and full decomposition of the tars. However, neither of the Iowa gasifiers had such a lower hearth constriction; temperature levels were maintained by connecting each air inlet (tuyere) directly with a turbocharged air supply. This gasifier design minimized fuel feeding, bridging, and slagging problems.

Gas filtering tests with off-the-shelf truck air filters were disappointing but inconclusive. A simple wet filter, in which the gas was bubbled through oil, was more satisfactory. A cooling tower in which the gas line was surrounded by a water jacket was found to be cheaper and involve less maintenance than a radiator-type air cooler. The engine operated smoothly when operating on as much as 80% producer gas, although the available 35 kW generating set was too small for a fully satisfactory test. The study report recommended full-scale tests with a 1 MW generating set.

A system has been designed at Chulalongkorn University in Thailand to produce 40 kW of electric power through the downdraft gasification of maize cobs. The experimental unit is a part of a research and development program on biomass gasification funded by the U.S. Agency for International Development in Thailand. The cobs will be fed into a 700 mm diameter cylindrical hopper and drop into a 300 mm diameter firebox with a 100 mm chokeplate. Ashes will be removed by a rotating eccentric grate. The gas cleaning equipment for the Chulalongkorn system includes a high efficiency cyclone, a wet scrubber, condenser, and safety filter. Testing of the system will begin late in 1983.

Pelletized char from maize cobs will be used with other charred agricultural residues in small gasifier which is being developed by the Indian Institute of Technology in New Delhi under an official U.S.-Indian energy collaboration program. The ITT unit will be designed to power a 5 HP pumpset; three million of these pumping units are used for irrigation in India. The three-year gasifier development project, which will also include a small wood chip gasifier, is being assisted by a U.S. team coordinated by the MITRE Corporation of McLean, Virginia.

4. SUGARCANE BAGASSE

Bagasse, the remainder of the sugarcane stalk after the juice has been removed, is used as a boiler fuel in sugar mills in at least 27 countries. In most mills the bagasse is burned to make process steam which is used for heating and evaporation of the cane juice and in turbines to produce mechanical power.

Some modern mills are equipped to produce high pressure steam and to use it in turbine generators to generate electric power. Such plants usually produce much more power than is needed in the plant, and excess power is sold to adjacent communities or the national power grid.

Several factors tend to limit the role of bagasse as a source of energy or power for use outside the sugar industry: (a) Due to the high moisture content and high sugar content of the bagasse, it must be kept under cover and burned promptly to avoid fermentation and possible spontaneous combustion. There is therefore little prospect of its use as a fuel outside the sugar mills. (b) Most sugar mills have rather inefficient combustion systems and cannot produce high-pressure steam or generate electricity; economic factors prevent the retrofitting of these mills so that they could contribute power to the grid. (c) Even the fully-equipped mills can only produce a surplus of power during the cane-harvesting season. Since the bagasse cannot be easily stored, the mills can provide power to the grid only during about half of each year. Power production from sugar mills can reduce the use and cost of fossil fuel in other generating plants, but is not a substitute for year-round generating capacity.

5. COFFEE BEAN HUSKS

The inner husks of the coffee beans are burned to provide heat for coffee drying at a plant in El Salvador built by GEKA Warmetechnik of Karlsruhe, Germany. The husks are screw fed from a storage silo to the GEKA combustion chamber where they are burned in a special layer suspension process. The hot gases are cooled to 400°C in a rolling gas heat exchanger, cleaned in a multicyclone dust separator, and further cooled to 50°C in a gas/air mixer. The resulting mixture is fed directly to the coffee driers, without passing through a heat exchanger. The system burns up to 350 kg/hour of coffee bean husks and produces 1 gcal of heat per hour. The ash content of the husks is only about 2%.

6. PEANUT HULLS

The heating value of peanut hulls (8,000 Btu/pound or 20 MJ/kg) and the ash content of the hulls (1.5 to 4%) are similar to wood fuels.

Peanut hulls from a peanut processing plant are burned as a boiler fuel at the Gold Kist soybean oil extraction plant in Valdosta, Georgia. The hulls are unloaded from trailer trucks by a hydraulic truck dumper and conveyed to a storage silo with a drag chain conveyor. Automatically controlled variable-speed screw feeders deliver the hulls to the three cells of the 60,000 pound/hour water tube boiler. The steam is used for drying and toasting soybean meal and for other process heat.

Agricultural engineers at Auburn University in Auburn, Alabama, have been burning peanut hulls for peanut drying in a Sukup grain drying system (see page 7). Stack gases are used directly for drying, without a heat exchanger. Initial tests indicate no contamination of the peanuts, but tests are continuing.

PART TWO: HIGH-ASH RESIDUES

1. RICE HUSKS

Rice residues are the most abundantly available agricultural residues in most of the Asian countries and some other rice producing countries. It is estimated that India produces 80 million tons of rice residues annually. Rice straw usually remains on the farms, where it is used for livestock feed, livestock bedding, roof thatching, mats, and other domestic purposes. However, the rice husks are removed from the kernel only at the rice mill; there are few uses for the husks, and the large accumulation of the residues at many mills presents a serious disposal problem.

There are important problems associated with the use of rice husks as a fuel arising from the high ash content of the husks. They contain from 15 to 23% ash; no other residue discussed in this Report has a higher ash content. Moreover, 90% of this ash is silica. Due to the high ash level, the percentage of combustible material is lower than in most agricultural residues; the heating values of the husks indicated in various research reports have ranged from 5,700 to 7200 Btu/pound and from 13 to 15 MJ/kg. The high ash level causes two types of operating problems when rice husks are used in direct combustion or gasification systems:

a. The rapid accumulation of ashes requires more complex grates and ash removal equipment in order to avoid or minimize ash fouling, i.e., the blocking of the flow of combustion air by the accumulated ashes. The ash fouling problem is intensified by the silica skeleton of the rice husks which remains intact after most of the carbon has been gasified. Moreover, minute projections on these skeletons prevent them from moving past each other readily; this interlocking causes bridging which inhibits both fuel feeding and ash removal.

b. Another type of blockage is created when the ash melts into slag and later resolidifies into clinkers. Silica oxides, which can make up as much as 97% of the rice husk ash, have rather high melting points (from 1300 to 1700°C) which are above the normal operating temperature for combustion units and gasifiers. However, the silica forms an "eutectic" mixture with small amounts of sodium and potassium which are also present in the ash; the melting point of the mixture can be much lower than that of the silica, depending on the size of the fractions of each material. Moreover, due to the ash fouling and air flow problems described above, hot spots often form within a downdraft gasifier. The temperature of these hot spots can exceed the melting point of the eutectic mixture; the resulting slag reforms into clinkers when the temperature drops. The clinkers inhibit ash removal and air flow and may contribute to new hot spots, more slag, and more clinkers.

The extent and seriousness of these fuel feeding, ash fouling, and slagging problems depend on the type of combustion of gasification system being used. The following sections review experience with the use of rice husks in direct combustion units, updraft gasifiers, downdraft gasifiers, fluidized bed gasifiers, and pyrolytic conversion units.

a. Direct Combustion of Rice Husks

(1) Process Steam in Rice Mills

Rice husks have been used as a boiler fuel in some rice mills for over a century. A husk-fired boiler was installed in Burma as early as 1880. The typical husk-burning mill has used steam producer with husks for one of the following purposes: (a) heat for rice drying, (b) heat for rice parboiling, (c) mechanical power from a steam engine or turbine, or (d) electrical power via a steam engine or turbine.

A world survey of rice husk use for the UN Food and Agriculture Organization in 1975 revealed no mill anywhere in which steam from husk-fired boilers was being used for both process heat and mechanical or electrical power. The 14-country field

survey indicated that the most extensive use of rice husks as a boiler fuel was in India and Thailand; the husks were also fueling some boilers in Sri Lanka, Philippines, Surinam, Pakistan, Portugal, and Italy.

Rice husks are burned in three types of conventional furnaces: inclined step-grate furnaces, suspension burners, and spreader-stokers. In each case a large amount of excess air is used to prevent high furnace temperatures and reduce the chance of slagging problems. However, the excessive amount of air results in inefficient combustion and leaves black ash with a considerable carbon content. The step-grate furnaces, used in most mills in India, have an efficiency of less than 40%. Suspension burners usually carry burning hulls into the boiler tubes; the very erosive hulls reduce the life of the tubes. In the spreader-stoker furnace a large ash fraction is carried into the water tube boiler which is usually paired with this type of furnace.

About half of the production of parboiled rice in India is from mills using husk-fired boilers to provide the heat for rice parboiling. Several parboiling mills in Italy and Sri Lanka use steam produced with husks. Prior to a fire in 1976 at Guyana's largest rice mill, steam heat for parboiling was provided in three boilers which cofired rice husks, wood, and fuel oil.

Some mills have used steam from husks for rice drying. A 20,000 pound/hour water tube boiler uses 40% of the rice husks at the Guyana Rice Board's Anna Regina mill. Slab wood is hand-stoked to Dutch Oven boiler; the rice husks are blown in and burned on top of the slab wood pile. Superheated steam is supplied to steam coil air heaters for three rice dryers; four other dryers at the facility are oil-fired.

Rice husk boilers systems built by the Ray Burner Company of San Francisco have been installed in Spain, Thailand, Taiwan, and the Philippines. A metering screw and material handling fan deliver the rice husks from a fuel silo to the top of the boiler, where it drops onto live grates. At start up the rice husks are ignited by an oil flame. A forced-draft fan provides underfire air for the three-pass firetube boiler. Flyash is captured by high efficiency cyclones and is reinjected into the combustion zone to insure complete combustion. Ashes are blown through an ash duct to a transportable ash receiver. A diagram of the Ray Burner biomass boiler is shown on the opposite page.

A Taiwan firm has installed three 600 HP/hour Ray Burner boilers. The units burn a 4:1 or 3:1 mixture of rice husks and wood waste. There is some slagging in the grate and tubes, but this is not considered a serious problem. Boiler operation stops each morning for 30 minutes for manual and air cleaning of the grate and tubes.

(2) Steam for Power in Rice Mills

In the period around 1925 many large rice mills around the world used steam engines to provide mechanical power for mill machinery; many of these engines ran on steam produced from rice husks. However, in recent decades the use of steam for mechanical power declined due to rural electrification, the greater convenience of diesel engines and electric motors, the limited availability of steam engines, and other factors. The survey of rice husk utilization in 1975 for FAO listed Thailand as the country with the most extensive use of steam power from husk-fired boilers; however, a survey of 158 rice mills in Thailand in 1983 indicated that only 11% used steam engines, 15% were powered by electricity, and 73% had diesel engines.

Two modern plants using steam from rice husks to produce electric power were described in the report of the rice husk survey for FAO in 1975. A 1920 kW power plant is located at 25 ton per hour rice mill at Tacurong, Mindanao, Philippines. The power plant consists of two inclined-grate furnaces, two 20,000 pound/hour boilers, and three Spilling 640 kW steam motor-generator sets. About 800 kW is used for mill operations, and about 1,000 kW is sold commercially to a local community. The power plant uses 5 tons of rice hulls per hour.

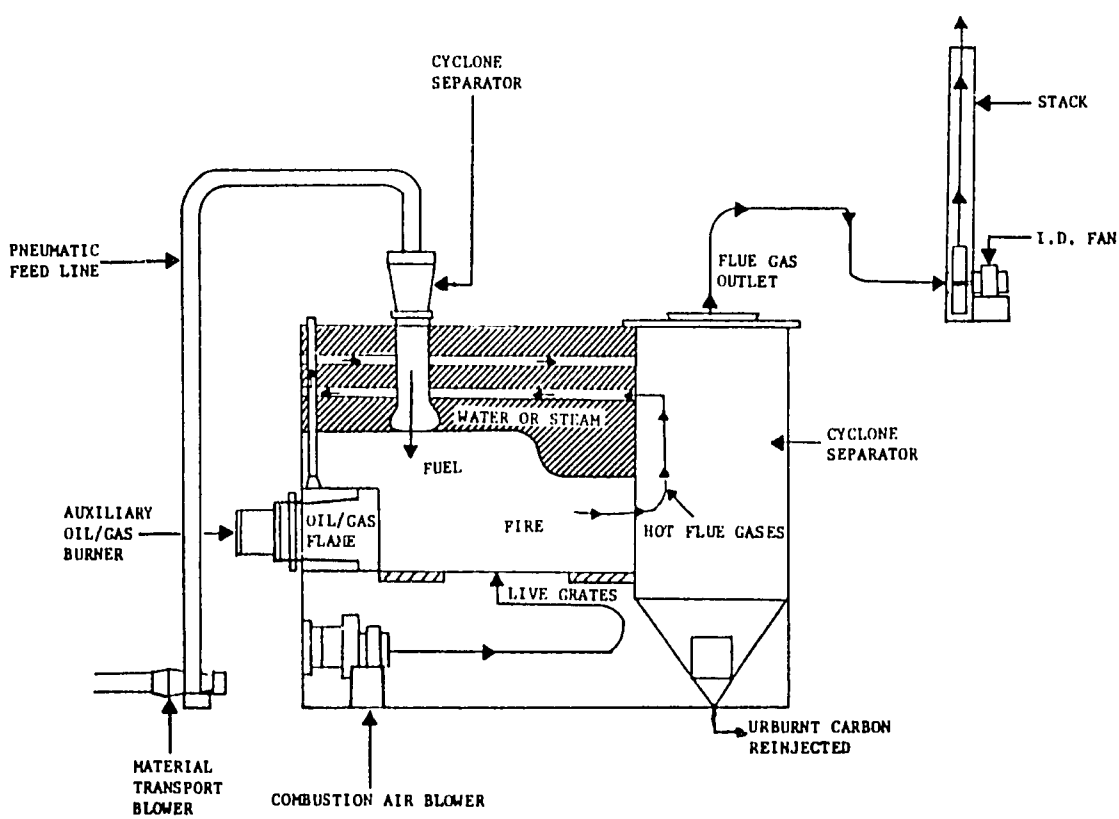
In 1971 a 1200 kW husk-fired power plant was installed at a 15 ton/hour rice mill at Wageningin in Surinam. The system included two inclined-grate furnaces, two boilers each of which produces 5.5 tons of steam per hour, a 5-stage Perry steam turbine, and a 1220 kW AEG generator. The system is reported to use 3 tons of husks per hour.

A system designed to provide 315 kW of electric power through the combustion of rice husks is being built at the National Food Authority's facility in Cabanatuan in the Philippines. It will include a 10,350 lb/hour Ray Burner Company biomass boiler of the type shown below and a non-condensing steam turbine generator with a net output of 278 kW. The system, which is being built with the assistance of the U.S. Agency for International Development, will burn about 1.5 tons of rice husks per hour.

The Government of Malaysia has funded the construction of two pilot plants at rice mills, each of which uses about one ton of rice husks per hour to generate 350 kW of electric power. The plants became operational in the spring of 1983.

The first of the new plants in Malaysia was built by a British firm, Parkinson Cowan. It burns 1.3 tons of husks per hour; 70% comes from the mill output, but 30% comes from the husk stockpile. The husks are pneumatically conveyed to the furnace and dropped into a vortex chamber. About 5,400 kg/hour of steam is produced in the three-pass horizontal fire-tube boiler. A three-stage Terry turbine operates a 350 kW induction generator. Excess steam is used for drying wet paddy. The power cost is estimated at US $.03/kW hr. The complete system cost about US $1.2 million.

The second pilot plant was built in Malaysia by the Industrial Machinery Co. (IMACO) of the U.S. It consists of a mechanical feeder, a special vertical cyclonic furnace, a heat recovery water tube boiler, a Coppus steam turbine generator, ash collector, and draft fan. The IMACO system was designed to burn one ton/hour of rice husk and produce 5,215 kg/hr of steam at a much higher pressure than the Parkinson Cowan system. A second turbine may be added later to use exhaust steam and increase power output to 650 kW. This plant cost about US $1.5 million; power costs will be about $.02/kW hr.



(3) Other Process Heat and Grain Drying

A low-cost and easily fabricated rice husk burner has been developed at the Indian Institute of Technology in Kanpur. It is known as a "Tube-in Basket" ("TiB") burner.

The rise husks are burned in a cylindrical basket with an inner layer of at least 0.75 mm thick wire mesh and outer layer of expanded metal with 10 to 20 mm openings. The basket is 100 cm high and 50 cm in diameter. A perforated metal burner tube is inserted in the center of the basket: it is made of at least 1 mm thick metal with 3 mm diameter openings spaced 4 to 5 mm apart. The basket and burner tube are supported by a frame made of mild steel strips, rods, or angle irons.

When an initial layer of rice hulls is ignited with kindling material, flame shoots out of the burner tube and the entire basket is the filled with husks. After the husk level falls, additional husks can be added once or twice. The unit burns 10 to 15 kg of husks in one continuous run of 60 to 90 minutes. Flame temperature 15 cm above the burner tube was 800° to 900°C. After the flame dies out or recedes into the burning tube, the unit continues to emit smokeless hot air for 4 to 6 hours unless the ashes are emptied immediately by tipping the unit.

The TiB burners have many potential applications including post-harvest drying of rice, other grains, and tobacco; process heat for various types of smaller rural industries; heating water and raising steam for parboiling in small rice mills; and operating Stirling engines.

The University of the Philippines at Los Banos developed a low-cost continuous grain drying system using rice husks as the fuel. In a 4.5 hour test run, 27.7 kg of moisture per hour was removed from 1728 kg of paddy. Druing the test the unit consumed 55 kg of rice husks and produced 60,5000 Btu/hour with a furnace efficiency of 33.5%. Such drying units have been more expensive than kerosene burners; however, due to the savings in fuel costs, the higher capital costs may be justified if the unit is used for extended periods.

A new type of rice husk burner, apparently designed primarily for grain drying, has been developed by Padiscor, a firm in Pasig near Manila. The husks are fed to a 32" (81 cm) diameter combustion chamber by a metering feeder; the unit can handle up to 70 kg of husks per hour. The chamber has a cyclonic design and hot ash is deposited at the bottom. The ash passes through a rotating cast iron grate and is discharged at a rate which equals the fuel feeding rate. As in most other husk combustion units, slagging is avoided by reducing temperatures with surplus air; a large carbon fraction remains in the black ash.

(4) Domestic Fuels

Rice husks are burned as a domestic fuel in several Asian countries. A mixture of the husks and rice straw was burned in open top burners in China; the remaining ash and char was then used as an absorbent for human wastes and the combined waste material was used in the fields as organic fertilizer.

A team from Volunteers for Technical Assistance (VITA) studied the expanded use of rice husks to reduce the high consumption of charcoal at refugee camps in Thailand. The team found that in most situations it was cheaper to burn rice husks than charcoal. VITA staff and volunteers designed an efficient mud/clay stove with a special grate for burning rice husks. It has two 19 cm cooking holes with baffles. A hole at one end holds a 10 cm x 1 m concrete chimney pipe, which is supported by a bamboo pole stuck into the ground.

Hot water heaters burning rice husks are commercially available in Japan and India; rudimentary units are frequently used for water heating in motels and restaurants in India.

About 10% of the rice husks produced in Japan are used in some type of "carbonizer" to produce a charred husk fuel consisting primarily of carbon and silica. Due to the high silica content of the husks, the heating value of the char is much lower than that of wood charcoal. However, the

product is marketable as a domestic fuel in Japan and at least six Japanese firms manufacture furnaces of various types to produce the rice husk char.

The Thailand Institute for Science and Technology has developed a screwpress machine to produce press logs for fuel from a mixture of rice husks and sawdust. Further efforts are being made to decrease the unit's consumption of electric energy and increase the durability of the pressing screws and dies.

A small family firm in Thailand has developed an extrusion machine to produce fuel logs from rice husks. An initial machine built in 1980 was later improved by replacing a gasoline engine with an electric motor for improved speed control, by using a better quality steel in the extrusion cylinder, and by drying and grinding the husks before extrusion. The present twin-head extruder produces 75 kg of rice husk fuel logs per hour. Development of the process was aided by a small grant from Volunteers in Technical Assistance under a renewable energy program funded by the U.S. Agency for International Development. Continuing problems with the process include the production of dust, the high temperature of the heating unit, limited quality control, and smoke produced when the logs are burned.

(5) Mechanical Power Via Stirling Engines

Several agencies in the U.S. and Asia are cooperating in a program to develop an improved design for a Stirling-cycle external combustion engine system burning rice hulls and other biomass. The units would produce shaft power for water pumps, small agricultural machinery (hullers, grinders, and presses), compressors for refrigeration, and fans for crop dryers.

The goal of the program, which is funded by the U.S. Agency for International Development through the Asia Foundation, is to develop a final design which would be available for unrestricted manufacture in developing countries using materials and techniques available in those countries.

A prototype was built by Sunpower, Inc., of Athens, Ohio. The husks are burned in a furnace made from part of a 55-gallon oil drum lined with fire bricks. The single cylinder Stirling engine produces 5 HP. About 18 kg of rice husks per hour were used to pump 10 liters of water per second (450 gallons per minute) from a 10 meter depth or to operate a 3 kW electric generator. Other suitable fuels include corn cobs, peanut shells, bagasse, sawdust, coconut shells, wood, charcoal, and coal.

The prototype was shipped to Bangladesh for evaluation by the Asia Foundation in cooperation with the Kumidini Welfare Trust. Some design changes were made to permit the use of local materials and fabricating techniques. Several Stirling engines are being built at the Trust's facility near Dacca. Further tests have been scheduled to establish the safety and reliability of the units. A final design should be available in 1985.

b. Gasification of Rice Husks

(1) Updraft Gasification

Updraft rice husk gasifiers were built by Italian and British firms during the first half of this century to provide fuel for internal combustion engines in small rice mills. A unit for engines up to 120 HP was advertised as early as 1910 Steam engines were not economic in small or medium-sized mills in which there was no need for steam for process heat. In these mills producer gas systems were the only feasible means of using rice hulls to provide mechanical power. In some mills the gas-fueled engine operated machinery directly through a lineshaft drive; in others the engine ran a generator providing power to electric motors on the milling machinery.

By World War II, 57 rice mills in Italy were powered with producer gas systems using rice husks. A 60 HP unit provided power for both a lineshaft drive and an electric generator at a two-ton per hour rice mill at Monticello, Italy. It used about 200 kg of rice husks per hour. The Monticello unit was installed in 1940 and

was still operating 35 years later in 1975. Since then it has been dismantled.

A British firm, Crossley Brothers, built updraft rice hull gasifiers in the 1920's and 1930's in Indo-China, Burma, Spain, and Italy. The units were installed under the supervision of Crossley's foreign field engineer, E. R. Mellenger, who is still active as a consultant in Saint Johns, New Brunswick, Canada, and retains drawings and patent rights on the Crossley units.

Two of the Crossley rice hull gasifiers are reported to be still in operation in Cholon, Vietnam, and Amposta, Spain. Another Crossley unit, which had operated in Burma from 1926 to 1952, was recently discovered more or less intact at Henzada, Burma.

Three years ago Mellenger built a 150 kW gasifier power plant fueled with rice husks at a rice mill near Santo Domingo in the Dominican Republic. This plant is very similar to the Crossley units of the 1920's and 1930's. The updraft gasifier is fed by a feed bell mounted above the gasifier and reached by a steel ladder. A single-engine system requires manual feeding of 64 pounds of rice husks every 18 minutes. Gastight covers at the top and bottom of the feed bell have interconnected levers which prevent both covers being opened at the same time and thus prevent gas from escaping when the rice husks are being added.

The gas cleaning system consists of four units: (1) A cyclone removes particulates. (2) The gas then flows to the bottom of a wet scrubber and rises through cascading water and finely divided spray from high-pressure nozzles. (3) At the top of the scrubber the gas enters a centrifugal tar separator. The tar flows back down through the scrubber to a settling tank, where it floats on the surface of the water and can be drawn off. About 85 pounds of tar is produced for each ton of rice husks gasified; at some earlier plants, it was used for rodd building or mixed with equal parts of diesel oil and used as fuel oil. (4) After leaving the tar separator, the gas passes through a dry scrubber consisting of a cylinder with trays of wood shavings.

After passing through these cleaning units the gas is ready for use in a turbocharged International V-8 engine originally designed for use with natural gas. The engine is connected to a Markon alternator.

Mellenger indicates that the total cost including engine of this type of system can be as low as $410 to $570 per kW, depending on the size of the system, compared to costs of around $2500 per kW for steam power plants.

(2) Downdraft Gasification

Several problems arise when rice husks are used in downdraft gasifiers:

a. Fuel Feeding: Bridging and caking are a common problem with rice husks. One means of preventing fuel bridging is to use engine vibration. At the University of California at Davis a small gasifier and engine were mounted together on a free-swinging frame; the results indicated that, with suitable mountings, engine vibration can be used to prevent caking in small rice hull gasifiers. Another anti-caking option is to supplement the gravity flow of the fuel with some type of force feeding mechanism. However, force feeding is feasible only if the fuel flow is not inhibited by the narrow throat usually built into downdraft gasifiers to create a homogeneous hot carbon bed through which the hydrocarbons must pass. The UCD research indicated that such a bed can be created by better air distribution and heavy insulation of the fire zone column. Fuel feeding must also be synchronized with ash removal.

b. Ash Removal: The UCD research indicated that any successful rice husk gasifier would have to have a continuous ash removal system. The most successful of several simple grates tested at UCD was a rotating concentric wiper. Powered rotating grates have been included in several other rice husk gasification systems.

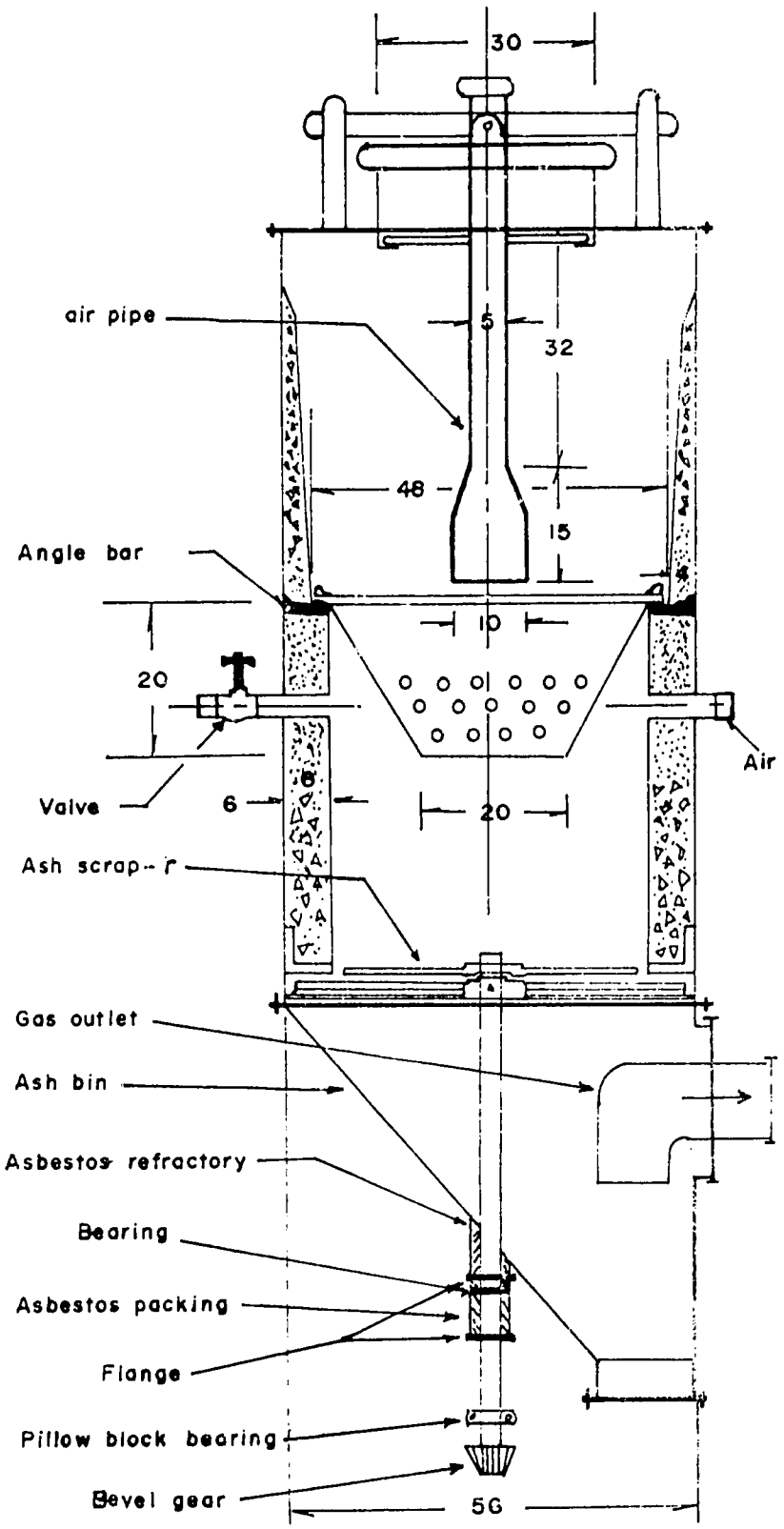
c. Slagging: These problems, which were outlined on page 11, can be minimized or eliminated if the temperatures

in the gasifier are kept below the ash melting point and "hot spots" are avoided. The extent of the slagging problem is influenced by the design of the gasifier chamber and of the fuel feeding and ash removal equipment.

d. Gas Cleaning: Producer gas made from rice hulls requires more elaborate gas cleaning equipment than gas made from most other fuels. In experiments at the University of the Philippines with the gasification of wood chips and corn cobs, a "compact" gas cleaning unit had proved satisfactory. It included a gas cyclone, a scrubber of the cascading water type, a wet filter in which the gas bubbled through a bath of diesel oil, and a final cyclone to remove entrained oil particles. However, when loose rice husks were used in this system, the gas was not sufficiently cleaned and the engine pistons were "seized" after less than ten hours.

A more elaborate gas cleaning train was developed for rice husk gasification at the University of the Philippines. It included (1) a bigger cyclone to separate entrained char; (2) a tar condenser that cooled down the gas, condensed the tars and liquors, and reduced the load on the wet scrubber; (3) a mechanical filter filled with rice hull char, changed about every 30 hours; (4) the compact cyclone-scrubber-filter unit used for other fuels; and (5) a final mechanical filter filled with char or rice husks to dry the gas before it passed into the engine.

In order to reduce the load of tars on the gas cleaning train, experiments have been conducted at the University of the Philippines with a "double-fire" gasifier shown in the adjacent sketch. The primary air enters through a central air pipe which reached into the center of the reactor from its top, where the fuel also enters. Drilled holes in the detachable conical throat allow tars and pyrolysis gas to pass through to a secondary conduction area around the throat; secondary air is admitted to this area through three 1" (2.5 cm) diameter air holes. Ash is removed through a fixed slotted grate through the movement of a rotating ash scraper turned by a shaft reaching through the slanted bottom of the ash bin. The unit has been extensively tested with loose, pelletized, and briquetted rice husks; the gas was used in a 2-cylinder engine driving a 7.5 kW generator. The tar in the producer gas was significantly reduced and the ash removal system proved satisfactory.



An apparently successful rice hull gasification system producing 140 kW of electric power was developed in China's Jiangsu province in the 1970's. The gasifier, shown on the opposite page, has several novel features. There are no air inlets in the side of the downdraft gasifier; air and fuel enter together at the open top. The gasifier is a vertical cylinder with no throat or choke plate; the fuel bed is suspended on a slightly convex sleve grate rotated by an electric motor. The ash falls through the grate into a sealed water pool and is removed periodically by a slurry pump.

The first element of the gas cleaning and cooling train for the Jiangsu gasifier in a "ash-flushing tube", a form of wet scrubber. The gas passes up through a spray of cooling water; the water drops to the open bottom of the tube which is immersed in a settling tank. The gas then passes through two "filter-cooler towers". In each tower the gas goes through two sets of filters consisting of plastic balls and two more water sprays. It then flows into a larger-diameter gas storage tank, from which it is fed to the eingine.

The Jiangsu gasifier, which has a 6.8 m^3 gasification chamber, consumes 280 kg of rice husks per hour, and produces 785 m^3 of gas per hour. The gas is used in a six-cylinder, 600 RPM engine connected to a synchronous generator. The unit can generate 140 kW of power for an initial 12-hour period, although output is gradually reduced to 125 kW during a long period of continuous operation. If installed in a 25 ton/day rice mill, about 30 to 40 kW would be used for rice processing and 90 to 100 kW would be available for use by the adjacent community.

A FAO group visited one of these gasifiers in a 75 ton/day rice mill in China in 1982. Two of the units have operated for a decade in the African republic of Mali. One unit has operated for 54,000 hours, the other for 28,000 hours; there have been no slagging problems. The German Agency for Technical Cooperation (GTZ) is purchasing one of the Jiangsu systems from China and will install it in a rice mill in Mali associated with a GTZ agricultural project.

Copies of a doctoral dissertation at the University of California at Davis on the downdraft gasification of rice husks are available from the German Agency for Technical Cooperation (GTZ). The author, Dr. Albrecht Kaupp, was also co-author of a study on small producer gas engine systems sponsored by the Bioenergy Project of the U.S. Agency for International Development; he is now a specialist on thermal gasification systems for GTZ in Germany.

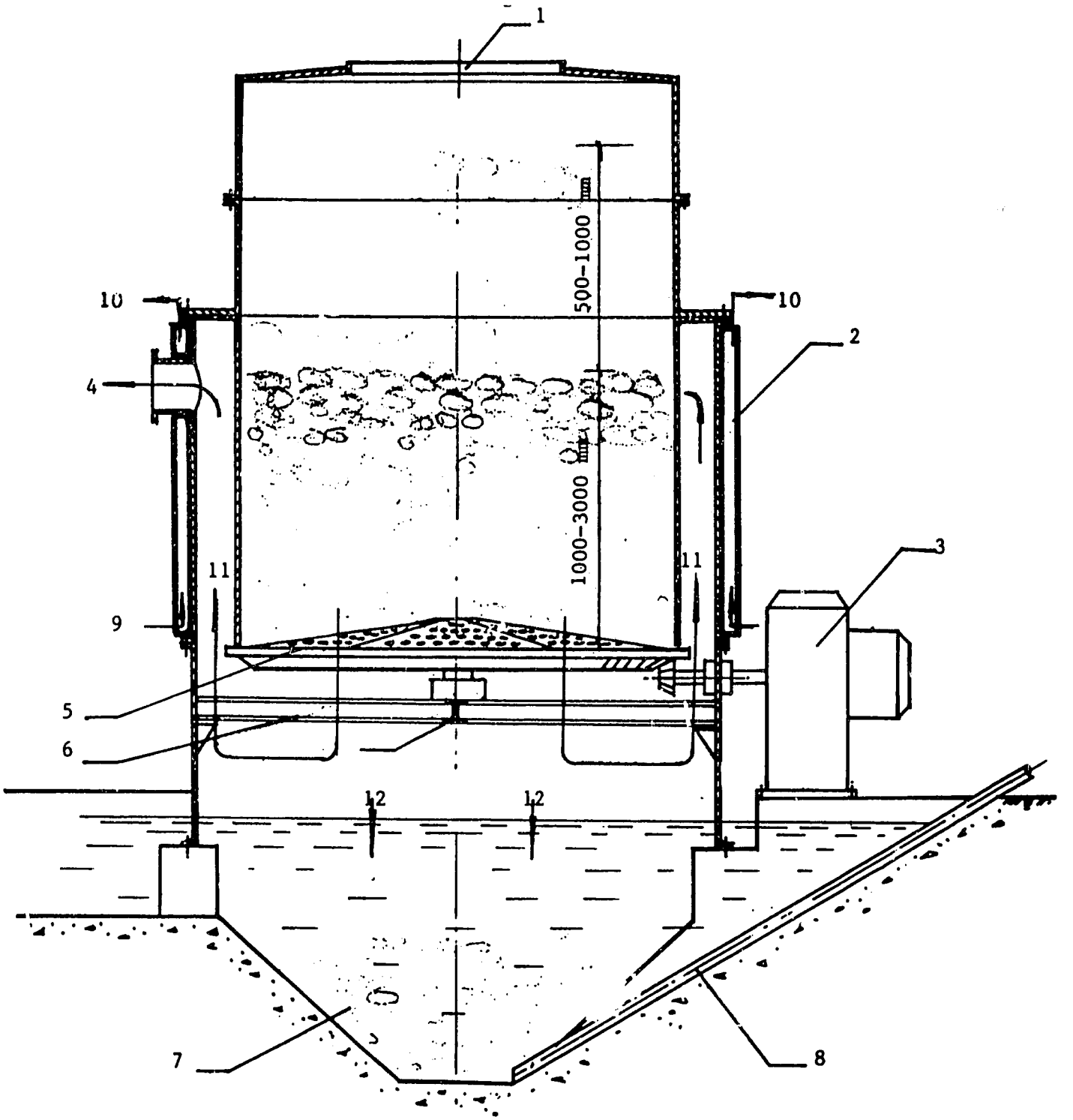
(3) Fluidized Bed Gasification

Some researchers and manufacturers believe that fluidized bed gasifiers provide the best means of gasifying high-ash fuels including rice husks. In such a unit a bed of sand or other inert material is raised to a high temperature and kept in flux with air forced through the unit with powerful fans. By controlling the flow of air, the temperature in a fluid bed gasifier can be more effectively controlled than in other types of gasifiers. It is thus easier to keep temperatures below the ash fusion temperature and avoid slagging and clinkers.

However, fluidized bed gasifiers are more complex and more expensive than fixed bed gasifiers. They require closer supervision by personnel with more sophisticated training. The fluidizing fans consume considerable electrical or mechanical power. Sand and ash leave the bed with the gas, and the separation of the solid particles may require a double cyclone.

Researchers at Twente University in Enschede, Netherlands, gasified rice hulls in a 50 kg/hour fluidized bed gasifier. The bed of inert alumina particles was fluidized by forced air entering through the bottom of the unit. Loose rice husks were augered out of a hopper into the fluid bed, mixed with the bed material, heated to the bed temperature, and gasified.

The Twente tests indicated that the heating value of the producer gas was highest at relatively low bed temperatures (750°C). However, higher temperatures (up to 940°C) produced cleaner gas; the tar content of the gas dropped rapidly as bed temperatures increased. Tar levels in



1. Fuel & Air inlet
2. Cooling water jacket
3. Furnace grate reduction box
4. Gas outlet
5. Rotary grate
6. Grate support
7. Ash settling pond
8. Ash removing tube
9. Cooling water intake
10. Cooling water effluent
11. Gas
12. Ash

the gas from rice husks remained significantly higher than the tar levels in gas produced at comparable temperatures from beech wood. No slagging problems were encountered, even when the unit was operated for six hours at 940°C. Ash was removed exclusively from the gas stream through a double cyclone separator. The particulates trapped in the cyclone contained up to 30% carbon which indicated a loss of 10% of the net energy input to the unit.

c. Pyrolytic Conversion of Rice Husks

The Thailand Institute of Scientific and Technological Research (TISTR) is developing a pyrolytic unit which converts rice husks to char, gas, and pyrolytic oil. the project is supported by the National Energy Administration and the U.S. Agency for International Development in Thailand. A prototype one ton/day unit, based on designs by Tatom Associates, has been tested. The hulls are fed from a storage bin with an air feeder coupled with a screw feeder. Process air is introduced by a slowly turning "airgitator" which continuously stirs the bed to break up bridges and eliminate cavities. The temperature is controlled by the air-to-fuel ratio.

The unit produces charcoal, producer gas, and pyrolytic oil. Charcoal is discharged into a sealed drum through a penumatically-controlled rotating grate. The char is mixed with a starch binder and briquetted. Although 35 to 50% of the char is ash, the briquetted char has a higher calorific value per kilogram than rice husks.

The gas produced by the unit passes through a cyclone, which removes particulates, and on to a dual-jet condensor which removes the pyrolytic oil. The oil contains up to 53% water and will not burn easily; it is also an acidic solvent which would cause rust problems if used as an engine fuel. After the oil is removed the gas passes through a wet scrubber, a condenser-cooler, and a fiberglass filter. The gas was used to replace 30 to 60% of the diesel fuel in a 11 HP diesel engine driving a 5 kW generator.

2. CORN (MAISE) STOVER

The stalks, leaves, and husks of the corn or maize plant, known collectively in the U.S. as corn stover, have a slightly higher heating value (7800 to 9,500 Btu per pound or 18 to 22 MJ/kg) than the corn cobs. However, the stover has a higher ash content (6 to 7%) and is a much less desireable fuel than the cobs.

The Stormor Company of Fremont, Nebraska, is marketing a simple combustion unit for grain drying which burns corn stalks as well as other crop residues. The 28 m^3 firebox has an outer shell of galvanized sheet metal; two large swing-out doors (3.1 m x 2.6 m) allow bales or stacks of crop residues to be loaded with a tractor equipped with a front-end loader. A heat exchanger on top of the burner transfers heat to an air supply flowing through an adjoining grain drying bin. A Stormor unit was tested with baled corn stover at the U.S. Department of Agriculture's research center at Tifton, Georgia. Conversion efficiency for corn stover (45%) was lower than for cotton stalks and soybean residues, apparently because ashes on the corn stover bales did not readily fall away to expose unburned material and allow rapid oxidation.

Tests at the University of California at Davis indicated that, due to the relatively high ash content and the relatively low ash fusion temperature (1715°F, 935°C), corn stover was not an appropriate fuel for downdraft gasification. Severe fuel bridging and extensive slagging problems were encountered in the tests at Davis. The DeKalb gasifier-combustor described on pp. 8-9 has been operated successfully with a considerable quantity of corn husks attached to each cob, but there was a signficiant increase in bridging and slagging problems.

3. WHEAT STRAW

Research data on the heating value of wheat straw ranges from 14.2 to 18.9 MJ/kg; the range of ash content data is also rather wide, from 4.3% to 10.4%.

About thirty German firms and several Danish and Austrian firms build furnaces for

space heating which burn straw in some form. Units have been designed to use standard rectangular bales, large circular bales, high pressure condensed bales, and chopped straw. Most of the units are used for heating farmhouses and other farm buildings in Europe.

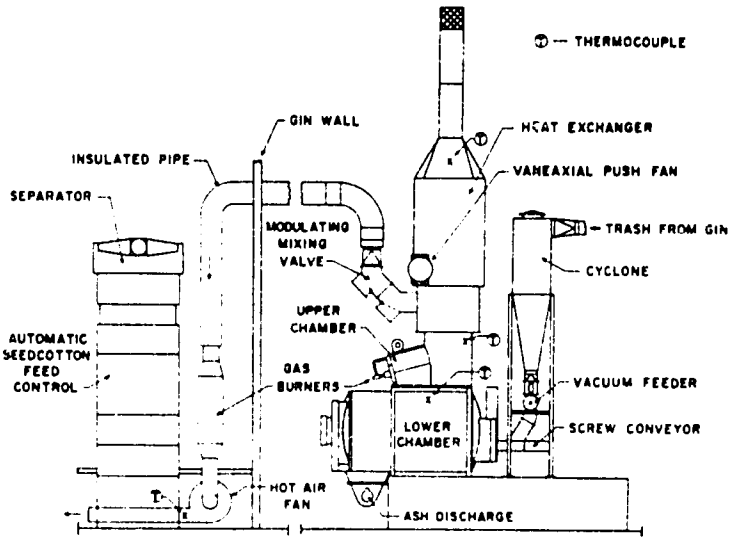
Due to the relatively high ash content recorded in most tests, wheat straw is not a good fuel for downdraft gasification. Severe slagging problems were encountered when wheat straw was tested in downdraft gasifiers at the University of California at Davis, at Cornell University in New York state, and at the Beijer Institute in Stockholm.

4. COTTON GIN TRASH

Cotton ginning mills produce large quantities of cotton gin trash which consists of cotton fibers, stems, and leaves. The trash has little commercial value and is a fire hazard and disposal problem at most mills. The trash has a heating value of 7,000 to 8,500 Btu/pound or 16 to 19 MJ/kg. It also has a high ash content and a fairly low ash melting point. Ash fouling and slagging problems are encountered with cotton gin trash which resemble those with rice husks.

Several researchers experimenting with cotton gin wastes in California have listed ash contents of the wastes between 15 and 22%. However, studies by the U.S. Department of Agriculture's Cotton Gin Research Laboratory at Stoneville, Mississippi, indicated that the ash content varies widely between the various types of gin wastes. The leaves of mature cotton plants have an ash content about three times that of the bolls, seed, and stems and about ten times that of cotton lint.

The Cotton Gin Research Laboratory experimented with the burning of cotton gin waste in a small incinerator to produce heat for cotton drying. The multichamber unit was rated at 470 pounds per hour. An initial batch feed system was replaced with a continuous-feed system consisting of a high-efficiency cyclone, a vacuum feeder, and a screw conveyor. Ashes were discharged by an automatic ash removal cylinder. Air velocities in the lower combustion chamber were controlled so that ash particles were not carried to the upper chamber, where the unburned gases were rapidly oxidized through the introduction of additional air. The system is shown in the sketch below.



The original heat exchanger was replaced by a new unit designed at Stoneville consisting of three coaxial cylinders. The ambient air entered at the bottom of the outer cylinder, rose to the top, was piped through to the inside cylinder, and exited at the bottom of the unit. The stack gases rose through the space between the inner and middle cylinders. Fins in the inner chamber and stack gas chamber increased the surface area and extended the time that the stack gas remained in the exchanger. Natural gas burners were used to assist with the initial start-up of the system and to supplement the heat from the heat exchanger, when necessary. The unit recovered 2100 Btu per pound of gin trash.

Cotton gin trash has been burned since 1976 for cotton drying at the J. G. Boswell Company facility at Corcoran, California. During one initial season, the facility had to shut down six times for the removal of high-silica slag. With the assistance of the California Energy Commission, the system was modified to minimize slagging problems by improving the temperature controls and ash removal equipment and by predrying the waste to permit efficient combustion

at lower temperatures. In a subsequent season the facility processed 35,000 bales of cotton without any mechanical failures, produced all the heat needed for cotton drying, and saved 140,000 gallons of propane.

A $2.6 million cogeneration facility using cotton gin trash is currently in the shakedown stage at Farmers Cooperative Gin, Inc. at Buttonwillow, California. During the ginning season cotton gin trash will be burned in a 54 million Btu/hour cyclonic suspension-fired furnace. The boiler produces 42,000 pounds of steam per hour at 650 psig. High pressure steam is used in a high pressure turbine generator; exhaust steam is also used in a low pressure turbine generator. The two generators produce a total of 1.65 MW. Exhaust steam from both turbines will be used to dry cotton, replacing natural gas.

Other biomass fuels produced in the Buttonwillow area, including wheat straw and barley straw, will be burned to maintain power production in the February-September season when the cotton gins are not in operation. The system has been designed to produce 11 million kW hr/year of electricity and 60 million Btu/year of process heat; most of the power will be sold to the Pacific Gas and Electric Company. Although the system was designed to avoid ash fouling and slagging problems through a staged combustion process, slagging deposits accumulated on boiler tubes and combustor walls in shakedown tests in 1982.

Beginning with the 1983 ginning season, 1.5 tons per hour of cotton gin trash will be burned to provide heat for cotton drying at the Westside Farmers Cooperative Gin at San Joaquin, California. The new system uses two low-temperature combustors to produce 16 million Btu/hour. The heat is captured in a heat exchanger and used in existing cotton dryers. The system cost $313,470, nearly half of which was provided by the California Energy Commission. It is expected to displace 96,000 gallons per year of liquid propane, previously used for cotton drying, and save the cooperative nearly $87,000 per year.

5. COTTON STALKS

In the U.S. cotton stalks are generally left in the fields; insects on the stalks are killed by frost during the winter. In the Sudan, however, it is necessary to burn the stalks to kill the insects; this field burning produces no useful energy, and there is great interest in the Sudan and some other cotton-producing countries in techniques for capturing some of this lost energy. The heating value of the stalks has been reported to be from 16 to 21 MJ/kg. The UN Development Program is sponsoring a feasibility study on the gasification of cotton stalks in the Sudan.

Downdraft gasification tests with cotton stalks at the University of California at Davis indicated a very high ash content (17.2%) and severe slagging problems and led to the conclusion that the stalks were not a suitable fuel for downdraft gasification.

Advanced Energy Applications, Inc., of Los Altos, California, tested cotton stalks in a 100 ton/day fluidized bed gasifier at a California cotton gin. After reconfiguration of the fuel feeding system to accommodate the stalks, they proved to be a good fuel which produced a high quality gas.

Pyrenco, Inc., of Prosser, Washington, is discussing a gasification system fueled with pelletized cotton stalks with the National Dairy Development Board of India. The 190 kW system would be built in a milk processing plant.

Cotton stalk pellets are among the agricultural residues being tested in a 40 kW gasifier power plant at the Royal Institute of Technology In Stockholm.

In the tests in Georgia of a Stormor biomass combustion unit for grain drying described on page 20, the combustion efficiency of baled cotton stalks (63.7%) was higher than that of soybean residues or corn stover. The cotton stalks had a relatively low density which permitted better air circulation than the denser residues.

BIOENERGY USER NETWORK

A plan for the establishment of a Bioenergy User Network (BUN) was prepared in an organizational meeting in Washington from July 25 to 27, 1983. BUN will be an independent international association composed of developing countries which have active bioenergy programs or are seriously considering initiating such programs. The basic BUN objective is to promote cooperation and collaboration among developing countries with bioenergy programs.

Interest in the creation of the network developed at a workshop in Manila in March 1983 on "Bioenergy Approaches to National Development." The workshop was co-sponsored by the Bioenergy Systems and Technology Project of the U.S. Agency for International Development and the Government of the Philippines. Participants from seventeen countries agreed that a mechanism was needed for sharing experience on the systems management aspects of bioenergy utilization as well as on bioenergy technologies.

An Organizing Committee was nominated at Manila; it met in Washington in July to develop plans for the Network. The members of the committee are Dr. Albert Binger, Scientific Research Council, Jamaica; Dr. Alvaro Umana, Ministry of Energy, Costa Rica; Dr. Ahmed Hassan Hood, Renewable Energy Project, National Council for Research, Sudan; Mr. Luluk Sumiarso, Ministry of Mines and Energy, Indonesia; and Mr. Jose Remulla, Gasifier and Equipment Manufacturing Corporation, Philippines.

Initial activities of the Network will be carried out through five international task forces, each headed by a member of the Organizing Committee: (1) Producer Gas Systems (Dr. Umana), (2) Charcoal Production (Dr. Hood), (3) Biomass Fuels for Small Industries and Decentralized Power Generation (Dr. Binger), (4) Fuelwood Production and Transportation (Mr. Sumiarso) and (5) Bioenergy Program Development and Management Systems (Mr. Remulla).

BIOENERGY '84 WORLD CONFERENCE GOTHENBURG, SWEDEN, JUNE 18-21, 1984

The Bioenergy '84 Conference and Exhibition will focus on the commercial development of bioenergy technologies. The events are being organized by the Swedish Trade Fair Foundation and the Swedish Bio-Energy Association in cooperation with the Bio-Energy council of the U.S.

At "state-of-the-art" sessions experts from industry and research centers will present up-to-date summaries of the present stage of development in the production and use of biomass for energy. The sessions will cover production costs, experience with specific systems, research trends, commercial feasibility, and environmental effects. A series of parallel scientific-technical sessions will cover specific biomass fuels, conversion processes, and uses of bioenergy systems.

The Exhibition will contain commercially available equipment for the collection, harvesting, transportation, storage, and handling of biomass fuels and equipment for the thermochemial and microbial conversion of biomass to energy including fermenters, gasifiers, and digesters.

Simultaneous pre-conference tours will be offered to plants using straw as fuel in Denmark, to peat production and utilization sites in Finland, to wood stove manufacturers and charcoal production sites in Norway, and to forestry residue systems and energy planatations in Sweden. During the conference period excursions will be offered to facilities near Gothenburg using forest residues, straw, municipal wastes, and peat for fuel, to biogas plants, and to plants producing briquettes and pellets.

Additional information may be obtained by writing to Bioenergy '84, Swedish Trade Fair Foundation, P.O. Box 5222, S-402-24 Gothenburg, Sweden or to the Bioenergy Council of the United States, Suite 825A, 1625 Eye Street, N.W., Washington, D.C. 20006 USA.

INTERNATIONAL BIOGAS CONFERENCE CAIRO, EGYPT, NOVEMBER 17 - 24, 1984

An international conference on the State-of-the-Art on Biogas Technology, Transfer and Diffusion, will be held in Cairo from November 17 to 24, 1984. The conference is being organized by the National Research Centre of Egypt in cooperation with the Egyptian Academy of Scientific Research and Technology, the U.S. Agency for International Development, and the U.S. National Academy of Sciences. The meeting will focus on the production and use of biogas in developing countries.

Conference organizers have issued a call for papers on the following topics: (A) Key factors leading to success and/or failure in (1) the engineering design of biogas units, (2) biological conversion processes, and (3) transferring biogas technology into local socio-cultural systems; (B) Cost-benefit analysis of biogas systems; (C) Strategies for optimizing financial and institutional infrastructure for promoting biogas technology, and (D) Conditions necessary for developing a regional or national program for adapting biogas technology to large numbers of end users. The deadline for abstracts is March 1, 1984. They should be sent to Prof. Dr. M. M. El Halwagi, Head, Pilot Plant Laboratory, National Research Centre, 12 Al Tharir Street Dokki, Cairo, Egypt.

AVAILABILITY OF EARLIER REPORTS

Institutions in developing countries may request copies of five previous Bioenergy Systems Reports: (1) June 1982, Thermochemcial Conversion of Biomass for Energy (Thermal gasification, charcoal production, thermal conversion of agricultural residues); September 1982, Biomass Fuels for Vehicles; (3) December 1982, Growing Trees for Fuel & Wood Fuels for Industry; (4) March 1983, Bioenergy for Agriculture; and (5) June 1983, Bioenergy for Electric Power Generation. Requests should be sent to the Editor at the address on page 1.

AN APPEAL TO READERS

A Bioenergy Systems Report to be published in 1984 will review the present state of development of thermal gasification systems, especially those involving the use of producer gas in internal combustion engines. Institutions involved with thermal gasification projects are urged to send current information on these projects to the Editor. The Report will focus on the design of gasifiers (including fuel-feeding devices, the configuration of gasifier chambers, and ash removal equipment) and on the design and operation of gas-cleaning equipment.

During the first months of 1984 the Editor and the project staff for the AID Bioenergy Systems and Technology Project will be reviewing options related to the types of informational materials to be sponsored by the Project in the future. Readers are urged to submit comments on the usefulness of the present Reports and suggestions regarding topics or categories of information which could be covered in future Bioenergy Systems Reports or in other types of published materials.

The Editor expresses his appreciation to all those who have contributed information used in this Report and previous Reports.

OTHER PUBLICATIONS

Rice Husk Conversion to Energy, by Eldon Beagle, FAO Agricultural Services Bulliten #31, 1978, Food and Agricultural Organization, Rome.

Utilization of Agricultural Wastes for Energy Conversion and Product Processing, 1982, FAO Regional Office, Phra Atit Road, Bangkok 10200, Thailand.

Rice Hull Gasification: Theory and Practice, by Albrecht Kaupp, 1983, German Appropriate Technology Exchange (GATE), P.O. Box 5180, D-6236 Eschborn 1, West Germany.

Producer Gas 1982, Proceedings of the First International Producer Gas Conference, Colombo, Sri Lanka, 1982, The Beijer Institute, Box 50005, 1005 Stockholm, Sweden.