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Bioenergy Systems Report

DECEMBER 1982: (1) GROWING TREES FOR FUEL; (2) WOOD FUELS FOR INDUSTRY

Introduction

This Report, the fourth in this series to be published in 1982, covers two major aspects of the use of wood for energy. Part One reports on the production of fuelwood in village woodlots, fuelwood plantations, and individual farms in developing countries. Part Two provides a broad survey of the growing use of wood fuels in industry.

Two other aspects of the use of wood for energy were covered in a Bioenergy Systems Report on "The Thermochemical Conversion of Biomass for Energy" published in June 1982. That Report reviewed the production of charcoal and the production and use of a low-Btu fuel gas through the thermal gasification of wood.

These Reports are sponsored by the Bioenergy Systems and Technology (BST) Project of the U. S. Agency for International Development. Dr. Paul Weatherly is the manager of the Project in the AID Office of Energy.

The BST Project includes several types of activities designed to assist USAID missions and governments of developing countries with the identification and development of bioenergy projects. BST staff and contractors have made field reconnissance and pre-feasibility studies on potential bioenergy projects, prepared several publications on bioenergy systems and technologies, and conducted educational workshops and study tours.

From 1980 to 1982 BST activities were coordinated and administered by a team provided by the U. S. Department of Agriculture/Forest Service under an interagency agreement with the Agency for International Development. Beginning in fiscal 1983 staff support for the AID Bioenergy Systems and Technology Project is being provided by a team from the Tennessee Valley Authority. The TVA team is based in Rosslyn, Virginia, in the AID Office of Energy.

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Bioenergy Workshop

The Bioenergy Systems and Technology Project, jointly with USAID Manila and the Government of the Philippines, is sponsoring an international workshop which will focus on the planning of bioenergy systems. The workshop will be held in the Philippines from March 13 through 22, 1983. It will emphasize the experience which is being gained from two large-scale bioenergy programs in the Philippines. One is the "dendrothermal" power program to produce electricity from wood-fired generating plants. The other is a program to produce charcoal from fast-growing trees, convert it to fuel gas in thermal gasifiers, and use the gas in internal combustion engines for irrigation pumping and other purposes. Persons in developing countries who are interested in additional information on the workshop should contact USAID missions in their countries.

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PART ONE:
GROWING TREES FOR FUEL

1. Introduction

Most of the fuel used for cooking and other domestic purposes in developing countries is wood or other biomass. Even in countries with major forested areas, a relatively small percentage of the people are able to obtain fuelwood directly from the forests. Indonesia has half the tropical forest in Asia, but there is a fuelwood shortage in several dry but heavily populated islands. In many countries the largest rural populations, as well as most urban populations, live a considerable distance from the forests. Most of the fuelwood used by these rural and urban people comes from vegetation growing in non-forest areas.

In rural areas in many countries members of each family, usually women and children, must walk long distances to gather fuel, returning with heavy loads. In some parts of Tanzania a family member must spend 20 to 25 days a month in fuel collection. The United Nations Food and Agriculture Organization (FAO) estimates that 100 million people are unable to obtain sufficient fuelwood to meet minimum energy needs.

Many rural families must burn dried dung, crop residues, or other low-quality biomass fuels. In some cases the burning of this biomass deprives the farmer of needed fertilizer or livestock feed. Urban families must pay higher prices for wood or charcoal brought to the city from distant forests; a USAID study indicated that the average urban family in Upper Volta spends 20 to 30% of its income on firewood.

In most developing countries demand for fuel has grown due to population increases; however, the supply of high-quality biomass fuels has decreased, primarily due to the clearing of land for agricultural use. Some of the land is cleared pursuant to government agricultural development programs, but most cutting of trees is by small farmers practicing shifting agriculture; they clear new land when the fertility of previous fields is exhausted.

Until recently, forestry problems in developing countries received relatively little attention. A U.S. Forest Service survey in 1980 of ongoing or proposed forest-related international aid projects indicated projects costing $524 million for industrial projects utilizing forest resources, but only $87 million for projects involving the planting of trees.

However, there has been a significant increase in the priority and funding for tree planting activities in the past several years. The U. S. Agency for International Development began a new forestry effort in 1979 and now has 96 ongoing and planned forestry-related projects in 37 countries. About one-fourth of the $215 million which has been budgeted by AID for these projects is being used for direct tree-planting activities. The total "life of projects" cost of these AID-supported projects has been estimated at $771 million. The U. S. Peace Corps has about 225 volunteers working on forestry-related projects in developing countries. Tree planting projects are also being supported by the World Bank, the United Nations Development Program, the Food and Agriculture Organization, and development assistance agencies in Germany, France, Switzerland, Sweden, Norway, Canada, and the United Kingdom.

Not all of these are energy projects. Many trees are planted to reduce erosion, flooding, or desertification. Other trees are planted to increase the supply of poles, lumber, or pulpwood and to produce income for villagers or individual farmers. However, many of these tree-planting projects have been designed to produce fuelwood. These have included projects to produce wood for local use, for sale as firewood in urban areas, for charcoal production, and for

industrial projects including electric power generation. In some cases the ultimate use or uses of the wood will depend on the greatest value of the wood at the time it is harvested.

These fuelwood projects have varied widely as regards size, sponsorship, financing, type of local organization, tree species, and techniques for planting, maintaining, and protecting the trees. Some of the most important characteristics of these projects will be examined in subsequent sections of this Report.

2. Organizing Village Fuelwood Projects

In some of the early firewood projects donor agencies gave priority to strengthening forestry agencies and infrastructure; woodlots and plantations were planted by personnel of forest departments, but there was not adequate provision for the subsequent care and protection of the planted area. Project planners soon realized that, although they could hire men to plant seeds or seedlings, the plants would not survive without a substantial commitment by members of the adjacent rural community.

Several of the early woodlots were destroyed because of lack of understanding of the project on the part of the villagers. A woodlot financed by the World Bank in Niger, which had been planted in a traditional communal grazing ground, was destroyed when the villagers continued to allow their livestock to graze through the area. In Senegal villagers refused to help fight a fire in a woodlot which they thought belonged to the foresters and was thus not their responsibility. In some villages the need for maintenance and protection of the plantings was explained to the men but not to the women, who traditionally did such work in the village.

Lack of advanced consultation with villagers was recognized as one of the reasons for limited success during the first year of a USAID-funded woodlot program in Senegal; extensive efforts were made to involve the villagers in decisions on planting and maintenance activities during the project's second year.

In most rural areas there had been no established tradition of cooperation between foresters and members of the rural community. Forest rangers and guards were generally uniformed and frequently armed and were regarded by villagers as policemen or revenue collectors. Forestry personnel usually had no training or experience in extension work and typically felt more comfortable in their traditional role as enforcers of the forest protection laws. However, successful woodlot or plantation projects have required the development of projects have required the development of effective cooperative relationships between foresters and villagers.

In addition, effective projects require substantial inputs from national governments and/or other outside supporting agencies. In Colombia's community forestry program the government's natural resources agency provides nurseries, seedlings, technical assistance, incentive payments, and work supervision; the local community provides labor, tools, and land.

The most effective projects have involved the utilization of an existing community organization or the creation of a permanent organization to organize the planting of trees and the maintenance and protection of planted areas. In Korea more than 643,000 hectares of village woodlots have been planted, tended, and harvested by government-mandated Village Forestry Associations consisting of a representative of each village family. Under a government program in Nepal the village council or Panchayat is assigned responsibility for the reforestation of a 124-hectare area of government-owned land. Two types of associations of farmers are planting fast-growing Leucaena trees in upland

areas in the Philippines; Integrated Service Associations will produce and sell charcoal, while other farmers associations will sell wood to rural electric cooperatives for use in wood-fired electric generating plants.

Non-profit voluntary organizations manage several USAID-supported projects. A major reforestation program in Haiti is conducted by three American voluntary organizations - CARE, Pan American Development Foundation, and Operation Double Harvest. These organizations have developed reforestation projects in cooperation with private voluntary organizations in Haiti including church mission organizations, relief agencies, and agricultural cooperatives. Catholic Relief Services and Africare manage tree planting projects in several African countries.

A number of techniques have been used to motivate or compensate those who plant and tend these fuelwood projects. Some of the clearing and planting is carried out by salaried forestry personnel, by other government employees, or by workers hired by contractors. In some countries villagers engaged in tree planting projects are compensated with food commodities under AID's "Food for Work" program. However, most of the village woodlots have been planted and maintained by villagers working as volunteers to provide a future source of firewood for use in the village.

Such community self-help projects are most successful when there is effective local leadership, a strong tradition of cooperation within the community, a clear understanding of the methods to be used and the objectives to be achieved, good cooperation between the community and forestry agencies, and effective technical and material support from government or donor agencies.

Since most of the woodlot projects are relatively new, only a few countries have much actual experience with the harvesting and use of fuelwood produced by the woodlots. In Korea, Village Forestry Associations distribute firewood among the village households; money from the sale of any surplus wood is used primarily for community development projects, although there are also small payments to the owners of land used for woodlots.

In some cases there has not been a clear consensus on the ultimate use of the wood. In a small woodlot project in Senegal which had been designed to produce fuelwood for village use, an evaluation revealed that most local leaders and farmers assumed that the wood would be sold outside the village to generate income for village development projects.

Some projects and programs have in fact been designed to produce income for the members of the rural community through the sale of wood or charcoal. Farmers associations engaged in tree planting in the Philippines will produce and sell charcoal or sell wood for use in wood-fired electric power plants; income from the sale of wood or charcoal will be distributed among association members in proportion to their participation in the group's energy activities.

3. Establishing Woodlots & Plantations

There are a number of essential requirements for the establishment and maintenance of a successful village woodlot or fuelwood plantation:

Land

Ideally, a woodlot or plantation area should be relatively fertile, well-watered, level, moderately accessible, and rather easy to clear for planting. However, in many regions such land is in great demand for food production, and tree plantations can be planted only on considerably less desirable land. In the Philippines *Leucaena* plantations to support the government's charcoal and "dendro-thermal" electric power programs are being planted on steep, deforested mountain slopes. Rainfall, drainage,

temperature, and soil characteristics at the proposed site must match the requirements of the species to be planted. A reasonable degree of accessibility is essential if villagers are to provide the necessary maintenance and protective services; poor maintenance at a USAID-supported woodlot in The Gambia was attributed in part to the excessive distance between the village and the woodlot.

Most woodlots and plantations have been planted on land owned by the government or on communal village land. In some countries land ownership patterns have limited reforestation projects. In Korea the owners of land designated for reforestation by the Village Forestry Association must replant their own land or turn it over to the FVA for replanting in return for small future payments.

Site Preparation

Techniques for preparing the site and the costs of site preparation vary widely from project to project. Spot preparation of the immediate planting area for each seedling may be satisfactory for some species which are tolerant of competition from grass; but complete site preparation which removes all grass is necessary for Eucalyptus and some other species. The Florestal Acesita charcoal plantations in Brazil and some plantations in Africa are cleared by a chain pulled by two tractors or bulldozers; other equipment may be used to fell a few large trees. Bulldozers and tractors are used for site preparation in a large-scale fuelwood plantation supported by AID in Senegal, but most of the village woodlots have been cleared by hand.

After trees are cut by U. S. paper companies, logging residues are bulldozed into rows and burned before new trees are planted. The controlled burning limits competition from weeds and grass for the nutrients, moisture, and sunlight needed by the new seedlings; it also reduces the danger that the new trees will be destroyed by uncontrolled fire burning through the site. Controlled burning was used in Zambia to destory weed seeds and surface termites at a plantation site; seeds or plants were planted in the ash patches, and the ashes fertilized the new trees. However, controlling the fires proved difficult and the ash often washed away in the rain. In Brazil, Florestal Acesita found that burning cleared vegetation created an imbalance in the top layer of the soil and the firm has abandoned burning.

Seed

Successful tree planting requires an adequate supply of high quality seed. U. S. companies with extensive tree plantations maintain large seed orchards. The production of high quality seed is accelerated by grafting sprigs from superior mature trees on established root stocks. Specialized equipment has been developed to extract, dry, sort, and test the seed. Establishing plantations of exotic (non-native) species in developing countries often requires importing the seed from another country. Brazil imports about 80% of the seed for its large Eucalyptus plantations. The seed should come from trees grown in areas with temperatures and e rainfall patterns similar to those in the areas to be planted. FAO in Rome publishes a directory listing seeds by species which can be obtained from seed banks in a number of countries.

The seed of some species requires pre-treatment before sowing to insure adequate germination. In Africa the very hard Acacia seeds are usually immersed in concentrated sulphuric acid for from 20 to 80 minutes, depending on the Acacia species. In the Philippines Leucaena seeds are usually soaked for several minutes in hot water and for an hour in cold water, before planting.

Nurseries

Direct seeding is feasible only in situations in which seed is plentiful and cheap, germination rates are high,

and the seedlings grow fast enough to avoid a prolonged period of weeding and tending. Leucaena plantations are established by direct seedling on steep mountain slopes in the Philippines. However, most woodlots and fuelwood plantations have been established with seedlings grown in nurseries. USAID-supported fuelwood projects a dozen African countries include the operation of nurseries.

In Haiti Operation Double Harvest provides a central nursery with a capacity of three million seedlings per year. The large-scale fuelwood plantation project in Senegal includes a nursery producing one million seedlings annually. However, there are some disadvantages to centralized nurseries arising from the need to transport the seedlings for considerable distances from the nursery to the planting site: these include high transportation costs and rather high seedlings mortality rates. Most of the USAID-supported fuelwood projects use medium- or smaller-scale nurseries. A village woodlot project in Senegal conducted by Africare Inc. used seedlings produced by 20 village nurseries. Several small 1,000-seedling nurseries, managed by village women, have been set up in Upper Volta.

In tree nurseries in the U. S. seeds are thickly planted in sandy soil which is shaken from the roots at transplanting time; the bare-root seedlings are transported to the planting sites in packing materials designed to prevent root drying. However, in most nurseries in developing countries the seedlings are planted and transported in individual pots or other containers. Thin plastic pots have been widely used in nurseries in Africa. Florestal Acesita in Brazil plants Eucalyptus seeds in polyethylene bags (11 cm diameter, 15 cm tall).

Nurseries need a good water supply. Water with high percentages of salt, lime, or other dissolved solids is unsuitable for use in nurseries. Most large tree nurseries in the U. S. use overhead spray irrigation. Smaller nurseries can be watered by hand with buckets, hoses, or pressure sprayers or by trench irrigation.

Spacing of Plantings

In woodlots and fuelwood plantations trees can be planted closer together than in plantations producing timber or pulpwood. In Brazil Florestal Acesita is increasing the number of Eucalyptus trees per hectare in its charcoal plantations and reducing the "rotation age" (the age at which the trees are cut) from seven years to three or five years. Research is under way to determine the optimum rotation age. Spacing tests in Brazil have indicated that the optimum area per tree for E. grandis is about two square meters. The agency responsible for the Philippine charcoal program, the Farm Systems Development Corporation, recommends Leucaena spacing of 2m x 2m if the trees are to be used for both fuel and poles; if the plantation is to raise both fuel and forage, the recommended spacing is 1m x 1m.

Some plantations are initially planted at very high densities but the trees are thinned as they grow larger. In China's Leichow Peninsula, Eucalyptus seedings are planted at a density of 4500 plants/ha and are successively thinnned to 3,000 trees/ha at year five, to 1,500 trees/ha at year seven, and to 900 trees/ha at year 10 or 12.

Fertilization

Maintaining soil fertility is extremely important in short-rotation plantations. Some fast-growing species are nitrogen-fixing legumes, but other elements may be needed. Fertilization after the first weeding is recommended in the Philippine Leucaena plantations. Experiments in Brazil have indicated that Eucalyptus which have been fertilized are 50 to 70% more productive than non-fertilized trees; the commonly used NPK formula is 10-28-6 plus added

boron, zinc, and copper. Many eucalypts need more boron than is usually available in savannah soils. Florida researchers noted dramatic increases in the growth of Eucalyptus grandis when phosphorous was added to the phosphorous-poor Florida soils.

Water

In developing countries seeds or seedlings are usually planted just bee fore the beginning of the rainy season; the timing of the transplanting of seedlings is crucial. Some of the village woodlots in the Sahelian countries of Africa have suffered greatly due to inadequate rain after transplanting. Rainfall patterns and the moisture requirements of the particular species must be carefully considered in advance of planting to determine whether acceptable survival and growth rates can be expected. These rates can be predicted with greater confidence if an indigenous species is to be planted in an area which is part of its natural habitat.

Soil moisture and fertilization are interrelated. If newly planted trees are fertilized during a dry season, there may not be enough soil moisture to dilute the fertilizer salts and avoid root damage.

Fencing

In most areas a physical barrier is necessary to keep out animals, including both domestic animals and wildlife. In the Gambia, the Forestry Department provided fence posts, barbed wire, and staples for fencing village woodlot projects. While most foresters have thought that wire fencing was essential, funding or materials were frequently not available. In several countries locally available materials including thorn bushes, mats, and stalks have been used effectively. A village reforestation project in Mali found that a trench around a nursery, deepened by piling the soil in front of the trench, formed an effective barrier against cattle.

Weeding

Seedlings of fast-growing tree species must compete for sun and moisture with even faster-growing weeds. Research in Tanzania indicated that 80 to 90% of the early tree mortality was due to weed competition. Some species including the eucalypts are very sensitive to competition; weeding around the trees is necessary until they are large enough to "close canopy" and shade out the weeds.

Many of the tree plantations in the U. S. are spaced to permit mechanical weeding; however, the close spacing used in fuelwood and charcoal plantations in developing countries usually precludes the use of machinery for weeding. In the Philippines members of tree cooperatives are advised to remove weeds from a one-meter radius around the Leucaena saplings each month during the first four months after planting. In the Sudan Acacia senegal is weeded twice a year in both the first and second years.

Other Maintenance

If seedlings mortality is high, the dead plants should be replaced as soon as possible within the same season. Pruning may be necessary, to remove sprouts that are poorly formed to make more space for healthy growth. Protection of seedlings from destructive insects may be important, depending on the area and species. Several types of insecticides are used in Brazil to protect Eucalyptus seedlings from leaf-cutting ants. In some countries termites are a serious problem.

Fire Protection

Fire is a constant threat to woodlots and plantations, especially in dry climates. A replanted woodlot in The Gambia, which had been destroyed by drought during the first year, was wiped out by fire during the second year. Some of the planted areas have been surrounded by firebreaks, i.e., unplanted areas to prevent a nearby fire

from spreading into the plantation, but these are effective only if the grass can be kept out by periodic plowing.

Fire control is a major responsibility of the hired or volunteer guards provided for many village woodlot projects by local communities. However, the effectiveness of these guards may be limited by the lack of effective means of spreading the fire alarm and/or of fighting the fire.

4. Species for Fuelwood Production

A comprehensive survey of species suitable for use as firewood crops in various climatic zones in developing countries has been funded by the U.S. Agency for International Development and conducted by the Board on Science and Technology for Development of the National Academy of Sciences. This study resulted in the publication in 1980 of Firewood Crops: Shrub and Tree Species for Energy Production which contains detailed information on 60 recommended fuelwood species.

Much of the information in the following paragraphs is from this publication, which is available without charge to institutions in developing countries (see p. 12). Additional information is drawn from a not yet published compendium on firewood crops prepared for the Bioenergy Systems and Technology Project by Elbert L. Little, Jr., retired chief dendrologist of the U.S. Forest Service.

Characteristics of Fuelwood Species

Any species planted in a woodlot or fuelwood plantation should (a) be easy to establish and require minimum care and management, (b) grow rapidly, even on poor soil, (c) resist diseases and pests, (d) be able to survive droughts, and (e) produce wood with a high heating value. It is also highly desirable for the species to have the ability to coppice, i.e., to regenerate itself by producing new sprouts from the stump after the main tree is cut.

The environmental requirements of the species must match the conditions in the area to be planted. When planting some exotic (non-native) species, it is important to obtain seed from trees which are growing in climatic conditions similar to those in the area to be planted. Unless the contemplated species is native to the immediate area, the suitability of the species should be demonstrated through field trials before large-scale plantings are undertaken.

Other factors may influence the choice of species. Some trees may be chosen in part because they make good windbreaks, provide needed shade, or inhibit soil erosion and desertification. Others may be chosen because they are legumes which fix nitrogen in the soil and enhance soil fertility. Some species are valued as much for their contribution of forage, fruits, medicines, or building materials as for firewood.

Fuelwood Species for Humid Tropics

Acacia auriculiformis, a vigorous small Asian tree, has been planted on large-scale fuelwood plantations in Indonesia where it produces 17 to 20 m^3/ha with 10 to 12 year rotations.

Albizia falcataria, native to the tropical rain forest of Southeast Asia and the Pacific, is one of the fastest growing trees in the world; it has grown as much as 7m in height in little more than a year and up to 30m in 10 years.

Calliandra calothyrsus, a small fast-growing bush with excellent coppicing ability, has been planted on 30,000 ha of plantations and individual farms in Indonesia; large plantations in India produce excellent firewood and tough poles.

Casuarina equisetifolia, a tall tree resembling pines, grows in South and East Asia and has been introduced in Africa and the Caribbean. It tolerates salt, grows well in sand, and has been

planted to control erosion along coasts in China and elsewhere. C. glauca, a medium-sized evergreen tree, is widely planted in Hawaii; because of its root-suckering habit, it is an excellent species for erosion control but can become a nuisance.

Derris indica, a fast-growing coppicing tree, grows in lowland areas of tropical America which have more than 1,500 mm of annual rainfall. It is widely used for living fences and fence posts.

Gmelina arborea, a fast-growing deciduous tree, has been planted for timber and pulpwood in plantations in Brazil, the Philippines, Malaysia, and several African countries. This coppicing species is very promising as a fuelwood crop; production of up to 35 m^3/ha/year may be feasible with five-year coppice rotations.

Eucalyptus robusta grows naturally in swamps and on saltwater estuaries. It is the most common eucalypt in plantations in Hawaii; the trees reached 27 m heigth and 40 cm diameter in 15 years in Puerto Rico.

Leucaena leucocephala, a tall tree or low shrub depending on the variety, grows in lowland areas in the tropics and subtropics where annual rainfall is between 600 and 1,700 mm. The species thrives on steep slopes, in marginal soils, and in areas with long dry season. It is a legume which adds nitrogen to the soil; its nitrogen-rich leaves are an excellent feed for cattle, buffalo, and goats but can be toxic to other livestock. In the Philippines, where it is known as ipil-ipil, dense plantations have been planted to provide wood for the government's charcoal and "dendrothermal" electric power generation programs. Cutting of the trees begins during the fourth year, when they are 6 to 7 m tall and 20 cm in diameter. Annual increments of from 30 to 40 m^3/ha are expected.

Mangroves cover some 45 million ha of shallow water and tidal flats in the tropics and subtropics. These "forests of the sea" consist of tree species belonging to many genera; the most widely distributed are Rhizophora, Avicennia, and Bruguiera. The wood is usually collected in boats. There have been few attempts to establish mangrove plantations, but mangrove swamps have been managed for fuelwood in Malaysia since 1900. The Indonesian government is now considering expanded use of mangrove wood for charcoal production.

Other species listed by the National Academy of Sciences for fuelwood production in the humid tropics include: (a) Guazuma ulmifloia, widely used as a street and shade tree and for fuel in tropical America; (b) Mimosa scabrella, which once produced fuel for railroads in Brazil but is virtually unknown elsewhere; (c) Muntingia calubura, a shade and fruit tree which is also used for firewood in tropical America; (d) Sesbania bispinosa, a quick-growing shrub which produces firewood in six months in Pakistan and Vietnam; (e) Sesbania grandiflora, a traditional firewood species in Southeast Asia; (f) Syzygium cumini, a widely distributed Asian shade and fruit tree; (g) Terminalia catappa, a very quick-growing and easily propagated Asian tree which thrives in sand dunes and other problem sites; and (h) various Trema species which are well distributed in the Asian tropics.

Fuelwood Species for Tropical Highlands

Acacia mearnsii is a large tree which yields excellent firewood and is a very good species for village woodlots and small farms. It is grown on 7 to 10 year rotations in individual farms in the highlands of central Java as well as in cooler areas in southern and eastern Africa, South Asia, and Central America. The tree is the world's main source of tanbark.

Alnus (alder) species are well distributed between 1,200 and 3,200 m elevations in tropical mountains in Asia and the Western Hemisphere. A. rubra, one of the most productive trees in North America, prospers in a wide variety of environments and has produced 17 to 21 m^3/ha/year in short coppice rotations. A. acuminata is cultivated extensively in plantations from Costa Rica to Peru. A. nepalensis grows quickly to heigths of up to 33 m in the hills of northern India.

Casuarina cunninghamiana, a frost hardy species, grows on Mexican plateaus and the northern Andes; it is widely grown for shelterbelts and windbreaks.

Eucalyptus globulus, a large evergreen tree 40 to 55 m tall with a massive trunk, is growing in plantations totalling more than 800,000 ha in dozens of countries. The species grows best in mild temperate climates and cool tropical highlands. It is the principal fuelwood species for the peoples of the Andes highlands from Colombia to Peru. It is planted at elevations between 2,000 and 3,000 m in East Africa. In India, where it is extensively cultivated for fuelwood and charcoal, some trees grew to 16 m in three years. Wood production has ranged from 10 to 30 m^3/ha/year in various countries.

Eucalyptus grandis is extensively grown in South America, the East African highlands, and South Africa. Huge plantations have been established in Brazil, where up to 100,000 hectares are planted annually. Five year old trees grown by Florestal Acesita in Brazil for charcoal production were about 16 m high and 13 cm in diameter; total wood production during the five years was 173 m^3/ha. Annual production of 35 to 45 m^3/ha has been recorded in Africa. The species grows best in moist, well-drained soils in areas with between 1,000 and 1,800 mm of annual rainfall; it has been grown near the equator at altitudes between 2,000 and 2,700 m. E. grandis is sometimes confused with a closely related species, E. saligna (with which it will hybridize) which grows naturally on cool mountain slopes.

Gleditsia triacanthos, a hardy temperate zone tree, produces good firewood and fenceposts in the Eastern U.S. and has been introduced in tropical highlands and semiarid regions.

Grevillea robusta has been cultivated in areas with from 400 to 2,500 mm of rainfall and from sea level to above 2,300 m. Timber yield in 14 years in Tanzania was 217 m^3/ha.

Robinia pseudoacacia, which is native to the Appalachian and Ozark mountains in the U.S., can grow in moist or humid temperate areas with hot summers and cold winters.

Fuelwood Species for Arid and Semiarid Regions

Eight species of Acacia are recommended by the National Academy of Sciences for fuelwood production in arid and semiarid regions. Most of these are small trees from 12 to 15 meters tall. They have deep roots; some species can survive in climates with less that 200 mm of annual rainfall and a long dry season. Most Acacia species produce excellent firewood; the seed pods of some species make a high quality livestock feed.

A. senegal is the source of gum arabic; gum worth $15 to $20 million is exported from Sudan each year. This very drought-resistant species grows throughtout the Sahelian zone of Africa from Senegal to Somalia. It is a nitrogen-fixing legume which is often intercropped with watermelon, millets, forage grasses, and other crops. A. seyal is also native to the Sahel and other arid parts of Africa; natural growth of this species yielded 12 to 17 m^3/ha in Sudan. Along with A. tortilis, it provides fodder for sheep and goats in much of Africa. A. nilotica is a very popular fuel in India and Pakistan; the wood is used as a boiler fuel in

Sudan. The leaves and pods are the main diet of goats and sheep in India. Other Acacia species recommended for fuelwood production in arid areas are A. brachystachya, A. cambagei, and A. cyclops.

Adhatoda vasica (or A. zeylanica), a thicket-forming shrub in India and Southeast Asia, makes excellent cooking fires.

Albizia lebbek, a medium to large deciduous tree common in India and other tropical and subtropical areas, is also suitable for areas with up to 2,000 mm of rainfall.

Anogeissus lattifolia, which grows naturally in the dry forests of India, makes fine firewood and excellent charcoal.

Azadirachta indica (neem), native to the dry forest of South and Southeast Asia, has grown well in plantations in the Sahel and other African areas, especially Nigeria. First rotation fuelwood yields were from 108 to 137 m^3/ha in Ghana. Neem grows well when intercropped with nitrogen-fixing legumes.

Byrosonima crassifolia (nance) is often planted in tropical America for its fruit but could be planted for fuel as well.

Cajanus cajan, a food crop known as pigeon pea, is widely grown in India; the tall woody stalks are used as cooking fuel.

Cassia siamea, a medium-sized evergreen, was the most widely planted species in plantations in Africa early in this century; the high-calorie wood was once used for locomotives.

Colophospermum mopane, a medium-sized tree of lowland areas in central and southern Africa, produces an excellent firewood on land with poor soil and bad drainage which will not grow much else. The extremely hard wood is very difficult to cut.

Dalbergia sissoo is widely planted in arid and semiarid regions for wood and shade; the wood is valuable for furniture.

Emblica officinalis, a deciduous tree, is prized in tropical Asia for its thrist-quenching fruit. Livestock relish its foliage.

Eucalyptus camaldulensis is the most widely distributed eucalypt in arid and semiarid regions. It is the dominant eucalypt around the Mediterranean. Plantations have been established in several South American, African, and Asian countries. It usually needs about 400 mm of rainfall but may thrive in areas with less rain but seasonal flooding or a high water table. Seed must be selected from areas with similar climate and soils. With well-chosen seed and a good site, annual production may reach 20 to 30 m^3/ha with 7 to 10 year coppice rotations. However, much lower yields and longer rotations have been reported when the trees were planted on poor sites. The species has been planted in recent years in several Sahelian countries including Upper Volta, Niger, and Senegal; however, initial production data indicated that the production of these plantations will be considerably lower than was orginally anticipated.

Eucalyptus citriodora is a major source of firewood in Australia and of charcoal for steel production in Brazil. It needs 600 to 800 mm of annual rainfall but tolerates a long dry season. Production from an 8-year coppice in Tanzania was 15 m^3/ha/year.

Eucalyptus gomphocephala grows well in areas with 350 to 1,000 mm of rainfall. Over 66,000 ha of plantations have been established in Morocco; others have been planted in Tunisia and Libya. From 21 to 44 m^3/ha/year has been produced on irrigated fertile soils in Morocco, but about 7 m^3/ha/year is typical on less fertile sites. The species is widely used to stabilize sand dunes and for windbreaks.

Eucalyptus microtheca tolerates high temperature and rainfall as low as 200 mm or as high as 1,000 mm. It grows well in wet, heavy soils. The species is planted in many woodlots in the Gezira area of Sudan and several other African and Near Eastern countries.

Eucalyptus occidentalis grows in difficult sites with very saline or alkaline conditions. It is very drought-tolerant species which grows naturally in an Australian area with 300 to 750 mm of rainfall, but it also grows on alluvial flats subject to seasonal flooding and near salt lakes. Good results have been reported from planting in dry desert areas of Israel. Its growth rate is slower than the other eucalypts described above.

Haloxylon aphyllum, a salt-tolerant tree, is planted to stabilize deserts and combat wind erosion. It was formerly used for charcoal, locomotive fuel, and domestic firewood in Soviet Central Asia. H. persicum is the principal source of fuelwood in desert areas of Central Asia.

Parkinsonia aculeata, a small spiny tree in arid and seimiarid regions of tropical and subtropical America, regenerates vigorously after drastic pruning.

P. halepensis, a hardy and drought-resistant species, is the dominant pine in the Mediterranean region.

Several Prosopis species have been recommended for fuelwood plantations in arid and semiarid regions. Most of these species are round-crowned trees from 5 to 15 m high which grown in areas with very high temperatures and very low rainfall. Some of these species, generally known as mesquite, grow naturally on 72 million acres of arid land in the western U.S. Studies on the use of mesquite as fuelwood at the University of California at Riverside and the Texas A & I University at Kingsville indicated that P. chilensis is the most drought-resistant and consistently high yielder of the numerous Prosopis species tested.

P. chilensis is native to parts of Chile, Argentina, and Peru. It is used as a fodder tree in India at altitudes from 340 to 1,230 m and has been introduced in arid areas of the Near East and North Africa. The Peruvian Forest Service used Prosopis successfully to turn 1,000 ha of shifting sand dunes into an oasis producing 6 to 7 tons/ha of high protein cattle feed (in the form of edible seed pods) as well as firewood. The most successful species used in a village woodlot project in Senegal was P. juliflora. A study of the energy potential from native brushland in Niger for USAID recommended that P. africana be planted in a brushland experiment along with other native species. P. tamarugo has transformed large deserts in northern Chile to open forests supporting sheep and goats. P. cineraria is widely grown by farmers in South Asia because it adds fertility to the soil around the trees and produces the best fodder available in some areas. Other Prosopis species which have been recommended for fuelwood are P. alba, P. pallida, and P. farcta.

Information Sources

Three publications of the Board on Science and Technology for International Development, National Academy of Sciences, 2101 Constitution Avenue NW, Washington, D.C. USA 20481 are available without charge to institutions in developing countries: (a) Firewood Crops: Shrub And Tree Species or Energy Production, 1980; (b) Tropical Legumes: Resources For The Future, 1979; and (c) Leucaena: Promising Forage And Tree Crop, 1977.

Information on tree planting practices and plantation management is provided by several publications of the Food and Agriculture Organization of the United Nations (FAO) in Rome. These include (a) Tree Planting Practices In African Savannas, 1974, and (b) Forestry For Local Community Development, 1978.

PART TWO:
WOOD FUELS FOR INDUSTRY

1. Introduction

Although water power played an important role, the Industrial Revolution of the 19th century was powered primarily with steam engines. Early in that century these engines - in railroad locomotives, steamboats, and industrial plants - were fueled with wood. Later in the century coal gradually replaced wood as the most important fuel for industry.

In the twentieth century most of the mechanical power used in the transportation and industrial sectors has been provided by internal combustion engines fueled with gasoline or diesel oil or by electric motors. While many industries have continued to need steam for space heating and/or industrial process heat, it has been produced primarily in boilers burning fuel oil or natural gas.

However, the rapid increases in the prices of fuel oil and natural gas during the past decade, coupled with concern about the continued availability of these fuels, have led many industries in the U.S. and other countries to consider alternative energy sources. An impressive number of industrial plants and public institutions in the U.S. are now using woody biomass as a boiler fuel or for process heat.

Wood has always been widely used as a fuel in small-scale industries in developing countries including the baking of bread, the drying and processing of agricultural products, and the manufacture of bricks, tile, pottery, and metal products. In some developing countries these industries have accounted for 15% or more of the total consumption of wood. Rubber processing used 300,000 m^3 of fuelwood in Thailand in 1970. About 1.1 million m^3 of fuelwood was used for tobacco curing in Tanzania in the same year; about one hectare of savanna woodland was needed to cure each hectare of tobacco. Brick-making consumes large quantities of wood in some countries; one kiln in Niger uses about 2,000 kg of wood daily.

In some developing countries these industrial uses of wood have accelerated deforestation and intensified the shortage of fuelwood. Other countries have an adequate supply of wood and/or the capacity to produce more fuelwood in plantations of fast-growing trees; in such countries expanded use of wood fuels in industry may be an important means of reducing expensive imports of fuel oil.

Forest products industries have utilized wood residues for fuel for many years. Combustion systems using wood residues to produce steam and/or industrial process heat are widely used in lumber mills, paper mills, furniture plants, and other woodworking industries. In 1978 researchers at Dartmouth College compiled a list of 150 companies using wood-fired boilers in five states in the New England region of the U.S.; all but a few of these are companies which process forest products and are mainly burning wood residues produced in their own operations. Technical information on the use of wood residues as fuels is widely available within the forest products industry, notably through the publications of the Forest Products Research Society (see p. 24). Therefore, this Report will focus primarily on the use of wood fuels in other industrial sectors and in public institutions.

Most of the wood energy systems in use in the U.S. today are heating systems. In addition to the rapid growth in the use of wood heating stoves in homes in the past few years, many industries and public institutions are turning to wood to reduce heating costs. Some of these wood heating systems merely heat air or water, but most of the larger systems produce steam in wood-fired boilers. In addition, quite a few industrial plants have installed new systems or retrofitted older systems

to produce steam with wood fuels for industrial process heat.

Due to high labor costs, industrial wood energy systems in the U.S. have been designed to minimize the use of labor and maximize the use of automatic equipment. These automatic systems require the use of wood fuel which has been chipped, hogged, or pulverized. Equipment for the storage, preparation, and handling of the fuel represents a very high percentage of the rather high capital costs of these systems.

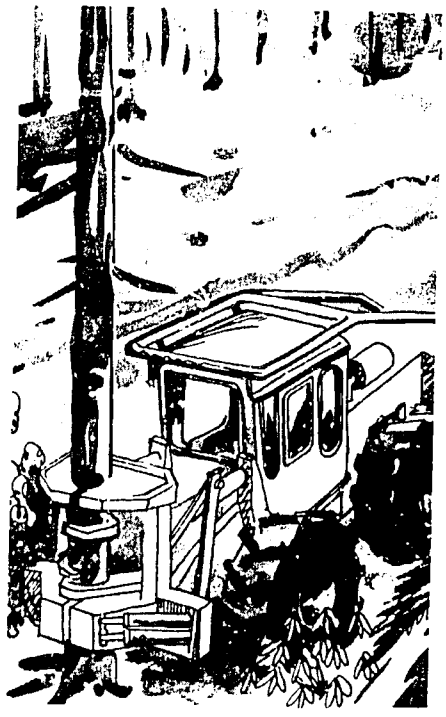
A study of the direct combustion of biomass by the Nor'West Pacific Corporation in Seattle has suggested that in developing countries the capital costs of larger-scale wood energy systems could be reduced by using manual labor for most aspects of the harvesting and preparation of the fuel. However, there is not yet very much actual experience in developing countries with the use of wood fuels in larger-scale industries other than the lumber and wood products industries. Therefore, this Report will focus primarily on wood energy systems in industries and institutions in the United States.

Examples of various types of equipment and sub-systems will be drawn primarily from the following facilities in the U.S.: (1) a retrofit system which permits the use of chipped wood residues as fuel in one of the boilers at the plant providing heat for the Vermont state capitol and other state buildings at Montpelier, Vermont; (2) a two-boiler system using wood chips to produce 20 MW of electric power at the Burlington Electric plant in Burlington, Vermont; (3) a system using wood residues for space heating and lumber drying at the True Temper Company's woodworking plant at Wallingford, Vermont; (4) a system which uses dry residues from furniture production and purchased slabwood and wood chips to heat buildings and dry lumber at the Hale Companys plant at East Arlington, Vermont; (5) a system using wood chips to produce process steam at the Integrated Products carpet yarn plant in Aragon, Georgia; (6) a system using wood wastes as well as peanut hulls and pecan shells to produce process steam at the Gold Kist soybean oil extraction plant at Valdosta, Georgia; (7) a two-boiler system producing process steam from wood residues at the Russell Corporation's large textile plant at Alexander City, Alabama; (8) another large two-boiler system at the Jack Daniels liquor distillery in Lynchburg, Tennessee; (9) a heating system burning whole tree chips at the Dorothea Dix Hospital in Raleigh, North Carolina; and (10) a system burning sawdust to heat brick-drying kilns at the Cherokee Brick plant in Moncure, North Carolina.

2. Fuel Preparation and Handling

Industrial wood energy systems vary widely as regards the type of fuel used and the kind of fuel preparation and handling which is necessary. Many lumber mills and woodworking plants burn their own residues with a minimum of fuel handling steps other than size reduction. Some of the wood energy systems in non-forest industries buy wood residues from sawmills or woodworking plants which are too small to be able to utilize their residues. Huge piles of sawdust, accumulated over many years, are available at many sawmills. These mills and other woodworking plants produce various types of slab wood which can be hogged or chipped for use as fuel.

The preparation of the fuel may be carried out at the plant of origin or at the plant where it will be burned. The Vermont Capitol heating system burns sawmill residues which have been converted into chips at the mill before delivery to the heating plant; the True Temper company supplements its own residues with slab wood purchased from a sawmill. A number of the newer wood energy systems are designed to use green chips produced by chipping whole trees in the forest.



Harvesting Trees for Industrial Fuel

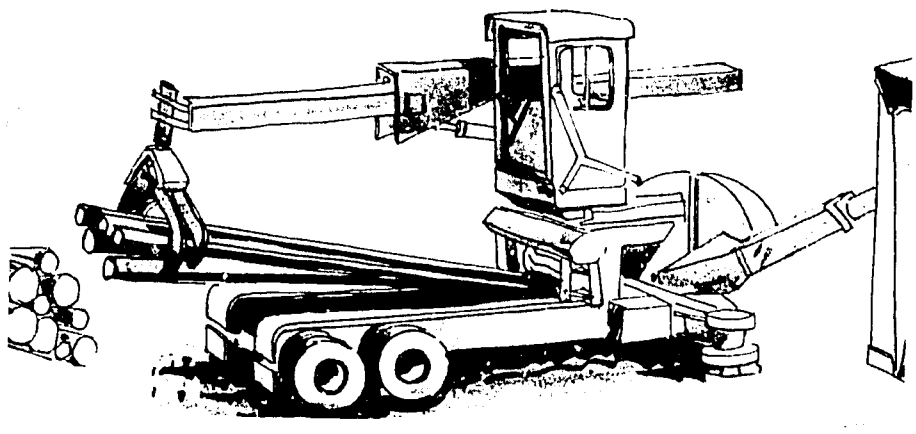
In recent decades the harvesting of trees for the lumber and paper industries has been revolutionized by the development of several types of mobile units. A powerful "feller-buncher", shown above, grasps the tree and shears it at ground level. Several small diameter trees can be held in the unit's accumulator and then stacked together. Limbs are usually removed by men with chain saws. A "grapple-skidder" with a hydraulic rearend grapple tows the logs to the loading or chipping area.

In some operations the logs are loaded onto trucks by a "knuckleboom loader" with a grapple on a two-part boom. In a chipping operation the logs are brought to a whole-tree chipper, shown below; the machine's own grapple feeds the logs to rollers and knives which quickly converts them to 1/2" to 1" (1.3 to 2.5 cm) chips. The chips are blown into waiting trucks or trailers.

These heavy machines were developed for the lumber and paper industry prior to the increased interest in wood fuels after the rapid increases in oil prices in the mid-1970's. Since equipment to convert whole trees to chips was already available, a number of companies have developed systems and equipment for the use of whole tree chips as fuel for industrial boilers.

Several factors may tend to limit the use of these machines in developing countries. Such mechanical harvesting equipment involves rather high initial capital costs and substantial fuel and maintenance costs. Although feller-bunchers can harvest small diameter trees, their suitability for harvesting densely-planted fuelwood plantations has not yet been fully established. The machines cannot operate on very steep slopes or in swampy areas.

Although experimental equipment for the harvesting of brush and small diameter trees has been developed in Finland, Sweden, Canada, and the U.S., very little equipment for this purpose



is commercially available. The U.S. Forest Service's experiment station in Pineville, Louisiana, and a private firm have been developing a mobile, tracked chipper equipped with a frontend bar to fell small trees. The Irish Peat Bureau tested a unit towed behind a tractor for the harvesting of short-rotation willow trees; the unit produces 6 to 10" (15 to 25 cm) billets.

Most of the woodlots and fuelwood plantations in developing countries are being or will be harvested by hand. Most of the eucalypts in the Florestal Acesita charcoal plantations in Brazil are cut with axes. The firm uses manual labor whenever feasible; using axes creates twice as many jobs as would be necessary if workers were equipped with chain saws. The use of hand tools to harvest short-rotation energy plantations is feasible due to the relatively small diameters of the trees in such plantations.

Such harvesting techniques usually produce stick wood; this type of wood fuel is generally used in charcoal production and in ovens, kilns, and dryers in small-scale industries in developing countries. Although stick wood is being widely used again in domestic heating stoves in the U.S. and other colder countries, there is very little experience anywhere in this era with the use of stick wood as a fuel for industrial boilers. Due to high labor costs, industrial wood energy systems in developed countries have used chipped or hogged fuels which can be handled and stoked by mechanical equipment. However, developing countries have an opportunity to recapture some of the earlier experience with wood-fired boilers and to design efficient systems using stick wood which is cut and stoked by manual labor.

Another option is to combine harvesting by hand and chipping by machines. A study of dry forest energy farming in the Dominican Republic by the Mitre Corporation assumed that the trees would be harvested by hand but chipped by chipping machines operating in the forest.

Fuel Storage

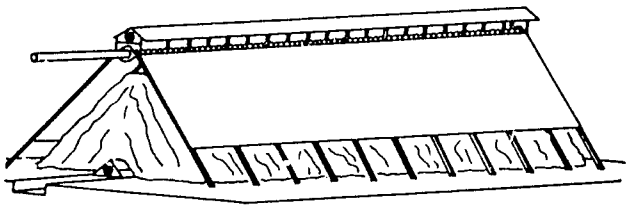
In the U.S. wood fuel for plants is usually delivered in large truck-drawn trailers. Several types of unloading systems are used. At the Gold Kist, Jack Daniels, and Russell Corporation plants both truck and trailer are raised to an angle of about 45° on a large hydraulic dumper. At Burlington Electric and Cherokee Brick only the detached trailers are elevated for dumping. At the Integrated Products plant the fuel is transported in self-unloading trailers equipped with "live-bottom" devices to convey the fuel out of the truck. Fuel for the Vermont Capitol system is unloaded with a small bucket unloader which drives directly into the trailer from the dock. All of these unloading systems could be replaced in developing countries with manual unloading with shovels or wheelbarrows.

At most of the wood-using plants some or all of the fuel is stored in open areas. The Russell Corporation has nearly an acre of concreted open storage. The Jack Daniels plant has room for 2,000 tons in the open. Integrated Products stores enough fuel for 15 days in a concreted storage pad.

Research at the Virginia Polytechnic Institute indicated that, if wood fuel is stored outside in high piles with a steep 40 to 50° angle of repose, the inner zones of the pile are not very affected by rainfall. These piles are created with automatic conveyors on tall booms or by frontend loaders which climb up the piles to stack the fuel.

Some of the industrial wood energy systems include a covered fuel storage shed or building. These structures must be well ventilated to disperse the heat and moisture rising from the piles of moist fuel. Typically the sides of the structures are open and a row of vents allows air to escape near the peak of

the roof. The following sketch shows a design for an A-frame storage shed with automatic infeed and outfeed:



At the Dorothea Dix Hospital wood chips are dropped into two piles inside a storage building which holds a three to five day fuel supply. Originally the sides of the building were open, but wind screens were added later to prevent scattering of the wood particles in high winds. The Russell Corporation and Jack Daniels plants have covered storage for 2,000 and 1,400 tons of fuel, respectively. Some type of covered storage would probably be necessary during the rainy season in most developing countries.

In some of the systems in the U.S. the fuel moves from the open or covered storage into a concrete storage silo. These silos provide a steady supply of fuel during weekends, holidays, or periods when fuel handling is restricted by bad weather. These silos are not suitable for long-term storage; if left for very long in the silo, the fuel compacts and "bridging" prevents its removal.

Fuel for about seven days is stored in two 80' (24 m) high silos at the Gold Kist plant; silos at the Integrated Products and Hale Company plants hold fuel for two to three days. At the Jack Daniels plant the silo provides only sufficient fuel for the overnight operation of two large boilers.

At the Russell Corporation plant and the Dorothea Dix hospital, wood fuel moves directly from the covered storage shed to the boilers. Burlington Electric's fuel goes directly to the boilers from open storage.

Fuel Drying

The combustion efficiency and heating value of wood fuels is affected by the moisture content of the fuel. Burlington Electric and several other plants burn whole tree chips which have a moisture content of 50 to 55%. The Vermont Capitol plant uses chipped barkless slabwood from sawmills which contains only 30 to 35% moisture. Some of the furniture and other woodworking plants burn residues from cured or kiln-dried lumber which has only 5 to 15% moisture.

Only one of the industrial wood energy systems described in this Report includes a fuel dryer; at the Cherokee Brick Company the moisture content of the sawdust fuel is reduced from 50 - 60% to 8 - 12% in a dryer which uses heat recirculated from the brick kilns. Most industrial wood energy systems have been designed to use available fuels without fuel drying.

In the developing countries stick wood could be stacked and air dried for a period of time before used in industrial systems. In the Phillippines Leucaena wood will be dried in stacks along the roads for 90 days before conversion to charcoal; during this period the wood will lose 30 to 35% of its original weight due to loss of moisture.

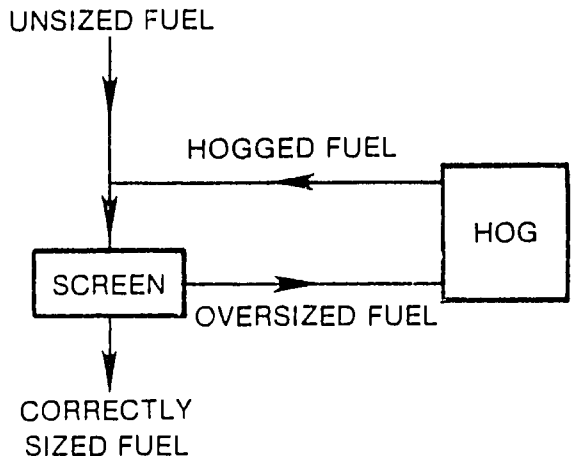
Fuel Screening and Sizing

The need for size reduction equipment in an industrial wood energy system depends on the type of fuel and the ability of the fuel handling system and the combustion unit to accommodate large fuel pieces. The fuel used by the Integrated Products and Gold Kist plants has already been chipped or hogged by fuel suppliers; these systems to not include size reduction equipment. Most of the other systems include a "hog" for size reduction.

Two types of hogs are used. In the "hammer hog" free-swinging hammers on a rotating core break the pieces of fuel

until they are small enough to pass through a screen at the bottom of the hog. In a "knife hog" the fuel is shredded by a series of knife blades.

At the Burlington Electric and Vermont Capitol plants, all the fuel passes through a hog. In most other plants the fuel is screened first and only the pieces too large for the screen are conveyed to a hog for size reduction as indicated in the diagram below:



A disc screen at the Russell Corporation plant retains only pieces larger than 2 1/2" (6.3 cm) for hogging; maximum fuel size at the Burlington Electric and Jack Daniels plants is 2" (5 cm). Other systems have been designed to use fuel with much smaller particles. At the Vermont Capitol wood chips are pulverized before they are fed to the boiler. The kiln-heating system at the Cherokee Brick Company uses sawdust, sanderdust, and other residues which have been ground into very small particles. Only particles smaller than 1/4" (.63 cm) pass through a series of six shaker screens; larger pieces are hammermilled.

The Nor'West Pacific Corporation's direct combustion study has suggested that some biomass fuels could be adequately sized in developing countries through a manual labor operation with machetes or chopping cleavers. Such an operation may be feasible if the fuel consists mainly of relatively small diameter stems and branches and if the fuel handling and combustion systems are designed to accept relatively large pieces of fuel.

Fuel Conveying Equipment

Belt conveyors use an endless loop of rubber or fabric running between two or more pulleys; a series of rollers bend the belt into a shallow trough. Belt conveyors are relatively inexpensive but the angle of ascent or descent is limited to about 27° and these conveyors are not appropriate for exterior use where the fuel will be exposed to wind or rain. The Russell Corporation and Jack Daniels plants use several belt conveyors to elevate fuel to storage silos.

Chain conveyors use an endless loop of chain driven by a powered sproket and riding in a metal trough. Metal wings at intervals on the chain pull the fuel through the trough. Gold Kist uses a drag chain conveyor at a 45° angle to carry fuel to the top of two storage silos. A chain conveyor carries fuel from the hog to the top of the Burlington Electric boiler.

Bucket or elevator conveyors usually have a series of buckets attached to chains and enclosed with sheet metal. These conveyors are very expensive, operate at a rather slow speed, and have a limited capacity. A bucket elevator is used to raise the fuel to the storage silo at the Integrated Products plant.

Screw conveyors or augers are widely used for conveying wood chips, sawdust, and other pulverized wood residues. The screw rotates within a tube or pipe. Augers are used at the Gold Kist, Integrated Products, and Vermont Capitol plants.

Pneumatic conveyors are used for sawdust and other pulverized fuel; high velocity fans blow the fuel through circular ducts. These conveyors are the least expensive to install but the fans consume considerable electrical energy.

At the True Temper plant sawdust and shavings are blown through pneumatic tubes from the woodworking area to the boiler. The Hale Company uses a pneumatc system to move pulverized fuel from the storage silo to the boiler.

The Nor'West Pacific Corporation has suggested that much of the fuel conveying could be handled with manual labor in a developing country with a large supply of low-cost labor. Fuel could be elevated to a silo or fuel hopper by laborers using wheelbarrows on an inclined ramp or pulley-hung baskets.

3. Combustion Systems for Wood Fuels

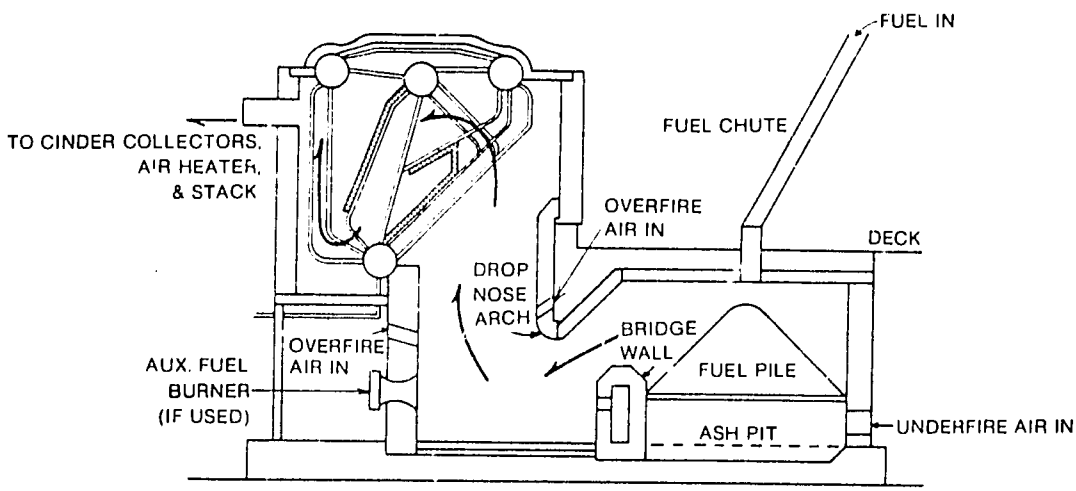
A very wide range of equipment is available for the direct combustion of wood fuels. A guide to wood fuels for small industries published by North Carolina State University lists 56 U. S. firms which manufacture industrial-scale wood combustion units. A Dartmouth College publication lists 89 companies that make wood combustion equipment.

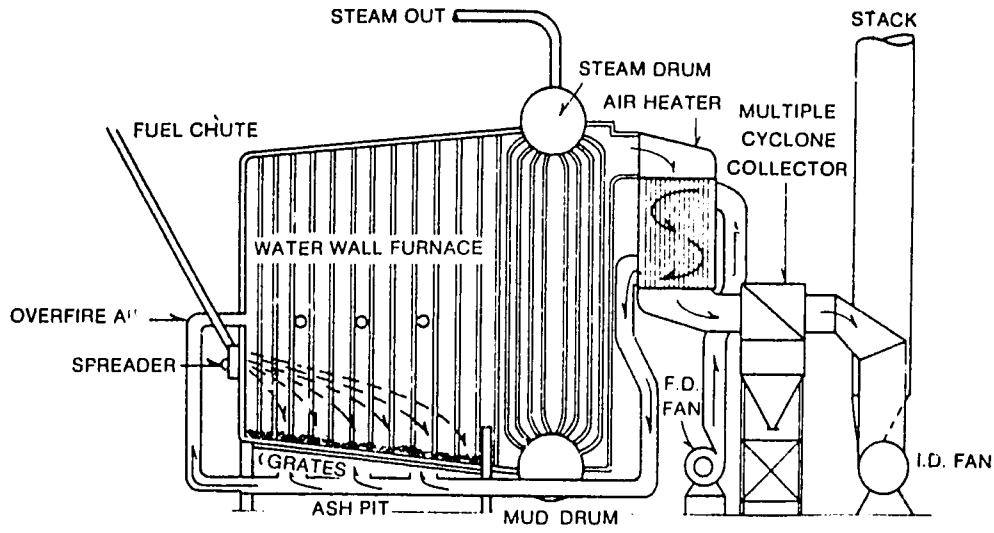
This plethora of equipment suppliers is a mixed blessing. The potential customer may need expert help to identify a few companies whose equipment or systems are appropriate for his situation and potential fuel. Most of the manufacturers have concentrated primarily or exclusively on one type of system. The typical system is designed for wood fuel with a specific range of particle sizes and moisture content. For example, some of the combustion units used in woodworking plants are suitable for rather dry wood residues but are not appropriate for green wood chips or other fuels with a rather high moisture content. Some systems can handle relatively large pieces of chipped or hogged fuel, while others can only accommodate pulverized fuel with rather fine particles. Although the fuel handling system may impose some limitations on particle size and/or moisture content, these limitations are usually determined primarily by the type of combustion system.

There are several ways of classifying combustion units. This Report will describe four moderately distinct categories of combustion systems involving (a) pile burning, (b) grate burning, (c) suspension burning, and (d) fluidized bed combustion.

Pile Burning

The oldest type of combustion unit still in use in industry is the Dutch Oven. Early models (and some units still used in sugar mills and elsewhere in developing countries) were designed to be hand-stoked through a door in the front of the oven; these units could burn slabs or sticks of wood. In most of the newer Dutch Ovens shredded fuel is fed to the fuel pile through the top of the combustion chamber as shown below:





However, at the Vermont Capitol the fuel is fed to the bottom of the pile with a stoking auger. In Dutch Ovens fuel drying and gasification takes place in the initial combustion chamber, aided by radiant and reflected heat from the refractory brick surfaces; the gases are burned in a secondary chamber.

Advantages of the Dutch Oven include ability to use fuel with up to 65% moisture content, steady heat output, compatibility with almost any boiler design, and relatively low cost of construction. Disadvantages include the need for high quality refractory brick and skilled masons for the construction of the refractory enclosure, the need for periodic rebricking, and the slow response to load changes due to the heat-holding characteristics of the large refractory area.

Grate Burning

There are several types of grate burning systems, some of which were originally designed for burning coal. In some systems movement of parts of the grate stirs the fuel and improves combustion.

The most common modern systems for the direct combustion of biomass are "spreader-stoker" systems which combine features of grate burning and suspension burning; an example is shown above. Fuel enters the furnace well above the grate; small particle burn in suspension, while the rest of the fuel falls to the grate where it burns. At the Jack Daniels plant the wood fuel is fed into the front wall of the boiler about 8 feet (2.4 m) above the travelling grate, using a swing-spout stoking device. The systems at the Integrated Products and Hale Company plants use air sweep spreaders; air pressure forces the fuel through a stoking nozzle which spreads it over the grate as shown on the above sketch.

These spreader-stoker systems can handle fuel with particles up to 1.5" (3.8 cm) and moisture content up to 55%. The limitation on the size of fuel particles arises primarily from the characteristics of the fuel feeding system. At the True Temper plant pneumatic tubes feed pulverized residues from the woodworking machines to a larger boiler with a fixed grate; at night pieces of slab wood are hand-stoked through the boiler door twice an hour by the nightwatchman.

There are several types of inclined grate systems; fuel drying and some volatilization and burning occurs while the fuel moves by gravity down the sloping grate.

Suspension Burning

In a suspension burner, fine dry wood particles are burned in suspension in a

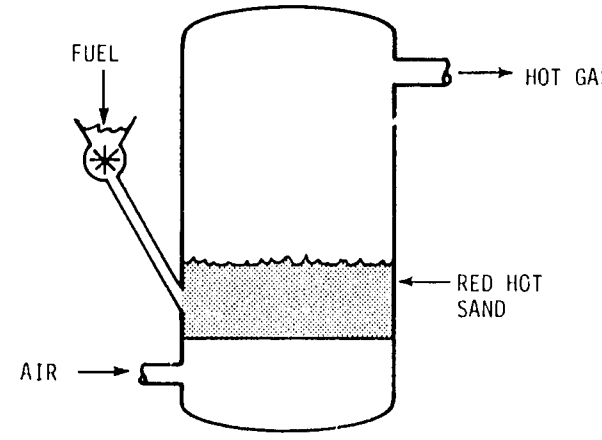
small combustion chamber. Although some large units can use larger particles with a higher moisture content, the most common suspension burners require less than 15% moisture and particles smaller than 1/8" (.30 cm). Most of these units have been installed in lumber mills or other wood-working plants in which dry sawdust, shavings, sanderdust, or other residues are available and process heat is needed for kilns and dryers. However, suspension burners have also been used to provide heat for package boilers.

There are two basic types of suspension burners. In the injection type, the dry pulverized fuel is mixed with the correct amount of air in a turbulent jet inside the firebox. In the cyclone type the fuel and air are combusted while they circulate at relatively high speed inside a cylindrical furnace such as that shown below.

Due to the requirement for dry and finely pulverized fuel, suspension burners are limited mainly to the wood-working industry. The True Temper firm found that suspension burning was not appropriate for a mixture of its own residues and wetter sawmill residues.

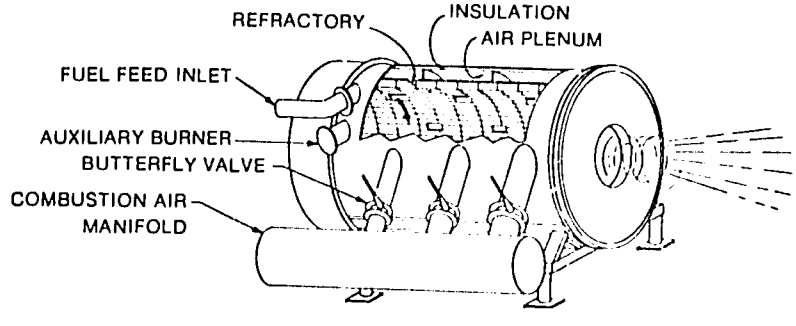
Fluidized Bed Combustion

In a fluidized bed combustor (shown above) the fuel is burned in a very hot bed of sand, limestone, or other non-combustible material which is kept in turbulent suspension by powerful fans.



Fluidized bed combustors have several advantages: (a) Due to the high operating temperatures (1600 to 2,000°F or 870 to 1090°C), fuel combustion is very rapid and a relatively small unit can utilize a large quantity of fuel. (b) Fluid bed combustors can accept rather wet fuel; the units normally use fuel with moisture content from 55 to 60% and one facility handles bark with as much as 67% moisture. (c) The units can process fuels with irregular sizes and shapes as well as mixtures of wood and other biomass.

Disadvantages of fluidized bed combustors include higher capital and maintenance costs, the need for highly skilled operators, and the electric power load from the operation of the fluidizing fans. This relatively new technology may not be the best choice for locations remote from sources of experience with fluid bed systems.



Retrofitting Existing Boilers

Some of the wood-fired units in industrial plants have been developed by retrofitting boilers originally designed to burn other fuels. The technical feasibility of retrofitting for wood fuels depends mainly on the characteristics of the original system. In some plants there is not sufficient space for the storage of the wood fuel and/or for the necessary equipment for the screening, sizing, conveying, and stoking of the fuel. However, in most cases the principal limitation is the design of the boiler itself.

A wood-fired unit must have an appropriate device for feeding the fuel into the boiler, a grate or refractory platform to hold the fuel, and openings for both underfire and overfire air. Because of the lower heat content of wood fuels, wood-fired boilers require larger combustion chambers than oil-fired units. Wider spacing between the water tubes is necessary due to the soot deposits which accumulate on heat transfer surfaces. Blowers are needed to remove these deposits periodically. Ash handling facilities are necessary, and pollution control devices may be required by air quality regulations.

Since boilers originally designed to use coal have most of these characteristics, they tend to be easier to retrofit for wood than boilers designed to burn oil or gas. In the U.S., fuel cost savings from conversion to wood from coal are usually not large enough to cover the retrofitting costs, but the economics of such conversions might be quite different in a country which must import coal.

On the whole, factory-built "package" boilers, which are rather compact to facilitate shipment, are usually less suitable for retrofitting than larger, field-erected boilers. If burning wood fuels within the boiler is not feasible, it may be possible to convert the wood fuel to a gas in an external gasifier and burn the gas in the boiler.

4. Gas Fuels From Wood

Most of the wood fuels used in industries and institutions is burned in one of the types of direct combustion systems described above. However, there are also two other options for the use of wood for fuel in industrial plants. One is to convert the wood to charcoal. Because charcoal has a much higher energy content per unit of weight than wood, it can be transported economically for much greater distances than wood. The charcoal produces an intense heat which is highly desirable for metal-smelting industries. Most of Brazil's iron and steel is produced with charcoal, and it is used in smelting industries in several other developing countries.

The other alternative to the direct combustion of wood is to convert the wood into a low-Btu gas through a thermal gasification process; this gas can be burned directly in boilers or burners or can be used as a fuel for internal combustion engines. Although some industrial gasifiers were built earlier in this century and several million vehicles were operated in Europe during World War II by gasifying wood or charcoal, gasification technology remained largely unused in several subsequent decades. However, since the petroleum price increases of the mid-1970's, many companies and institutions have undertaken gasification projects.

Quite a few of these projects have involved the use of the relatively clean gas from down-draft gasifiers in internal combustion engines. This type of thermal gasification was described in detail in a Bioenergy Systems Report published in June 1982 (see p. 1).

Several U.S. companies manufacture gasifier/burners in which a gasifier is close-coupled to a combustion unit; some of these are designed to be retrofitted to existing boilers. The hot gases from the gasifier flow directly into the boiler firebox, where they are burned.

Quite a few of these systems are used to burn wood residues in lumber mills; steam produced in the boilers is typically used in lumber drying kilns. Some mills also purchase whole tree chips from chip suppliers to supplement their own residues. The Forest Products Associate plant in Greenfield, Massachusetts uses only chips in a system with a 6 million Btu/hour gasifier and a 100 HP package boiler. In Brazil a special high-caloric charcoal is burned in gasifier/burners designed to provide gas fuel for industrial boilers and burners.

Two large updraft gasifiers are making gas fuel for boilers from wood chips in the southeastern U.S. At the Northwest Georgia Regional Hospital in Rome, Georgia, green wood chips are converted to low-Btu gas in a 25 million Btu/hour gasifier located outside the hospital's boiler room; the gas is piped in to a 19,000 pound/hour package boiler which makes steam for heating the hospital buildings.

A similar but larger gasifier, rated at 30 to 35 million Btu/hour, is being tested with wood chips and other biomass fuels at the Florida Power Corporation's electrical generating plant at Ellaville, Florida. Liquids are condensed from the gas and piped separately to a 350,000 pounds/hour boiler; the gas fuel and the liquids are burned together in a special burner along with natural gas in five other burners. The gasifier system cost about one million dollars but may pay for itself in about five years.

5. Economics of Wood Energy Systems

As with other bioenergy systems, the economic feasibility of an industrial wood energy system can only be determined by a detailed examination of the probable costs and savings resulting from the use of a specific fuel in a specific conversion system at a specific site. The analysis of the costs should include: (a) the capital costs of the total system including fuel handling equipment, combustion unit, and other necessary equipment and facilities; (b) fuel costs, including costs of growing, harvesting, purchasing, and/or transporting the wood fuel or the handling and preparation of wood residues produced at the site; and (c) operating costs including labor costs, maintenance, repairs, and miscellaneous direct costs.

Due primarily to the automatic fuel handling equipment, capital costs of wood-fired systems in the U.S. are much higher than those of systems burning oil or natural gas. The Georgia Institute of Technology estimates that these wood-fired boiler systems cost about nine times as much in the southeastern U.S. as those burning fossil fuels. As indicated earlier, it may be possible to greatly reduce these capital costs in developing countries by the use of manual labor for most aspects of fuel handling and preparation. However, since there is still very little experience with such methods, data on the capital costs of such systems is not available.

Despite the high capital costs of wood systems in the U.S., payback periods for these systems have been relatively short due to the very large savings in fuel costs. At present it seems prudent to avoid projections of high rates of future escalation in world oil prices, even though such projections have been widely used in feasibility studies for renewable energy projects in recent years. However, many U.S. firms have found that even at present oil price levels the savings from a wood energy system are sufficient to repay the capital costs of the system in only a few years.

The Tennessee Valley Authority, which has sponsored feasibilty studies on wood energy systems in 54 industries in its area, found that most of the proposed systems would be cost-effective. The most favorable economic assessments were on (a) wood systems in forest products

industries which produce wood wastes and need a year-round supply of low-pressure steam, and (b) large plants in other sectors which now use large quantities of fuel oil to make steam.

In 1979 and 1980 the Georgia Institute of Technology conducted feasibility studies on the installation of wood energy systems in 14 industrial plants in Georgia. Seven of these studies examined the replacement of existing oil and gas systems with wood-fired systems. The estimated cost of the largest system (60,000 pounds/hour was $1,714,000; however, the study showed that the system would save $950,000 in the first year in fuel costs and would pay for itself in less than two years. The capital costs of five possible systems with capacities ranging from 400 to 770 hp were from $350,000 to $500,000; estimated annual savings in fuel costs ranged from $63,000 to $291,000 and payback periods ran from 1.5 to 3.7 years.

There are substantial economies scale in wood energy systems. For example, the capital cost of a 770 hp system in Georgia was expected to be only about 50% higher than the cost of a 400 hp system.

Conclusions drawn from feasibility studies in one country are not transferable to a similar project in another country. Capital costs for identical systems would be higher in most developing countries than in the U.S. due to the need to import some or all of the equipment and some of the necessary engineering and construction services. These increased capital costs may be offset by using less automatic equipment and more manual labor. Moreover, the potential for very large savings in fuel costs may be even greater than in the U.S. due to the very high price of fuel oil in most of the developing countries. With somewhat simplified systems and even greater savings in fuel costs, payback periods could be somewhat comparable to those in the U.S.

Information Sources

Energy Generation and Cogeneration From Wood, 1980, 182 pages, Forest Products Research Society, 2801 Marshall Court, Madison, Wisconsin USA 53705. $18.

Industrial Wood Energy, 1981, 286 pages, Forest Products Research Society, $20.

Decisionmaker's Guide To Wood Fuel For Small Industrial Energy Users, 1980, 165 pages, Solar Energy Research Institute, 1536 Cole Blvd., Golden, Colorado USA 80401, $8.

An Evaluation of Wood Waste Energy Conversion Systems, by B. H. Levelton and Associates Ltd., 1980, 111 pages, ENFOR Report C-111, Canadian Forestry Service, 351 St. Joseph Blvd., Hull, Quebec, Canada KIA 1G5.

A User's Guide to Wood Engineering and Equipment, by John Bressoud, Resources Policy Center, Dartmouth College, Hannover, New Hampshire USA 03755, $3.

AN APPEAL TO READERS

A primary purpose of these Reports is to contribute to the interchange of information among those involved with bioenergy projects in developing countries. Reports planned for 1983 will focus on specific applications of bioenergy technologies in developing countries. A report due in March will review the use of bioenergy in the production and processing of agricultural products, while a June report will examine the use of fuels from biomass for the generation of electric power.

Organizations planning or conducting bioenergy projects in the agricultural sector or for power generation are urged to send information on the projects to Bioenergy Systems Reports, P. O. Box 591, Front Royal, Virginia USA 22630. The Editor will also greatly appreciate comments and reactions by readers on any of the Reports published in 1982.