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Bioenergy Systems Report

JUNE 1982 : THERMOCHEMICAL CONVERSION OF BIOMASS FOR ENERGY

Introduction

This series of Reports provides information on the use of biomass for energy which may be needed by energy planners and technical personnel in developing countries and by personnel of the U.S. Agency for International Development missions in such countries. The Reports focus on bioenergy projects in developing countries; however, they also provide information on projects in other countries which may be of interest to energy planners in developing countries.

Funding for the preparation of these Reports is provided by the Bioenergy Systems and Technology (BST) Project of the Agency for International Development. The BST Project helps USAID field missions and host country energy officials to identify and plan bioenergy projects. BST activities have included field reconnaissance and prefeasibility studies, "state-of-the-art" reports on each of the major biomass conversion systems, a handbook of bioenergy conversion processes, and a recent workshop on energy plantations and charcoal production.

The project staff includes the AID project manager in the Office of Energy, Dr. Paul Weatherly, and a four man staff contracted from the U.S. Department of Agriculture/Forest Service. The team leader is Dr. Gus Wahlgren. All correspondence concerning BST activities should be addressed to :

S&T/Office of Energy,
Room 508, SA-18, AID,
Washington, D.C. 20523.
Telephone : (703) 235-8092.

This Report covers three aspects of the thermal conversion of biomass : (1) the production and use of low-Btu gas (LBG) through the thermal gasification of biomass ; (2) the production of charcoal from wood and other biomass ; and (3) the use of agricultural residues as fuels in thermal conversion systems. It does not cover the direct combustion of wood or residues or the production and preparation of wood for conversion to energy.

This report has been compiled primarily from research and project reports received from organizations in both developing and developed countries. Additional information was obtained during recent visits by the editor to three institutions conducting gasification research, four companies which have built gasifiers, and four charcoal plants in the U.S. These visits were made with three officials of Philippine agencies engaged in gasification and charcoal projects. Highlights of research results have been provided as feasible. However, the editor and sponsoring agencies can accept no responsibility for the accuracy of specific technical data.

Space limitations in this report have precluded the inclusion of names and addresses of individuals conducting thermochemical conversion projects and the full addresses of research institutions and firms mentioned in the text. However, the name and address of the key person responsible for any study described in this report will be provided on request to the Office of Energy. Alternatively, a letter requesting information on a specific study or project will be forwarded to the appropriate person.

The reports in this series are compiled and written by Dean B. Mahin, International Energy Projects, P.O. Box 591, Front Royal, Virginia USA 22630, telephone (703) 636-2126, under a contract with the U.S. Department of Agriculture funded through the Bioenergy Systems and Technology Project of the U.S. Agency for International Development. Copies are distributed primarily through USAID missions in developing countries.

PART ONE: THE THERMAL GASIFICATION OF BIOMASS

1. Overview

Biomass can be converted to gaseous fuels through two quite different processes. The first Report in this series, published in March 1982, reviewed the production and use of "biogas" in developing countries. Biogas is produced through anaerobic digestion, i.e., the action of microbes on animal and human wastes and plant material. It consists of about 60% methane and 40% carbon dioxide.

The present Report covers the production of a quite different type of gas through the thermochemical conversion of cellulosic biomass. This thermal gasification involves incomplete degradation of the biomass through controlled air intake. It produces a low-Btu gas which is commonly known as "producer gas" but is referred to hereafter in this Report as "LBG".

Low Btu gas (LBG) from biomass can be used as a fuel in spark-ignition and diesel engines, in boilers, and in burners for heating and drying applications. Steam produced with LBG can be used for many heating and power applications. Engines fueled with LBG have been used to pump water, generate electric power, and operate vehicles.

LBG contains a mixture of energy-rich and inert gases. Most of the energy in the LBG is in the form of carbon monoxide (CO); this partially oxidized carbon represents only about 17 to 27% of the gas by volume. Additional heating value is added by hydrogen (7 to 16% of the gas), methane (2 to 5%) and various tars and hydrocarbons. About half of the LBG is nitrogen. The total energy content of the LBG varies from about 100 to 200 Btu per cubic foot (or 2,500 to 5,000 MJ/m^3). Although gases with higher heating values can be produced by thermal gasification processes using pure oxygen instead of air, this Report is limited to air gasification.

Thermal gasification is not a new technology. Stationary engines and vehicles were powered with gas from the thermal gasification of wood or charcoal before World War I. The technology was perfected in the 1920's and 1930's. When World War II cut off supplies of oil to most European countries, the number of gas-powered vehicles grew very rapidly. By 1946 more than one million vehicles were operating with LBG from biomass in Europe, especially in France, Germany, and Sweden. Over the next three decades however, gasification technology was discarded. Today, with the new emphasis on the use of renewable energy sources, efforts are being made to recapture and improve this earlier technology.

Even though (as one expert put it) we have not yet worked our way back to 1945, gasification technology is developing very rapidly. Major research programs on biomass gasification, involving projects carried out by a number of institutions and firms, have been funded by the governments of the United States and Canada. In Europe funding for gasification research has been provided by the European Communities and by the governments of the United Kingdom, France, Germany, and Sweden.

In developing countries thermal gasification activities are not as extensive as plants for the production of biogas through anaerobic digestion. However, thermal gasification projects have been identified in thirteen developing countries. Philippine agencies are developing an impressive program to use gasifiers with engines for water pumping and electric power generation as well as in vehicles and boats. About 100 gasifiers are in use in Brazil. Substantial gasification research activities have been undertaken in India and China. Research or operational projects are underway or planned in Guyana, the Dominican Republic, Costa Rica, Indonesia, Tanzania, Cameroon, Mali, Nigeria, and Gabon.

2. Gasification for Mechanical and Electrical Power

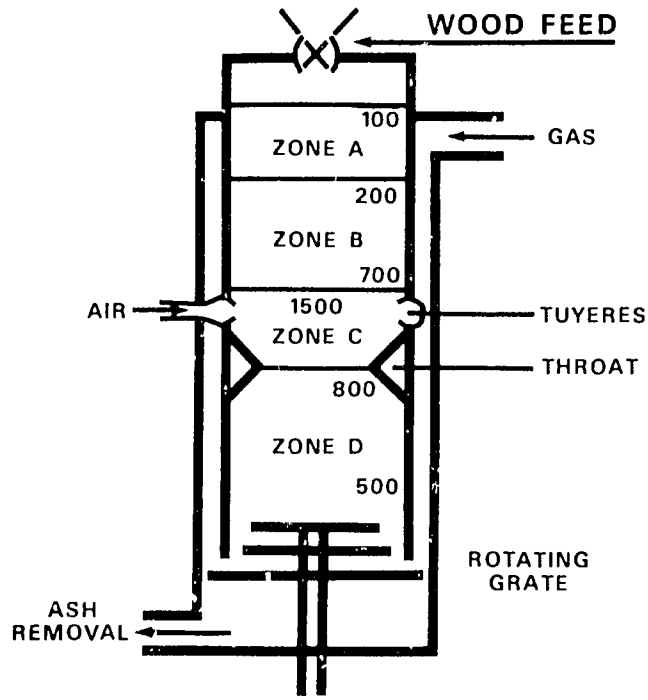
There are two main types of uses of low-Btu gas (LBG) from the thermal gasification of biomass: (a) as a fuel for internal combustion engines and (b) as a source of heat for boilers, furnaces, dryers, and other industrial processes. This section covers the production of LBG for use in engines and the operation of LBG-fueled engines to produce mechanical and electrical power.

Down-Draft Gasifiers

Virtually all of the gasifiers currently being used with engines are down-draft units. The air enters through nozzles or tuyeres at the side of the unit just above the point where the diameter of the gasifier is narrowed by a throat or choke plate. The gases travel down through the hottest oxidation zone (Zone C in the adjacent sketch) and exit through the grate at the bottom of the gasifier. Because the air and gases move downward with the fuel, this type of gasifier is also known as a "co-current" unit.

The principal advantage of the down-draft or co-current gasifier is that most of the oils and tars produced during the pyrolysis of the fuel in the upper part of the unit are converted to gas as they pass down through the very high temperatures in the oxidation zone. The gas from these units is much cleaner than LBG made in updraft gasifiers which allow the tars and oils to escape in the gas stream without passing through the oxidation zone. However, even the LBG from the down-draft units must be thoroughly cleaned before it can be used in an engine. If the gasifier is producing substantial quantities of impurities and the cleaning system is ineffective, the engine can be ruined very quickly.

Most modifications of gasification systems after initial installation have involved improvements in the fuel preparation and handling equipment and/or in the gas cleaning system. One ex-



A Down-draft or Co-current Gasifier

perienced builder of gasification systems has stated that, if the LBG is to be used in engines, the design and effectiveness of the gas cleaning system is more important than the design of the gasifer.

The system must also provide for the cooling of the gas in order to condense out the tars and deliver the gas to the engine at an acceptable temperature. Most gas cleaning and cooling systems have included (a) a cyclone separator to trap the larger particulates through centrifugal action, (b) either a wet scrubber (which removes tars by bubbling the gas through oil or water) or a "dry" system with a condensing coil or heat exchanger to cool the gas and condense out the tars, and (c) a final filter or filters made of fabric, fiber glass, plastic foam, or biomass materials such as rice hulls. Some systems use a heat exchanger in which the cool intake air for the gasifier is preheated by absorbing heat from the LBG.

Down-draft gasifiers suitable for use with engines have rather specific fuel requirements: (a) They require fuels

with no more than about 20% moisture content. (b) Fuels with more than about 5% ash content are not suitable for down-draft gasification; the downward flow of air may be inhibited by ashes or by slag or cinders formed from melted ash. (c) Too high a percentage of fine pieces in the feedstock can inhibit the air flow and lead to uneven combustion.

Several European and American firms have built relatively large down-draft gasifiers. Imbert Energietechnik of Weilerswist, Germany, successor to a firm which built more than a half million gasifiers up to 1945, now makes downdraft units which are almost identical with those built during World War II except for modern materials and some modern instrumentation. The Imbert systems include 60 to 120 kW mobile units and 300 to 500 kW stationary units. Duvant Moteurs of Valenciennes, France, builds gasifiers to fit its 85 kW to 740 kW engine/generator sets. Pillard, Inc., of Marseilles, France, is reported to have installed a number of down-draft gasifiers in developing countries. Biomass Corporation of Yuba City, California, has built four large down-draft units; three of these have been used to provide LBG for engine/generator sets in the 150 to 200 kW range.

Although nearly a million small gasifiers were built in Europe during World War II, no present manufacturer has extensive experience with the production of small units. The University of California state-of-the-art report on small gasifier/engine systems indicated in 1980 that a worldwide search has revealed no manufacturer which could sell and install an off-shelf unit and guarantee its performance. This situation remains essentially unchanged in 1982 although several firms have now offered small gasifier/engine systems.

The Fritz Werner company of Geisenheim, Germany, offers 50 kW, 100 kW, and 150 kW electrical power plants which are fueled at present with LBG from Imbert gasifiers. However, radically redesigned gasifiers are promised in the near future. A new firm, Northamerican Gasifier Company of Sacramento, California, offers three models of small down-draft gasifiers which can be used for irrigation pumping (20 to 130 hp) or power generation (12 to 90 kW). Marelco, Inc. of Alexandria, VA, developed a trailer-mounted 60 hp wood waste gasifier which could be used to generate 35 kW of electric power. Biomass Corporation has recently completed a 5 to 7 hp gasifier/ engine system which will be evaluated at the University of California at Davis. A small firm, R and R Wood Products of California, Missouri, builds small gasifiers which are designed to operate with sawdust.

Small gasifiers have been built by research institutions in several developing countries. However, the only firm manufacturing sizeable numbers of small gasifiers in a developing country seems to be the Gasifier Equipment and Manufacturing Company (GEMCOR) of Manila. It was established during the past year by the Philippine government to build small gasifiers for use with irrigation pumping systems and in vehicles and fishing boats.

The Use of LBG in Engines

Many spark-ignition engines can be operated solely on LBG after minor modifications of the air and fuel intake equipment and the ignition timing. The best performance is in rather old-fashioned low speed engines.

Due to the lower heating value of LBG compared to gasoline, the power output from spark-ignition engines using LBG is considerably lower than that obtained with gasoline. At the Tropical Products Institute in England, a 20 kW Ford engine produced from 55% to 80% of its rated output depending on the type of carburetor and the engine speed. An Indonesian research agency found that a 5 kW Honda engine/generator set generated 60 to 70% of the rated power when operating on LBG. A University of California at Davis paper indicates that

most spark-ignition engines will operate at about 60% of rated power output when fueled with LBG.

Although a spark-ignition engine can be operated solely with LBG, it is not possible to run a diesel engine on LBG alone. After the engine is started on diesel oil, it will operate as a dual- fuel engine on a mixture of LBG and diesel oil. Some diesel fuel is needed as a pilot fuel to ignite the gas. The amounts of diesel oil needed for satisfactory dual-fuel performance (stated as a percentage of the amount of oil needed without LBG) have ranged from as low as 10% to as high as 50%.

At the Unversity of the Philippines 27% diesel oil was used in a 5 hp single-cylinder diesel engine dual-fueled with LBG from coconut shells; a 12 hp diesel, tested with LBG from wood and from corn cobs, needed 23 to 37% diesel oil. The Economic Development Foundation in the Philippines used 25 to 35% diesel oil in a 30 kW engine/ generator set dual-fueled with LBG. In research tests the Farm Systems Development Corporation (FSDC) in the Philippines used only 11% diesel oil in a 40 hp irrigation pumping set and only 8% diesel oil in a 60 hp pumping unit. However, considerably higher percentages of diesel fuel were required for other irrigation units in field operation

Due to the higher compression ratios of diesel engines, the power loss from using LBG is less than in spark-ignition engines. Horsepower reduction of from 5 to 14% were recorded in tests of LBG in a 65 hp diesel engine coupled to an irrigation pump in the Philippines. The Duvant company in France derates its engine/generator sets from 15 to 25% when they are used with LBG. The University of California at Davis gasification research indicates that, with optimum operating conditions, the power loss from the use of LBG in diesels should be no more than 10 to 20%.

The choice between a spark-ignition and diesel engine for a LBG-fueled system should be made after careful consideration of the advantages and disadvantages of each option. The biggest advantage of the use of a spark-ignition engine is that it can operate entirely on LBG and thus avoid any expenditure for fossil fuel. Other advantages are the availability in many developing countries of used automobile engines at moderate prices, the reduced financial loss if such an engine is ruined due to a malfunction of the gas cleaning system, and the availability of mechanics who are familiar with the servicing and repair of such engines. The principal disadvantage of the spark-ignition engine is the reduced power output with LBG.

The main advantages of using a diesel engine are the higher percentage of rated output, the ability to use lower cost diesel oil during periods when the gasifier is not operating for any reason, and the feasibility of adding gasifiers to provide fuel for existing diesel-powered pumps and generators. The main disadvantage of the use of diesels with gasifiers is that they will always need some diesel oil while a gasoline engine can operate only with LBG.

Mechanical Power Applications

The shaft power produced in a LBG-fueled engine can be used to propel a vehicle or boat, to operate various types of stationary mechanical equipment, or to generate electrical power.

In most countries, although oil prices have risen rapidly since 1973, there has not been sufficiently prolonged concern about the availability of gasoline to re-awaken widespread interest in the use of LBG as an automotive fuel. However, a few vehicles have operated successfully with LBG in the U.S. and elsewhere. In 1979 the Solar Energy Research Institute published a translation of a Swedish book which provides a detailed account of the wide range of automotive gasifiers developed and used in Sweden from 1939 to 1945. A full picture of more recent experiments with gasifiers on vehicles will be provided by a

forthcoming report from the U.S. National Academy of Sciences. (See bibliographical listings on p. 24, the last page of this report).

A wider variety of mechanical power applications with LBG-fueled engines is being planned in the Philippines than in any other country. Twenty-five vehicles with gasoline engines and three deisel-power vehicles were retrofitted with charcoal gasifiers during 1981. The endurance of the gasifier-equipped vehicles was tested in a one-month caravan and a six-day, 2500 km road rally. The Philippine gasifier manufacturing company, GEMCOR, is developing several types of vehicular gasifier systems including units mounted on the rear and mid-section of the vehicles and on a trailer pulled by the vehicle. The National Electrification Administration (NEA) has ordered a gasifier-equipped jeepney for each of the 100 rural electrification districts in the Philippines.

The Farm Systems Development Corporation has tested gasifier/engine systems to operate 65 hp diesel irrigation pumps; FSDC hopes to have more than 1100 of these units in operation in the Philippines within three years. FSDC and GEMCOR are developing gasifier/ engine systems to propel fishing boats and to operate rice mills.

Twente University of Technology in The Netherlands, which has considerable experience with down-draft gasifiers, is participating in village-level tests of gasifier/engine systems in Tanzania. LBG from corn cobs, produced in a 0.66 m diameter down-draft gasifier, was used in a diesel engine in 1980-81 to operate a corn-grinding mill at a test site and later in a village. Eighteen-month tests of gasifiers in five typical village situations in Tanzania will provide hard data on equipment reliability, maintenance and repair needs, operator training, diesel oil savings, biomass fuel consumption, system costs, and the social, economic, and environmental effects of the systems.

A pump powered by a gasifier/engine system will be included in AID-sponsored demonstrations in Malaysia of the use of several renewable energy sources for water pumping. Technical and economic studies on the use of gasifier/engine systems for water pumping have been carried out at the Indian Institute of Technology in New Dehli and other Indian institutions.

Electrical Power Generation

Electrical power has been produced via the thermal gasification of biomass for more than 50 years. Several large generators were operated on LBG from biomass in Africa before World War I. Power for Tahiti's capital was provided by the gasification of coconut residues from 1928 to 1945. Since the oil price increases in the mid-1970's, projects to use LBG for power generation have been developed in a number of countries.

The World Bank is financing three projects which contain components for power production through the thermal gasification of biomass. These include rice mills in Cameroon and Mali and a large sawmill in Guyana. In the Guyana project wood wastes will be gasified to produce 4.5 MW of electric power, including 2.9 MW for the mill and 1.6 MW for the adjacent township. Two small Imbert gasifier/ engine/generator units (75 kW to 145 kW) have been used temporarily during the manufacturing of large multiple Imbert units which will be installed during 1982. Problems encountered with the Cameroon and Mali projects due to the high ash content of rice hulls will be reviewed in the discussion of the thermal conversion of rice hulls on page 20.

In a village electrification project in the Philippines the Economic Development Foundation replaced 65% to 75% of the diesel oil in a 80 hp engine with LBG from coconut husks. The engine drove a 37.5 kVA generator which provided power for 100 households. The National Electrification Administration (NEA) is installing a gasifier on Batangas island

which will provide fuel for a second-hand automobile engine driving a 30 kW generator. Two more 30 kW units may be added to make a 90 kW system. If this system is successful, NEA plans to use similar units on other islands in the Philippines. The units will operate with wood chips and/or charcoal made from coconut shells.

In Brazil the Energy Company of Sao Paulo (CESP) and a research institution have produced electrical power from LBG in two large pilot plants. A 500 kW unit uses eucalyptus wood cut into 20 cm pieces, while a 450 kW plant is fueled with charcoal made from the eucalyptus wood.

Two electric power agencies in North America have conducted experiments with power production from the gasification of wood. In Canada the Saskatchewan Power Corporation used LBG made from rather wet wood chips to operate a Deutz diesel engine rated at 200 kW for diesel oil operations; it was coupled to a 150 kW Brown Boveri generator. After initial problems with the fuel feed system and the gas cleaning equipment were resolved, the system produced nearly 150 kW of electrical power.

In Alaska, Marenco, Inc. is developing a wood gasification and power generation project for the Alaska Village Electric Cooperative. The system uses a three million Btu/hour down-draft gasifier built by Biomass Corporation, wood preparation and gas cleaning equipment built by Marenco, and a modified Caterpillar spark-ignition engine with generator rated at 170 kW for operation with natural gas. During initial testing problems were encountered with the fuel handling and gas cleaning systems, most of which have been resolved.

Future plans include testing of the present gasifier with a diesel engine generator and design of a new unit which would be installed in a remote Alaskan village for field testing. Citizens Energy Project of Boston, Massachusetts, is financing a 27.5 kW wood gasifier/ generator system for rural electrification in Costa Rica.

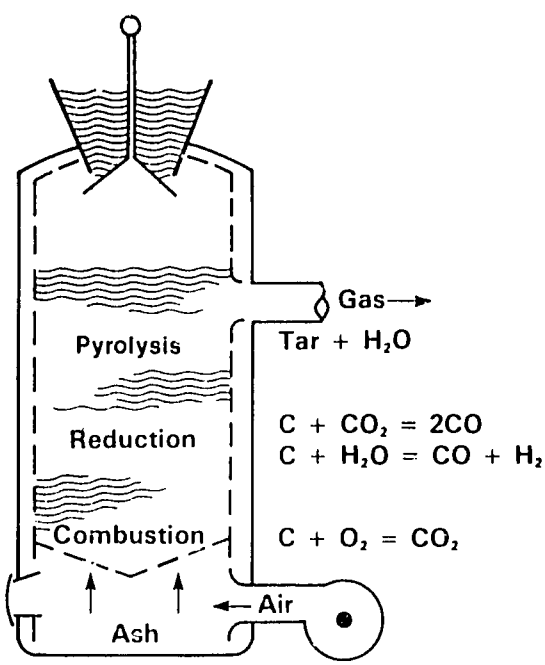
Several organizations have attempted to analyze the comparative costs of power generation with LBG and with conventional diesel systems. These studies use widely varying assumptions as to capital, fuel, labor, and maintenance costs. Although individually useful in evaluating specific projects, these studies as a group provide only rather limited guidelines to persons seeking to evaluate other gasification projects in quite different settings. The following is an outline of some of the factors to be considered in making such evalutions:

a. Capital Costs: The costs of the gasifier is only part of the cost of the system, even if it is retrofitted to an existing engine/ generator set. Larger systems may require rather complex equipment for the storage, sizing, drying, and feeding of the biomass fuel, and modifications of this equipment may be necessary after initial testing. Effective gas cleanup equipment is vital but it adds substantially to system costs. Moreover, given current problems with gas cleanup, most systems have required some modifications in this equipment after initial tests. Annual capital costs will depend on interest rates and capital recovery periods in each country; wide variance in these annual capital costs from country to country greatly limit the transferability of any of these economic evaluations to another country.

b. Fuel costs: Project evaluations generally assume that the increased capital costs of gasification projects compared to conventional diesel systems, will be offset over a period of time by net savings in fuel costs. Estimating these fuel cost savings is complicated by two factors: (1) The future prices of fossil fuels are not known; some earlier studies projections have assumed future rates of price escalation for fossil fuels which now seem excessive. (2) Due to the lack of extensive previous experience with gasification projects, precise estimates

of the total cost of biomass fuels (including possibly the purchase, production, collection, storage, drying, and/or sizing of these fuels) are very difficult.

c. Labor and maintenance costs: Those with most experience with gasification projects assert that in the forseeable future all gasification systems will need to be closely watched and tuned by a full-time attendant. A Canadian study indicated that, despite fuel costs savings, total annual costs of a 150 kW gasification systems in Canada would be twice as high as a conventional diesel system; the conventional system would need only periodic checks but the LBG-powered system would require a full time attendant during each of three shifts. These labor costs must be evaluated in each country. Due to the still experimental nature of gasification system, some experts suggests that an annual sum equivalent to 10% of capital costs should be budgeted for maintenance, repairs and modifications.



Schematic Diagram of an Up-draft Gasifier

3. Gasification for Industrial Process Heat

In addition to the uses of LBG in internal combustion engines described in the preceding section, the gas can also be burned as a boiler fuel and used in various other burners in dryers, heaters, kilns, and furnaces. While most of the gas used in engines is made in down-draft gasifiers, most of the gas intended for use in boilers or other burners is produced in updraft or fluidized bed gasifiers.

Updraft Gasifiers

In the updraft gasifiers air enters at the bottom through a grate and exits at the top of the unit. Because the air is moving in the opposite direction from the downward movement of the fuel, this type of gasifier is sometimes known as a "counter-current" gasifier. Most of these gasifiers are vertical units similar to the adjacent sketch.

Advantages of the updraft gasifer are its relatively low cost, simple construction, and relative ease of operation. The principal disadvantage is that the rising gas picks up tars and oils from the descending and incompletely converted fuel. Due to the high tar content, gas from updraft gasifiers is not suitable for use in internal combustion engines without further cracking. However, updraft units are appropriate for stationary applications in which they are close-coupled with a combustion unit which can utilize the heating value of the tars before they can condense and cause operating problems.

Between 1934 and 1967 the Powergas Corporation built 22 large updraft gasifiers for use with biomass materials such as cotton seed husks, olive pits, bagasse, and wood wastes. Some of these are reported to be still in operation.

Several U.S. companies make gasification/combustion units designed to be used with existing boilers. Nine gasifier/burner units built by Forest Fuels Inc., of Marlborough, New Hampshire, have

been retrofitted to boilers in sawmills, lumber drying plants, and other installations in the U.S. Wood waste in pieces no bigger than one inch are fed uniformly across an inclined stainless steel grate. Air passes up through the grate; the gas exits through the side of the unit and passes directly into the boilers. A Forest Fuels system in Greenfield, Massachusetts, includes delivery of wood chips in self-unloading trailers, a chip storage and feed system, a fuel dryer operated with stack gas, a 6 million Btu/hour gasifier, and a 100 hp package boiler. Steam produced by the system is used in a series of hardwood lumber kilns.

Two "Bio-Therm" gasifier/burner units built by C.H.H. Technology Inc. of Warsaw, Virginia, will soon replace small oil-fired boilers at the South Pacific Brewery in Lae, Papua New Guinea. The Bio-Therm units have been retrofitted to boilers in several institutions and industries in the U.S. and have burned sawdust, green wood chips, poultry litter, and peanut hulls. The planned units in Lae will operate on 4300 tons per year of hogged wood wastes. The choice of the Bio-Therm units was recommended in an assessment of wood gasification and combustion options for the brewery made by the MITRE Corporation of McLean, Virginia. The Mitre study indicated that the payback period for the Bio-Therm units would be about two years.

The largest updraft gasifier in the United States provides gas fuel for an existing boiler at the Northwest Georgia Regional Hospital in Rome, Georgia. The system was sponsored by the Georgia Forestry Commission and designed in cooperation with the Georgia Institute of Technology. The fuel is green wood chips with 45 to 50% moisture which are trucked into Rome in trailers; the chips are unloaded with a hydraulic tipping system into a live-bottom pit. A conveyor system transports the chips into a storage silo from which they are fed into the gasifier at the rate of about three tons per hour. The gasifier, built by Applied Engineering Company of Orangeburg, South Carolina, has a carbon steel shell, firebrick lining grate, ash hopper, ash screw, and a combustion air blower. It produces LBG with a heating value of about 25 million Btu/hour which is burned in a 19,000 lb/hour steam boiler. Initial problems with tar accumulation in the gas line between the outdoor gasifier and the indoor boiler now seem to be resolved. Project officials estimate fuel savings of about $200,000 in a year and a payback of the $600,000 capital cost of the system in about three years.

In Brazil a unique "Cargas" system, using gasifier/burners and special charcoal supplied by Hatsuta Industrial S.A. of Sao Paulo, provides fuel for industrial boilers and burners. The special Cargas charcoal is carbonized at low temperatures to retain oils and tars; Hatsuta indicates that the caloric value of the charcoal may reach 7,800 kcal/kg or 14,000 Btu/lb. The fuel is ground and delivered to users in plastic bags. The Cargas gasifier/burners are based on experience with 38 prototypes; they use hot compressed air and ejectors to produce a very high flame temperature suitable for metalurgical processes. The units are available in three sizes (250,000, 500,000, and 1,000,000 kcal/hour).

Fluidized Bed Gasifiers

In a fluidized bed gasifier the fuel drops into a hot bed of sand or other inert material which is kept in suspension by very turbulent air currents produced by large blowers. Gasifiers of this type can use fuels which are not suitable for use in fixed bed gasifiers. Due to more precise temperature controls and other factors, they can use high ash fuels without the slagging problems which preclude the conversion of these fuels in fixed bed gasifiers. They can use fuels with as high as 55% moisture content, although the LBG will have a higher heating value if drier fuel is utilized. Fluidized bed units can use sawdust and other fuels with a high percentage of small particles.

Fluidized bed gasifiers are more complex and expensive than fixed bed units, and control of fluidization and combustion is difficult. Fluidized bed systems smaller than 10 million Btu/hour have not been considered economic, although smaller units are now being developed.

A large fluidized bed gasifier built by Omnifuel Gasification Ltd of Toronto, Canada, began operation in 1981 at a plywood mill at Hearst, Ontario, Canada. The system is designed to use about 6.5 tons of wood waste per hour to produce approximately 80 million Btu/hour. The LBG is used primarily to heat oil which is then used in multiple locations in presses and dryers and for heating buildings. The total system cost including boiler retrofits was $2.4 million, but the payback period is estimated to be less than three years.

Two units for the fluidized bed gasificaton of sawdust have been operated in Missouri. More than one ton per hour of sawdust has been gasified in an experimental unit at the University of Missouri at Rolla. At Belle, Missouri, the Energy Resources Co. of Cambridge, Massachusetts, has built a fluid bed gasification/carbonization system at a Kingsford Co. charcoal plant. The system was designed to use ten tons of sawdust per hour to produce LBG and char. The LBG is burned in a briquette dryer ; the char, which equals about 20% of the feedstock, is used in briquettes. Modifications of the system are underway following initial testing.

The fluidized bed gasification of cotton ginning wastes, almond shells, and olive pits are described in Part Three.

In Sacramento, California, fifteen tons of chipped tree prunings or other wood wastes per hour will be fed to a fluidized bed gasifier at a plant which provides heating and cooling for 16 buildings.

The Sur Lite Corporation of Santa Fe Springs, California, is now offering fluid bed gasifiers which are small enough to be transported on a truck trailer. The units are produced under license from Advanced Energy Applications, Inc. of Los Altos, California. They can use from 1,000 to 10,000 pounds of feedstock per hour and produce from 5 to 50 million Btu/hour depending on the system size and feedstock. One of these units is currently being tested with crushed walnut shells and rice straw at the University of California at Davis.

Twente University of Technology in The Netherlands is now developing a small fluidized bed gasifier. It will have a combined air preheating and tar cracking system ; tars condensed from the LBG will be recycled back to the gasifier. A design for a small fluid bed gasifier built with a 55 gallon oil drum and suitable for use in developing countries has been developed at the University of Missouri at Rolla.

4. Characteristics of Biomass Fuels for Thermal Gasification

Moisture Content

The biomass used in down-draft gasifiers must have no more than 20 to 25% moisture. Up-draft and fluid bed gasifiers can accept fuels with as much as 50 to 55% moisture. However, high moisture levels limit gasifier efficiency and reduce the quality of the gas. The Forintek Canada Corp. found that the gas produced from wet wood chips contained only about 17% carbon monoxide (CO), the most important source of energy in LBG, while LBG from dry wood chips contained about 25% CO.

Ash Content

Biomass with a high ash content such as rice and cotton residues causes two kinds of problems in gasifiers. The heavy accumulation of ash can block the flow of air and fuel through the unit. If the temperatures are high enough to melt the ash, the molten slag or cinders formed from the slag can block the flow of air and fuel. The down-draft gasification tests

at the University of California at Davis indicated that slagging occured with most fuels having ash content of more than 5%. Slagging problems can be controlled through temperature controls which prevent the ash from melting and gasifier design features which avoid the creation of "hot spots" within the unit.

Fuel Sizing

The size of the pieces of the biomass influences its suitability for use in a given gasification system in two ways. First, the fuel size must be appropriate for the type of fuel handling system being used. Second, fuel sizing must be consistent with the type and design of gasifier. Most down-draft gasifiers work best with moderate sized fuel; if too many small particles are mixed with the larger pieces, the flow of air is partially blocked. However, a Missouri firm has developed a down-draft unit which operates satisfactorily on sawdust. Fluidized bed gasifiers work well with finely ground fuels but cannot accept large fuel pieces.

Charcoal As A Fuel For Gasifiers

Charcoal was widely used in automotive gasifiers in Europe and Australia during World War II. Today charcoal is being used again in gasifiers in several countries including Brazil and the Philippines.

There are several advantages to the use of charcoal in gasifiers, compared to the direct use of wood: (a) Since most of the tars have been removed from the charcoal during carbonization, gasifiers using charcoal require less elaborate gas-cleaning equipment. (b) Charcoal has about twice as much energy content per unit of weight as wood. The lighter fuel weight is a major advantage for vehicular gasifiers and in other situations where the fuel must be transported for a considerable distance. (c) Converting wood fuel into charcoal eliminates most of the problems associated with reducing the fuel to pieces small enough to flow through the gasifier.

However, there are some major disadvantages to the use of charcoal as a gasifier fuel: (a) A charcoal-fueled gasifier requires much more wood than a gasifier using wood directly. (b) Due to the loss of hydro-carbons during the carbonization process most charcoal produces a gas with a somewhat lower energy content than gas produced directly from wood. The Duvant company in France states that LBG made with charcoal does not provide maximum diesel oil savings when used in its large dual-fueled engines. (c) Maintaining proper sizing of the charcoal may be difficult since it tends to disintegrate due to rough handling or transport. (d) Due to the labor involved in charcoal production, the real cost of charcoal is considerably greater than that of unprocessed wood fuel. However, this difference may be offset in part by savings in the cost of chipping the wood fuel to permit its use in a gasifier.

Summary

Thermal gasification systems offer many promising opportunities to convert biomass to fuels in developing countries. The technical feasibility of the use of LBG from biomass in engines, boilers, and industrial burners has been fully demonstrated. At present no commercial firm has very wide experience with small-scale systems and the reliability of several new systems remains to be demonstrated. Many larger gasification projects have encountered problems (typically with the flow of fuel or air and/or with the gas cleaning equipment) which have required equipment modifications.

The economic feasibility of a gasification project can be determined only through (a) realistic and site-specific estimates of capital, feedstock, labor, and maintenance costs and of net savings in fuel costs and (b) a careful examination of experience with similar systems under comparable field conditions.

PART TWO: THE PRODUCTION OF CHARCOAL

1. Introduction

Charcoal has been used for many centuries as a domestic fuel and for the smelting of metals. Because charcoal has a much higher energy content per unit of weight than wood, it has been feasible to transport it over considerable distances even in countries with poorly developed transportation facilities. In many developing countries the largest use of charcoal as a domestic fuel is or at least was in urban areas where consumers do not have direct access to wood or other biomass fuels. In recent decades many of these urban consumers have shifted to kerosene stoves, but some governments are now promoting the return to charcoal to reduce imports of fossil fuels. Brazil, India, Malaysia, Uganda, and some other countries use charcoal extensively in metal-smelting industries; new industrial uses of charcoal are being explored in other countries such as Kenya.

A high percentage of the charcoal used in developing countries is made in rather inefficient traditional kilns. There is substantial interest in a number of countries in improved methods for charcoal production. In response to this interest. the Bioenergy Systems and Technology Project sponsored a workshop on the production of wood and charcoal for twenty participants from developing countries in Brazil from March 21 to 26, 1982. The workshop program was arranged by Florestal Acesita SA, a Brazilian firm based in Belo Horizonte, which operates large-scale tree plantations and charcoal production units in the state of Minas Gerais. Much of the information in this part of this Report is drawn from a comprehensive review of charcoal production in Brazil prepared by Florestal Acesita for the workshop and from papers presented by workshop participants from other countries.

2. Biomass Feedstocks for Charcoal

In many developing countries deforestation is a serious and growing problem and the supply of fuelwood for the rural population is shrinking rapidly. Without proper planning and management, increased charcoal production could intensify these serious problems.

Two approaches are being used to insure that greater charcoal production does not add to deforestation and fuelwood problems. One approach is to use only biomass residues for which there is no other practical use and which would otherwise be burned or allowed to rot. These include the parts of the tree which remain unused after logging and sawmill operations, whole trees which are removed when land is cleared for agricultural use, and some tree crop and agricultural residues which can be used to make charcoal. For example, a new charcoal program in Sri Lanka will initially utilize wood from the planned clearing of about 162,000 hectares (400,000 acres) of forest pursuant to various government development projects.

The other way to ensure a wood supply for charcoal without contributing to deforestation is to establish plantations of fast-growing trees which are earmarked for conversion to charcoal. In Brazil, which needs large quantities of charcoal for its steel industry, more than 750,000 hectares (1,853,250 acres) have been planted in charcoal planations. Florestal Acesita have planted more than three million Eucalyptus trees on more than 142,000 hectares in the state of Minas Gerais. The trees grow very rapidly even on marginal land without irrigation and with little fertilization. The average growth is 30 m^3 per hectare per year. After the first cutting when the trees are six years old, new shoots sprout from the stumps. Over a 18-24 year period a total of four cuttings can be made from a single planting. This productivity permits an investment in land preparation, planting, road building, and infrastructure for the charcoal plan-

tations which would not be warranted if only a single tree harvest was expected.

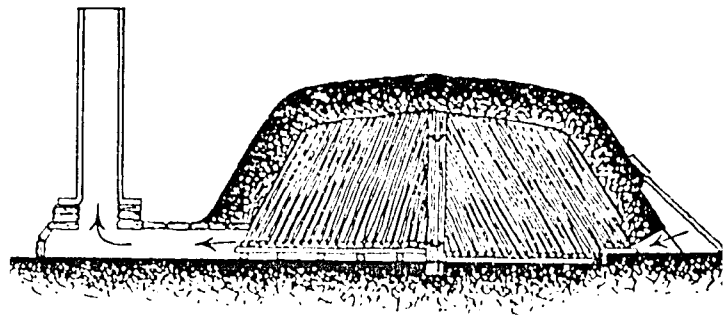
The Philippine government has launched a major charcoal program which will be based on plantations of fast-growing trees. Plantations will range from 200 to 2,000 hectares. Each 100 hectare module will be cleared and planted by about 15 farmers who are members of a local charcoal producers association. Subsequently each farm family will be responsible for maintenance of an assigned section of the plantation. Roads will be built and brick beehive kilns will be constructed on each plantation during the period prior to the first tree harvest. The program is administered by a state corporation, the Farm Systems Development Corporation (FSDC).

3. Types of Charcoal Kilns

In developing countries almost all charcoal is produced in some form of kiln through a multi-stage process which includes (a) initial heating through the combustion of kindling material and some wood with full air flow; (b) dehydration of the feedstock at lower temperatures after air intake is reduced; (c) an exothermic stage in which various substances including acetic acid, methyl alcohol, and tars are distilled from the wood at high temperatures; and (d) a cooling stage in which the kiln is sealed and the charcoal is allowed to cool.

Earthen Mounds and Pits

In developing countries charcoal is most frequently made in some type of earth pit or mound. Each of these earthen kilns must provide for the intake of air and the exit of smoke and for the sealing of these air and smoke ports when carbonization is completed. Some have only air holes at the bottom and smoke holes on the top of the mound. Others have a smokestack similar to that in the traditional Swedish charring stack shown in the adjacent sketch. In Senegal a high chimney was built for a mound-type kiln



Swedish Charring Stack

from three oil drums. Low air intake and chimney pipes are used in a pit kiln for the charring of coconut shells in the Philippines.

In each pit or mound kiln the wood must be stacked in a manner which will provide sufficient air circulation but maintain physical support for the earthen covering. Usually some type of available biomass such as straw, grass, or banana leaves is spread over the wood before the earth cover is added. When carbonization begins, this biomass may burn and there may be cave-ins. These must be promptly repaired or the excess air intake will permit the full combustion of the wood and leave only ashes.

Some charcoal is made in uncovered pits. Household charcoal is often made in the Philippines by igniting a few coconut shells in the bottom of a pit, filling the pit with additional shells, and quenching any flame with water. When the shells are fully carbonized, the pit is covered with banana stalks and leaves and left to cool.

The principal advantage of these simple types of charcoal kilns is that they require only labor and need no capital expenditure. However, there are many disadvantages including (a) the need for an experienced operator to maintain satisfactory production, (b) poor charcoal quality due to uneven burning and contamination with earth from the pit or mound, (c) rather low yield, typically only about 15% of the original weight of the wood, and (d) very slow carbonization.

The length of the total cycle for the earth kilns depends on the size and design of the kiln, the type of wood used and weather conditions especially wind. While the process can be completed in as little as a week, cycles of two and three weeks are not uncommon.

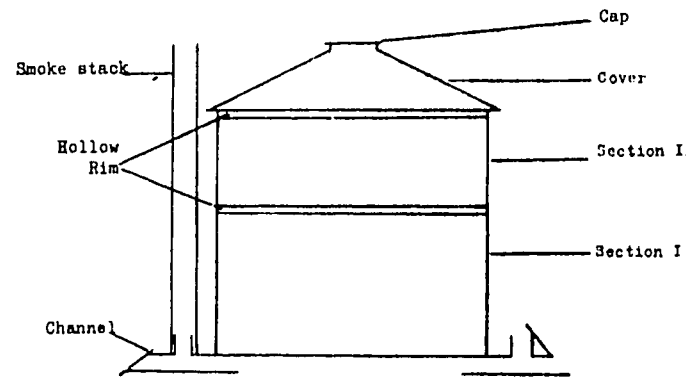
Oil Drum Kilns

The basic oil drum kiln has an open top and air holes at the bottom. A fire is started with a small amount of feedstock (usually wood or coconut shells) at the bottom and the drum is then filled. When charring is complete, the top of the drum is covered, the air holes are blocked, and the drum is allowed to cool. The Forest Products Research and Industries Development Commission in the Philippines has developed improved drum kilns with a sheet metal chimney built into a top cover plate; one model uses two drums stacked vertically.

Advantages of the oil drum kilns over the earth mound kilns include relative ease of operation, production and cooling of charcoal in less than 24 hours, elimination of the contamination of the charcoal by the earth from the mound or pit, and the portability of the drums. Limitations may include the cost or availability of the drums, the rather small capacity of each drum, and inability to use large logs and pieces.

Transportable Steel Kilns

Circular kilns consisting of several steel sections assembled in the forest have been used in a number of developing countries. Designs from around 1930 were improved by the Forest Department in Uganda around 1970. The kilns were introduced by the Forestry Development Authority in Liberia in the later 1970's. The Tropical Products Institute in England has designed an improved steel kiln, produced two handbooks and a 10-minute 16 mm film on its operation and conducted training programs on the kiln for forestry personnel of ten developing countries. The Charlanka Company, formed in Sri Lanka in 1981 in



Components of a Steel Kiln

cooperation with the State Timber Corporation, plans to use portable steel kilns made by Shirly Aldred Ltd. of England in a large-scale charcoal program.

The components of the transportable steel kiln are shown in the above sketch. The wall of the kiln consists of two steel cylinders. (Dimensions and gauges given here are those of models currently used in Liberia). The bottom section is made of 3 mm thick steel sheet and is 36" high and 7'7" in diameter. The top section is of 2 mm sheet and is 2'6" high. A conical cover, also of 2 mm steel, is 18" high in the center. The lower section of the wall rests on eight air channels (8" x 4" x 20") arranged radially around the bottom of the kiln. During carbonization, smoke stacks (5" diameter and 7'6" high) are fitted on four of the air channels, using collars provided for this purpose, while the other four channels serve as air inlets. The smoke stacks are moved to the alternate air channels after 8 to 10 hours to avoid excessive combustion and ash at the air inlets.

These steel kilns have several major advantages ; (a) The yield is substantially higher than in traditional earth kilns. The Forestry Development Authority in Liberia reports average yields of 25% of the original weight of the wood, compared to only 14% for traditional pit kilns. However, a FAO publication

indicates typical yields from the steel kilns of only 20%. (b) Charcoal production is much faster than in traditional kilns. The steel kilns can produce a batch of charcoal in only about 48 hours including both carbonization and cooling, although three to four days may be needed if winds or rain cool down the steel walls. (c) The steel kilns can be moved to new locations to use wood produced by land-clearing or timberharvesting operations. The major components can be rolled or carried short distances, although longer moves require truck transport.

There are however, important economic, logistical, and practical limitations on the use of these kilns. The steel components must be imported or locally manufactured. Steel kilns produced by a British manufacturer are reported to cost $1,000 per kiln. Manufacture of the kilns by local craftsmen may be feasible in a shop which has basic welding, rolling, drilling, and cutting capabilities. Either way, the use of the kilns requires investment capital, transportation facilities, repair capabilities, and a mobile workforce.

There are also some operating problems with the kilns. Wood must be reduced to block form (usually no larger than 30 x 10 x 10 cm) while earthen kilns can use thicker and longer logs. Since the kilns have no doors, wood and charcoal must be lifted over the top edge of the lower section. Air leaks at the ground line may cause hot spots which lead to buckling and the collapse of sections of the kiln wall. For this reason and others, the life of the steel kiln is usually limited to a period of from two to four years.

Brick Beehive Kiln

In Brazil, which now produces four to five million tonnes of charcoal per year, virtually all the wood is carbonized in brick beehive kilns. Although some smaller kilns are used, the production of charcoal for the iron and steel industry is usually in 5 m diameter kilns.

Most of the Brazilian steel companies use batteries of from 46 to 108 kilns; this scale of operations permits more mechanized wood handling systems, better control of production and quality, and concentration of worker housing and infrastructure.

Each kiln is built of about 8,000 ordinary fire bricks (25 x 10 x 5 cm). The bricks are laid with a mixture of about 3 to 4 parts clay slurry and one part fine sand and water. The kiln consists of a cylindrical wall with the doors for wood charging and charcoal discharging, six exterior brick chimneys, and a domed brick roof with a central opening for igniting the kiln. Air enters through 18 holes along the bottom of the cylindrical wall; additional air holes are located in the side of the wall and in the dome.

Two workers charge the kiln by hand. Logs are packed vertically in the cylindrical portion of the kiln; thinner pieces of wood are packed horizontally in the dome section. After charging, the doors are sealed by piling up bricks; no mortar is used, but the door bricks are plastered with a mix of 1 part clay slurry and 1 part sieved sand and water. Charging and sealing the kiln takes about four hours.

The kiln is ignited by adding a shovelful of embers through the central opening, which is then closed. Carbonization moves from top to bottom and also horizontally. When smoke from the chimneys becomes dark, dome portholes are closed and the side portholes are gradually closed. When the smoke turns bluish, all chimneys are closed and cooling begins. Carbonization takes about four days and cooling requires a similar period. Charcoal is removed by two men with a special fork and basket in about four hours; it is transported by truck to consuming areas.

The beehive kiln is relatively easy and inexpensive to build and the domed structure has great strength. The yield is much higher than that of pit or mound kilns. A 37 m^3 charge of wood is

converted to 18 to 20 m^3 of charcoal. The yield is 33% by weight (dry basis).

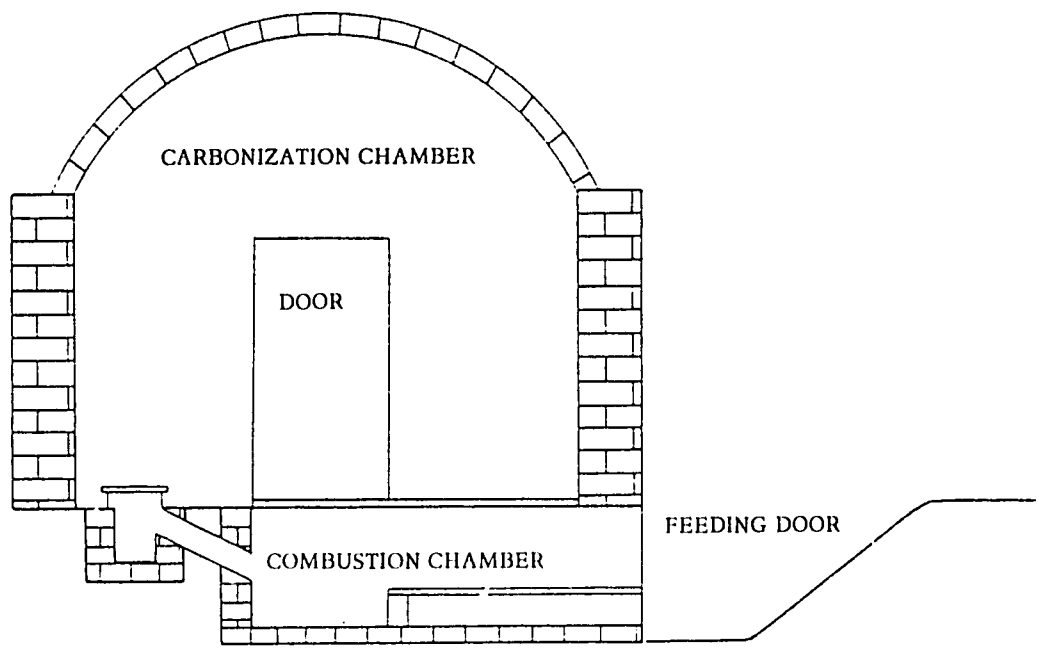
Florestal Acesita is testing 50 brick beehive kilns which have a separate combustion chamber under the floor of the kiln, as indicated in the sketch below. Carbonization temperatures are created by the hot gases passing from the combustion chamber into the carbonization temperature. Air inlet holes in the kiln are eliminated; excessive temperatures are avoided by controlling the air flow with a butterfly valve in the feeding door. Preliminary results indicate the following advantages for this new type of kiln: high yields, longer kiln life due to the absence of excessive temperatures, easier operation due to the elimination of the opening and closing of inlet portholes, and reduced dependence on external conditions including wind direction.

In the Philippines the Farm Systems Development Corporation is planning to build brick beehive kilns on most of the charcoal plantations being established. The typical kiln will convert 41 m^3 of wood in a 12-day cycle.

"Missouri" Concrete & Steel Kilns

In the United States the most common type of batch kiln is known as the "Missouri" kiln. It is a rectangular building, typically 12 m long, 7 m wide, and 4 m high. While some early kilns of this type were made of concrete blocks, the blocks were not able to withstand the high temperatures of the carbonization process. Today most Missouri kilns have walls of poured concrete or steel; the best combination is thick concrete for the first 1.5 m from the bottom, with steel for the upper portion of the wall. Kilns with all-concrete walls may also have a concrete roof, while those with steel walls normally have a steel roof. The kiln usually has four chimneys and four air inlet holes along each side at the bottom.

Large steel doors at one end permit a truck or tractor to be driven into the kiln. Roundwood is usually stacked in the kiln by hand from the back of a flat-bed truck. Sawmill slabs are stacked with a tractor equipped with a front-end loader. The Missouri kiln holds from 40 to 50 cords (145 to 180 m^3) of wood. After ignition the doors are sealed with mortar. Carbonization requires from



Brick Beehive Kiln With Combustion Chamber

four to eight days. When the smoke turns blue, carbonization is completed and the kiln is sealed for a cooling period of about 10 days.

In the U.S. the principal advantages of the Missouri kiln are its large capacity, long life, and ease of loading with trucks and tractors. These may be disadvantages in developing countries. Nonetheless, a version of the Missouri kiln may be appropriate for those situations in developing countries where a permanent, high-capacity kiln is required.

4. By-product Recovery Systems

None of the kilns described above normally includes any means of capturing and using the oils, tars, and gases produced during carbonization. Several techniques have been used to recover these by-products.

Basic Tar Recovery Techniques

Two new techniques for recovering tars and oils were reported at the recent charcoal seminar in Brazil. In Senegal the previously described smoke-stack built with three oil drums for a mound kiln contains a drainage pipe and bucket to catch tars which condense inside the stack. In Brazil, Florestal Acesita is developing a process for extracting the tars from the volatile gases generated in brick beehive kilns. The gas is collected at the center of the bottom of the kiln; the tars are scrubbed out in a washing tower and collected in drums. The firm states that the tar has a high heating value (5,500 to 6,500 kcal/kg) which is about 60% of that of fuel oil. During 1982 Florestal Acesita plans to install twenty of these tar recovery units each with a capacity of 3.6 tons per month. The tar will be used as a substitute for fuel oil for heating furnaces in the Acesita steel plant.

Continuous Charcoal Systems

In developed countries recovery of by-products is provided in large continuous and semi-continuous charcoal production systems. In the horizontal steel oven or retort, the wood is loaded on steel wagons; after carbonization they are pulled out to separate cooling chambers and replaced immediately with new wood or other wagons. Heat is supplied externally by natural gas, oil, or coal. Tars condensed from the gas produced during carbonization are used to manufacture various chemicals.

The most common type of continuous charcoal production with by-product recovery is the Heereshoff multiple hearth furnace. The wood is reduced to pieces no larger than 3/4" in a hammermill or hogger. The furnace consists of several circular hearths or burning chambers arranged vertically in a steel shell or refractory lining. A rotating vertical shaft turns rabble arms within each hearth; the feedstock drops through holes in each hearth to the next hearth below. These systems can use sawdust, other sawmill wastes, and nut shells; they produce a high quality charcoal. However, they are extremely expensive. Florestal Acesita estimates that modern continuous systems are 40 times more expensive in Brazil, per unit of output, than charcoal production with brick beehive kilns.

A unique multiple-purpose continuous system has been developed at a coconut processing cooperative on the island of Mindanao in the Philippines. Five tons of coconut shells per day are mechanically fed into a 20 m vertical cylindrical steel kiln lined with locally-made refractory bricks. High grade charcoal made in the unit is sold to Union Carbide for use in batteries. Gas produced during carbonization is burned to dry bricks; excess heat from the facility is used to dry copra.

"Pyrolysis" Systems

Pyrolysis is the inital stage in all processes for the thermal converson of biomass; the feedstock is broken down into char, liquids, and gases. In combustion and gasification systems most of the char and liquids are subsequently

converted into gases. However, a "pyrolysis" system, as the term is currently used, produces liquid and gaseous products as well as charcoal.

Several firms have developed pyrolysis systems. Experimental pyrolysis units have been built with American assistance in Ghana, the Philippines, Indonesia and Costa Rica. The United Nations Industrial Development Organization is sponsoring a program in the Philippines to develop a range of pyrolytic converters suitable for use in the Philippines and to adapt existing and small-scale technologies for the utilization of the three basic types of pyrolysis products.

Several inherent problems have been encountered with these systems. They require continual adjustments of the flow of air and feedstocks, but control over the quantity and quality of the char, gas, and oil is limited. An increase in the quality or quantity of one of the products usually results in a reduction in the amount or value of one or both of the other products. If more of the carbon in the feedstock remains in solid form as charcoal, less carbon will be converted to carbon monoxide which provides most of the energy in the gas produced by most gasification systems. The condensation of tars and other hydrocarbons in liquid form eliminates the contribution of these tars to the heating value of the fuel gas.

The full use of such a "pyrolysis" system would require a profitable use or market for each of the three products. Charcoal is the only one of three which is relatively easy to transport. In many locations in developing countries where there is a large supply of a biomass feedstock there may be no practical use or available market for one of the pyrolysis products.

Although the idea of making a liquid fuel from biomass is very appealing, there are many unresolved questions concerning the practical value as a fuel of the liquid product of these systems. This liquid, known as pyrolytic oil or pyroligneous acid, is viscous, highly corrosive, and chemically unstable at high temperatures. Despite a few successful tests, the suitability of pyrolytic oils for use as a substitute for fuel oil in boilers or other burners remains to be clearly established. Due to the corrosive character of these oils, very substantial changes in piping, storage, and pumping equipment would be required. Although a large industrial enterprise may be able to use these oils, the technical and investment problems associated with their use may be insurmountable for smaller organizations in developing countries. Experiments with the use of pyrolytic oil as a fuel in diesel engines have had only limited success due to the accumulation of tar deposits in the pistons.

Much of the experimental work with pyrolysis systems in developing countries has concentrated on the conversion of rice hulls. Due to the high silicon content of the hulls, the charcoal produced from the hulls has a rather low heating value. In tests in Indonesia oil from the pyrolysis of rice hulls did not prove to be a satisfactory substitute for kerosene in lamps and cookstoves.

Summary

A choice among types of charcoal kilns should be based on an analysis of (a) availability and cost of materals, (b) availability and cost of skilled labor for construction and operation, (c) degree of centralization and permanence of production units, and (d) transportation facilities for wood and charcoal.

Illustrations: p. 3: "Wood Gasification", National Research Council, Canada. p. 8: "Survey of Biomass Gasification", SERI. p. 13: "Generator Gas", SERI. p. 14: "A Report on Charcoal", FAO. p. 16: "Charcoal Production in Brazil", Florestal Acesita.

PART THREE: THE THERMAL CONVERSION OF AGRICULTURAL RESIDUES

Residues remaining from the processing of agricultural crops are used for industrial fuels in many developing countries. Virtually all of the industrial use of crop residues for energy is in mills and plants which produce these residues, although many such plants are not equipped to utilize the residues they produce.

Bagasse

The remainder of the sugar cane stalk, after the juice has been removed, is used as a boiler fuel in sugar mills in at least 27 countries. The bagasse contains 50 to 55% moisture and must be kept under cover to avoid absorption of additional moisture. Because it still has a high sugar content, the bagasse will ferment if stored and there is some danger of spontaneous combustion.

The general practice of sugar mills is to burn bagasse to produce process steam which is used in turbines in the milling department and for heating and evaporation of the cane juice. Most modern mills also use a part of the steam to produce electricity for use in the mill; in a few countries excess electric power from sugar mills is sold to adjacent communities or to the national power grid. The power output of many mills is limited by the inefficient systems used for the combustion of the bagasse. Boilers in use range from hand-stacked "Dutch oven" boilers in some older mills to modern spreader-stocker and inclined grate systems in newer plants.

Due to the characteristics of bagasse, there is little prospect of its use as a fuel outside of sugar mills. However, with more efficient combustion equipment and better management techniques, the sugar industry in some countries could produce a substantial surplus of electric power for the grid. An engineer from Managua, where sugar mills contribute substantially to the national grid, studied the potential for increased power production from bagasse in Nicaragua. He concluded that the country's sugar mills could supply at least 5% of the national power needs with present harvesting techniques and up to 15% of the nation's power if the leaves of the sugar cane plant were also brought to the mills and used with the bagasse for fuel.

Since bagasse cannot be stockpiled and is only available during the cane harvesting season, power production from bagasse is sugar mills can reduce the use and cost of fossil fuel in other generating plants but cannot be a substitute for year-round generating capacity. In Hawaii, the Davies Hamakua Sugar Company wanted to sell power to the electric company and solved the problems of fuel in the non-harvesting season by building the world's first bagasse pelletizing facility. During harvesting periods the bagasse is screened; the coarser pieces are burned directly and the finely ground fiber is used for pelletization. Moisture content is reduced to 35% in a rotary dryer using flue gas. A "Woodex" pelletization process, developed by the Bio-Solar Research and Development Corporation of Eugene, Oregon, converts 75,000 tons of bagasse per year into 58,000 tons of pellets; they are stored and used for fuel when no cane is being harvested. This additional fuel permits the company to provide 10 MW of power to the grid all year.

Combustion Equipment Associates of Stanford, Connecticut, which has developed a process for producing a powdered fuel from municipal refuse, has conducted a feasibility study on the production of a dry, powdered fuel from bagasse and the leaves and tops of the sugar cane plants. The proposed plant in Puerto Rico would process 275,000 tons per year of the cane residues and sell the powdered fuel to cement plants.

Experience with the gasification of bagasse is limited. The Duvant company indicates that bagasse must be compacted before it can be used in the company's systems.

A prototype gasifier to make LBG from bagasse is being built by a Swedish engineering firm for testing by the research department of the State Sugar Council in the Dominican Republic. A Denver firm is reported to be developing a system for the gasification of bagasse in Guyana.

Rice Hulls

The hulls or husks of rice are the most abundantly available crop residue in many Asian and African countries. Unfortunately, the high ash content of the hulls causes problems when the hulls are used in thermal conversion systems. The hulls contain 15 to 20% ash, and about 90% of the ash is silicon which has a relatively low fusion point. Ash fouling, slagging, and clinker problems are common when rice hulls are gasified.

Despite these problems, rice hulls are reported to be in use as a boiler fuel in rice mills in nearly a dozen countries. A World Bank report states that nearly half of the Indian rice crop is processed in mills which use the hulls as fuel. Two Italian firms manufacture combustion systems to produce steam with rice hulls. A biomass boiler built by the Ray Burner Company of San Francisco will produce steam for the generation of 800 kW of electrical power at a rice mill in the Philippines.

In the U.S., the California Energy Commission is supporting two projects for the combustion of rice hulls. Whole rice hulls and ground rice straw will be burned in a rotary kiln at a clay products plant to produce 50 million Btu/hour and displace 80% of the natural gas formerly used by the plant. Poultry litter consisting of 50% rice hulls and 50% chicken manure will be burned in a 8.4 MW cogeneration facility with a fluidized bed boiler in Livingston, California ; excess electric power will be sold to the regional electric utility company. A Portland cement company in Goias, Brazil, has successfully co-fired 20% rice hulls with 80% fuel oil and hopes to increase the percentage of hulls to 35%. The University of the Philippines and others have used rice hulls as a fuel in low-cost crop drying systems.

The gasification of rice hulls was extensively developed in Italy between 1915 and 1945. Ash fouling and slagging problems which could clog a down-draft gasifier were avoided by using up-draft gasifiers ; the heavier tar content of the gas produced in these units was removed by using centrifugal tar separators. Although some of these Italian units operated in rice mills for several decades, no recent use of these techniques has been reported.

Tests of agricultural residues in down draft gasifiers at the University of California at Davis indicated that rice hulls (and other fuels with more than 5% ash content) were not acceptable fuels for down-draft gasification. However, a gasifier/engine system especially designed for use with rice hulls is now being tested at Davis. The Biomass Corporation in California also reports successful gasification of rice hulls in a small (5 hp) gasifier/ engine system. However, no commercially successful unit for the gasification of rice hulls is available at present.

A rice milling project funded by the World Bank in Cameroon includes power generation from the gasification of rice hulls. Slagging and packing problems were encountered in initial tests of a small Duvant gasifier with a diesel enginegenerator. This temporary unit has been replaced by a conventional diesel system while design modifications are made in the larger permanent gasification system. The World Bank and OPEC will also be funding the production of 2 MW of electric power from rice hulls in Mali ; technical operations are being evaluated very carefully in light of the known difficulties with the gasification or rice hulls and the initial problems encountered with the gasification project in Cameroon.

The Energy Resources Company of Cambridge, Massachusetts, is studying

the feasibility of a fluidized bed system to produce LBG from rice hulls and use it to generate 5 MW of electric power at a rice mill in Texas.

Rice hulls were extensively tested without slagging problems in a large rotary furnace combustion/pyrolysis system which is now marketed by Universal Energy International based in Oklahoma City; temperature in the furnace's primary combustion zone was kept below 1500°F (815°C) to prevent ash fusion.

In the Philippines char, LBG, and pyrolytic oil were produced from rice hulls in a 1 ton/day pyrolysis unit. Philippine officials hope for better performance from a 6 to 10 ton/day plant, supported by the United Nations Industrial Development Organization, which will have more sophisticated equipment to deal with air and fuel flow problems encountered with the smaller unit.

An "appropriate technology" pyrolytic converter for rice hulls was built at the Development Technology Center in the Institute of Technology in Bandung, Indonesia. The unit produced charcoal which contained 45% silicon; its heating value was only 18% higher than that of the original rice hulls, although the greater bulk density of the "fireballs" made from the charcoal made them a more desirable fuel than the hulls. Production of pyrolytic oil from the unit was rather limited. Due to poor wicking action, suspended carbon particles, and other factors, the unrefined oil did not prove satisfactory as a substitute for kerosene in cookstoves and lamps. Gas produced by the unit was used to replace 60% of the diesel oil in a 6 hp engine.

Rice Straw

The Indonesian Technology Agency, (BPPT) built a prototype unit to make charcoal from tied bundles of rice straw. Since the straw has a high silicon content, briquettes made with this charcoal have a low heating value and must be considered a substitute for wood rather than for charcoal. Work is underway on the development of a special stove to burn this rice straw charcoal, possibly using an initial charge of wood to initiate boiling which could then be maintained with the rice straw charcoal.

Tests of the gasification of rice straw in a fluidized bed gasifier will be conducted in 1982 at the University of California at Davis.

Other Straws

Straws from other cereal grains are extensively used as fuel in Europe. Fifteen German firms produce boilers that can accommodate small bases of straw. Two Austrian firms have produced more than 600 boilers designed to be handstocked with bases of straw.

Several European research institutions are developing systems using chopped or pelletized straw as fuel. The German Government is funding a greenhouse boiler fueled with blow-in straw. An inexpensive low power furnace with automatic charging for straw and wood chips is being developed by a university research unit in Munich. In England the University of Nottingham operates a system which is continuously fed with chopped straw.

Tests at the University of California at Davis showed that, due to their relatively high ash content, barley and wheat straws are not acceptable fuels for down-draft gasifiers. However, satisfactory results were obtained with the steam gasification of wheat straw in a fluidized bed gasifier at Kansas State University.

Coconut Shells and Husks

In American Samoa the Coconut Processing Corporation uses coconut residues in a burner/gasifier made by American Fyr-feeder Engineers of Desplaines, Illinois.

Several large electrical generators were powered by LBG from the

gasification of coconut shells in West Africa before World War II; four or five of these are reported to be still in operation in the Ivory Coast and Gabon. Electricity for Papeete, capital of Tahiti, was generated with LBG from coconut wastes from 1928 to 1945. Several new plants have been built in recent years. Since 1978 LBG from the husks and shells of about 500 coconuts per hour has fueled a 190 kW generator on the Pacific island of Bora Bora. Coconut shells are used in a large Duvant gasifier/engine/generator system in the Ivory Coast.

In the Philippines, the Economic Development Foundation used LBG from coconut husks to replace 65 to 75% of the diesel fuel in 80 hp diesel engine driving a 37.5 kVA generator; about 2.5 kg of husks were needed to produce 1 kwh of electric power. Maya Farms in the Philippines plans to gasify coconut fronds and husks to operate stationary engines.

Charcoal for domestic use is widely made from coconut shells in pit kilns in the Philippines. The Tropical Products Institute (TPI) in England made charcoal successfully from coconut shells and coconut palm timber in the TPI transportable steel kiln; gas produced during the carbonization of the shells was used in a copra drying unit. As indicated earlier, a continuous charcoal production system using coconut shells has been developed in the Philippines. An American firm has proposed the production of high-quality activated charcoal from coconut shells at a large coconut processing plant in Mexico, using a modern continuous carbonization process.

Residues From Other Tree Crops

Several American firms are using nut shells as boiler fuels. Tri-Valley Growers in Modesto, California, retrofitted an oilfired boiler to burn finely ground walnut and almond shells as well as peach, olive, and cherry pits. Pecan shells are used as a boiler fuel, along with peanut hulls and wood chips, at the Gold Kist soybean processing plant at Valdosta, Georgia. A company processing macadamia nuts in Hawaii burns the hulls in a 200 hp boiler; the heat is used for nut drying. A similar facility is planned for a macadamia nut processing plant in Guatemala.

A large olive-processing facility at Lindsay, California, saves $500 per day in fuel costs by burning dewatered olive pits in a fluidized bed boiler. An Italian firm is producing small automated water heaters which burn olive husks.

Tests at the University of California at Davis showed that most nut shells and the pits of prunes, peaches, and olives are good fuels for down-draft gasifiers. Crushed walnut shells were found to be too dense for satisfactory use in these gasifiers, but these shells are now being tested in a fluidized bed gasifier. At a large almond processing plant in Bakersfield, California, owned by Tenneco Oil Company, three tons of almond shells per hour will be fed into a fluidized bed gasifier. The steam produced with the LBG will be injected into adjacent oil wells to aid the recovery of heavy oils. Palm nut kernels are reported to be used in a gasifier in the Ivory Coast.

About thirty companies in Brazil are using charcoal made from the shells of babassu nuts to fire furnaces in foundries and steel mills. The Kingsford Company makes charcoal from almond shells and wood wastes in a multiple-hearth furnace at Elk Grove, California.

Cotton Gin Trash

Trash consisting of cotton fibers, stems, and leaves is a fire hazard and disposal problem at cotton gins. The ginning wastes contain 15% to 22% ash; the ash has a low melting pint and an even lower refreezing point. Consequently, severe ash fouling and/or slagging problems have been encountered when cotton gin trash has been burned in conventional incinerators and burners. Moreover, such combustion produces severe air pollution problems including a

high level of particulates due to the high ash level and large amounts of nitrogen oxide.

The California Energy Commission is supporting two projects which will use new combustion techniques to burn these wastes. The Farmers Cooperative Gin (FCG) of Buttonwillow, California, is building a cogeneration facility which will produce 11 million kwh of electricity and 60 billion Btu of process heat annually from cotton gin trash. The FCG combustion system is designed with staged combustion and flue gas recirculation to avoid slag formation and minimize nitrogen oxide emissions. Westside Farmers Cooperative Gin at San Joaquin, California, will burn cotton gin trash in a low-temperature combustion system design to avoid ash slagging.

University of California tests indicated that, due to the high ash content, cotton gin trash is not an appropriate fuel for down-draft gasifiers. Advanced Energy Applications, Inc. of Los Altos, California, built a 100 ton/day fluidized bed gasifier which used cotton gin trash to provide heat for cotton drying at a cotton gin in Hanford, California. Slagging and ash fouling problems were avoided through careful control of process temperatures.

Corn Residues

Corn cobs are an excellent fuel for both combustion and gasification systems. The cobs are burned to produce heat for seed corn drying in several plants in Europe. Two American seed corn companies have used gasifiers fueled with corn cobs for seed corn drying. Agricultural engineers at Purdue University, the University of Florida, and the University of California at Davis have experimented with the gasification of corn cobs. A corn mill was operated in Tanzania during 1980-81 on LBG produced from corn cobs in a system designed by Twente University of The Netherlands. Further tests of corn cob gasification units in Tanzanian villages are planned.

Agricultural engineers at Iowa State University have used a concentric vortex biomass furnace for the combustion of cornstalks. Large bales of the stalks were burned in a special furnace at the University of Georgia. Cornstalks have a higher ash content (6.4%) than corn cobs and may cause slagging problems in down-draft gasifiers. The University of California at Davis conducted tests of the gasification of corn stalks in a 100 kW gasifier/engine system funded by the John Deere Company in 1978. Gas with a rather high heating value was produced from corn stalks om a fluidized bed gasifier at Kansas State University.

Other Agricultural Residues

Hot air for the drying of coffee berries is produced by burning coffee husks in a plant in El Salvador built by GEKA Warmetechnik of Karlsruhe, Germany. A Central American research institution reports increasing interest in the direct burning of coffee pulp bagassse after pressing. Coffee bean residues from the production of instant coffee have been tested as a boiler fuel by a Brazilian organization.

Peanut hulls are used as a boiler fuel in a soybean processing plant in Georgia and a furniture plant in North Carolina. The hulls are reported to be used in boilers in several African Countries.

A satisfactory grade of charcoal has been produced from the stalks and leaves of the banana tree in the Philippines.

Summary

Bagasse, rice hulls, and coconut residues are widely used in thermal conversion systems in developing countries. Interesting experiments have been conducted with other residues. The suitability of a given residue for thermal conversion is determined by its moisture content, ash content, sizing, and storability.

A REQUEST FOR INFORMATION

Two additional Bioenergy Systems Reports will be published in 1982. The third Report, to be distributed in September reviews projects, plans, and potentials for the production of alcohol fuels in developing countries. The fourth Report, due in December, will discuss social, economic, cultural, institutional, environmental, and educational aspects of the use of biomass for energy.

A primary purpose of these Reports is to contribute to the interchange of information and experience among those involved with bioenergy projects in developing countries. Organizations engaged in or planning such projects are urged to send information on them to Bioenergy Systems Reports, P.O. Box 591, Front Royal, Virginia, USA 22630. Reports on innovative equipment or systems, the use of unusual feedstocks, or any experience that tends to contradict generalizations in this Report are especially welcome. The editor expresses his sincere thanks to all those who have provided information used in this Report.

A THERMAL CONVERSION LIBRARY

1. Proceedings of conferences of the Forest Products Research Society, 2801 Marshall Court, Madison, Wisconsin USA 53705 :

Energy Generation and Cogeneration from Wood, 1980, 182 pp, $18.00.

Industrial Wood Energy, 1981, 286 pp $20.00.

2. Publications of the Solar Energy Research Institute, 1536 Cole Blvd., Golden, Colorado USA 80401 :

Decisionmaker's Guide to Wood Fuel for Small Industrial Energy Users, 1980, 165 pp, $8.00.

Generator Gas: The Swedish Experience from 1939 to 1945, 1979, 329 pp, $14.00.

A Survey of Biomass Gasification, Vol. Two (Principles of Gasifiction), 1979, 219 pp, $12.50; Vol. Three (Current Technology and Research), 1980, 284 pp., $12.50.

3. Publications of the Board on Science and Technology for International Development, National Academy of Sciences, 2101 Constitution Avenue NW, Washington, DC USA 20418 (free to institutions in developing countries):

Firewood Crops: Shrub and Tree Species for Energy Production, 1980, 237 pp.

Producer Gas: Another Fuel for Motor Transport (to be published in 1982)

4. Publications of the Tropical Products Institute, 56/52 Gray's Inn Road, London WC1X 8LU England:

Charcoal Production Using a Portable Metal Kiln, 1980, 18 pp, 85 pence.

The Construction of a Transportable Charcoal Kiln, 1982, 20 pp.

5. Publication of the Bio-Energy Council, 1625 Eye Street NW, Washington, D.C., USA 20006.

International Bioenergy Directory, 1981, 1201 p. $90.00.

6. The Bioenergy Systems and Technology Project has commissioned comprehensive reports on the state-of-the-art in various bioenergy sectors. Reports have been prepared on these thermal conversion technologies: (a) direct combustion systems to produce power from wood, forest, and agricultural residues; (b) small-scale gasifier/engine systems up to 50 kW; (c) large-scale biomass gasification systems; (d) the pyrolysis of wood and other biomass; and (e) retrofitting combustion systems to burn solid, liquid, and gas fuels derived from biomass. Copies of these reports may be obtained by special request through a USAID mission.