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INDUSTRIAL ENERGY AND ELECTRIC POWER FROM WOOD RESIDUES

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ABSTRACT

Industrial Energy and Electric Power from Wood Residues

Although wood residues are widely used in the USA and some other developed countries to produce industrial process heat, to generate electricity, and for space heating, such uses are not yet common in developing countries.

This report describes the characteristics, availability, and uses of forest residues from logging and land clearing and of mill residues from forest products industries. It provides an introduction to commercially available technology and equipment for the collection, transportation, preparation, and combustion of wood residue fuels. It discusses the use of wood residues for producing industrial process heat and mechanical and electrical power. Finally, it summarizes factors influencing the economic attractiveness of wood residue utilization for energy and assesses the environmental impacts of wood residue disposal techniques and of production of energy from residues.

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Mention of manufacturers' names in this report does not imply endorsement by Winrock International or the U.S. Agency for International Development.

INTRODUCTION

About 75% of the standing volume of trees harvested for timber in developing countries ends up as logging residue in the forest or as mill residue in sawmills and other woodworking plants. The annual volume of logging residues is somewhat larger than the 240 million cubic meters of sawlogs and veneer logs harvested annually in all developing countries. About half of the volume of the logs harvested becomes mill residues. Although some logging and mill residues are used for domestic fuel and for charcoal production, vast quantities of potential wood fuel are burned for disposal or allowed to rot.

During the 1970s and 1980s development assistance agencies, international organizations, and national agencies have sponsored many studies and projects designed to maintain adequate supplies of fuelwood in developing countries and to promote more efficient use of the available fuelwood. These activities have focused primarily on wood harvested in forests for fuel and on the use of the fuelwood for domestic cooking. Development assistance organizations have stressed the need for programs for the sustained management of forests that would provide continuing supplies of fuelwood as well as necessary timber extraction.

A few international agencies have examined the use of wood fuels by small rural industries. Most of these studies have focused on wood harvested for fuel. Only a few address the use of the residues from lumbering, sawmills, or wood products factories.

Wood residues are widely used in the USA and some other developed countries to produce industrial process heat, to generate electricity, and for space heating. Such uses of wood residues are relatively rare in developing countries. North American and European firms offer a wide range of equipment for the handling and combustion of wood residue fuels, but there is little evidence that such equipment is being installed in developing countries. The limited use of wood residue fuels and technology to produce industrial energy and power in developing countries is attributable to a number of factors:

- U.S. and other manufacturers of wood energy equipment have focused primarily on domestic markets. They have made little effort to adapt equipment or systems to conditions in developing countries such as the need to minimize capital costs and to maximize employment. At present, however, several U.S. firms are actively exploring opportunities in developing countries to market their extensive experience in the USA with wood residue energy systems.
- Most of the commercially available equipment in developed countries has been designed for the handling, preparation, and combustion of pulverized wood fuels (ground bark, sawdust, shavings, and solid residues that have been chipped or hogged[1]). The use of pulverized wood fuels is rare in developing countries. Most furnaces and boilers in these countries have been designed for firing with roundwood or stickwood.
- Information on wood energy systems and equipment in developed countries is not widely available in developing countries. A major purpose of this report is to provide an overview of current technology and examples of facilities in the USA and in developing countries that are producing industrial process heat or electric power from wood residues.
- Most medium-sized and large lumber mills in the USA burn mill residues to produce steam for the kiln drying of lumber. Most sawmills in developing countries air-dry lumber, although in some countries interest in kiln drying is growing as a means of increasing the export market and value of the lumber.
- Unlike the USA, developing countries seldom use wood residues for electric power generation, despite the acute power shortages in many of these countries. Factors that have limited power generation with wood residues include inadequate funds and foreign exchange for modernization of sawmilling and woodworking industries, the lack of incentives for such investments in some countries due to low-cost or subsidized energy, the absence of grid connections or other power customers at many sites where residues are accumulated, and policies of many governments and electric utilities that discourage power generation for the grid by private firms.

Despite these limitations, several trends and developments point to the greater use of wood residues for industrial energy and power in developing countries in the 1990s. Growing recognition of the need for sustainable long-term management of forests is raising interest in maximizing the utilization of the trees that are harvested. A number of governments have adopted new programs and policies designed to expand the use of domestic energy resources and to increase the role of private firms in providing electric power for the grid. Many governments and industries in developing countries are reassessing energy options, and there is rising interest in some countries in using wood residues as fuel for the kiln drying of lumber.

In the USA in the 1980s, wood residue energy systems have clearly demonstrated that they can provide significant net savings in energy costs for forest products industries, other industries, and public institutions and can contribute significantly to the supply of electric power for the public grid. This experience will be reviewed in appropriate sections of this Bioenergy Systems Report.

Chapter 1 reviews the characteristics, availability, and present uses of wood residues including forest residues from logging and land clearing and mill residues from forest products industries. Chapter 2 provides an introduction to the commercially available technology and equipment for the collection, transportation, preparation, and combustion of wood residue fuels. Chapter 3 discusses the use of wood residues for industrial process heat, while Chapter 4 reviews the production of mechanical and electrical power from wood residues. These chapters include concise descriptions of a number of installations using wood residues for energy in the U.S., several other developed countries, and a number of developing countries. Factors influencing the economic attractiveness of wood residue utilization for energy are summarized in Chapter 5. The environmental impacts of present wood residue disposal techniques and of the production of energy from these residues are reviewed in Chapter 6.

Most of the numerical data in the Report is included to indicate the general level of performance of various types of wood energy systems and the rated capacity of various components rather than the precise performance of the systems or components. Data is given in metric units with English units in parentheses. The abbreviation "t" means "tonne (1,000 kg). The term "ton" refers to the English short ton (2,000 lb).

Information and conclusions in the Report are drawn from many sources. Most of these are cited in the footnotes at the end of each chapter. Conclusions concerning the involvement of private firms, development assistance agencies, and national agencies in the utilization of wood residues are based primarily on the pattern of responses to inquiries sent to about 50 private firms producing wood energy equipment and systems and to about 60 international and national agencies in 35 countries. Most of the examples of wood energy installations in the USA are drawn from publications of the several regional biomass energy programs that are funded by the U.S. Department of Energy.

Information on the utilization of wood residues for energy in Ghana, Costa Rica, Indonesia, and Honduras is derived from the following major studies:

(1) The Joint UNDP/World Bank Energy Sector Management Assessment Program (ESMAP) and the Canadian International Development Agency (CIDA) co-funded a study in 1986-7 of the utilization of sawmill residues in Ghana.[2]

(2) A study of the utilization of forest residues in Costa Rica in 1988 was co-funded by the program and the Government of The Netherlands.[3]

(3) A prefeasibility assessment of the potential for wood waste power systems in the wood products industry in Indonesia was funded in 1986-87 by the Office of Energy of the U.S. Agency for International Development under the Bioenergy Systems and Technology Project.[4]

(4) An overview study of the potential for wood waste power systems in Honduras was conducted in 1990 by Winrock International under the Biomass Energy Systems and Technology (BEST) project, which is funded by the U.S. Agency for International Development. A report entitled *Energy From Sawmill Wastes in Honduras* was published in 1991.[5]

Notes

1. U.S. term meaning wood that has been reduced to a small size.
2. Energy Sector Management Assistance Program [ESMAP], *Ghana: Sawmill Residues Utilization Study* (Washington D.C.: UNDP/World Bank, 1988)

3. Energy Sector Management Assistance Program [ESMAP], *Costa Rica: Forest Residues Utilization Study* (Washington D.C.: UNDP/World Bank, 1990).
4. Bioenergy Systems and Technology, *A Prefeasibility Assessment of the Potential of Wood Waste Power Systems for the Indonesian Wood Products Industry*, Office of Energy Report 88-17 (Washington D.C.: U.S. Agency for International Development, 1988).
5. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras: Industry Overview*, Office of Energy Report 91-05 (Washington, D.C.: USAID/Honduras and U.S. Agency for International Development, 1991).

1. CHARACTERISTICS, AVAILABILITY, AND UTILIZATION OF WOOD RESIDUES

Residues from Logging and Land Clearing

Residues generated during logging operations include branches and tops of the harvested trees (often called "slash"), broken and defective logs, dead or injured standing trees, and small-diameter trees. The quantity of these residues per hectare depends on the species, the age of the stand, forest management techniques, and logging practices.

FAO estimates that in developed countries logging residues amount to 50% of the initial standing tree volume, including 45% of the standing volume of the harvested trees and a 5% loss of volume in trees damaged during harvest. In the USA, a Forest Service paper states, "about half of the above-ground biomass of each harvested tree is left in the forest."[1] More than 56 tonnes of residues per hectare (25 tons/A) are left on the ground after the logging of old growth forest in the Pacific northwest.[2]

Inefficient logging practices contribute significantly to the high level of logging residues. The Forest Service paper lists the chief inefficiencies as excessive stump height, excessive minimum top diameters (thus maximizing unused tops of trees), damage to harvested and other trees during felling, skidding damage to logs and other trees, unused secondary species, and unused small diameter trees.[3]

In temperate climates, the typical forest has a single dominant tree species and is harvested after slow regeneration over a long period of years. Tropical forests usually have multiple species and rather short regeneration cycles and are harvested with quite different techniques than those used in developed countries. For these reasons, the experience of developed countries with the use of logging residues is less relevant to developing countries than their extensive experience with the use of mill residues (see Chapter 2).

The ratio of logging residues to standing timber appears to be higher in developing countries. FAO estimates that logging residues comprise 65% of the initial volume of standing trees, including 50% of the standing volume of harvested trees and a 15% loss of volume in trees damaged during harvest.[4] A study in the Philippines in 1986 found that damaged residual trees accounted for 50% of the logging residues and an additional 14% of the residue was stumps and abandoned logs.[5]

In most developing countries, the volume of logging residues has not been accurately measured. Rough estimates can be derived from statistics on the production of sawlogs and veneer logs. Indonesia, which harvests about 25 million cubic meters of such logs annually, generates a considerably larger volume of logging residue.[6] The annual production of about 18 million cubic meters of sawlogs and veneer logs in India may produce as much as 25 million cubic meters of logging residues.[7]

A virgin Philippine mahogany forest selectively logged by the Paper Corporation of the Philippines produces about 60 cubic meters of residues per hectare including trimmings, stumps, tops, branches, splits, knocked-down trees, and culled defective trees. Up to 45 cubic meters of logging residues per hectare can be recovered from a 15- to 20-year-old second-growth forest under a timber stand improvement program.[8]

In Costa Rica a UNDP/World Bank study indicated that present selective logging of only large-diameter trees leaves branches and reject stems equal to 23 cubic meters of solid wood per hectare, but the strip cutting of all trees would produce logging residues equal to 110 cubic meters of solid wood per hectare.[9]

The volume of logging residues available in a given area in a given year depends in part on the extent of the timber extraction during that year. Due to a downward trend in the economy of the Philippines, the volume of logging residues generated in that country declined from over 5 million cubic meters in 1979 to only 2.7 million in 1986.[10]

Physical or economic constraints can prevent the recovery of much of the residue left by logging operations. As in the U.S., the inaccessibility of many logging areas greatly limits the use of logging residues. The UNDP/World Bank team in Costa Rica noted that

10 of 15 potential forest-residue producing areas were 16 kilometers (10 miles) or more from even the nearest dirt road.[11] Even if recovery is technically feasible, the cost may be prohibitive. Residue can be removed from the forest only if its value at the point of use exceeds the total cost of recovery. This total cost is influenced by equipment costs, fuel costs, labor costs, and transportation costs.

The extent of the use of logging residues for domestic or industrial fuel depends on the accessibility of the harvested forests, distances to population centers, adequacy of road or other transportation networks, and availability and cost of other fuels. In Sri Lanka the Forest Department states that it is uneconomic to transport fuelwood for distances over 80 kilometers (50 miles).[12] Due to the serious shortage of industrial fuels in some parts of India, biomass fuels are often transported for distances up to 160 kilometers (100 miles).[13]

A UNDP/World Bank study in Ghana indicated that an unknown fraction of the 1.1 million cubic meters of logging residues is transported for distances up to 150 kilometers (93 miles), but transportation costs of $\$10/m^3$ for such a haul limit the volume of residues that is transported to distant users.[14] Analyses of several industries by the UNDP/World Bank team in Costa Rica indicated that investments in wood residue energy systems burning logging residues transported 150 to 180 kilometers (93 to 111 miles) with transport costs of $\$9/m^3$ to $\$11/m^3$ would be financially attractive.[15]

A study of sawmill wastes in Honduras observes that thinnings and harvesting wastes could be used to supplement sawmill wastes at residue-fired power plants. Removal of the residues from the forest floor would contribute to sustainable forest management, because residues that remain increase the potential for damage from wildfires.[16]

Statistics and studies on fuelwood use in developing countries have rarely differentiated between trees cut for fuel and logging residues. Few countries have estimates of the use of logging residues for domestic or industrial fuel. In the Philippines, these residues are clearly the principal sources of domestic fuel and of fuel for small industries in villages near recently logged areas.[17] The Philippine government encourages the collection of forest residues by companies licensed to harvest timber and by others who obtain permits to collect logging wastes. In some areas the collection of forest residues for use as fuel is an important source of employment and income.[18]

Logging wastes are a major source of fuel for a large Paper Corporation of the Philippines (PICOP) facility, which includes a sawmill, a veneer and plywood mill, and a pulp and paper mill. PICOP sends a 1,000-tonne barge to locations 400 to 600 kiiometers (250 to 375 miles) upriver to purchase logging and sawmill residues brought to the river landings by entrepreneurs.[19]

In some countries a significant percentage of the logging residue is converted to charcoal. For villagers who lack saws and axes to cut up large pieces of waste wood, converting them to friable charcoal in earth mound kilns may be the only way to use the wood for cooking. Others produce charcoal from forest residues for sale in urban areas.[20] The Natural Resources Institute in Great Britain notes that converting forest residues to charcoal doubles the fuel value per tonne and increases the distance that the fuel can be transported economically. NRI also notes that, even in efficient kilns, up to 50% of the energy in the wood is lost during the carbonization process.[21] The Timber Utilization Research Center in Tanzania estimates that in typical inefficient kilns in Africa the loss of calorific value during carbonization is as high as 60%.[22]

Charcoal makers usually take damaged logs and sizable branches, ignoring smaller branches and twigs. In Kenya, a portable CUSAB (Charcoal From Unwanted Shrubs and Bushes) kiln, designed by FAO in 1971, was a failure because charging it with branches and twigs led to a high percentage of fines that were not usable for domestic charcoal and charcoal makers saw no need to use twigs and branches when better wood was available. University of Nairobi tests indicated that the best wood for charcoal had diameters up to 0.12 meters and lengths of about 0.45 meters.[23]

The clearing of forest land for agriculture is another large source of forest residue, some of which is used as fuelwood or for charcoal production. In 1985 the clearing of land for agricultural development on Nicaragua's Pacific coast produced a wood supply equal to 90% of the national fuelwood consumption.[24] In Costa Rica land clearing creates a larger supply of potential fuel than logging operations do.[25] Under a "transmigration" program in Indonesia to resettle people from overcrowded Java, the clearing of forests in outlying islands generated an estimated 90 million cubic meters of wood annually in the mid-1980s.[26]

Most of the wood cut during land clearing is burned to dispose of it, and efforts to recover energy from such wood are rare. In the early 1980s Sri Lanka's State Timber Corporation (STC) initiated a program to produce charcoal in portable steel kilns from some of the 22.5 million tonnes (25 million tons) of wood available over a 5-year period from the clearing of the vast Mahaveli forests.[27] STC is now the major producer of charcoal in Sri Lanka, but more of the wood from land clearing is used for fuelwood than for charcoal production.[28]

Residues of Forest Products Industries

Vast quantities of wood residues are produced by sawmills and other primary forest products industries (i.e., plywood and veneer mills) that process sawlogs and by a wide range of secondary woodworking industries that utilize lumber or other products of the primary industries. These residues of processing industries are generally known as mill residues.

Characteristics of Mill Residues

In the USA, bark is usually removed by a debarker before the log is sawed. Because of its availability and low moisture content, the pulverized bark is widely used as a boiler fuel in U.S. forest products industries. Some wood energy systems burn only bark, but it is usually burned with other residues. Due to its high ash content, bark used as fuel creates cleanup problems in boilers and may lead to the glassing of furnace grates when furnace temperatures exceed the ash melting point.[29] Debarking of logs is apparently relatively rare at sawmills in developing countries. The bark usually remains on the edges of the offcuts, slabwood, and other solid residues.

In developing countries, most of the mill residues are solid pieces of wood, plywood, or veneer. The UNDP/World Bank study in Ghana indicated that 79% of the residues from wood processing industries in Ghana were solid wastes: 49% slabs and edgings, 15% offcuts, 6% veneer cores, and 9% other veneer wastes.[30]

The only form of pulverized wood residue available in quantity in most developing countries is sawdust. In conventional sawmills in the USA 12 to 25% of the volume of the log ends up as sawdust. The UNDP/World Bank team in Ghana estimated that sawdust represented 14% of the log input at sawmills and 21% of the total volume of wood residue produced in the country.[31]

Although there is some variation in the fuel value of wood wastes from species to species, the primary factor determining the fuel value of wood waste is moisture content. Industrial wood energy systems in the USA are divided into two reasonably distinct groups. One group burns green (wet) mill residues, while the second group burns much drier residues from woodworking plants that utilize kiln-dried lumber. Typical fuel values for these two groups of residues are shown in Table 1.

Table 1. Fuel Values Of Mill Residues.

Type of Residue	% Moisture	BTU/lb	MJ/kg
Wet mill residues			
Bark, Louisiana	50	4500	10.5
Bark, Oregon	50	4625	10.7
Sawdust, Virginia	55	3400	7.9
Sawdust, Oregon	45	5088	11.8
Sawdust, Florida	40	4000	9.3
Hardwood residues, Central Africa	50	4130	9.6
Mill residues, Honduras	45	4967	11.5
Sawmill trim, Oregon	45	5000	11.6
Hardwood slabs, Arkansas	45	4000	9.3
Veneer mill residues, Alabama	40	4000	9.3
Planer shavings, South Carolina	40	4000	9.3
Mill residues, Ghana	36	5120	11.9
Dry residues of woodworking industries			
Sawdust, Georgia	30	6000	13.9
Hardwood residues, Malaysia	25	7745	18.0
Plywood mill residues, Indonesia	23	6600	15.3
Planer shavings, Virginia	13	7000	16.3
Scraps & shavings, Mississippi	12	7000	16.3
Chipped hardwood residues, Kentucky	10	7000	16.3
Panel mill trim, Oregon	10	8190	19.0
Sawdust, Kentucky	6	8500	19.8
Furniture plant wastes, Virginia	6	8000	18.5

Availability of Mill Residues in Developing Countries

The U.S. Forest Service estimates that an average of 65% by volume of the wood entering mills in developing countries ends up as residues. The percentage of residues tends to be lower in larger and more modern mills.[32] In rather modern plywood factories in Indonesia the residue figure is about 48%.[33] In Honduras sawmill residues, including bark, vary between 47% and 52% of the incoming logs, depending of the efficiency of the sawmill and the extent of the recovery of secondary products from the solid residues.[34] In Ghana the average residue rate for sawmills is 55%.[35]

Estimates of the total volume of mill residues generated in developing countries are scarce The volume of residues from a sawmill is rarely measured accurately. Most national estimates of mill residues have apparently been made by multiplying the statistics on the production of forest products by an assumed percentage of residues. When two estimates are available for a country, they are often contradictory. Variations are attributable primarily to differences in the assumed percentage of residues.

But planners of an installation using wood residues as fuel should not be concerned by unavailability or unreliability of national estimates of wood residues the if they have reliable estimates and projections of the potential fuel available in the vicinity of the proposed installation.

Utilization of Mill Residues

The principal uses of mill residues for energy are as domestic fuel, as feedstock for charcoal production, and as industrial fuel to produce process heat, electric power, or both. The extent of the utilization of residues from a specific mill for energy depends on the location and energy needs of the mill, the fuel needs of adjacent industries and population, the local availability and cost of other fuels, and other variables.

Slabwood from sawmills is widely used as domestic fuel in both developed and developing countries. The extent of this use depends mainly on the size of the population that is relatively near the sawmill and the availability and cost of other fuels. In areas in the USA and Europe near small sawmills that do not burn their residues for industrial energy, slabwood is widely used in wood stoves for home heating. In developing countries, scraps and slabs from sawmills are often used as cooking fuel. The UNDP/World Bank team in Ghana estimated that about 15% of the wood industry residues are used for cooking in commercial and household sectors.[36]

In many developing countries and in some areas in the USA, slabwood and large scraps from sawmills are widely used as feedstock for the production of charcoal. Until recently, the substantial charcoal industry in the Ozark mountain area of Missouri used wood cut from nearby forests, but now most of the charcoal is made from slabwood from sawmills. In Ghana about 35% of the wood industry residues are converted to charcoal in primitive earth mound kilns. As indicated in Figure 1, almost all of this residue consists of slabs and edgings.[37]

Sawdust remains the least-utilized type of wood residue in both developed and developing countries. One large sawmill in Chile is reported to have a stockpile of sawdust that covers a 9 hectare (22 A) area to a depth of 12 meters (40 ft). Sawdust is not a satisfactory fuel for domestic use. When only sawdust is burned in piles or on grates, ash and unburned sawdust tends to smother the fire. Sawdust can be carbonized, but the resulting powdered charcoal has a low market value. In Ghana where most furnaces were designed to burn solid fuels, the use of sawdust requires the installation of pinhole or inclined/stepped grates and increased forced or induced draft air to permit suspension burning of the sawdust.[38] Many woodworking industries in the USA burn dry sawdust from kiln-dried lumber in specially designed suspension burners, but sawdust from green lumber cannot be used in these burners.

In recent years the use of water to guide high-production saws has doubled the moisture content of the sawdust. At many mills in Ghana excessive amounts of water are sprayed on band and circular saw blades with a garden hose. As a result, because the sawdust contains over 70% moisture, it is difficult to burn without pre-drying, and is rarely used as a boiler fuel. The sawdust is usually stored outdoors, and rainwater adds to the moisture content.[39] A study by Virginia Polytechnic Institute notes that the use of sawdust could be expanded if a low-cost energy-efficient sawdust dryer were developed.[40]

In the USA the most common industrial use of mill residues is to produce direct heat or steam for lumber drying kilns. This use of mill residues (Chapter 3) is rare in developing countries. Most of the lumber is air dried, so the typical sawmill has no need for process heat. Mill residues are also burned in many industries and institutions in the USA to provide hot air, hot water, or steam for space heating. Space heating is not a major need in developing countries, which are mostly in warm climates. In a few installations in the U.S., steam from residues is used in absorption chillers for air conditioning.

The generation of electric power in steam plants fueled with mill residues has grown rapidly in the USA during the past decade. These plants (see Chapter 4) include both power plants within forest products industries and "stand-alone" power plants producing power for the grid. Few developing countries report forest products industries that burn residues to generate power.

An Australian research institution concluded that plywood factories could be nearly self-sufficient in energy if they fully utilized their output of bark, log trim, veneer cores, veneer rejects, and sander dust in systems producing both process heat and electricity.[41] These residues are not fully utilized at most plywood and veneer factories in developing countries.

In 1987/88 plywood factories in Indonesia processed about 13 million cubic meters of logs, produced about 7 million cubic meters of plywood products, and generated about 6 million cubic meters of residues. A study of residue use in 28 plywood factories in Indonesia in 1987 reported that all of the factories burned residues to produce steam for dryers and hot presses, but only 20% used wood wastes to produce electricity. One large factory using power from the grid produced 47,000 cubic meters of residues per month; only 29,000 cubic meters were used to produce process steam, leaving 18,000 cubic meters of unused residues.

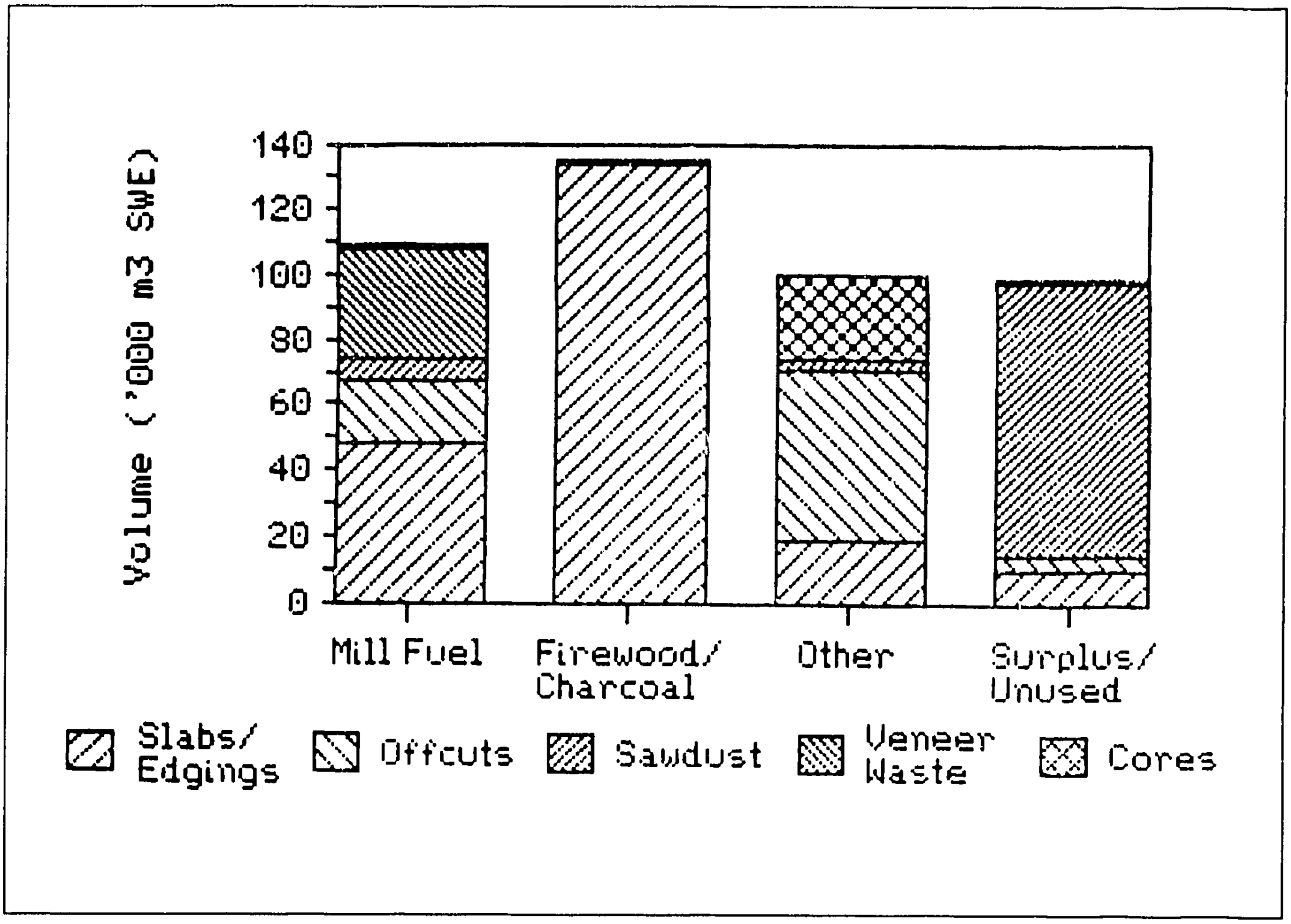

Fig. 1. Utilization of mill residues, Ghana, 1986 (SWE = solid wood equivalent). (Source: *Ghana: Sawmill Residues Utilization Study*, UNDP/World Bank, 1988)

A smaller plywood factory using grid power generated 6,000 cubic meters of residues monthly, used 3,600 cubic meters for process heat, and left an unused surplus of 2,400 cubic meters.[42]

The UNDP/World Bank study in Ghana listed 13 plywood or veneer factories that were burning residues to produce process heat, but only one was producing electricity with residues.[43]

A study of sawmill residues in Honduras found that sawmills producing more than 3,500 cubic meters (1.5 MBf) annually produced sufficient residues to be energy self-sufficient. In larger mills only a fraction of the residues are required for energy self-sufficiency, e.g., a 23,600 m^3/yr (10 MBf/yr) mill needs only 35% of its residues to meet its energy needs[44]

Research for this report has not identified any site in a developing country in which electric power is generated with wood residues for distribution through the public grid or to a rural community other than the homes of employees of the forest products industry.

Although statistics on the use of mill residues in developing countries are scarce, many observers report that large quantities of these potential fuels are wasted:

Overseas Development Administration, U.K.: "Sawmill wastes (offcuts and sawdust) are often left unused [in developing countries]. In many sawmills, their disposal is considered a nuisance and they are dumped, burned off, or just left to pile up, constituting a fire hazard."[45]

Sawmill manager, Thailand: "Large quantities of wood wastes are produced in the sawmilling industry in Thailand. Only a small portion of these wastes is used as fuel, which is burned in inefficient furnaces capturing little of the energy content."[46]

Asian Institute of Technology, Thailand: "Large amounts of residues are ... available in sawmills in the form of sawdust .... Rice husk, bagasse, and sawdust are important as (potential) substitutes for fuelwood."[47]

Ministry of Forestry, Indonesia: "There are large quantities of wastes from wood processing activities .... Very little is at present used in wood processing industries."[48]

Forest Institute, Pakistan: "The use of wood residues for industrial energy and/or electric power is negligible."[49]

Forest Department, Sri Lanka: "Very large quantities of wood wastes ... await utilization for energy production in the country."[50]

African Regional Office, Biomass Users Network: "There is a well developed sawmill industry [in Africa] ... but the large volumes of wood residues from these enterprises are being wasted away, mainly through burning."[51]

Report on a workshop on wood energy in East Africa: "Sawdust is normally disposed of in incinerators, with no subsequent use of the generated heat."[52]

Sawmill engineer, Tanzania: "Waste amounts to nearly half the sawlogs' solid volume including bark. In the developing world, the wood residues are normally not used for industrial energy purposes."[53]

UNDP/World Bank study of utilization of sawmill wastes, Ghana: "Ninety percent of all sawdust produced is not utilized."[54]

Winrock International study of energy from sawmill wastes, Honduras: "Most sawmills in Honduras derive their energy requirements from imported petroleum products. At the same time they generate and discard large quantities of energy-rich wood wastes, a practice which entails both economic and environmental costs."[55]

Notes

1. Forest Products Laboratory, "Technologies for Residues Utilization in Developing Countries" (Madison, Wisconsin: U.S. Forest Service, 1990), 32 (unpublished).
2. Pacific Northwest and Alaska Regional Biomass Energy Program, *Biomass Energy Project Development Guidebook* (Portland, Oregon: Bonneville Power Administration, 1987), 1-9.
3. Forest Products Laboratory, 32.
4. Ibid.
5. P. V. Bawagan, *Wood-based Energy System in Rural Industries and Village Applications: Philippines* (Bangkok: FAO, 1989), 3.
6. FAO, *FAO Yearbook: Forest Products* (Rome, 1987).
7. Ibid.
8. Bawagan, 40.
9. Energy Sector Management Assistance Program [ESMAP], *Costa Rica: Forest Residues Utilization Study* (Washington D.C.: UNDP/World Bank, 1990), 1:20.
10. Bawagan, 3.
11. ESMAP, *Costa Rica*, 1:14.
12. V.R. Nanayakkara, "Wood Energy Development in Sri Lanka," 95 (unpublished)
13. International Development and Energy Associates, *Rice Husk Gasification in Developing Countries: A Case Study for Selected Areas in North India* (Washington, D.C., 1989), 37.
14. Energy Sector Management Assistance Program [ESMAP], *Ghana: Sawmill Residues Utilization Study* (Washington D.C.: UNDP/World Bank, 1988), 1:22.
15. ESMAP, *Costa Rica*, 1:58-61.

16. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras: Industry Overview*, Office of Energy Report 91-05 (Washington, D.C.: USAID/Honduras and U.S. Agency for International Development, 1991), 20.
17. Bawagan, 47.
18. Ibid, 4.
19. Ibid.
20. FAO, *Simple Technologies for Charcoal Making* (Rome, 1983).
21. Tropical Development and Research Institute [TDRI], *An Introduction to Small Scale Natural Draught Wood-fired Furnace Systems* (London, 1986), 20.
22. International Development Research Centre [IDRC], *Wood Energy in East Africa* (Ottawa, 1983), 137.
23. Ibid, 63.
24. Reynaldo Vega, "Country Overview: Nicaragua" (Paper delivered at the International Producer Gas Conference, Bandung, Indonesia, March 1985).
25. ESMAP, *Costa Rica*, 1:14.
26. T.N. Syachri, *Wood Energy News*, July 1987 (Bangkok: FAO), 8.
27. Susan V. Bogach, "Woodfuel Supply and Utilization in the Developing World" (unpublished report to the Canadian International Development Agency, Ottawa), 1982; "Sri Lanka's Energy Problem Comes Out of the Woods," *New Scientist*, 13 August 1981.
28. Nanayakkara, 93.
29. L.A. Grace, and W.B. Stuart, "Sawdust Utilization Technology," *Biologue* (National Wood Energy Association), September/October 1989, 33.
30. ESMAP, *Ghana*, 1:25.
31. Ibid, 1:23, 1:25.
32. Forest Products Laboratory, 32.
33. Bioenergy Systems and Technology, *A Prefeasibility Assessment of the Potential of Wood Waste Power Systems for the Indonesian Wood Products Industry*, Office of Energy Report 88-17 (Washington D.C.: U.S. Agency for International Development, 1988), 18.
34. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras*, 13.
35. ESMAP, *Ghana*, 1:23.
36. Ibid, 1:iii.
37. Ibid, 1:43.
38. Ibid, 1:40.
39. Ibid, 1:47.
40. Grace and Stuart, 33.
41. Y.H. Fung, "Wood Energy Prospects," *Energy From Forest Biomass* (New York: Academic Press, 1982), 158.
42. Bioenergy Systems and Technology, *Indonesian Wood Products*, 16.
43. ESMAP, *Ghana*, 1:32.
44. Biomass Energy Systems and Technology Project, 33
45. TDRI, 19.
46. Suvit Khlaisang, "Energy From Woodwastes in Sawmilling Industry," *Agricultural Wastes and Solar Technologies for Energy Needs in Farms* (Bangkok: FAO, 1983), 149.
47. S.C. Bhattacharya, *Wood Energy For Rural Industries: Thailand* (Bangkok: FAO 1986), 38.
48. Ministry of Forestry, Indonesia, "Energy From Wood Waste: Indonesia," *Wood Energy News* (Bangkok: FAO), March 1989, 8.
49. K. M. Siddiqui (Pakistan Forest Institute), letter to author, 19 July 1990.
50. V. R. Nanayakkara, "The Development of Fuelwood Resources as a Source of Domestic Energy in Sri Lanka," *The Sri Lanka Forester*, 3:8, 1983.
51. C.E. Chimombe (Biomass Users Network), letter to author, 22 August 1990.
52. IDRC, 233.
53. James L. Ngeleja, "The Utilization of Industrial Wood Residues for Energy Purposes" (n.p., n.d.), 2.
54. ESMAP, *Ghana*, 1:53.
55. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras*, 11.

2. HANDLING AND COMBUSTION OF WOOD RESIDUE FUELS

Wood Energy Technology for Developing Countries

Aside from the use of slabwood from sawmills in furnaces and boilers in a number of village-scale industries, the use of wood residues in developing countries for industrial process heat and for electric generation has been very limited. With only rare exceptions, the equipment and technology available in developing countries is appropriate for the combustion of stickwood or roundwood from the forest and of slabwood residues from sawmills, but is not appropriate for the combustion of pulverized residues (sawdust, shavings, bark, and other residues that have been ground or hogged.)

Few equipment manufacturers, system designers, research institutions, or development assistance agencies have apparently attempted to design wood residue energy systems for typical conditions in developing countries, especially the need to minimize capital costs and to maximize employment. Aside from attempts to develop effective gasifier/engine systems (including the testing of one or more units in sawmills), research for this report identified only one project by a development assistance agency that has focused on appropriate technology for the industrial utilization of wood residues in a developing country. A project operated in Belize by the Natural Resources Institute, a unit of Great Britain's Overseas Development Administration, developed and tested a small-scale system for the kiln drying of lumber using furniture shop residues as fuei (see Chapter 3).

In recent years some development assistance agencies have been reluctant to become involved with forest products industries, which were viewed as major contributors to the rapid deforestation in many developing countries. But there are now signs of increased interest in wood residue utilization by some development agencies and private firms. The sustained management of forests, a goal now widely recognized in the international development community, clearly requires more complete and efficient utilization of the biomass that is extracted from the forests in order to minimize the need for cutting trees. Moreover, it has been recognized that sustaining forest resources is also in the best interest of the forest products industries.

The expanded utilization of logging residues and mill residues in developing countries will require major new efforts to develop residue utilization technology and systems that are appropriate for these countries. Much of the experience and some of the equipment and technology of developed countries can be utilized or adapted in developing countries, but there is an urgent need for designing wood residue utilization systems suitable for their typical conditions.

The challenges facing designers of such systems include:

(1) maximizing use of laborers and hand-powered conveyers (wheelbarrows, pushcarts, etc.) for moving and handling of wood fuels and minimizing the use of expensive automatic conveying equipment.

(2) the use of hand-tools or simple semi-automatic devices for reducing the size of solid wood residues when necessary, in order to eliminate the need for expensive equipment to produce pulverized fuels.

(3) the design or redesign of furnaces and boilers to permit manual or semi-automatic stoking of solid pieces of wood waste, including fuel that has been reduced in size with hand tools.

(4) the design of combustion units that can burn the least utilized type of mill residue, sawdust.

(5) the design of equipment that provides a high degree of reliability, that can be maintained by unskilled workers, and that requires few if any imported spare parts.

(6) the maximum utilization of local materials and equipment and of skilled labor available in the country, in order to minimize the total capital cost and the foreign currency cost of the installation.

Minimizing the use of capital equipment can be justified as a means of reducing capital and operating costs, but it is also desirable as a means of increasing employment in developing countries. In some types of facilities, especially large plants, substantial reliance on

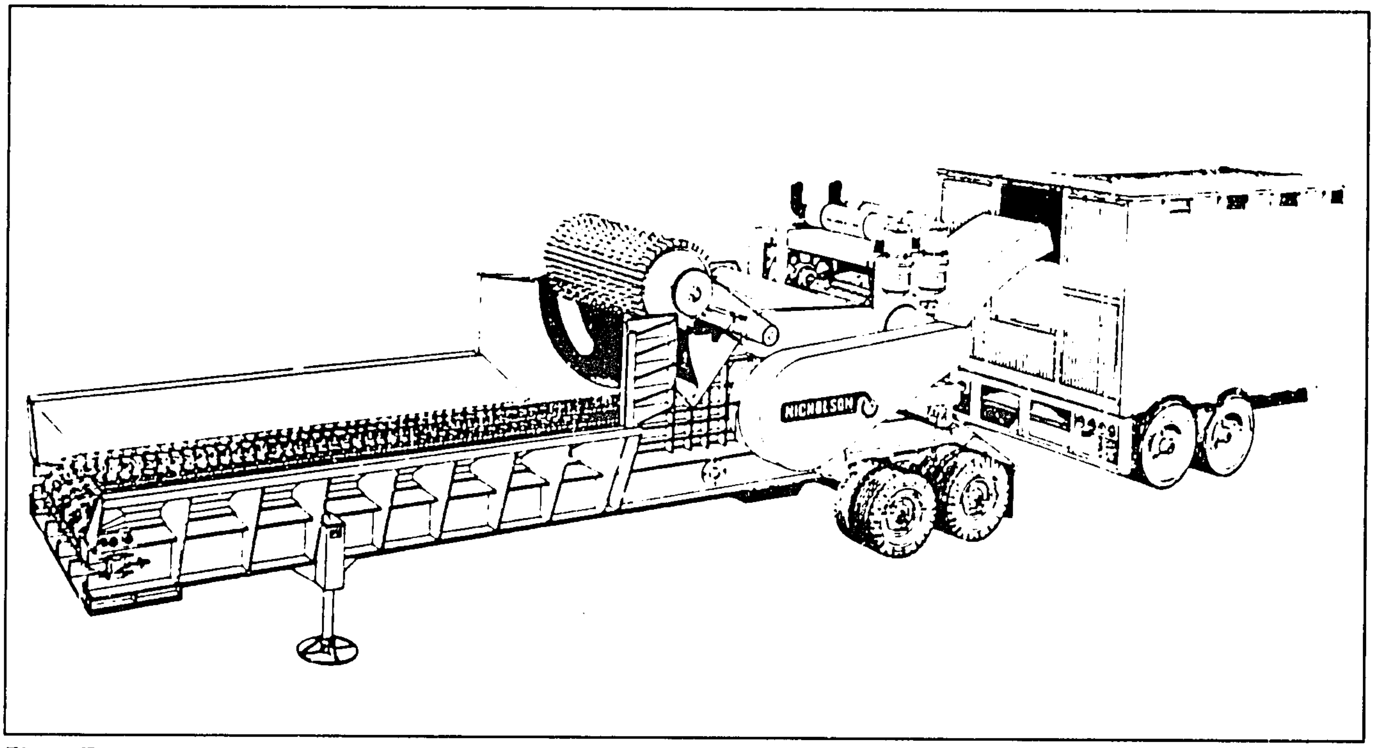

Fig. 2. Drum chipper for forest residues. (Source: Nicholson Manufacturing Co.)

manual labor for conveying, sizing, and stoking the wood residue fuel may prove to be impractical. In the absence of substantial experience with such labor-intensive plants and of proven system designs, the use of available designs and off-the-shelf mechanical equipment may be unavoidable in some wood residue utilization facilities built in the near future.

Preparation and Handling of Wood Residue Fuels

Techniques and equipment for the collection of logging residues vary widely from area to area depending on terrain, species, type of timber stand, logging techniques, and other variables. A comprehensive discussion of the available technology and equipment for the recovery of these residues is beyond the scope of this report. Most of the available equipment has been developed for use in temperate zone forests in North America or northern Europe. Experience in tropical forests in developing countries with the mechanized recovery of logging residues is very limited.

In the USA almost all of available technology is for the preparation and handling of pulverized fuels. Logging residues, when collected, are usually converted to wood chips in the forest and then trucked to the user. U.S. firms offer a rather wide range of chippers. The wood fuel processor built by Nicholson Manufacturing (Fig. 2) is used for chipping logging slash (tops and branches), damaged logs, and log yard residues. The drum chipper is powered with a 617 HP diesel engine and can accept logs with diameters up to 46 centimeters (18 in) for softwoods and 41 centimeters (16 in) for hardwoods. With high loading efficiency the machine can process 22.5 tonnes (25 tons) of biomass per hour.[1] Smaller chippers are available from several U.S. firms. No information is available on the use of chippers with extremely dense tropical hardwoods

A large percentage of the residues of sawmills and woodworking industries are generated in a pulverized form (i.e., pulverized bark removed by debarkers, sawdust, planer shavings, and sander dust). Most of the slabwood and other solid residues are pulverized prior to being used or sold as fuel.

A wide range of pulverizers and grinders are produced by U.S. manufacturers. Some of these units are known as "hogs" and produce a shredded or "hogged" fuel. West Salem Machinery Company builds a horizontally fed hog for wood and bark (Fig. 3). The smallest models require 25 to 75 HP; the largest model needs 600 to 900 HP.[2]

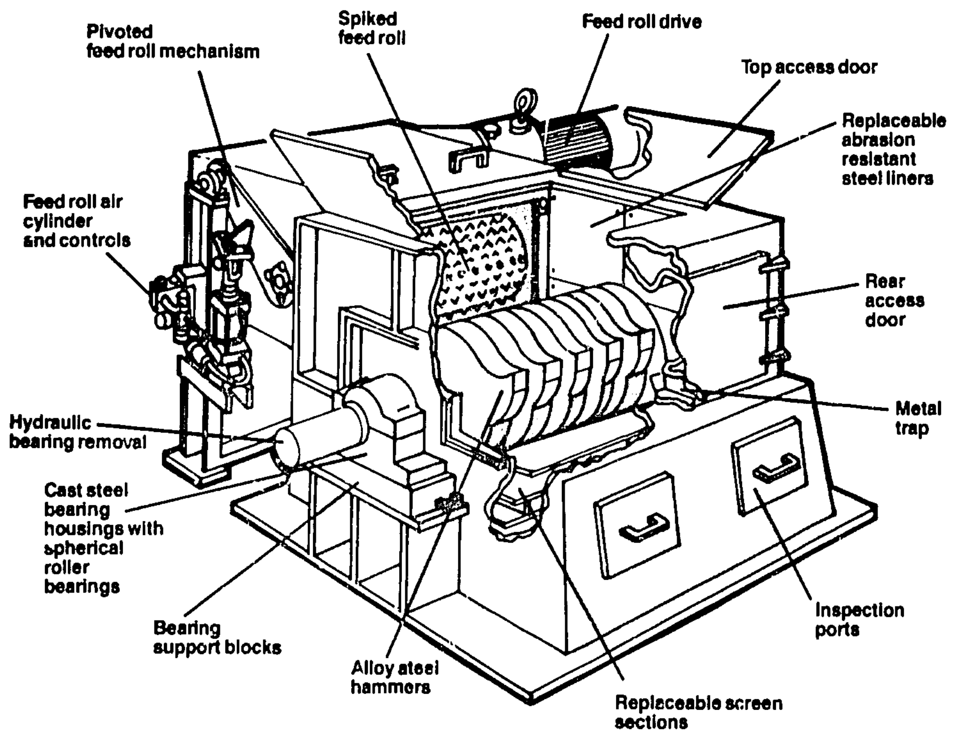

Fig. 3. **Horizontal wood and bark hog.** (Source: West Salem Machinery Co.)

Several wood-fired power plants in the USA receive wood fuels by barge or rail, but most wood fuel is shipped in conventional semi-trailer trucks, conventional dump trucks, or trucks with a built-in "live bottom" conveyor that pushes the fuel out the rear. In small facilities, conventional trailers are unloaded from a ramp or unloading dock by a front-end loader, a tractor with a large scoop. Larger facilities in the USA often use a hydraulic truck dumper. A platform raises the trailer or the truck and trailer to a angle of up to 60 degrees, emptying the trailer in 3 to 5 minutes.

In developing countries, most logging residues and solid mill residues are transported in the form in which they are available, with only some trimming to facilitate shipping. Chipping or hogging is not desirable if the fuel is to be burned in typical furnaces in developing countries that have been designed to use roundwood or stickwood. Although there are some opportunities in developing countries to transport wood fuels by rail or river barge, most wood fuel is transported on trucks that are manually loaded and unloaded.

In some wood energy systems in the U.S., sawdust and other wastes from green wood are stored in the open in uncovered piles. Some of these facilities stockpile fuel to avoid supply interruptions. At the minimum, the fuel should be heaped on solid, nonporous ground with good drainage. An asphalt or concrete pad reduces moisture absorption and prevents the mixing of soil with the fuel. The energy value of the fuel deteriorates in open storage due to spontaneous heating within the pile. Research by the U.S. Forest Service showed that the average net heating values of sawdust stored in piles 4.6 meters (15 ft) high declined by 40% after 1 year of open storage, with half of the decline taking place in the first 60 days.[3] Dry residues from kiln-dried wood must be stored in a covered but ventilated storage area or in a vertical silo, in order to avoid an increase in moisture content and decline in energy content.

Wood fuel stored in piles is usually recovered with a front-end loader or automatic conveyer. Two types of conveyers are used to carry pulverized fuel from the storage area or silo to the furnace or boiler. Wet fuels are usually carried by a mechanical conveyer with a belt, screw, chain, or bucket. Dry pulverized fuels are often blown through pipes in a pneumatic conveyer. The system shown in Figure 4 uses a mechanical "live-bottom" unloader and metering screw to recover dry pulverized fuel from a storage silo; the fuel is then conveyed pneumatically through a material handling fan to the boiler.

The stickwood and roundwood used in most wood-burning furnaces in developing countries is usually loaded, unloaded, and conveyed with the maximum use of manual labor and the minimum use of equipment. Several estimates of the cost of new wood residue energy systems in developing countries have assumed the use of pulverized wood fuels and of automatic equipment to prepare and handle such fuels. The high capital cost of such equipment is one of the reasons for the unfavorable economic evaluation of several of these projects.

A few wood energy systems include a fuel dryer. A rotary drum dryer from M-E-C Company is heated by burning some of the dried wood wastes.[4] Two power plants described in the section "Power for the Grid" in Chapter 4 have rotary fuel dryers heated by stack gas from the boiler.

The UNDP/World Bank team in Ghana examined the economic feasibility of converting boilers at several plants to sawdust burning. The projected systems included rotary dryers heated with flue gas to permit the combustion of the dried sawdust in retrofitted suspension burners. In each case the high installed cost of the imported dryer, burner, and fuel handling

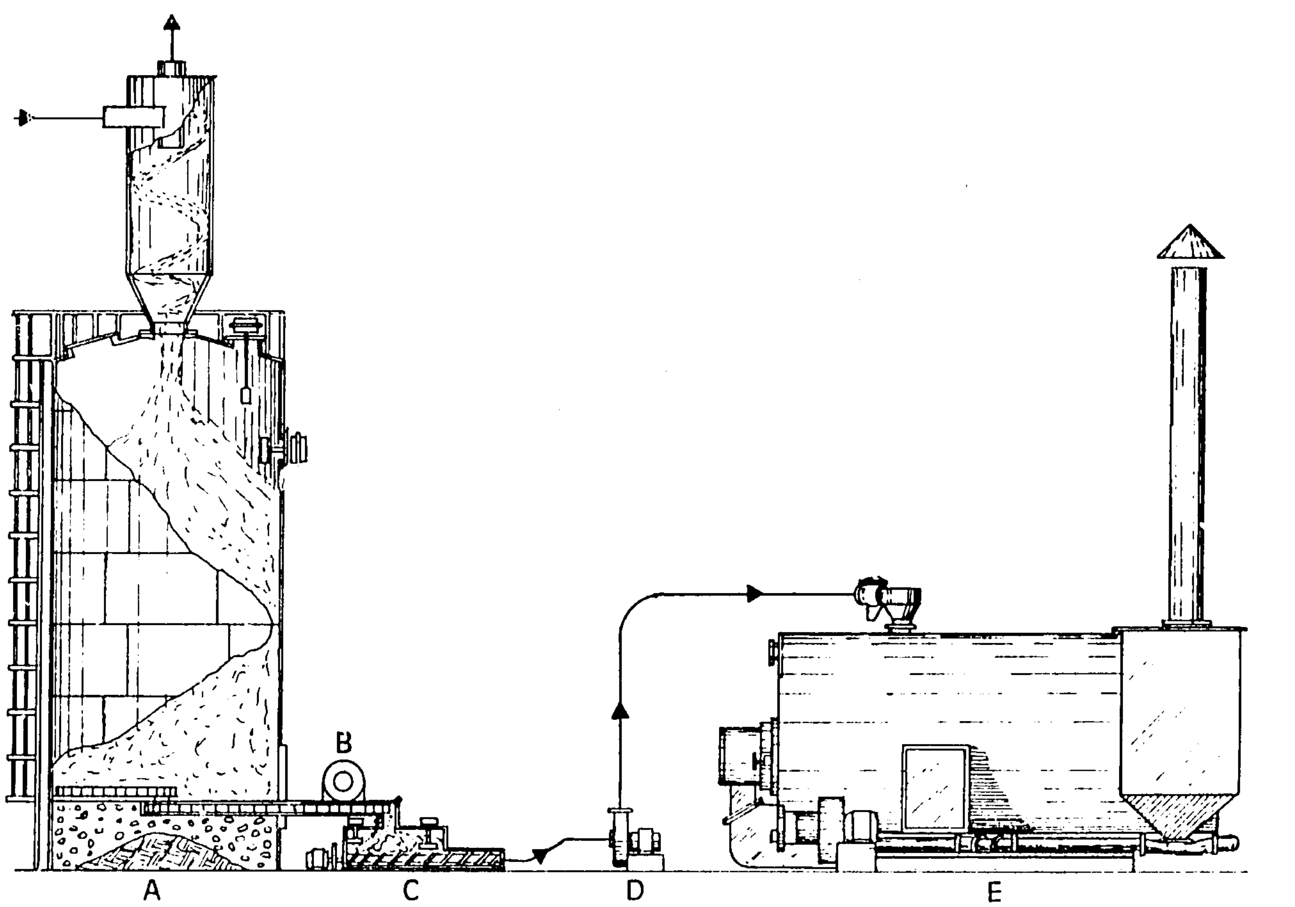

Fig. 4. Mechanical and pneumatic fuel handling. A and B. Mechanical "live-bottom" unloader. C. Metering screw. D. Material handling fan. E. Boiler. (Source: Combustion Systems Assoc.)

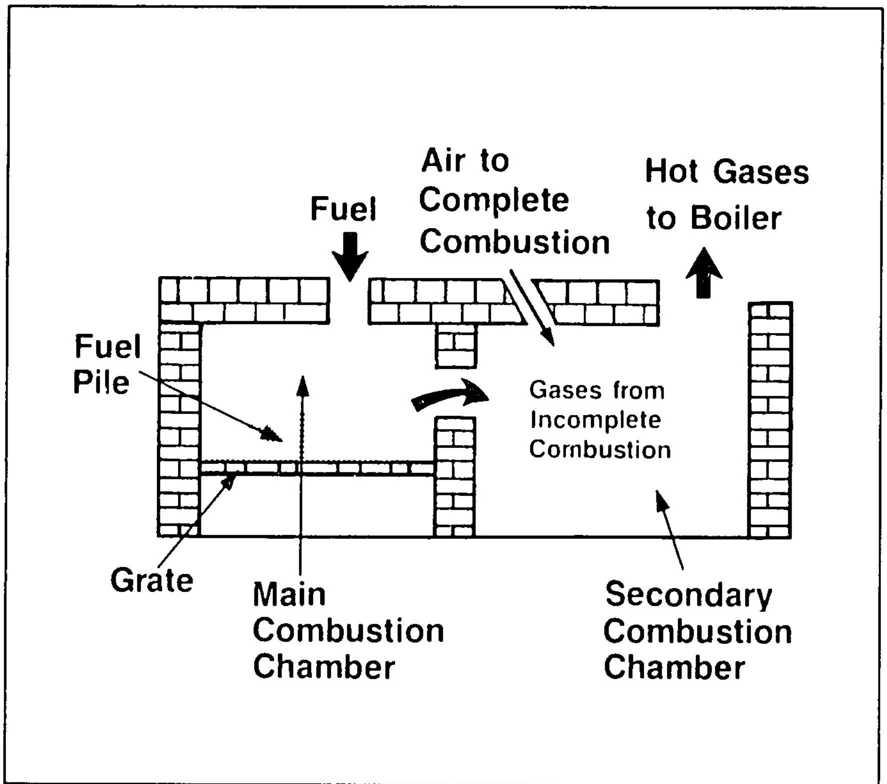

Fig. 5. Pile burning in a Dutch oven furnace. (Source: *Wood Energy Guide*, North Carolina Agricultural Extension Service / Southeastern Regional Biomass Energy Program)

equipment contributed to the unfavorable results of the investment analysis.[5]

Types of Combustion Systems

Manually Fed Furnaces

Small furnaces suitable for the manual feeding of solid pieces of waste wood or roundwood are produced by several U.S. firms. Most of these furnaces are used for space heating in woodworking plants and other facilities and for the direct heating of lumber drying kilns.

G&S Mill Inc. builds hot air furnaces that can be manually fired with pieces of waste wood up to 1.5 meters (5 ft) long. Some models are designed for dry wastes from kiln-dried wood; others have a small induced draft fan and can burn residues with up to 55% moisture. All models can also be fed with automatic stokers.[6] Decton Iron Works offers five models of hot air furnaces suitable for manual feeding or use with an automatic stoker. All models have circulating blowers.[7]

Although a few of these new furnaces are used with boilers and some older boilers are still hand-stoked, manual feeding of boilers is increasingly rare in the USA. In developing countries, however, manually fed "Dutch oven" furnaces are common. In this type of furnace (Fig. 5), the fuel burns in a pile in a simple brick firebox. Combustion of the gas is completed in a secondary combustion chamber. In developing countries, solid pieces of wood fuel are usually fed manually through a steel furnace door, and ashes are removed manually from under the stationary grate.

Dutch oven furnaces can accommodate fuels with a considerable variation in size and moisture content, but large pieces of fuel tend to burn better than smaller pieces because they allow better penetration of air into the fuel pile. The division of the furnace into primary and secondary combustion chambers minimizes the entrainment of particulates in the gas stream. The principal disadvantages of these furnaces are the high maintenance required for the refractory furnace lining and the necessity of interrupting steam production to remove ashes.[8]

Automatic Stoking Equipment

The great majority of wood energy systems in U.S. industries and institutions burn some form of pulverized fuel that is fed to the furnace by an automatic stoking system. The extensive use of pulverized fuels and automatic stoking equipment in the USA is due to (a) the large quantities of already pulverized residues including bark, sawdust, sander dust, and planer shavings produced by forest products industries; (b) the availability in some areas of logging residues that have been converted to chips by mobile chippers; (c.) the control of heat output and steam production made possible by automatically regulated stoking of pulverized fuels; and (d) high labor costs, which tend to preclude manual stoking in sizable facilities.

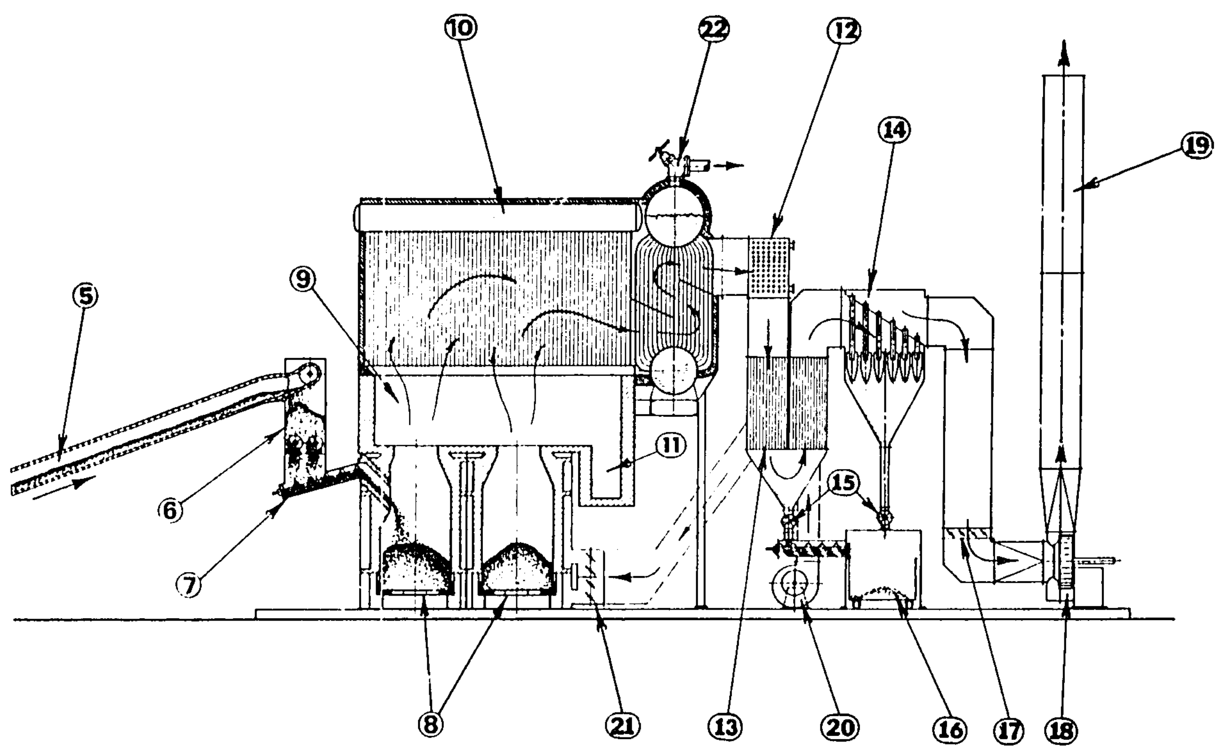

Fig. 6. Pile burning with screw auger overfeed stoker. (Source: Wellons, Inc.)

The principal types of automatic stokers convey the fuel with screw augers, drag chains, or pneumatic tubes. Stokers are also classified by their method of stoking (i.e, overfeed stokers, underfeed stokers, or spreader-stokers). The choice of stoker depends primarily on the particle size and moisture content of the wood fuel.

Drag-chain stokers and screw augers are used with fuel that has large particles, such as wood chips or hogged fuel, and relatively high moisture content. A drag-chain is usually an overfeed stoker, dumping the fuel on the top of the pile (Fig. 6). A screw auger may function as an underfeed stoker, pushing the fuel up through a hole in the bottom of the firebox (Fig. 7).

Pneumatic stokers are used with dry fuels that have small particles such as sawdust and shavings with less than 20% moisture. The lightweight fuel is blown into the firebox (Fig. 4.).

A spreader stoker combines features of mechanical and pneumatic stokers. The fuel is fed mechanically from a hopper, typically with a screw auger. A nozzle passes a stream of air through the incoming fuel and distributes fuel and air uniformly over each section of the grate or firebox. Fuel is fed to the firebox automatically when the temperature in the furnace falls below a preset point. Air is automatically supplied to match the added fuel, maintaining an optimum fuel-to-air ratio. In Figure 8, a spreader stoker distributes fuel over a traveling grate; these stokers are also widely used with fixed pinhole grates.[9]

Pile Burning Systems

A modified pile burning furnace with automatic stoking is built by Wellons, Inc. A twin-cell Wellons system is shown in Figure 6. Fuel is metered from a storage silo to the chain conveyer (5) as necessary to maintain a constant supply of fuel in the metering surge bin (6). Variable speed augers (7) are automatically controlled to feed a metered amount of fuel matching the steam load.

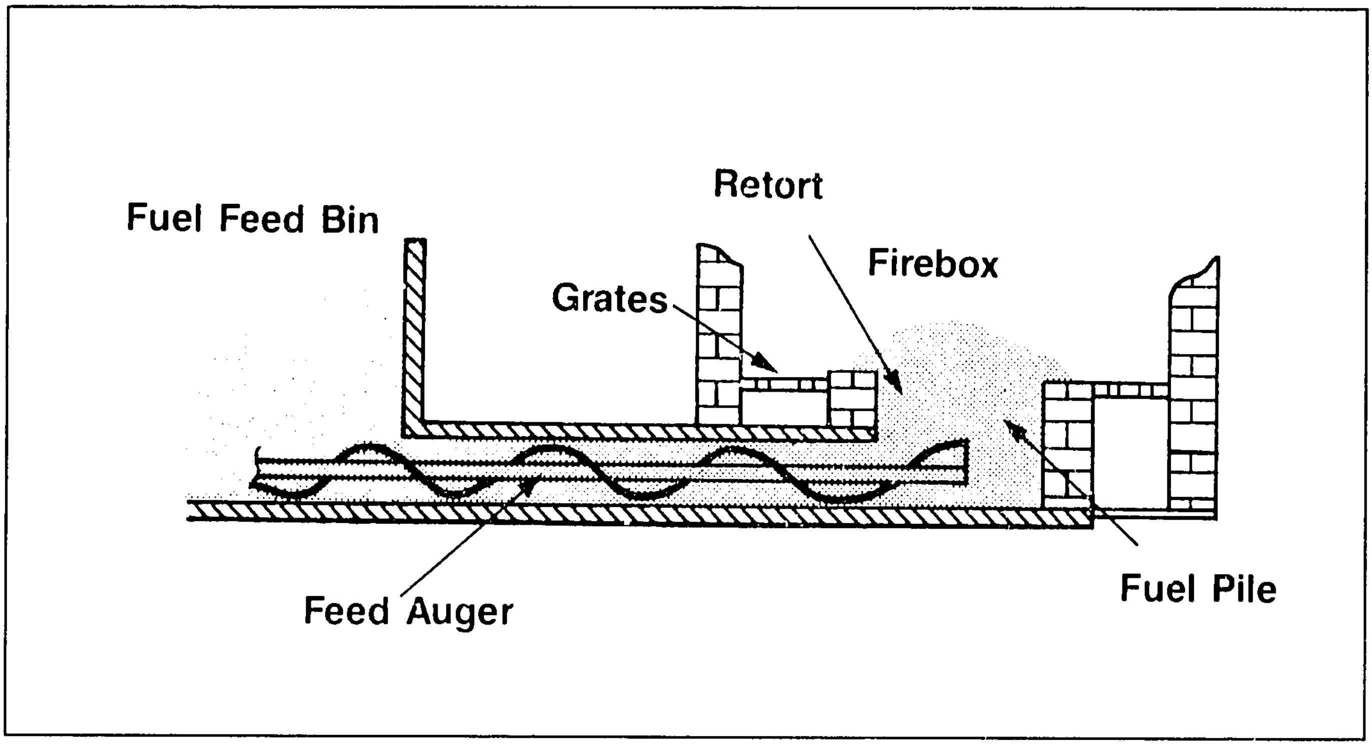

Fig. 7. Pile burning with screw auger underfeed stoker. (Source: *Wood Energy Guide*, North Carolina Agricultural Extension Service / Southeastern Regional Biomass Energy Program)

Forced air from the fan (20) passes through the air preheater (13) and enters the furnace through the water-cooled grates (8) and through ports above the fuel pile. Combustion is completed in the chamber (9) and radiant energy is directed to the watertube boiler (10). Ash falls into the dropout chamber (11). Exhaust gases pass through an optional economizer (12), a combustion air preheater (13), a multiclone particulate collector (14), and an induced draft fan (18), and exit through the stack (19).[10]

Grate Burning Systems

Grate furnaces are used in most "packaged" (factory-built) boilers and most large field-erected boilers for electric power plants. The grate permits the use of both underfire and overfire air and facilitates the removal of ashes. There are many types of furnace grates including fixed, moving, inclined, step, and other grates. Grate furnaces can handle a wide range of particle sizes and some models can burn fuels that have up to 65% moisture. They are fed with overfeed stokers, underfeed stokers, and spreader stokers. A traveling grate with a spreader stoker is shown in Figure 8.

Suspension Burning Systems

A suspension burner is usually fed with a pneumatic feeder. Fine dry particles of wood are blown into a relatively small firebox and burned in suspension. These burners require fuel with less than 15% moisture and particles no larger than 0.63 centimeter (0.25 in).[11] They usually burn dry residues from kiln-dried lumber (sawdust, planer shavings, sander dust, fines from particleboard production, and trim from plywood mills). The flow of air must be precisely matched to the flow of fuel to allow the proper residence time for efficient combustion and avoid entrainment of unburned fuel in the air stream. In some suspension burners, a cyclonic effect is used to increase the residence time in the furnace; this type of suspension burner is shown in Figure 9.

Suspension burners are widely used at lumber mills in the USA to provide direct heat or steam for lumber drying kilns.[12]

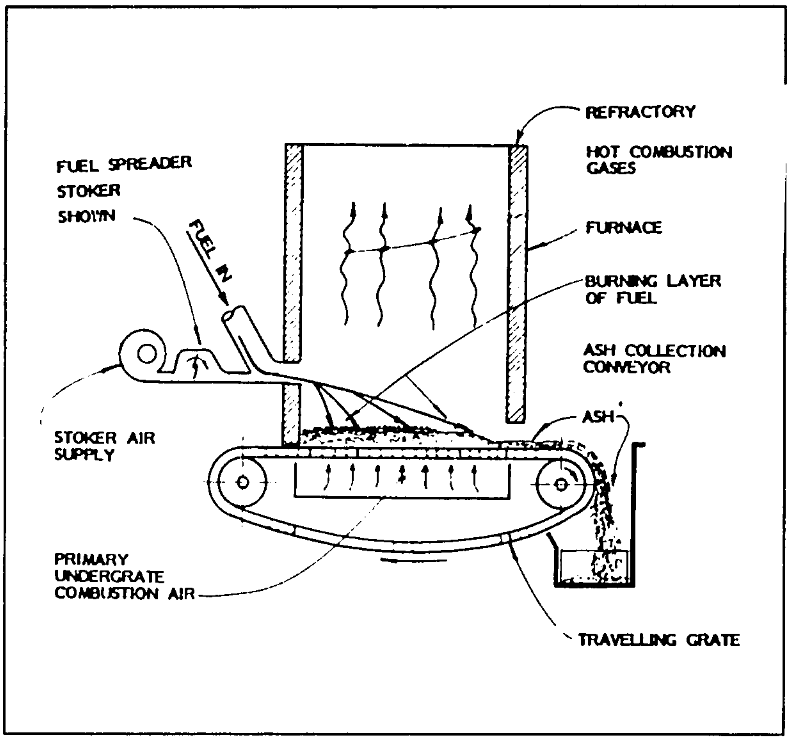

Fig. 8. Traveling grate with spreader stoker. (Source: *Biomass Energy Project Development Guidebook*, Bonneville Power Administration)

Fluidized Bed Systems

In a fluidized bed combustor, the fuel is burned in a very hot bed of sand, limestone, or other noncombustible material, which is kept in turbulent suspension by powerful fans. Among the advantages of these combustors are (a) ability to utilize fuels with irregular sizes and shapes and high moisture content and (b) rapid combustion due to high operating temperatures (870 to 1090°C), allowing a relatively small unit to utilize a large quantity of fuel. The disadvantages include high capital and maintenance costs, the need for highly skilled operators, and the substantial electric power demand imposed by the operation of the fluidizing fans.[13]

Circulating fluidized bed (CFB) technology was developed to burn solid fuels with large variations in moisture content and heating value. At a 28 MW CFB power plant at Woodland, California, chipped

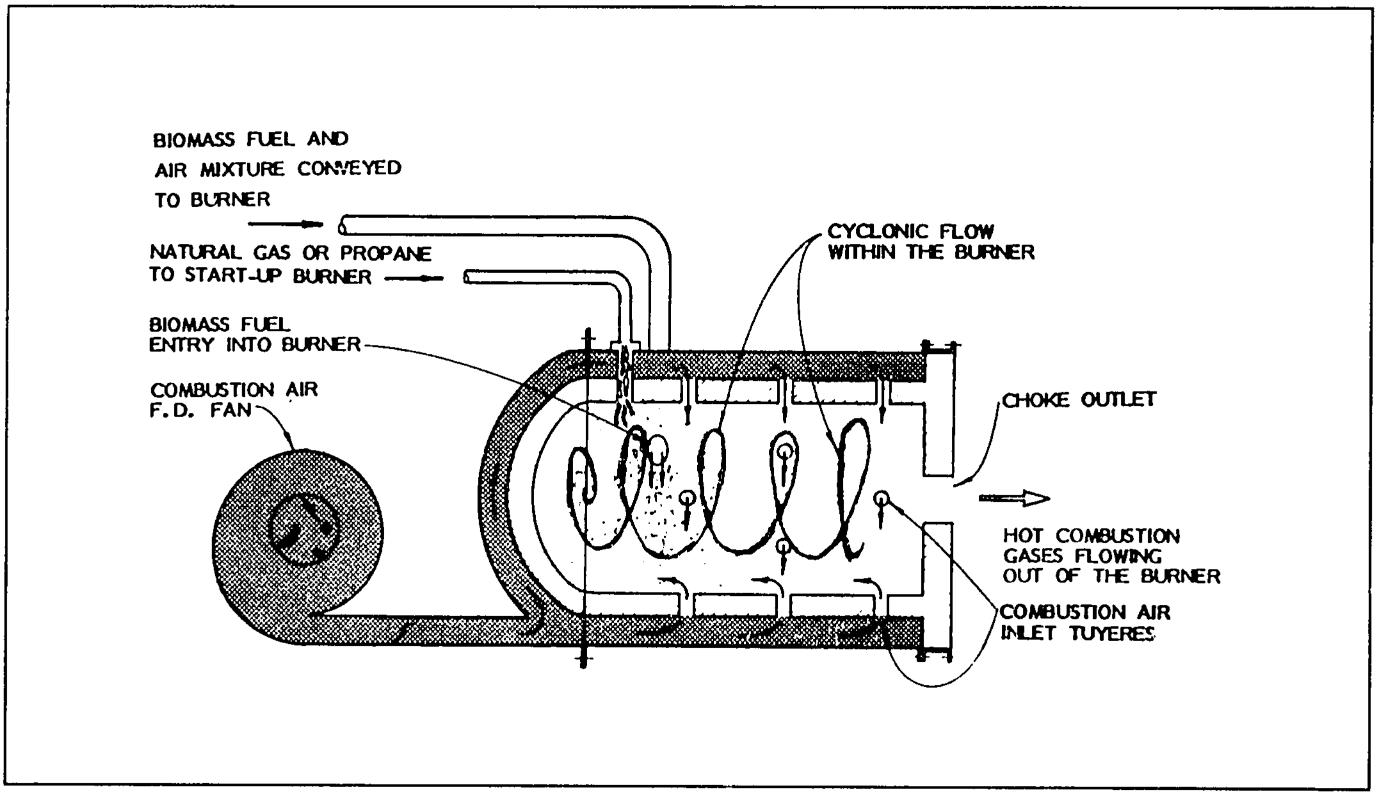

Fig. 9. Cyclonic suspension burner. (Source: *Biomass Energy Project Development Guidebook*, Bonneville Power Administration)

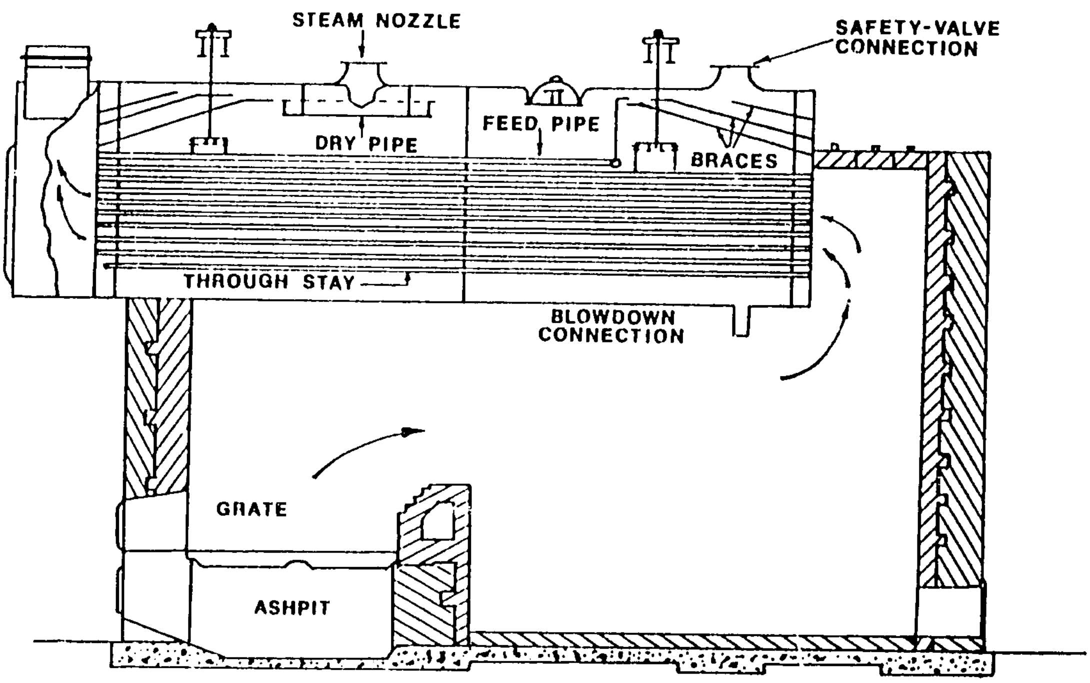

Fig. 10. Typical firetube boiler. (Source: *Improving Steam Boiler Operating Efficiency*, Georgia Office of Energy Resources)

wood wastes are 40% to 60% of the biomass fuel mixture; the balance is rice husks and rice straw. The plant was built and operated by Thermo Electron Corporation. The CFB boiler was provided by Gotaverken Energy Systems.[14] Energy Products of Idaho has built five fluidized-bed power plants fired with agricultural residues in California. These 12 to 32 MW plants burn wood residues as well as rice and wheat straw, cotton stalks, tree prunings, and nut shells.[15]

Boilers and Other Heat Transfer Systems

In some types of wood energy systems the combustion gases are used directly for industrial process heat or they pass through a heat exchanger to produce clean hot air for space heating. In the most common types of industrial wood energy systems and in virtually all wood-fired power plants, the heat is used in a boiler to produce steam. Steam can be used for space heating, for process heat, and to generate mechanical or electrical power. In some institutional and industrial systems, the boiler produces hot water for space heating rather than steam.

Many types of boilers are used in wood-fired systems. Relatively small systems usually have firetube boilers. In this type of boiler, the hot gases pass through tubes that are surrounded by water (Fig. 10). Design factors limit firetube boilers to outputs below 18,000 kg/hr (40,000 lb/hr) and pressures below 20 bar (300 psi).[16] Larger wood energy systems and power plants requiring higher steam pressures use watertube boilers. In watertube or waterwall boilers (.Fig. 11), the tubes contain water and are surrounded by hot gases.

Most smaller and medium-sized wood energy installations have "packaged" boilers that are built at the factory and shipped to the installation. Larger installations usually have "field-erected" boilers, which are assembled at the site using many factory-built components.

The efficiency of boilers varies widely depending on the design of the furnace and boiler, fuel characteristics, the effectiveness of the fuel stoking technique, the control of the combustion air, and other variables. Most of the boilers used in developing countries are rather old or old-fashioned units with low efficiencies.

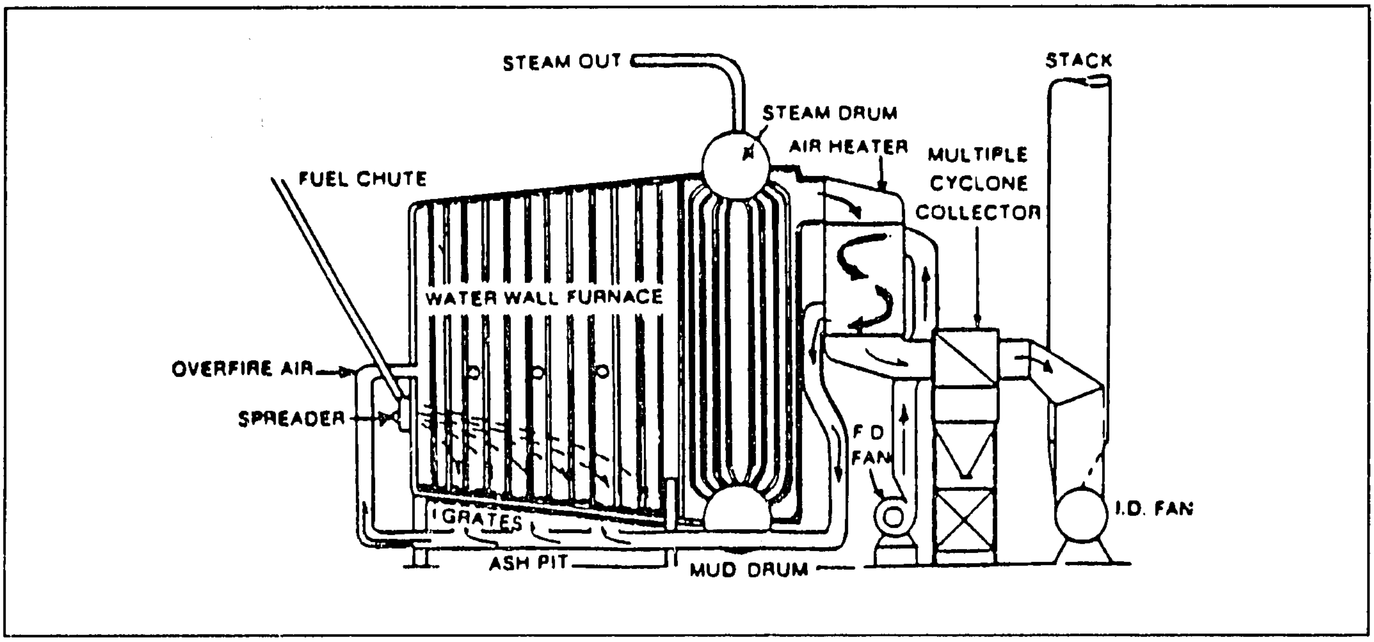

Fig. 11. Typical watertube industrial boiler with waterwall furnace. (Source: *Biomass Design Manual: Industrial Size Systems*, TVA)

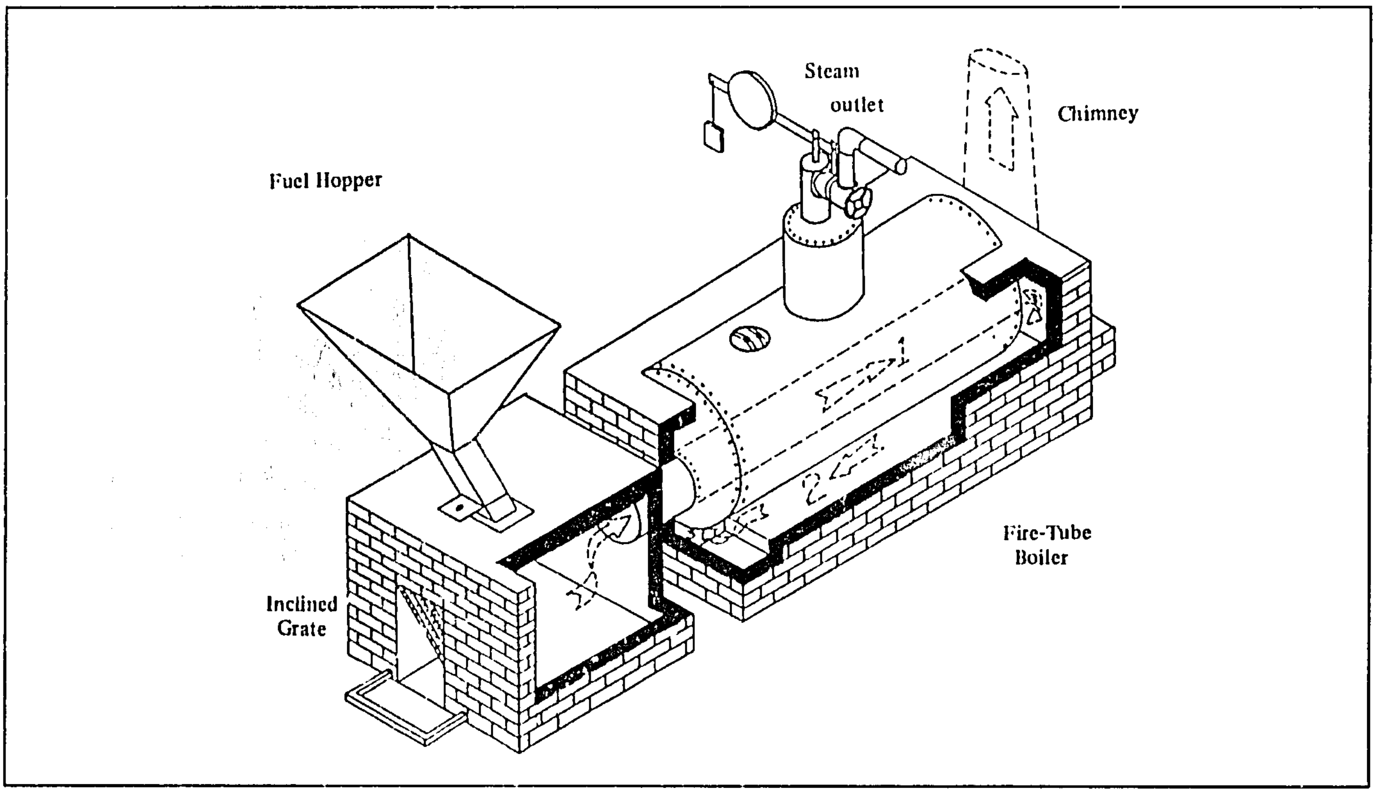

Fig. 12. Firetube boiler, Thailand. (Source: *Rural Energy*)

A type of firetube boiler common at rice mills (Fig. 12) has a fuel hopper and inclined grate for firing with rice husks. Similar installations at sawmills have steel furnace doors for manual feeding of slabwood. Hot gases flow from the pile-burning furnace through a large central firetube [1] inside the boiler tank and then pass around the outer surface of the tank [2] before exiting through the 20-meter high chimney.

Local boilermakers prefabricate the steel tank and experienced local furnace builders, who typically work without engineering drawings, custom-build the rest of the unit at the mill with firebrick and insulating brick. Such boilers provide steam at about 10 bar (150 psi) for the steam engines that provide direct mechanical power for approximately 2,000 rice mills and sawmills in Thailand.[17]

Systems provided by Konus-Kessel, a member of the Deutsche Babcock group, use hot oil as the heat transfer medium rather than steam or hot water. Pulverized wood fuels with up to 60% moisture are fed by a screw auger to the bottom of the fuel pile in the upright cylindrical burner. Air enters through side grates and through nozzles around the circumference of the burner. Hot gases rise through a coil of tubes containing oil. The heated oil supplies heat to a boiler, dryer, or other process.[18] As indicated in the next chapter, the Konus-Kessel systems are used in 24 particleboard, veneer, and other working plants in developing countries.

Notes

1. Nicholson Manufacturing Company, *Nicholson Wood Fuel Processor* (Seattle, n.d.).
2. West Salem Machinery Company, *Wood and Bark Hogs* (Salem, Oregon, n.d.)
3. M.S. White et al., "Effects of Outside Storage on the Energy Potential of Hardwood Particulate Fuels," *Biomass Abstracts* (Dublin: IRA Biomass Conversion Technical Information Service) 8(5):50, 1984.
4. M-E-C Company, *M-E-C Dryer Systems* (Neodesha, Kansas, n.d.)
5. ESMAP, *Ghana*, 2:89-109.
6. G&S Mill, Inc. *Industrial Wood Energy Systems* (Northborough, Massachusetts, n.d.).
7. Decton Iron Works, *Wood Waste Heating/Incineration* (Milwaukee, n.d.).
8. Virginia Division of Forestry, *Industrial Wood Energy: A Guide for Virginia* (Charlottesville, Virginia, 1985), 15.
9. D.L. Carver, *Equipment Selection for Stoker-Grate Firing of Wood* (Williamsport, Pennsylvania: Keeler/Dorr-Oliver Boiler Company [now Tampala Keeler], 1984).
10. Wellons, Inc. *Wellons Wood Fired Boiler Systems.*
11. Clifford T. McConnell, "Direct Fired Applications Using Dry Wood Residue," *Energy and the Wood Products Industry* (Madison, Wisconsin: Forest Products Research Society, 1976), 98
12. Ibid.
13. Dean B. Mahin, "Wood Fuels for Industry," *Bioenergy Systems Report* (Washington, D.C.: U.S. Agency for International Development), December 1982, 21.
14. Dave Precht (Thermo Electron Energy Systems), letter to author, 10 October 1989.
25. Michael L. Murphy, "Fluidized Bed Combustion of Agricultural Wastes: A Review of the Design and Operation of Five Plants," In *Energy from Biomass Wastes XV* (1991), 13 p.
16. Great Lakes Regional Biomass Energy Program, *Industrial/Commercial Wood Energy Conversion* (Chicago: Council of Great Lakes Governors, 1987), 34.
17. Naksitte Coovattanachai et al., "Steam Engine in Thailand," *Rural Energy* (Bangkok: FAO), 1989 (No. 2), 6.
18. Konus-Kessel Energy Systems, *Solid Fuel-Fired Energy Systems* (Atlanta, n.d.).

3. INDUSTRIAL PROCESS HEAT FROM WOOD RESIDUES

Process Heat for Forest Products Industries

Heat for Kiln Drying of Lumber

In the USA the most common industrial use of wood wastes is to provide heat for the kiln drying of lumber. The following descriptions of the residue-fired kiln drying systems at three companies in the USA and one in France illustrate the use of four types of combustion systems: a Dutch oven furnace, a suspension burner, a fixed-grate furnace, and a pile-burning system with an underfeed auger. The first two systems use dry residues from kiln-dried lumber, while the second two utilize wet sawmill residues. The first three systems heat the drying kilns with steam, while the fourth uses hot oil for heat transfer.

• Prior to 1974 the Burley Smith Lumber Company of Yazoo City, Mississippi, burned natural gas for the kiln drying of lumber. The lumber-surfacing firm contracted with Industrial Boiler Company to install a wood-fired boiler system. About half of the 4,350 tonnes (4,800 tons) of wood fuel burned annually is low-moisture planer shavings and hogged scrap wood produced on the site. Additional wood wastes are purchased from nearby lumber mills; the firm paid about $11/t ($12/ton) for wood wastes in 1986. The average fuel value is about 16.2 MJ/kg (7,000 BTU/lb). A screw conveyer carries the fuel from a storage silo or directly from automatically unloaded trailers. It is burned in an Dutch oven furnace and boiler that produces about 3,764 kg/hr (8,300 lb/hr) of steam at 10 bar (150 psi). The total wood energy system cost about $350,000. In 1986 it was producing annual savings of about $86,000; the payback period was about 4 years.[1]

• Stoltze-Conner Lumber Company of Darby, Montana, produces about 85 000 cubic meters (36 MBf) of lumber annually. Prior to 1983, the firm used an oil-fired boiler to produce steam for lumber drying kilns. Due to the doubling of the price of fuel oil, lumber drying was costing the firm about $210,000 per year. A new wood energy system burns about 13.5 t/day (15 tons/day) of dry planer shavings (8% moisture) in a suspension burner and produces 9,072 kg/hr (20,000 lb/hr) of steam for the kilns. The cost of the new system including a used boiler was $396,000. It paid for itself in 2.4 years.[2] The type of cyclonic suspension burner used in this system is shown in Figure 9.

• The Augusta Lumber and Supply Company of Staunton, Virginia, produces about 59 cubic meters (25,000 Bf) of lumber per day. In 1984 it installed a sawdust-fired boiler system that provides steam heat for four lumber-drying kilns. A screw conveyer carries 6,500 t/yr (7,200 tons/yr) of green sawdust (40 to 50% moisture) directly from the sawmill to the boiler room. A screen removes oversize pieces. Another screw feeds the sawdust into a Lambion fixed-grate furnace, where it is burned in partial suspension. A 350 HP Hurst waterwall boiler produces very low pressure steam (0.75 to 0.8 bar; 10 to 12 psi) that heats a large predrying chamber and four drying kilns. The system cost about $1 million. Augusta Lumber estimates that drying costs with the system are only about half those previously incurred in contracting with another mill for lumber drying.[3]

• Wet hardwood sawdust fuels four drying kilns at the Papin & Fils facility in western France. The firm imports tropical hardwood logs from Africa via the harbor at Nantes on the river Loire. The sawmill produces about 1,200 cubic meters of tropical timber per month. About 45 t/day (50 tons/day) of wet sawdust with 70% moisture is burned in a system from Konus-Kessel (see Chapter 2). Oil heated to 220°C transfers heat to four drying kilns with a total capacity of 500 cubic meters of timber. The system saves approximately 450 tonnes (495 tons) of fuel oil per year.[4]

In developing countries, although the lumber produced in most sawmills is air dried, kiln drying is becoming more common in countries that export significant quantities of lumber or that have substantial woodworking industries that require dry lumber. This conversion to kiln drying is likely to accelerate as a result of the European Communities decision to import only kiln dried lumber after January 1992.

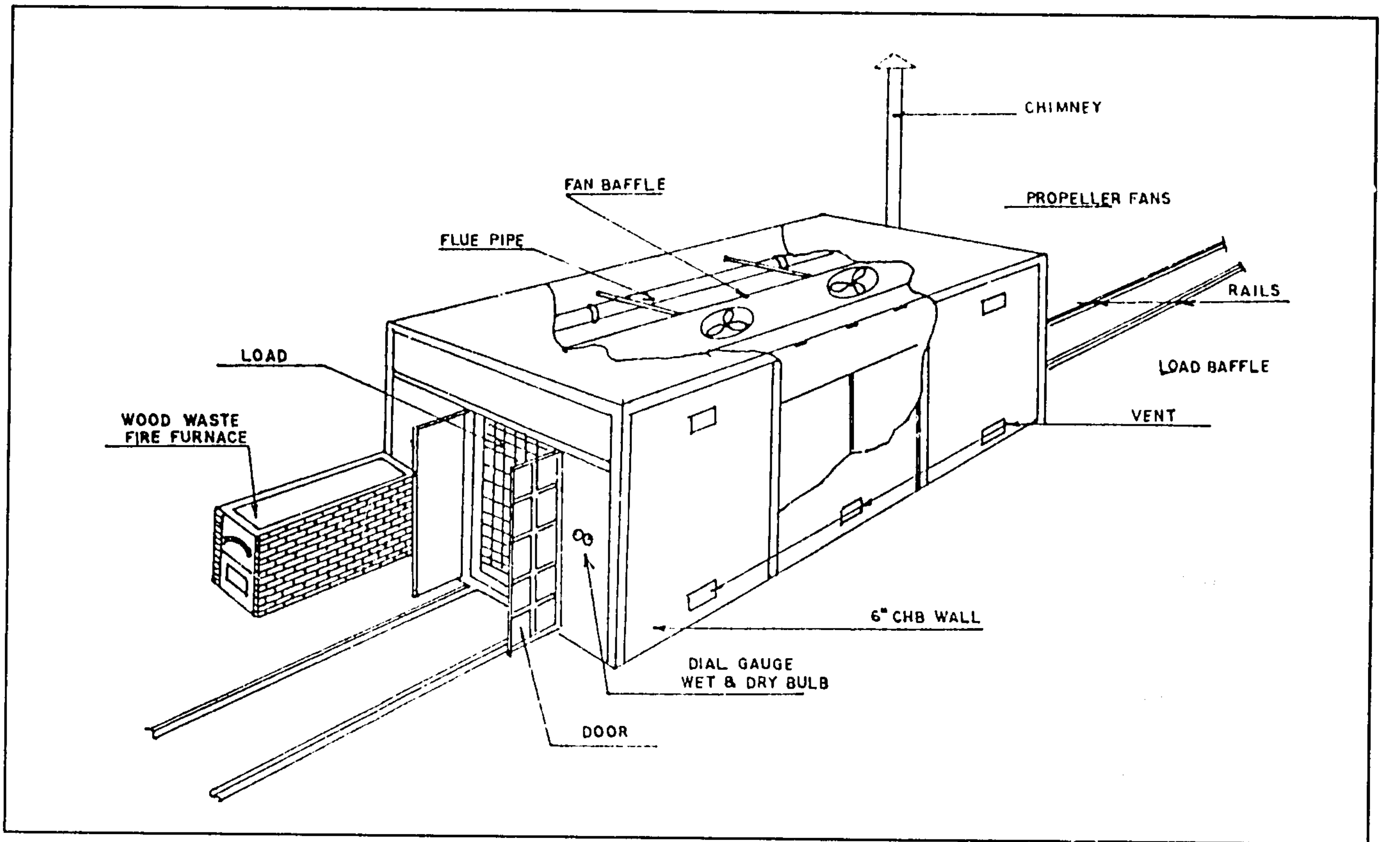

Fig. 13. Kiln drying with wood waste furnace, Philippines. (Source: "*Wood-based Energy System in Rural Industries, Philippines,*" FAO, Bangkok)

The Philippines annually exports over 300,000 cubic meters of lumber, of which 60% is kiln dried. In addition, of the 300,000 cubic meters of lumber used in the Philippine furniture and joinery industries, half is kiln dried. About 60 firms operate about 150 kilns ranging in capacity from 70 to 235 cubic meters. The larger kilns are usually heated with steam. Drying 1 cubic meter of 25 mm thick lumber requires about 315 kilograms of dry wood waste from furniture shops.[5]

A typical small lumber-drying kiln in the Philippines was described in a recent report published by the FAO Regional Office in Bangkok. The kiln (Fig. 13) has a rectangular brick Dutch oven furnace with grate bars. Wood wastes are manually fed through the furnace door, and ashes are removed from under the grate. A long horizontal flue pipe runs through the kiln, serving as an air-to-air heat exchanger. Fans on top of the kiln pull air through intake vents at the bottom of the kiln; the air is heated as it passes around the flue pipe. There is substantial loss of energy in these kilns due to the use of wet wood, poor firing practices, excess combustion air, heat loss from the open flame, and the high temperatures of the exhaust gas.[6]

The Natural Resources Institute, a unit of the British Government's Overseas Development Administration has developed and tested a system for heating lumber-drying kilns in developing countries by burning dry wood wastes. The unit (Fig. 14) uses dry sawdust and other pulverized dry residues from woodworking shops. A centrifugal fan sucks the fuel particles from a rotating table feeder and carries them to a suspension burner. The fuel feeding rate is controlled by adjusting the height of the hopper above the feeding table and the speed of the table's rotation. At startup the burner is preheated with a small fire; the fuel travels in a cyclonic path within the burner and burns completely in suspension.

The NRI system was tested in 1988/89 under commercial conditions at a woodworking shop in Belize that produces furniture, siding, and moldings. The burner consumed 17 to 19 kg/hr of dry sawdust and wood chips from the woodworking shop with 10% to 15% moisture. Combustion gases from the burner

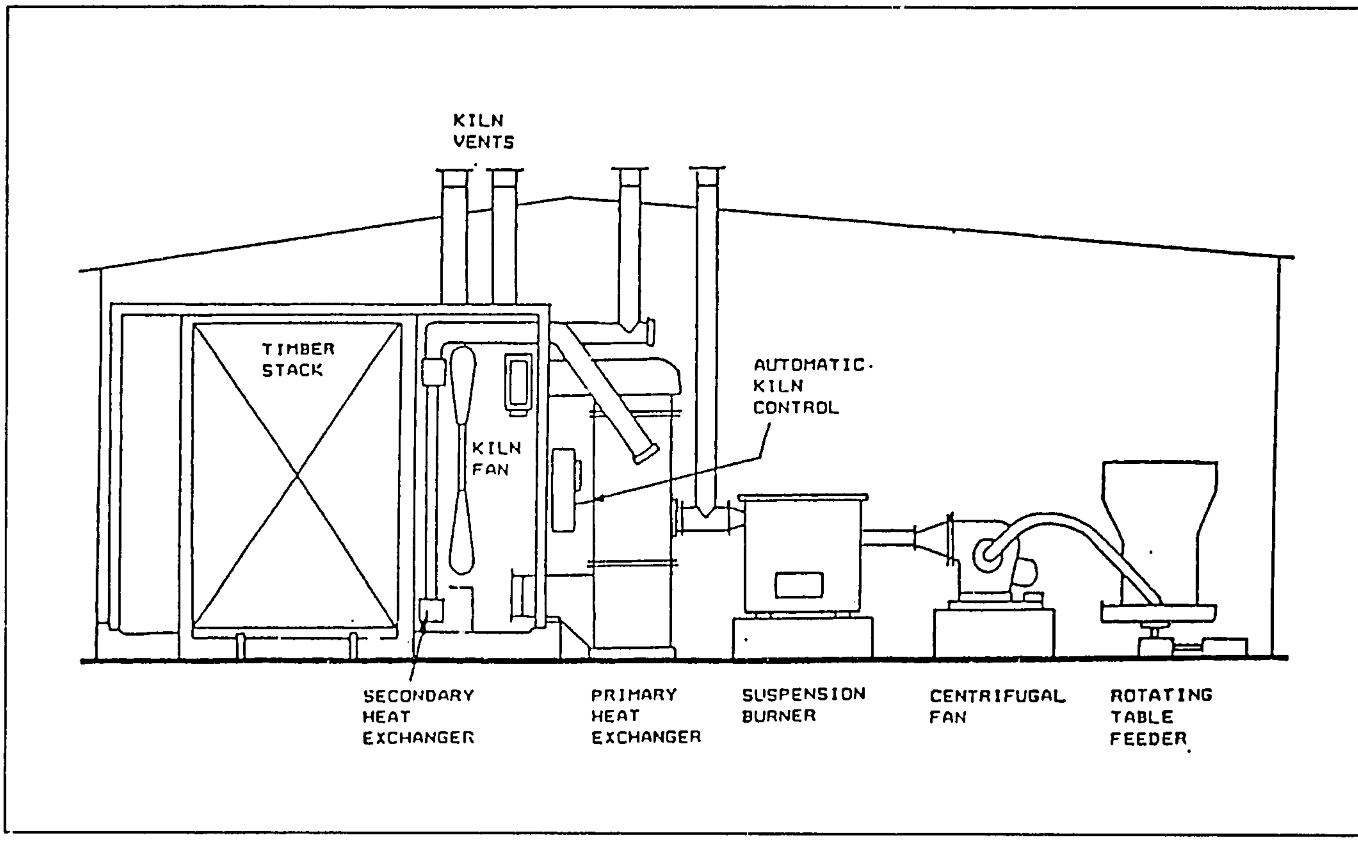

Fig. 14. Kiln drying with suspension burner, Belize. (Source: Natural Resource Institute, UK)

flow through a heat exchanger within the kiln, as in the Philippine kilns.

Due to an unexpectedly low heat transfer from the primary heat exchanger in the tests in Belize, a secondary heat exchanger was added. With the second exchanger, the gross heat output was 300 MJ/hr. The unit can burn up to 28 kilograms of fuel per hour and produce up to 500 MJ/hr. Future models will have only one heat exchanger, sized to match the output of the burner and the heat demand of the kiln.

The kiln in Belize was built of concrete blocks and had a capacity of 16 cubic meters (7,000 bf). In one 4-day test, 25-mm-thick mahogany boards, previously air dried to 30% moisture, were reduced to 10% moisture through 50 hours of burner firing. Pine boards of the same thickness, air dried to 32% moisture, were reduced to 7% moisture in a 4-day test with 65 hours of burner operation.

The NRI drying system is appropriate for small- to medium-scale sawmilling and woodworking industries processing 500 to 700 cubic meters (200,000 to 300,000 bf) of timber per year and for other installations with a supply of dry pulverized wood wastes and a demand for process heat. NRI is considering options for the commercialization of the system.[7]

In Ghana only a minor percentage of the lumber exported is kiln dried. However, the UNDP/World Bank team reported that demand for kiln drying is growing in Ghana as a result of the depletion of primary species and increased use of secondary species with higher moisture contents. In addition increasing numbers of producers hope to obtain added value for exported wood products through kiln drying. Air drying cannot reduce the moisture content to the 10% to 12% level required for the European market. Mill managers and exporters in Ghana estimated that kiln drying would increase the value of exported lumber by from 15% to 30% for redwoods and by 10% to 15% for whitewoods. In 1988 at least seven lumber mills in Ghana planned to add kilns heated by burning wood residues.[8]

The Winrock International team in Honduras noted that only a few Honduran sawmills use wood residues for kiln drying. However, the team concluded that kiln drying would have a significant impact on the value of 20% to 25% of the lumber produced at two surveyed mills and that the inclusion of kilns would require only 5% to 10% more total steam production by residue-fired power plants.[9]

The UNDP/World Bank team in Ghana evaluated a large proposed system for the steam heating of drying kilns at the privately owned Specialized Timber Products, Ltd. (STP) mill in Kumasi. STP planned to install six 150-cubic-meter kilns plus two log steaming vats. About 3.7 t/hr of steam at 5.3 kg/cm^2 (75 psi) would be produced by burning 11,000 t/yr of slabs, edgings, offcuts, and rejects with an average moisture of 38%.

The estimated total installed capital cost for the entire project including boiler system, kilns, and vats was about $1.2 million. The financial analysis indicated that the investment in kiln-drying capacity would be highly favorable from the entrepreneurial viewpoint. The cost of kiln drying was estimated at $16.60/m^3 for redwoods and $9.48/m^3 for whitewoods. The added market value would be $55.05/m^3 for redwoods and $21.00/m^3 for whitewoods, leaving net added values via kiln drying of $35.87/m^3 for redwoods and $10.04/m^3 for whitewoods.[10]

Process Heat for Plywood and Veneer Plants

All of the process heat requirements of the Williamette Industries plywood plant at Ruston, Louisiana, are met by a wood waste boiler system. About 80% of the 32,000 tonnes (35,000 tons) of fuel burned annually is wood waste from the plant, while 20% of the fuel is purchased. It is burned in suspension and on horizontal stationary grates in a watertube boiler. Average output is 9,979 kg/hr (22,000 lb/hr) at 17 bar (250 psi) and 204°C (400°F). The boiler and fuel handling system cost about $500,000 in 1972. Annual operating costs are around $200,000. The system saves the company about $570,000 a year in natural gas costs.[11]

In Indonesia, all of the 21 plywood factories surveyed for USAID in 1988 burn dry wood wastes generated in the factories to produce steam for dryers and hot presses. Typical waste has a moisture content of 23% and an energy content of about 15.3 MJ/kg (6,600 BTU/lb). In the 14 plywood plants that do not use steam for electricity generation, most of the boilers have capacities from 20 to 50 tonnes of steam per hour and produce steam at pressures from 15 to 21 kg/cm^2 (213 to 298 psi).[12]

The UNDP/World Bank study in Ghana identified 13 plywood or veneer mills that use residue-fired boilers to produce steam for rotary and sliced veneer dryers and for conditioning pits for veneer blocks and sterilization of log species subject to spore and fungus infestation. Boiler outputs ranged from 3 to 20 t/hr; steam pressures ranged from 3 to 23 bars (44 to 344 psi). The largest of these mills, Logs and Lumber, Ltd., in Kumasi, generates 25,365 cubic meters of residue annually and burns 14,744 cubic meters in three 15 t/hr boilers and one 3 t/hr boiler.[13] Another mill in Ghana that burns all of its residues in a cogeneration plant is described in Chapter 4.

Systems built by Konus-Kessel of Schwetzingen, Germany, with heat transfer via hot oil are providing process heat in 24 forest products plants in Africa, Latin America, and Asia: 4 veneer mills (Indonesia, Malaysia, and Singapore), 12 particleboard plants (Algeria, Tunisia, South Africa, Cuba, Brazil, Chile, Thailand, Indonesia, Malaysia and Singapore), and 8 other woodworking plants (Tunisia, Zambia, Malawi, Chile, Argentina, Malaysia, Singapore, and Philippines). The smallest units provide 4,200 to 10,500 MJ/hr (4 to 10 million BTU/hr). The largest installation is at a veneer mill in Indonesia, which has two Konus-Kessel systems producing a total of 52,740 MJ/hr (50 million BTU/hr).[14]

Data from the American Paper Institute indicates that residue fuels provided 56% of the total energy requirements of the U.S. pulp and paper industry in 1988. The industry burned 26.7 million tonnes (29.5 million tons) of unpulpable wood including dead trees, 14.4 million tonnes of bark, and 72.4 million tonnes of spent pulping liquors.[15]

Process Heat for Other Industries

In the areas of the USA in which wood residue fuels are available, they are used as boiler fuel in a wide range of nonforest industries. Many of these boiler systems are used primarily or exclusively for space heating. A series of case studies of biomass energy facilities in the southeastern USA found wood waste boilers producing process heat at plants that manufacture bricks, carpets, clothing, hosiery, leather, sausage casings, brooms and brushes, air conditioning units, and alcohol fuel. Descriptions of three systems from that study are provided below, along with one from New Zealand:

• Hampshire Hosiery's knitting mill at Spruce Pine, North Carolina, installed a wood waste system in 1981 to replace an oil-fired boiler that cost $300,000 per year to operate. The mill annually purchases about 8,200 tonnes (9,000 tons) of green wood chips and sawdust at 50% moisture from local sawmills at a cost of about $100,000 (about $12/t). The fuel arrives by truck. It is conveyed by a drag chain conveyer from the 11-tonne receiving hopper to a magnet that removes ferrous metal and then to a "hog" that grinds up slabs or oversize chunks of wood. A bucket elevator takes the fuel to a 15.8 meter (52 ft) high storage silo.

An automatically controlled auger feeds the fuel from the silo to the Dutch oven furnace and horizontal return tube (HRT) boiler. It produces up to 6,123 kg/hr (13,500 lb/hr) of steam at 7 bar (100 psi), which is used as process steam in the textile plant. The total system cost about $900,000. Net savings in energy costs are about $200,000 per year, and the payback period for the system was about 4.6 years.[16]

• Jack Daniels Distillery in Lynchburg, Tennessee, is the oldest and largest U.S. producer of premium whiskey. Prior to 1981, process heat and space heating were provided by boilers burning natural gas. In 1979-81 a new boilers was installed to permit the distillery to burn wood fuels. Until 1991, about 52,000 t/yr (58,000 tons/yr) of hardwood sawdust and whole tree chips at about 40% moisture were purchased from many suppliers through a fuel broker. Jack Daniels is now burning dry hardwood residues from discarded wooden pallets and crates provided by a wood-waste recycling firm. Due to the higher energy content of the dry residues, less fuel is required. The fuel handling system includes a truck dumper, dump bin, storage silo, magnetic metal remover, disc screen, hog for oversize particles, and trough belt conveyers. The fuel is gravity fed to spreader stokers, which distribute the fuel over a traveling grate of the type shown in Figure 8. The Keeler watertube boiler normally operates at 31,752 kg/hr (70,000 lb/hr). Steam at 11.5 bar (170 psi) is used for process heat (cooking, distillation, and cleaning) and for space heating.[17]

• A large steam plant, operated by Multitrade Group, Inc., near Martinsville, Virginia, burns mainly wood wastes and provides industrial process steam to six industrial customers in an adjacent industrial park. The plant buys wood chips and sawdust from local lumber mills. In 1986 the plant paid $11/t for sawdust and $12/t for chips. About 70% wood fuel is co-fired with 30% coal. The Keeler waterwall boiler has a traveling grate fed by a Detroit Stoker feeder. Average steam output is 30,391 kg/hr (67,000 lb/hr) at 14 bar (210 psi) and 210°C (410°F). The steam is distributed to the six industrial customers through 2,316 meters (7,600 ft) of steam lines. The total system cost $5.5 million; it produces about $3 million per year in revenue from steam sales. The largest customer is the Bassett Walker textile plant, which estimates that its annual fuel savings are about $700,000, not including the avoided cost of operating its own boilers.[18]

• Sawdust, bark, and chips from a nearby sawmill provide process heat for Hikurangi Cooperative Dairy Company, a large powdered milk plant in New Zealand. The wood waste is burned in a Konus-Kessel burner and hot oil transfers heat to two boilers producing a total of 25,000 kg/hr (62,500 lb/hr) of steam at 1,725 kPa (250 psi). The $1.1 million system was installed in 1979 by Konus-Kessel. It eliminated 80% of the cooperative's fuel bill and reduced New Zealand's fuel oil imports by 3,000 tonnes a year.[19]

In developing countries a wide range of small-scale industries utilize wood fuels for process heat. Most of this fuel is wood cut in the forest, but some is logging residue. Some of these small industries burn slabwood and scraps from nearby sawmills. The UNDP/World Bank team in Ghana found that bakeries, fish smokers, and small restaurants within a 10-kilometer radius of major wood processing centers were major users of sawmill slabs and edgings as fuel.[20] An FAO report says wood processing mills in the Philippines are good sources of fuelwood for small industries located nearby.[21]

Split pieces of slabwood from sawmills are used as fuel in traditional "snake" (tunnel) pottery kilns in Thailand. Roundwood is not easily fired through the small fuel ports of these kilns. Before firing, the wood is dried in storage or on the surface of the tunnel. A kiln 30-meters long uses about 28 cubic meters of sawmill wastes per charge.[22]

Few large industries in developing countries use logging or mill residues as fuel. Those that do, normally burn solid wastes; the industrial use of sawdust is especially rare.

A major Philippine sugar mill, the Victorias Sugar Milling Company of Negros Occidental, does not produce enough bagasse to meet its total needs for process heat and buys fuelwood from middlemen. The largest source is slabwood, log ends, and veneer cores purchased from sawmills. Some other sugar mills in the Philippines also buy fuelwood, some of which may be mill residues or logging residues.[23]

The UNDP/World Bank team in Ghana surveyed 61 industrial sites for energy use and found only one company (a brick and tile firm) that was a regular consumer of unprocessed sawmill residues. Another brick firm was a regular user of sawdust briquettes produced by a small plant operated by Chaowus, Ltd., in Akim-Oda, Ghana. In 1986 the plant was producing only about 1,100 tonnes of briquettes a year; about 60% of the sawdust consumed in the plant was used to heat the sawdust drier.[24] (This was the only instance of the industrial use of briquetted wood residues in developing countries identified during research for this report.)

A number of brick companies in the USA have installed systems that use sawdust to heat brick kilns. Isenhour Brick and Tile Company of Salisbury, North Carolina, drys about 23,000 tonnes (25,000 tons) of green sawdust annually in a rotary dryer and burns it in suspension to fire about a hundred million bricks per year. This use of sawdust saves the firm more than $1,000 a day in fuel costs.[25]

Although brick makers are major consumer of fuelwood in a number of developing countries, few use wood residues. The Central Building Research Institute in Roorkee, India, has developed and tested a kiln for firing up to 15,000 bricks that is heated primarily with sawdust or rice husks. At startup dry fuelwood is burned to raise the kiln temperature to 800°C. The firing temperature of about 1000°C is maintained for 3 to 4 hours by burning sawdust or rice husks in two small burners on each side of the brick kiln. The fuel is added through feeding holes and drops to a sloping grate. Heat is transferred to the bricks as the hot combustion gas passes through the rectangular kiln en route to the chimney at one end.[26]

The lack of low-cost technology for the industrial combustion of sawdust has greatly inhibited its use as fuel. The UNDP/World Bank team in Ghana evaluated options for retrofitting oil-fired boilers in several types of industries to permit them to burn sawdust, the only type of wood residue that is in abundant surplus in Ghana. The team assumed that in each system wet sawdust would be dried in a rotary dryer heated by flue gas from the boiler and that the dried sawdust would be burned in a suspension burner. The systems would also include mechanical equipment for screening and conveying the sawdust and facilities for dry storage of the sawdust. All of the equipment would be imported. The estimated total capital costs of the proposed installations ranged from $700,000 to $2,300,000. The team found no economic justification for retrofits with such high capital costs.[27] This is the only substantial effort to evaluate the economics of the use of sawdust as an industrial fuel in developing countries that has been identified during research for this report.

In Costa Rica, the UNDP/World Bank team examined the economic and technical feasibility of retrofitting oil-fired boilers and air heaters in several major industries to permit the burning of forest residues.[28] Some examples:

- Pretensados Nacionales, a producer of concrete products, currently uses wood from a company-owned forest in a locally built heat gasifier and Dutch oven furnace to produce steam heat for concrete curing. The wood is manually cut into small blocks using chain saws, axes, and hand saws. The team's analysis showed that a gasifier retrofit would also be an attractive investment if fired with logging residues that were collected by entrepreneurs, transported 150 kilometers, and sold to the concrete firm at $14.20/m^3.
- Fabrica Nacional de Licores is one of the largest distillers of alcoholic beverages in Costa Rica. The team examined the retrofitting of one of the firm's two oil-fired boilers with an imported wood gasifier.

The unit would be fueled with 12,000 m^3/year of logging residues that were transported 180 kilometers and sold to the distillery at $16/m^3. The residues would be chipped at the site in a 30-kW electrically powered chipper. Due primarily to the high price of the gasifier ($700,000), the analysis showed that the proposed investment would not be profitable at May 1988 oil prices, but could be attractive if oil prices rose 30%.

- In 1987 the energy system at the state-owned Industria Nacional de Cemento, the largest of two cement factories in Costa Rica, was adapted with USAID financing to permit the burning of petroleum coke, palmnut shells, and corn cobs in the plant's pre-calciner. Flame stability is boosted by a fuel oil burner. The UNDP/World Bank team examined the conversion of the pre-calciner and the plant's rotary kiln to burn forestry residues. The study assumed that the plant would burn 70,000 cubic meters (44,000 tonnes) of waste wood per year that would be transported 180 kilometers and chipped at the cement plant in two 10 t/hr chippers. The total fuel cost including chipping would be about $17/m^3$. The analysis indicated that the $3.6 million investment would be very profitable and would pay for itself in less than 1 year.

Notes

1. Meridian Corporation, *Case Studies of Biomass Energy Facilities in the Southeastern U.S.* (Muscle Shoals, Alabama: Tennessee Valley Authority, 1986), 37.
2. Pacific Northwest and Alaska Regional Biomass Energy Program, *Biomass Energy Project Development Guidebook* (Portland, Oregon: Bonneville Power Administration, 1987), 4-1.
3. Meridian Corporation, 69.
4. Konus-Kessel Energy Systems, *Dry Kiln Service Burns Mill's Waste* (Atlanta, n.d.).
5. P.V. Bawagan, *Wood Based Energy System in Rural Industries and Village Applications: Philippines* (Bangkok: FAO, 1989), 57.
6. Ibid, 14.
7. Alan Robinson, Natural Resources Institute, letter to author, 19 September 1990.
8. ESMAP, *Ghana*, 1:51.
9. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras: Industry Overview*, Office of Energy Report 91-05 (Washington, D.C.: USAID/Honduras and U.S. Agency for International Development, 1991), 24-25.
10. ESMAP, *Ghana*, 1:55.
11. Meridian Corporation, 36.
12. Biomass Energy Systems and Technology, *A Prefeasibility Assessment of the Potential of Wood Waste Power Systems for the Indonesian Wood Products Industry*, Office of Energy Report 88-17 (Washington D.C.: U.S. Agency for International Development, 1988), 25.
13. ESMAP, *Ghana*, 1:33.
14. Herr Deuster (Konus-Kessel Gesselschaft fur Waermetechnik), letter to author, 6 November 1990.
15. Michael Malloy, "Burning Hog Fuel," *Waste Age*, October 1990, 64
16. Meridian Corporation, 50.
17. P.C. Badger and C.D. Stephenson, "Case Studies of Two Industrial Wood Fired Boilers" (Tennessee Valley Authority, 1990, unpublished draft).
18. Meridian Corporation, 74.
19. Neil Rennie, "No Govt. Incentive but Hukurangi Steams Ahead," *The New Zealand Farmer*, 10 January 1980.
20. ESMAP, *Ghana*, 1:37.
21. Bawagan, 45.
22. S.C. Bhattacharya, *Wood Energy for Rural Industries: Thailand* (Bangkok: FAO, 1986), 7.
23. P. V. Bawagan, *Wood Based Energy System in Rural Industries and Village Applications: Philippines.* (Bangkok: FAO, 1989), 41.
24. ESMAP, *Ghana*, 1:37.
25. Meridian Corporation, 51
26. Satya Prakash, "Biomass Residues As Renewable Source of Energy to be Used as Fuel in Various Industries" (Central Building Research Institute, unpublished)
27. ESMAP, *Ghana*, 2:88.
28. ESMAP, *Costa Rica*, 1:58-62.

4. MECHANICAL AND ELECTRICAL POWER FROM WOOD RESIDUES

Power For Forest and Other Industries

Mechanical and Electrical Power From Steam Engines

In the 19th and early 20th centuries, most sawmills were operated with steam engines supplied by wood-fired boilers. By the middle of the 20th century, most steam engines had been replaced by diesel engines or by electric motors, but they still provide power for sawmills in a few countries.

In Thailand, researchers at Prince of Songkhla University estimated recently that around 2,000 steam engines provide mechanical power for sawmills and rice mills. Steam is usually generated in a horizontal locomotive-type firetube boiler. A boiler often used with these engines is shown in Figure 12. At one sawmill in Thailand, 60 kg/hr of wood waste is burned to produce 650 kg/hr of steam for a 52 HP steam engine. At a larger Thai sawmill, 100 kg/hr of wood residues is burned producing 700 kg/hr of steam for a 78 HP engine.

Most of these steam engines in Thailand are horizontal, compound-cylinder models with a common piston rod connecting the pistons. Although efficiencies are low, the engines are reliable and durable. Many of the engines have been in operation for over 30 years. At least seven companies in Bangkok custom build steam engines to fit the power requirements and fuel supply of the buyer. Some engines have cylinder bores as large as 45.7 centimeters (18 in) and flywheel diameters as large as 4.8 meters (16 ft). A low-speed 35 HP steam engine costs about $11,000, while a 101 HP engine costs $27,500.[1]

Steam engine power systems fueled with sawmill residues were installed in the mid-1980s at two sawmills in Honduras under FAO's Wood for Energy Project, which promotes the development of small rural power systems. Both installations include a "locomobile," a boiler/engine unit resembling a locomotive, which was widely used earlier in this century. One engine, at the National School of Forestry Sciences (ESNACIFOR) sawmill at Siguatepeque is rated at 64 kW (85 HP). Another one rated at 36 kW (50 HP) is installed at Chaguite Grande, a small forestry village, provides electricity for a sawmill operated by an association of workers and for the village.[2] In both systems, a belt drive links the large flywheel with a generator.

The locomobile system at the ESNACIFOR sawmill burns 0.19 tonnes of wood wastes per hour and 334 tonnes during a 1,750-hour annual operating period. The system produces 67,200 kWh/year, an average of about 38 kW/hr and 201 kWh per tonne of wood wastes. An economic analysis indicated that the installed capital cost of the ESNACIFOR system ($76,660) was nearly twice that of a diesel generating set of comparable capacity ($39,980). Due to the high capital cost per kilowatt of capacity (about $2,000/kW), the short annual operating period, and the $10/ton opportunity cost of wood residues, the unit cost of power from the locomobile system was high ($0.35/kWh) although lower than that from a diesel system with the same annual operation and output ($0.43/kWh).[3]

Large steam engines built by Mernak S.A. are reported to be producing power from wood residues at sawmills in at least three African countries. The large steam engines are similar to models that were widely used for industrial purposes early in the 20th century. The generator is powered by a belt drive from one of the engine's two large flywheels.[4]

A 1.2 MW cogeneration system in Africa built by Spillingwerk Gmbh uses Spilling steam motors, which combine some characteristics of a piston-type steam engine and some of a diesel engine. The Spilling system provides electric power and steam for wood drying at a sawmill that processes tropical hardwoods on the Sanga River in the Central African Republic. The mill produces 5.2 t/hr of chips, sawdust, and slabwood with 40 to 60% moisture. A screw conveyer feeds chips and sawdust from the 150 cubic meter fuel bunker to the step grate furnace; slabwood is added to the furnace manually via an air lock.

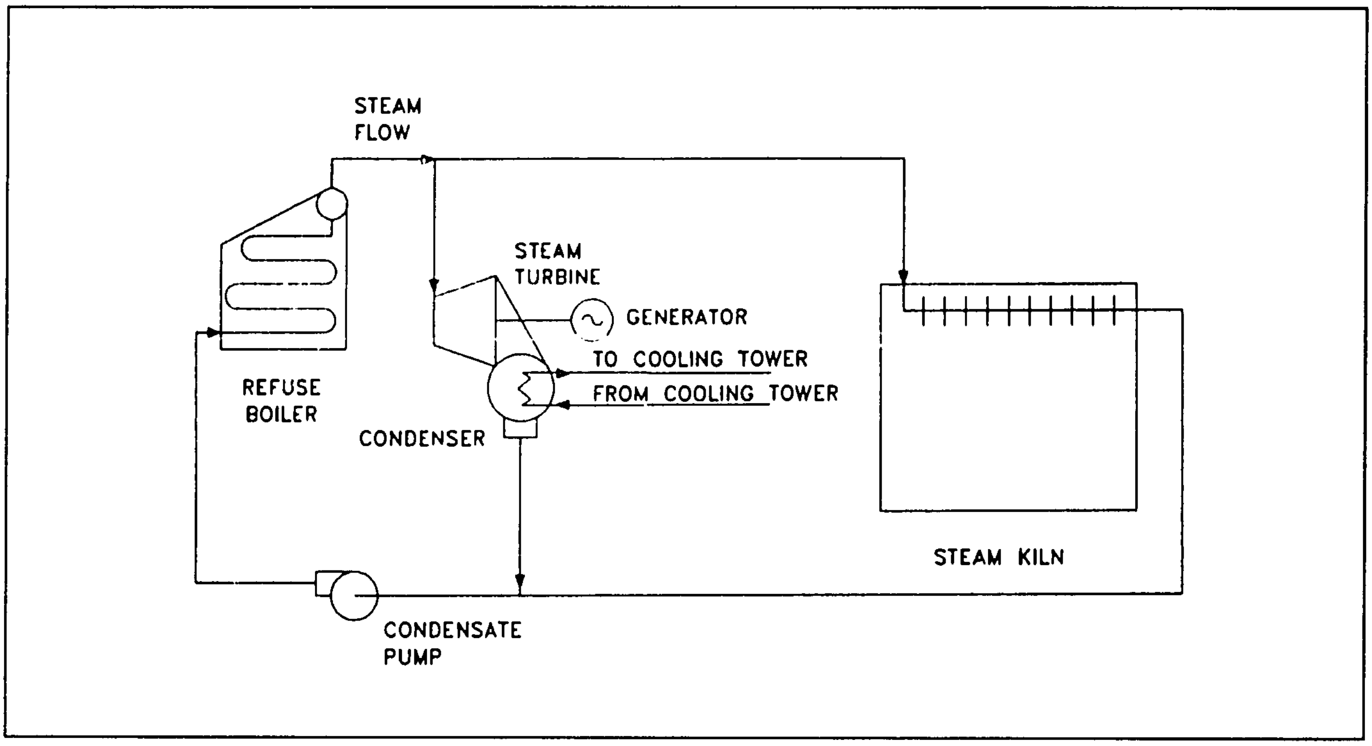

Fig. 15. Cogeneration in a sawmill with condensing turbine cycle. (Source: *Design Manual for Small Steam Turbines,* TVA)

The three-pass boiler produces 17,000 kilograms (37,500 lb) of steam per hour at 18 bar (264 psi). Most of the steam is used in two four-cylinder Spilling steam motors; each drives a 600 kW synchronous generator. The steam consumption is 13.3 kg/kWh. The total power output (1,200 kW) is used in the sawmill and in the homes of employees. Exhaust steam from the Spilling motors at 0.5 bar (7.3 psi) is used for wood drying.[5]

Electric Power Generation With Condensing Turbines

In a system with a condensing turbine cycle (Fig. 15), exhaust steam is not used for process heat. The turbine exhaust flows to an air condenser or to a condenser cooled by water. Because the steam enters the turbine at a high pressure and is exhausted from the turbine at low or negative pressure, the energy in the steam is fully utilized for electricity generation.

A design manual published by the Southeastern Regional Biomass Energy Program indicates that a typical single-stage condensing turbine/generator with a 17 bar (250 psi) boiler pressure and 0.7 bar (-10 psig) condensing pressure uses 14.2 kilograms (31.5 lb) of steam to generate a kilowatt-hour of power.[6] Systems operating at higher pressures require less steam per kilowatt-hour. Wellons, Inc., a major builder of wood-fired boiler systems, indicates that a condensing turbine with 20 bar (300 psi) inlet pressure and 10-cm Hga (4-in Hga) exhaust uses 6.8 kilograms (15 lb) of steam per kilowatt-hour.[7] Condensing turbines at several Indonesian plywood factories use 5.45 kg/kWh (12 lb/kWh) at 34 bar (500 psi).[8]

The actual steam rate (measured in kilograms per kilowatt-hour) of steam turbines varies considerably an depends on the inlet and outlet steam conditions and the size, speed, and design of the turbines. Data for specific cases is available in engineering handbooks or from turbine manufacturers.

Wellons indicates that a 20.4 bar (300 psi) condensing turbine system burning fuel with 50% moisture should produce around 440 kWh/t (400 kWh/ton) of fuel. A typical Wellons plant includes an economizer and a combustion air preheater (Fig. 6). The fuel rate is about 2.25 t/MWh (2.5 ton/MWh). This output per tonne of fuel is more than twice that of a backpressure (noncondensing) turbine with the same fuel and inlet pressure but an exhaust pressure of 1.36 bar (20 psi).[9] The UNDP/World Bank team in Ghana calculated that a 1.2 MW system using fuel with 34% moisture and operating at 23 kg/cm^2 (327 psi) would produce 350 to 385 kWh/t (312 to 343 kWh/ton) of fuel.[10]

A condensing turbine is appropriate for a facility that has no requirement for process heat, a boiler capacity substantially in excess of process steam requirements, or a residue supply sufficient to fuel separate boilers for process steam and for power generation.[11] Condensing turbine systems operated by three U.S. forest products industries are described below. (Four other power plants with condensing turbines are described later in this chapter under "Power For the Grid.")

• Pate Lumber Company, which operates a sawmill, dry kilns, and planer mill in Carrollton, Alabama, produces 40,000 cubic meters (17 MBf) of lumber annually. Until the late 1980s, most of its sawdust was being sold as fuel or poultry bedding, but continuing sales were doubtful and the firm was concerned about high future disposal costs. In 1989 Pate contracted with Southern Engineering and Equipment Company for a residue power plant.

The system was designed to burn 45 t/day (50 tons/day) of green sawdust and 18 t/day of bark. Due to a favorable market for bark for landscaping, no bark is burned at present. The 400 HP firetube boiler operates at 9.5 bar (140 psi). The steam is used in a condensing turbine linked to an induction generator with a capacity of 350 kW. Exhaust steam is condensed in a surface condenser cooled with water from an evaporative cooling tower. The cooling system uses 20 to 25 gallons (75 to 84 liters) per minute from the local public water system. Pate continues to burn dry planer shavings in a separate 250 HP boiler to provide steam for lumber-drying kilns.

The new power plant (boiler, turbine, generator, and other equipment) cost about $400,000 or about $1,140/kW. If it burned both sawdust and bark, it could eliminate the mill's previous $10,500 monthly power bill and pay for itself in about 3 years. Without the bark, the power bill is about $3,500/month and the payback period will be somewhat longer.[12]

• Before installing a 1 MW cogeneration system, the Huey Forest Products in Arenzville, Illinois, deposited its daily output of 72.5 tonnes (80 tons) of wood wastes in a landfill. The new system is designed to burn 36 tonnes of bark, 54 tonnes of sawdust, and 7 tonnes of waste wood every day. The fuel is pulverized in a processor/grinder and a five-knife chipper. It is fed by screw conveyers to a Dutch oven furnace and watertube boiler that produces 13,608 kg/hr (30,000 lb/hr) of steam at 17 bar (250 psi). The steam is used in a condensing turbine linked to a 1,000 kW generator that meets all of the mill's power requirements. Surplus steam at 1 bar (15 psi) heats five lumber-drying kilns.[13]

• The M.C. Dixon Lumber Company of Eufala, Alabama, produces about 2,000 cubic meters (850,000 Bf) of lumber per week. In 1979 a cogeneration system was installed by Southern Engineering and Equipment Company. The Wellons watertube boiler burns sawdust, bark, and planer shavings at 45% moisture. Average output is 22,680 kg/hr (50,000 lb/hr) at 20 bar (300 psi). Most of the steam is used in two condensing turbine generators producing a total of 2,500 kW. Some of the steam is used in two steam-heated drying kilns. Dixon Lumber formerly paid $35,000 a month for natural gas for a single kiln as well as about $25,000 per month in electricity costs. The total residue power system cost about $2 million but produces net savings in energy costs of about $373,000 per year. The payback period was about 5.3 years.[14]

Southern Engineering and Equipment Company, which installed two of the power systems described above, expects to provide a 500 kW condensing turbine system for a mahogany sawmill in Honduras in 1991. The sawmill's existing 5,806 kg/hr (12,800 lb/hr) boiler is hand-fired with slabwood and provides steam at 12 bar (175 psi) for lumber drying. Up to 1,100 kW of power is provided by two diesel generating sets. The boiler is being prepared for automatic firing with pulverized residues, and surplus steam will be used in the new turbine. If the initial unit operates satisfactorily, a second boiler and turbine may be installed to eliminate the use of diesel power.[15]

A survey for the U.S. Agency for International Development in 1988 indicated that seven Indonesian plywood factories generate electric power in wood-fired power plants with condensing turbines. Three of the factories have large boilers that produce 50 to 60 t/hr of steam at about 35 kg/cm^2 (497 psi) and around 380°C (716°F). The turbines in these plants produce 6.0 to 6.8 MW and meet all of the power requirements of the plywood factories. Four other Indonesian plywood factories have smaller systems with boilers producing 20 to 30 t/hr of steam at pressures ranging from 19 to 34

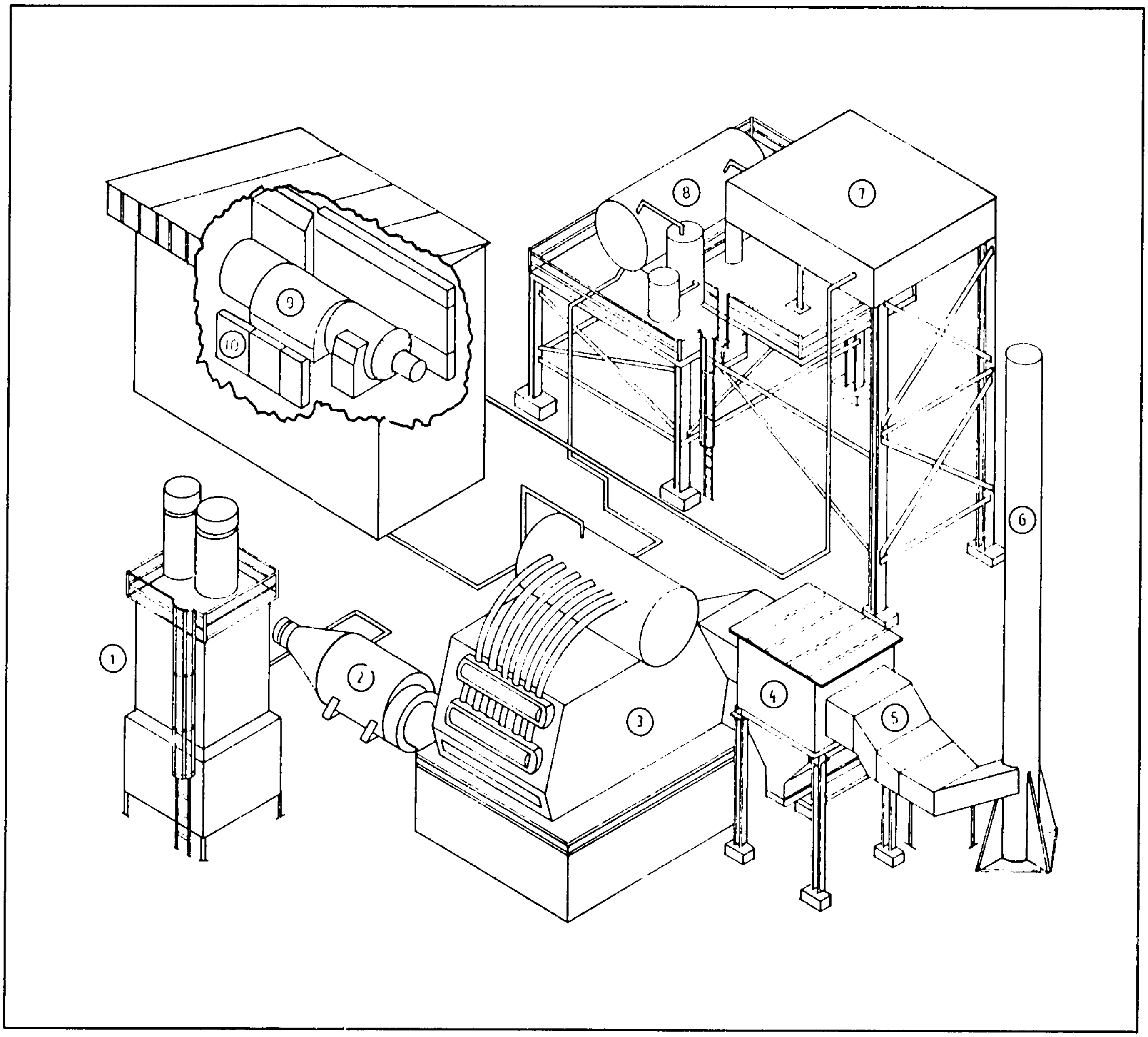

Fig. 16. Schematic diagram of a mini power station with condensing turbine, Malaysia. It includes a (1) fuel silo, (2) cyclonic burner, (3) Towler watertube boiler, (4) multiclone dust collector, (5) chimney ducting, (6) stack, (7) condenser, (8) deaerator, (9) turbine, and (10) electrical switchgear. (Source: MechMar Energy Sdr. Bhd., Malaysia)

kg/cm^2 (270 to 483 psi). The turbine generators produce from 2.2 to 2.5 MW. Each of these factories also has from two to seven diesel generators providing total outputs ranging from 225 kW to 1,450 kVA.[16]

MechMar Energy, Malaysia, has built three power plants fueled with wood wastes at forest products industries in Malaysia. A power plant producing 1,000 kW from chipped wood wastes was installed in 1988 at Syarikat Minho Kilning's facility in Kapar, Selangor. A second unit producing 1,200 kW was installed at the same facility in 1990.

MechMar's latest plant was commissioned in March 1991 at Hong Kong Teak's timber moulding factory at Kulasi, Johore, Malaysia. A shredder produces wood chips from log ends, center cores, shavings, and bark. About 3,538 kilograms (7,800 lb) of chips per hour are burned in a Titan Towler boiler that is designed with a water-cooled pinhole grate. The condensing turbine uses 11,203 kg/hr (24,700 lb/hr) of steam at 22.4 bar (325

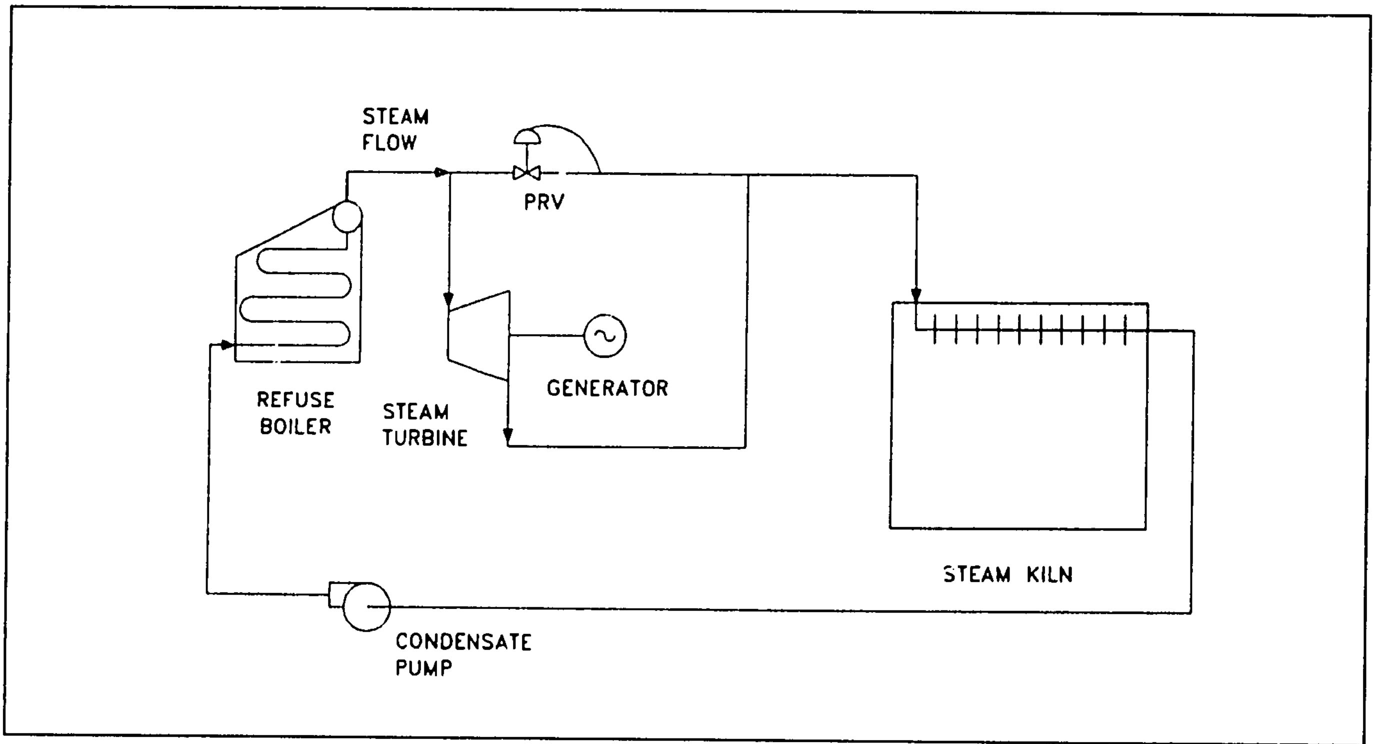

Fig. 17. Cogeneration in sawmill with noncondensing turbine (Source: *Design Manual for Small Steam Turbines*, TVA)

psi) and drives an alternator producing 1,400 kW. Exhaust steam is condensed in a tube-in-shell condenser with a two-cell, crossflow type cooling tower. MechMar estimates that if the factory operates 24 hours a day and 30 days/month and the cost of grid power remains stable, the power plant will pay for itself in about 2 years. A MechMar power plant with a cyclonic burner is shown in Figure 16.[17]

A 1,200 kVA wood residue power plant was installed in 1989 at Tanzania's largest timber products mill, SAO Hill Sawmill, Ltd. The mill complex includes a sawmill processing 60,000 cubic meters of logs annually, two planing mills, two pressure treating plants, a pole peeling plant, and associated shops producing prefabricated houses, furniture, and other items. These facilities generate about 30,000 cubic meters of wood residues annually. The total power requirement (up to 700 kW) was previously met with diesel generating sets.

The new power plant was installed with assistance from NORAD (the Norwegian development agency) through the Norwegian Forest Industry and Environmental Consulting Company. The power plant burns sawmill slabs and sawdust with 30% to 50% moisture and dry scraps and shavings from the wood processing shops with only 10% to 20% moisture.

The power plant includes a large furnace of refractory brick, an inclined water-cooled grate, and a firetube boiler producing steam at 26 bar (382 psi) and 800°C to 1050°C (1472°F to 1832°F). An automatically controlled fan provides the amount of combustion air needed to maintain the steam pressure at a preset level. The turbine inlet pressure is about 23 bar (1,338 psi). The turbine is linked to a 1,500 RPM generator producing 1,200 kVA. At present exhaust steam flows to condensers, and condensate is recirculated. In the future some of the exhaust steam will be used for kiln drying of lumber to meet special requirements in the building and furniture industries.[18]

Cogeneration of Electric Power and Process Heat

In a cogeneration system with a noncondensing or "backpressure" turbine, exhaust steam from the turbine is used for process heat (usually in a steam-heated kiln for lumber drying, as shown in Figure 17). To permit its further use, the steam is normally exhausted at a somewhat higher pressure than in a condensing turbine cycle. For this reason, a noncondensing turbine produces less electricity per kilogram of steam than a condensing turbine.

The *Design Manual for Small Steam Turbines* specifies that a single-stage noncondensing turbine using steam at 17 bar (250 psi) and exhausting process steam at 1.0 bar (15 psi) needs about 20.8 kilograms (43.6 lb) of steam to produce a kilowatt-hour of power, in contrast to 14.2 kg/kWh (31.5 lb/kWh) for a condensing turbine at the same inlet pressure.[19] Wellons Inc. indicates that a backpressure (noncondensing) turbine system burning fuel with 50% moisture with a 20 bar (300 psi) inlet pressure and 1.3 bar (20 psi) exhaust pressure would need about 18 kilograms (40 lb) of steam per kilowatt-hour. This system would produce about 165 kWh/t (150 kWh/ton) of fuel, less than half the output of a condensing turbine with the same fuel and boiler pressure.[20]

Cogeneration systems with noncondensing turbines are appropriate in forest products industries that need both process heat and electric power and have a serious waste disposal problem and thus consider high fuel consumption rates an advantage. Such systems have been installed in a considerable number of lumber and millwork firms in the USA that need steam for lumber-drying kilns. Some examples:

• Savage Lumber Company of Doyle, Tennessee, produces 35,000 cubic meters (15 MBf) of hardwood products annually, including flooring, dimension lumber, and hardwood for furniture. The firm generates about 45 tonnes (50 tons) of hardwood wastes per day. Until 1990, some of the residues were burned in a suspension burner and boiler to produce steam for the firm's lumber-drying kilns, some were sold to paper mills, and large quantities were dumped and left to rot. Under a project assisted by the Tennessee Valley Authority, the firm contracted with Southern Engineering and Equipment Company to design and install a cogeneration system to use a larger percentage of these residues.

The new system uses about 25 tonnes (28 tons) of residue per day, about half of the mill's residue output. Two thirds of the fuel is very dry sawdust and planer shavings (6 to 8% moisture) from the kiln-dried lumber processed in the firm's dimension lumber mill. The remaining 40% is green sawdust from the sawmill at about 80% moisture. The wet and dry sawdust is mixed before firing to keep the moisture content low enough for satisfactory firing in a suspension burner.

The 300 HP (10.5 GJ/hr) boiler produces steam at 15 bar (225 psi), that is fed to a backpressure (noncondensing) turbine. It drives a 200 kW induction generator that provides about 30% of the mill's power requirements. Exhaust steam from the turbine at 1 bar (15 psi) heats the firm's lumber-drying kilns as well as the mill buildings. The cogeneration installation is expected to pay for itself in less than 3 years.[21]

• Brattleboro Kiln Dry and Milling Company (BKD) of Brattleboro, Vermont, a subsidiary of a lumber company, operates 16 dry kilns that were formerly heated by an aging wood-fired boiler. Faced with steadily climbing rates for grid power, BKD contracted with Ewing Power Systems to design and deliver a cogeneration package.

The new system burns green wood scraps from the parent company's sawmill plus dry scraps and shavings from BKD's millwork production. The fuel is stored in a 52 foot (15.8 m) tall silo and is fed to the boiler by a variable-speed metering system that adjusts the fuel feeding rate to BKD's varying demand for steam. A new 660 HP boiler currently produces about 6,350 kg/hr (14,000 lb/hr) of steam at 15.4 bar (220 psi). It is fed to a backpressure (noncondensing) turbine linked to an induction generator with a capacity of 380 kW. Exhaust steam from the turbine at 0.7 bar (10 psi) heats the lumber-drying kilns.

The amount of electric power generated at BKD at any time depends on the steam demand at that time, but does not exceed the firm's power demand. During Vermont's cold winters, more steam is needed to heat the kilns, so the boiler is fed at a higher rate and the cogeneration system produces more than half of the electric power used in the mill.[22]

• Dean Lumber Company Inc. of Gilmer, Texas, produces about 236 cubic meters (100,000 Bf) of lumber per day. In the early 1980s the firm was paying $12,000 to $15,000 per month for electric power and up to $15,000 a month for natural gas for two lumber kilns. Wood residues were trucked 200 kilometers (125 miles) and sold as fuel to a paper mill, but these sales generated little net income after trucking costs. In 1985 the firm contracted with Wellons, Inc. for a complete new wood waste cogeneration system.

The Wellons single-cell cyclo-blast furnace is similar to the double-cell unit shown in Figure 6. It burns 11 cubic meters (400 ft^3) per hour of softwood sawdust and bark with 30% to 40% moisture. The boiler produces 9,072 kg/hr (20,000 lb/hr) of steam at 21 bar (310 psi) that is fed to a noncondensing turbine. The generator produces 500 kW and meets about 60% of the power requirements of the sawmill. Exhaust steam at 1.36 bar (20 psi) is used in three lumber-drying kilns. The system has saved the firm about $8,000 to $10,0000 a month in power bills and now also saves $30,000 per month in natural gas bills, because it is providing heat for an additional kiln. Payback for the system is estimated at about 7 years.[23]

Many pulp and paper plants in North America have cogeneration plants burning wood wastes. A recent survey indicated that over 1,800 MW of power was being generated with biomass fuels in 13 states in the southeastern U.S., mostly in cogeneration systems in pulp and paper plants.[24] Two examples of large cogeneration systems:

- A 16 MW cogeneration system burning wood wastes was installed in 1982 at the Stone Container Corporation's paperboard mill at Coshocton, Ohio. Residues are purchased from nearby sawmills and furniture plants at about $14/t ($13/ton). About 70% of the fuel is sawdust; the rest is bark and other mill residues. The fuel is delivered in 27-tonne (30-ton) trucks and unloaded on two hydraulic truck dumpers. It is conveyed to two large hoppers, to a metal detector that removes tramp iron, and to a rotating disc screen classifier that removes any piece of wood over 7.6 centimeters (3 in). Oversize pieces go to a grinder (hog) for size reduction.

About 1,090 t/day (1,200 tons/day) are burned in a Babcock and Wilcox pile-burning boiler designed to accept fuel with 50% moisture. The system has a capacity of 16 MW of electric power and 181,440 kg/hr (400,000 lb/hr) of process steam. It provides 40% of the mill's electric power and 83% of the mill's process heat. The wood energy system cost $35 million, but it saves over $20,000 a day in energy costs and paid for itself in 3 years.[25]

- St. Joe Forest Products Company's mill at Port St. Joe, Florida, produces 1,270 t/day (1,400 tons/day) of Kraft linerboard that is used in corrugated containers. The mill's present cogeneration system includes six turbines supplied with steam by four boilers. A 272,160 kg/hr (600,000 lb/hr) boiler replaced several smaller units in 1983. It burns 1,550 t/day (1,700 tons/day) of biomass fuel and 200 barrels/day of #6 fuel oil and produces steam at 85 bar (1,250 psi) and 485°C (905°F). About 30% of the biomass fuel is chips and bark generated in the mill; the rest is purchased through fuel dealers and consists of bark, sawdust, shavings from nearby mills and hardwood chips from whole tree chippers. The maximum power output of the total system is reported to be 40 MW, but actual output depends on the mill's need for process steam. Exhaust steam is extracted from the turbines at pressures of 14, 9.8, and 4.9 bar (200, 140, and 70 psi) and used as process heat in the mill. The company indicates that increased use of biomass and improved boiler efficiency has reduced the use of fuel oil by approximately 1,000 barrels per day.[26]

In developing countries, the cogeneration of electric power and process heat has been rare in the forest products industries due to the lack of a requirement for process heat at most sawmills, the low cost of subsidized power from the grid, and other factors.

In Ghana all but three of the major sawmills are located on the grid, and the relatively low price of grid power has limited incentives for investment in cogeneration systems. In 1986 the UNDP/World Bank team found only one off-grid mill with an operational cogeneration system, although two others had generating capacity that was unused for technical or economic reasons.

Glikster W.A., Ltd., a state owned mill in Ghana producing lumber, plywood, and veneer, generates 13,000 cubic meters of residues annually. In 1986 all of the residues were burned in four 1950-vintage locomotive-type boilers to produce 3.5 t/hr at 15 bar (220 psi). The steam was fed to two turbogenerators rated at 635 kVA and 437.5 kVA. Additional power was provided by a 690 kVA diesel set. In 1986, the firm was planning to install transformers allowing use of power from the nearby grid and to abandon power production at the mill.

During the same period a privately owned mill on the grid, Specialized Timber Products (STP), was installing a 6.4 t/hr residue-fired boiler and a 480 kVA back-pressure (noncondensing) turbine. STP planned to burn all of its residues (20,000 m^3/year), meet 80% of its power needs, and provide process heat to six 150 cubic meter kilns and two steam pits. The principal reason for the investment in cogeneration was interruptions of grid power, which cost the firm $33,000 in lost production in 1985.[27]

Power for the Grid

In the 1980s, a large number of wood-fired power plants have been built in the USA to generate power for the grid. This trend has been stimulated by the passage of "PURPA" legislation in 1978 that requires electric utilities to buy power from private companies at an "avoided-cost," price, i.e., the costs the utility avoids through the power purchase.

A survey for the U.S. Department of Energy in 1985 listed 107 existing and planned wood waste power plants with a total capacity of 1,792 MW. Only about 180 MW of this capacity was in plants owned by electric utility companies, while 1,611 MW was provided by city-owned electric plants, cogeneration plants in various industries, and independent power companies. Nearly half of the plants had capacities below 10 MW (Fig. 18).[28]

Although updated national figures are not available, the number of U.S. power plants fueled with wood residues and other biomass fuels has continued to expand. California leads the nation with over 950 MW produced with biomass fuels. Over 1800 MW are produced with such fuels in 13 southeastern states. Some estimates indicate that the national output with biomass fuels, including many large plants burning urban solid wastes, has reached 9000 MW.

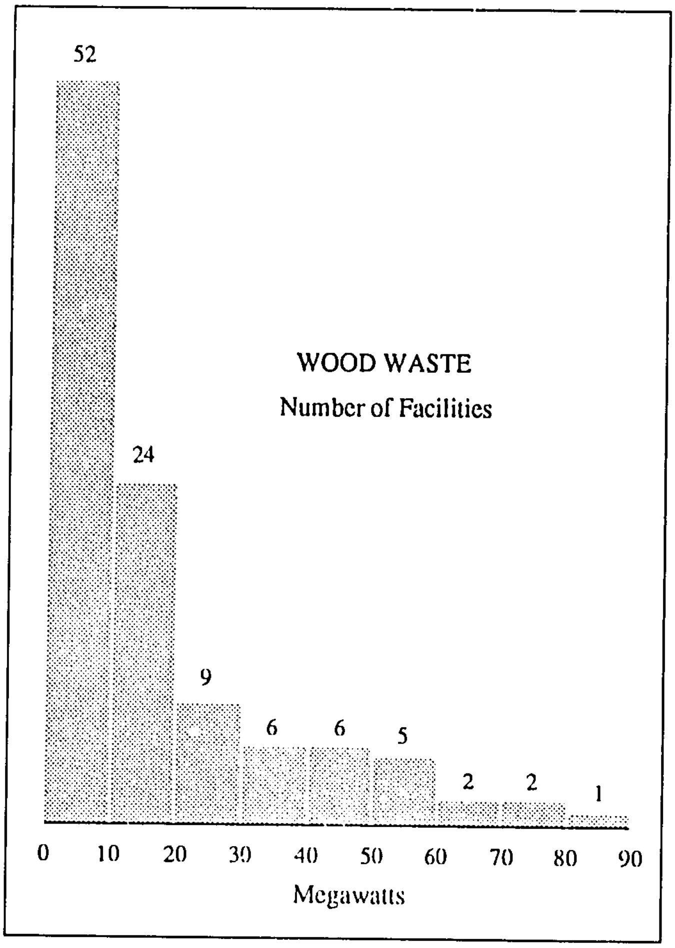

Fig. 18. Wood waste power plants, USA, 1985. (Source: *Electric Power from Biofuels*, U.S. Dept of Energy)

Five power plants in the USA that produce power for the grid from wood residues are described below. These examples involve several types of fuels, steam pressures, and levels of power output. The first three are at large sawmills: one is a cogeneration plant with a noncondensing turbine, while the other two have condensing turbines. The final two examples are "stand-alone" plants (also with condensing turbines) that are not located at forest products industries.

• A 10 MW cogeneration plant at the large Kinzua Corporation sawmill at Heppner, Oregon, provides process heat for lumber drying and generates power for sale to the grid. About 78% of the fuel is generated in the Kinzua mill, with 22% purchased from nearby mills. Fuel is fed to the boiler by a pneumatic stoker system with variable-speed fuel metering augers and is burned on a stationary, water-cooled grate. The Deltak boiler produces 54,432 kg/hr (120,000 lb/hr) of steam at 40.8 bar (600 psi) and 401°C (755°F). It is used in a General Electric 10 MW extracting (noncondensing) turbine. About 16,783 kg/hr (37,000 lb/hr) of steam is extracted at 12.9 bar (190 psi) for use in the kiln drying of lumber. The use of this exhaust steam allowed Kinzua to discontinue the use of its existing wood waste boiler, with annual savings of about $250,000. All of the power is sold to the local electric utility, Portland General Electric Company.[29]

• Big Valley Lumber Company in Bieber, California, produces 472 cubic meters (200,000 MBf) per day of kiln-dried pine lumber used in finishing mills. Prior to 1983 the driest waste was burned in a low pressure boiler to produce steam for lumber drying and for the generation of power for use in the mill; bark and other wet residue was burned for disposal in a teepee burner that also required the use of some fuel oil. A cogeneration plant was built in 1983 with assistance from a revolving biomass energy loan fund administered by the California Energy Commission. The plant burns the equivalent of 180 tonnes (200 tons) of dry mill residues daily. The pile-burning boiler produces 27,216 kg/hr

(60,000 lb/hr) of steam at 44 bar (650 psi) that is fed to a 10 MW Westinghouse condensing turbine. About 2 MW is used in the Big Valley Mill, and up to 7.5 MW is sold to the northern California utility, Pacific Gas and Electric. Energy savings and revenues from power sales paid for the power plant is about 4 years.[30]

• A 5 MW power plant operated by Catalyst Energy Corporation at North Powder, Oregon, generates power for the grid with mill residues from the nearby Idaho Lumber Corporation sawmill. The moisture content of the hogged fuel is reduced from about 37% to 25% in a rotary fuel dryer heated with boiler exhaust gas.

Up to 8 t/hr (9 tons/hr) of the dried fuel is burned in a fluidized bed gasifier provided by Energy Products of Idaho. Hot gas flows through a refractory-lined hot gas duct to the boiler, where it is ignited. The boiler produces up to 60,000 lb/hr (27,000 kg/hr) of steam at 29 bar (425 psi) and 440°C (825°F). The condensing turbine is linked to a 6,250 kVA generator. The capital cost of the power plant was $7.4 million ($1,480/kW).[31]

• The Biomass Power Corporation of Dunnellon, Florida, operates two 7 to 8 MW "stand-alone" power plants in Florida that are fueled primarily with sawdust purchased from local sawmills. Each plant burns about 77,000 tonnes (85,000 tons) per year of green sawdust (40% moisture) mixed with 13,600 tonnes (15,000 tons) of peanut hulls (6% moisture). The fuel is trucked to the plants in semi-trailer trucks and unloaded with hydraulic truck dumpers.

Each of the Florida plants has a boiler producing up to 40,800 kg/hr (90,000 lb/hr) of steam at 14 bar (200 psi). It is fed to condensing turbines producing 8,000 kW at the Jefferson City plant and 7,500 kW at the Madison City plant. The power is sold to the regional electric utility company. Each of the power plants cost about $11 million (around $1,400/kW).[32]

• A 10 MW "stand-alone" power plant at Burney in the forested mountains of northern California burns about 68,000 dry tonnes (75,000 tons) of waste wood annually. Half of the fuel is logging residue including branches and tops, chipped forest residues, and rejected logs. The other half is mill residue from nearby lumber mills including sawdust, shavings, hogged residues, bark, and chips.

The fuel receiving area at Burney can unload up to 60 trucks per day, each with about 23 wet tonnes (25 tons) of fuel. A hydraulic ramp tips each tractor and trailer to a 60 degree angle, dumping the fuel into a hopper. Ferrous metals are removed by a magnetic separator. A disk screen separates large pieces of wood that are reduced to less than 10 centimeters (4 in) by a chipper. The fuel is partially dried in a dryer using hot exhaust gases from the plant's boiler.

The plant at Burney burns 13.6 t/hr (15 tons/hr) of fuel with 40% moisture to produce up to 47,678 kg/hr (105,000 lb/hr) of high-pressure steam at 61 bar (900 psi) and 440°C (825°F). Particulates are removed by a multiclone dust collector and an electrostatic precipitator. The superheated steam drives a multi-stage condensing turbine and a 11.4 MW generator. The net output of about 10 MW is sold to the regional electric utility, Pacific Gas and Electric Company. The Burney plant is a joint venture of subsidiaries of Pacific Lighting Energy Systems and Ultrasystems, Inc.[33]

In Virginia, Multitrade Limited Partnership is developing the world's largest wood-fueled electric power plant. The plant is projected to be in service by 1993. It will burn 1,600 t/day (1,800 tons/day) of wood wastes and whole tree chips. Two turbine generators will produce up to 79.5 MW, which will be sold to the regional utility company, Virginia Power, under a 25-year contract.[34]

Research for this report has not identified any power plant in a developing country that is providing power for the grid through the combustion of logging or mill residues. The "dendro-thermal" power plants planned in the Philippines in the early 1980s were to obtain wood fuel from the harvesting of fast-growing trees in energy plantations. The plantations did not produce as rapidly as expected, and the five completed 3 MW plants have utilized additional fuel provided by entrepreneurs from private woodlots and public forests. Some of this fuel may be logging residue. Mill residues have apparently not been used as fuel for any of the dendro-thermal plants in the Philippines.[35]

One of the options examined by the UNDP/World Bank team for power production with mill residues at the Mim Timber Company in Ghana involved the net sale of about 1 GWh of power to the grid. The option involved the installation of a new boiler, a 1.2 MW condensing turbine-generator, and other equipment at a total capital cost of about $3 million. The analysis showed that the investment would not be financially attractive and the economic cost of the power would be equal to, or slightly higher than, available hydroelectric power.[36]

Off-grid Power for Rural Electrification

In the future, two distinct types of wood waste power plants may provide power for rural electrification in developing countries. One type of plant would be located on or near the grid and would sell power to the national or regional electric power agency. Such a plant could be within a forest products industry or could be a stand-alone plant that purchases residues from nearby woodworking industries. This type of plant has been discussed in the previous section.

A second type might be located in a forest products facility in an off-grid area, providing power for the facility as well selling surplus power to a nearby community, a rural electrification cooperative, or another industry. In such a project, the size of the power plant must match both the available supply of wood wastes and the total local demand for power.

The amount of power that can be generated with a quantity of wood waste depends on (a) the fuel value of the residue, which is determined mainly by its moisture content, (b) the efficiency of the boiler and turbine, (c) the type of turbine cycle, and (d) the steam pressure. Some data on prospective outputs with various turbine cycles and pressures has been provided earlier in this chapter.

The potential gross power output and the net power available for sale at a specific forest products industry can only be determined through a careful and site-specific analysis of the fuel characteristics, fuel supply, present equipment, assumed new equipment, and power requirements at that mill.

Notes

1. Naksitte Coovattanachai et al., "Steam Engine in Thailand," *Rural Energy* (Bangkok: FAO), 1989 (No. 2): 6-12,; Intermediate Technology Development Group, "Small-Scale Steam Systems in Thailand" (London, July 1990).
2. M.A. Trossero (Forest Products Div., FAO), letter 15 March 1991.
3. Mario R. Ogara, "Monitoreo y Evaluación Técnico - Económico de Las Unidades de Generación de Energia Instaladas en Siguatepeque y Chagüite Grande" (Tegucigalpa, 1987, unpublished).
4. Mernak S.A., *Steam Engines* (Cachoeira do Sul, RS, Brazil, n.d.).
5. R. Luetge (Spillingwerk Gmbh., Werftstrasse 5, D-2000 Hamburg, Germany), letter to author, 31 August 1989.
6. Gerald R. Guinn, *Design Manual For Small Steam Turbines* (Muscle Shoals, Alabama: Tennessee Valley Authority, 1990), 5.
7. Gerry H. Whiting (Wellons, Inc., PO Box 147 DTS, Portland, ME 04112 USA), memorandum to author, 18 September 1990.
8. Bioenergy Systems and Technology, *A Prefeasibility Assessment of the Potential for Wood Waste Power Systems for the Indonesian Wood Products Industry*, Office of Energy Report 88-17 (Washington D.C.: U.S. Agency for International Development, 1988), 34.
9. Whiting, memorandum to author, 18 September 1990.
10. ESMAP, *Ghana*, 1:78.
11. Guinn, 5.
12. H. Neil Turner (Southern Engineering & Equipment Co., PO Drawer 270, Graysville, AL 35073, USA), letter to author, 18 September 1990; Frank Pate, telephone conversation with author, 24 September 1990.
13. Great Lakes Regional Biomass Energy Program, "Illinois Wood-Waste to Energy Plant installed," *Biologue* (National Wood Energy Association), February/March 1990, 28; F.J. Kuzel and T. Miller, "Power Production for Captive Use in a Wood Waste-Fueled Cogeneration Plant" (Unpublished paper, n.d.).
14. Meridian Corporation, *Case Studies of Biomass Energy Facilities in the Southeastern U.S.* (Muscle Shoals, Alabama: Tennessee Valley Authority, 1986), 2; M.C. Dixon, memorandum to author, 16 November 1990.
15. H. Neil Turner (Southern Engineering & Equipment Co.), telephone conversation with author, 25 September 1990.
16. Bioenergy Systems and Technology, *Prefeasibility Assessment*, 15.
17. K.C. Lee (MechMar Energy), letter to author, 26 November 1990.
18. James L. Ngeleja, "The Utilization of Industrial Wood Residues for Energy Purposes" (Sao Hill Sawmill, Ltd., n.d.).
19. Guinn, 4.
20. Whiting, memorandum to author, 18 September 1990
21. James Savage, telephone conversation with author, 13 September 1990.
22. Ewing Power Systems, "Case Study: Brattleboro Kiln Dry Co." (unpublished, n.d.).
23. Gerry H. Whiting (Wellons, Inc.) letter to author, 12 September 1990; David Tackett (Dean Lumber Co.), telephone conversation with author, 24 September 1990.
24. Southeastern Regional Biomass Energy Program, "Number of Wood Fired Plants Growing in Southeast," *Biologue*, September/October 1989, 31.
25. Great Lakes Regional Biomass Energy Program, *Wood Burning For Energy: Case Studies From the Great Lakes*" (Chicago: Council of Great Lakes Governors, 1986), 32.
26. Meridian Corporation, *Case Studies*, 20; unsigned revision of power plant description received by author from St. Joe Forest Products Company, 19 November 1990.

27. ESMAP, *Ghana*, 1:34.
28. Meridian Corporation, *Electric Power From Biofuels: Planned and Existing Projects in the U.S.* (Washington, D.C.: U.S. Department of Energy, 1985), 13.
29. Pacific Northwest and Alaska Biomass Energy Program, *Biomass Energy Project Development Guidebook*, Supplement (Portland, Oregon: Bonneville Power Administration, 1989), CS3-1.
30 California Energy Commission, "Big Valley Lumber Company 5 MW Wood-fired Cogeneration System" (n.d.,n.p.); Marty Seuss (Big Valley Co.), telephone conversation with author, September 24, 1990.
31. Pacific Northwest and Alaska Regional Biomass Energy Program, CS1-1.
32. Meridian Corporation, *Case Studies*, 16.
33. Pacific Lighting Energy Systems, "Ultrapower I - Burney Power Plant" (undated brochure).
34. B. E. Brammer (Multitrade Group Inc.), letter to author, November 9, 1990.
35. P. V. Bawagan, *Wood Based Energy System in Rural Industries and Village Applications: Philippines* (Bangkok: FAO, 1989), 12, 33-35, 41.
36. ESMAP, *Ghana*, 1:78-83.

5. THE ECONOMICS OF WOOD RESIDUE UTILIZATION

Net Savings in Energy Costs

The primary reason for installing most wood energy systems in industries or institutions is to achieve a substantial net reduction in energy costs. The extent of these savings is influenced by the cost of the fossil fuels or grid power that is replaced by the new system and by the cost of wood residue fuels. These annual savings must be large enough to offset the annualized capital and operating costs of the wood energy system.

Avoided Costs of Fossil Fuels

In the U.S., many wood energy systems have replaced electric power from the grid generated by burning coal or process heat produced from fuel oil or natural gas. In developing countries, wood residue systems could often replace process heat from fuel oil, grid power generated with fuel oil, or power generated locally in diesel generating sets. The extent of the potential savings depends on the present level of fuel consumption and the price of the fuel. Potential savings are lower in countries in which the prices of fossil fuels are kept low by government subsidies.

A relatively large sawmill in Honduras that annually produces 19,000 to 23,000 cubic meters (8 to 10 MBf) of lumber uses 190 gallons of diesel fuel per day to provide around 115 kW of power. A smaller sawmill in Honduras that produces 4,700 to 9,400 cubic meters (2 to 4 MBf) annually uses about 130 gallons of diesel fuel per day to generate an average of 80 kW. When a Winrock International team arrived in Honduras in September 1990, the subsidized price of diesel fuel was $0.19/liter ($0.73/gallon); a month later the local price rose 50% due to increased world oil prices resulting from the Persian Gulf crisis.[1]

In 1986 Ghana's largest wood processing plant, Mim Timber Company, and associated plants produced 5.1 GWh of electric power with diesel generating sets. At that time diesel fuel cost $0.19/liter ($0.86/Imp. gallon); Mim's annual bill for diesel fuel and lubricating oil was about $526,000.[2]

In 1988 one Indonesian plywood factory met a 7.1 MW power demand with a 5.4 MW diesel system plus some purchased grid power and had a total energy bill of $92,000 per month. The bill would have been much higher if the factory had paid the world market price for diesel fuel. Direct energy costs are avoided entirely by another Indonesian plywood factory of similar size that meets all of its energy requirements by burning wood residues in a 6.8 MW cogeneration plant.[3]

Cogeneration of electric power and process heat with wood fuels at the Paper Industry Corporation of the Philippines (PICOB) facility replaced an average of 70 million liters of fuel oil annually between 1983 and 1986 and produced net annual savings of $750,000.[4]

Residue-fired energy systems are more attractive if fossil fuel prices are high. A study for USAID examined the attractiveness of a 2.5 MW wood waste power system that would replace diesel generating sets in an Indonesian plywood factory. The payback periods for the power plant with various prices for diesel fuel and for wood residue fuel are shown in Figure 19. If diesel fuel remained at the 1988 subsidized price of $0.13/liter ("low diesel" in the chart) and wood wastes were free, the payback period for the power plant would be about 6 years. If the diesel price in Indonesia rose to the 1988 world price of $0.26/liter ("high diesel"), the payback period would be only about 1 year even if a relatively high price was paid for wood. If the present diesel subsidy was phased out over a 5-year period ("subsidy out"), the payback period for the investment would be 3 to 4 years depending on the price of wood.[5]

Avoided Costs of Power from the Grid

If the rates charged industries for power from the grid are relatively high, an industry may achieve substantial net savings in energy costs by generating its own power with wood wastes. In the U.S., power rates vary considerably from region to region. The following examples are from regions with high rates:

- A new cogeneration plant at the Walnut Hollow woodworking plant at Dodgeville, Wisconsin, is expected to save about $100,000 per year in charges for

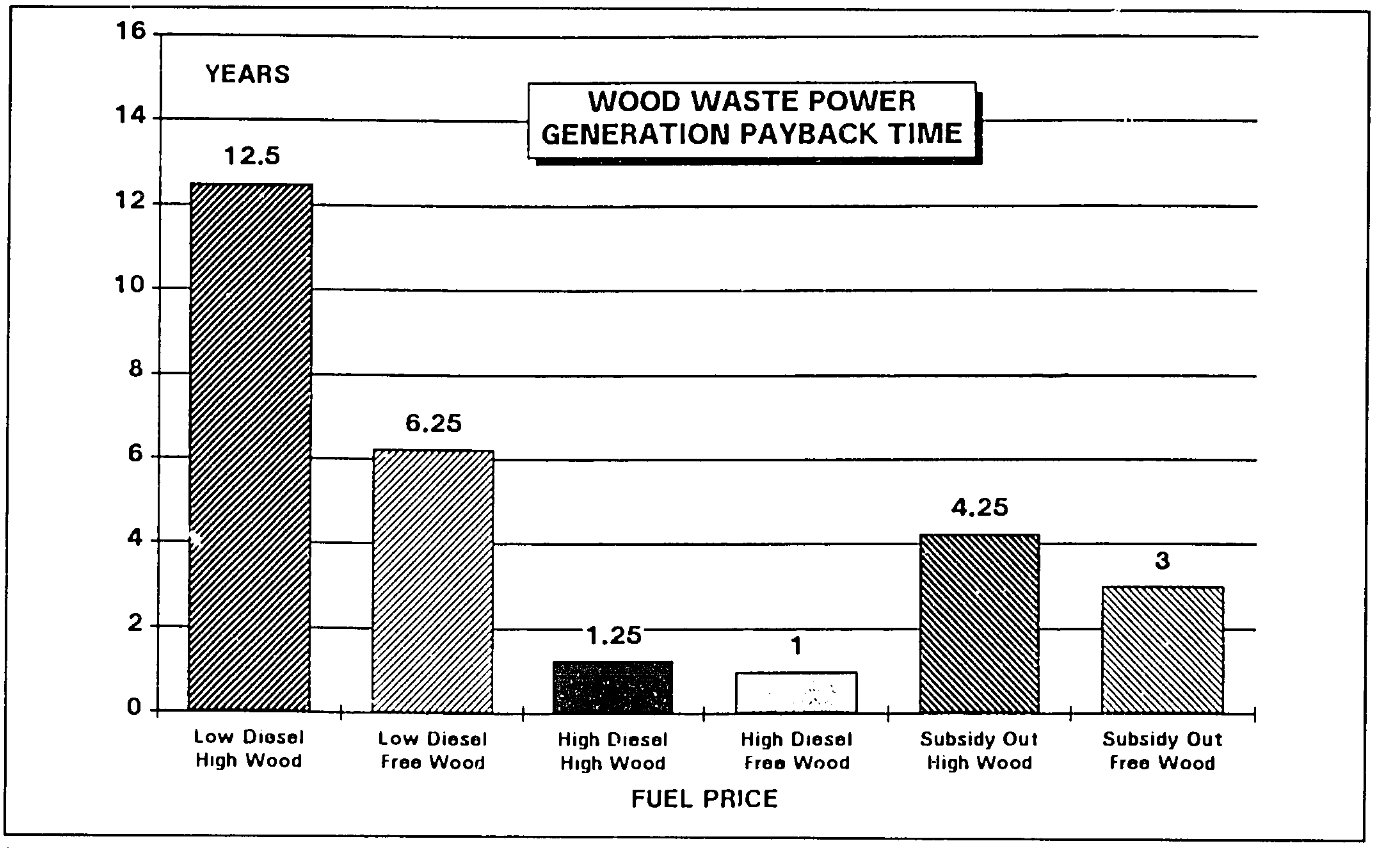

Fig. 19. Effect of diesel and wood fuel costs on payback time for wood waste power plant, Indonesia. Low diesel = subsidized price ($0.13/liter); high diesel = world price ($0.26/liter); subsidy out = subsidy phased out over 5 years; high wood = waste wood cost of $5/t. (Source: *Prefeasibility Assessment*, U.S. Agency for International Development)

grid power as well as $50,000 per year in fuel costs for process heat.[6]

• The Huey Forest Products sawmill in Illinois (see Chapter 4) formerly paid about $55,000 a year for power from the grid. The mill's new 1 MW cogeneration system will produce power worth about $170,000 and will enable the mill to increase operating hours, production, and revenue.[7]

In many developing countries, the rates charged industries for power from the grid are relatively low due to low-cost sources of power (usually hydroelectric power) or government subsidies, or both. Because almost all of the grid power is from hydroelectric plants, Honduran sawmills that have access to the grid pay around $0.045/kWh for power.[8] In countries that have such low rates, grid-connected industries have less incentive to invest in power systems using wood residues.

In Ghana in 1986, due to the low cost of hydroelectric power from the grid, no grid-connected sawmill generates its own power. Although power rates had increased nearly 400% between 1983 and 1986, the industrial tariff for a large sawmill was still quite low ($0.033/kWh) when the UNDP/World Bank team evaluated two cogeneration options at the Specialized Timber Products mill in Kumasi. The most favorable option, which had an estimated marginal generating cost of $0.076/kWh, was not competitive with the marginal cost of hydropower from the grid, which cost $0.052/kWh.[9]

Lumber mills near large cities in Zaire have access to some of the cheapest power in Africa. Malawi's mills also buy cheap power from the grid. Sawmills in Swaziland burn some residues to generate steam for dry kilns, sell the remaining residues to pulp mills, and buy cheap grid power that is imported from South Africa.[10]

In Ecuador, the ENDESA plywood, veneer, and blockboard mill near Quito burns residues to produce process steam but buys low cost power from the grid.

Wood residues from a Japanese-owned wood-chip plant near Madang in Papua New Guinea are burned for disposal in a teepee burner. A financial analysis indicated that an investment in a wood waste power system could not be justified due to the availability of low cost power from a nearby hydroelectric plant.[11]

In developing countries with high power rates, power generation with wood residues may be attractive at sawmills that can sell power to the grid or to another major customer. For example, Cameroon, which generates over 645,000 tonnes (700,000 tons) of mill residues annually and has one of the highest electricity tariffs in Africa ($0.143/kWh), appears to have favorable economic conditions for development of wood waste power plants.[12]

The relationship between the price of grid power and the economic attractiveness of wood waste power systems is demonstrated by experience of the Sri Maharaja Company, a 80-year old sawmill and woodworking enterprise in Cholburi province in Thailand. Earlier in this century, the mill produced its own electric power with steam turbines fed by a wood-waste boiler. Later the mill was connected to the grid, which provided power at relatively low rates. The wood-waste generating system was abandoned, and most of the mill's monthly output of 800 tonnes of wood chips and sawdust was unused. In the late 1970s power rates rose rapidly in Thailand. By 1980 the company was paying over $60,000 per month for grid power and it decided to return to power generation with wood wastes, using the old turbines. Power from wood wastes is now used in the sawmill, in several associated woodworking enterprises, and in the homes of 1,200 employees.[13]

Costs of Wood Residue Fuels

In each type of wood-residue energy system there are some costs associated with the acquisition, storage, handling, and preparation of the wood residue fuels.

In any project that involves the collection of forest residues or the utilization of mill residues at a site other than that at which they were produced, transportation costs are a significant component of total fuel costs. The UNDP/World Bank Team in Costa Rica assumed costs of $9 to $11/m^3 for transporting logging residues 150 to 180 kilometers to industrial sites.[14]

Many forest products industries in developing countries sell some of their residues for use as domestic or industrial fuel, as feedstock for charcoal production, or for other purposes. If there is a local market for wood residues, the economic analysis of a proposed wood energy system must include the "opportunity cost" of the fuel, i.e., the net income that could have been obtained through the sale of some or all of the residues.

The cost of wood fuel must be evaluated in relation to the cost of fossil fuels or grid power. The wood waste study for USAID in Indonesia (Fig. 19) indicated that if wood residues were purchased at $5/t and diesel fuel prices remained at the 1988 subsidized level, the payback period for a proposed power plant and a plywood factory would be long (12.5 years). If diesel fuel prices in Indonesia rose to the 1988 world price (i.e., approximately doubled), the wood-fired system would produce much greater net savings in fuel costs and the payment of about $5/t for wood residues would have only a marginal impact on the short (12 to 15 month) payback period for the wood waste power plant.[15]

Planning a wood energy project requires a careful long-term projection of wood fuel availability and costs. Both the supply and the market value of a biomass fuel in an area can change over time due to new economic conditions or the growth of other industries in the area that use biomass fuels. Plants using on-site residues are less affected by these changes than plants that use purchased biomass fuels.

In some areas increased demand for wood fuel has driven up the price of wood residues. Fuelwood prices have increased substantially in recent years in a number of developing countries. In California both the availability and price of wood residue fuels has been significantly affected by the rapid growth of biomass-fueled power plants in the 1980s. A study by Future Resources Associates indicates that the delivered prices paid by power plants in California for hogged wood fuel or the equivalent range from $42 to $55 per bone dry tonne ($38/ton to $50/ton), i.e., about $22 to $27 per tonne for fuels with 50% moisture. As a result of these high fuel prices two biomass power plants have closed, three others have converted to natural gas, and some plants curtail operations in periods of low demand for power.[16]

Avoided Costs of Wood Residue Disposal

Many forest products industries in the USA have avoided substantial disposal costs by installing residue-fired boilers or power plants. In many areas the high cost of residue disposal and pressure from government agencies for more environmentally acceptable means of residue disposal have been major incentives for investments in wood energy systems. Some examples:

• Sixty percent of the lumber processed by a producer of hardwood flooring, Colortile Manufacturing Company of Melbourne, Arkansas, ends up as wastes. By installing a cogeneration system that burns 6,500 tonnes (7,100 tons) of wastes per year, the firm avoided annual waste disposal costs between $75,000 and $100,0000.[17]

• Prior to investing in a cogeneration system, the Walnut Hollow woodworking plant in Dodgeville, Wisconsin, was paying $44/t ($40/ton) to dispose of wood waste, including transportation costs and a $35/t "tipping fee" to dump the residues at a landfill. The firm's disposal costs were about $145,000 per year.[18]

• Sullivan Industries, a furniture company in Lamar, Missouri, formerly paid about $6,000 a month to dump 80 to 90 tonnes (90 to 100 tons) of sawdust per day in the city-owned landfill. Recently the disposal of residues in landfills has become much more expensive as local governments have passed on to users the high costs of meeting new Federal environmental standards for landfills. In 1990 the city raised tipping fees from $1.00 per cubic yard to $3.75 per cubic yard. The firm now faces an annual sawdust disposal cost of $400,000 and is reportedly examining options for sawdust utilization.[19]

Residue disposal costs are also substantial for some mills in developing countries. In Ghana annual equipment, operational, and labor costs incurred in the dumping or burning of unused mill residues have ranged from $1,000 at small mills to $8,000 at larger mills.[20]

Income From Power Sales

The addition of substantial income from power sales can convert an economically weak prospective investment for energy self-sufficiency into a quite attractive investment. An analysis by the Winrock International team in Honduras indicated that an energy-efficient power plant using all the wastes of a large mill and selling power to the grid for at least $0.05/kWh would produce an internal rate of return on equity investment of 75% and would pay back the investment in about 3.4 years.[21] Further details on this analysis are provided in the subsequent section.

The economic attractiveness of a plant producing power for sale (to another firm, a rural cooperative, or electric utility) may be highly dependent on policies of governments or electric utilities.

In the USA, the construction of power plants using nonconventional sources of energy has been stimulated by "PURPA" legislation enacted in 1978. It requires electric utility companies to purchase electric power generated by other companies at an "avoided-cost" price equal to the fuel and other costs that the utility avoids through the purchase. Under the PURPA rules, the wood-fired plant receives a higher price for power when fossil fuel prices are high than when they decline. Due to reduced oil prices in the mid-1980s, the revenue received by two wood residue power plants in Florida dropped from $0.044/kWh in 1983 to $0.022/kWh in 1986.[22]

A study in 1987 demonstrated that in West Virginia, a coal-producing state, cogeneration plants burning wood residues were not economically attractive at moderate-sized sawmills, because the avoided cost price paid for power by coal-burning utilities was only around $0.035/kWh.[23]

In regions lacking inexpensive fossil fuels and hydro sources, the avoided-cost price is higher. The rather high prices paid for power in California have stimulated the rapid development of biomass-fueled power plants. By late 1990 the total capacity of operational biomass-fueled plants in the state had reached 800 MW.[24] Some California plants receive "offset fuel payments" because they use forest or other residues that would otherwise be disposed of by open burning, contributing to air pollution.

In 1989 the California utility Pacific Gas and Electric purchased 2.5 billion kilowatt-hours of power from private producers at an average price of about $0.082/kWh.[25] In 1987 a 5 MW wood residue power plant at North Powder, Oregon, was paid $0.059 for each kilowatt-hour of power generated plus a capacity payment of $5.32 per month for each kilowatt of reliable generating capacity provided by the wood-fired plant.[26]

In most developing countries there is little experience, legislation, or established procedure applicable to the sale of electric power by private companies. Government policies and regulations may encourage or inhibit the development of private power plants. The attitudes and rules of electric utilities may increase or decrease the opportunity of the private power firm to obtain a fair price for the power it generates.

Recently governments of several developing countries have adopted new policies and programs designed to increase the role of private firms in supplying some of the needed power. In 1989 the government of Costa Rica declared that the purchase of electricity from private firms was in the public interest and provided an institutional framework allowing the private sector to participate in the solution of power supply problems. At the time of the USAID-funded assessment of potential wood waste power projects in Indonesia in 1987/8, the national electric power agency was not interested in purchasing power from private firms.[27] In 1990, however, the government adopted a new program to expand power generating capacity that encourages generation of power for the grid by private companies.

Capital Costs

In order for a wood energy system to be financially attractive, the total annual savings and revenues generated by the new system must substantially exceed the annual costs of the system including annualized capital costs.

Detailed estimates of the capital cost of wood energy installations have been prepared for only a few sites in developing countries. Usually they have assumed that most of the major components would be imported from the USA or Europe.

The UNDP/World Bank team in Ghana concluded that the substitution of sawdust for oil fuel in several industries using imported rotary fuel dryers and suspension burners would not be economically attractive unless capital costs were substantially reduced or oil prices rose to above $30 per barrel.[28]

The Winrock International team in Honduras indicated that the total installed capital cost of power is the most important factor in determining the economic and financial attractiveness of power generation at sawmills. The team estimated capital costs for three types of residue-fired power plants that might be installed at a large sawmill (21,000 m^3/yr, 9 MBf/yr) and at a smaller sawmill (7,000 m^3/yr, 3 MBf/yr). In each case the team assumed that the investment for fuel-handling equipment would be limited to a fuel conveyer that could carry sawdust and random-sized pieces of solid waste to a feed chute, supplemented by manual firing of larger pieces through the furnace door. Each option assumed the use of imported major components, although the team felt that some components might be available in Honduras at considerable savings.[29] The analysis of these options demonstrates both the substantial economies of scale of wood-fired power plants and the low capital cost per kilowatt of energy-efficient plants.

- An energy self-sufficiency option would provide only the power needed for the operation of the mill. The estimated installed cost of a 275 kW plant for the larger mill was $532,012 ($1,934/kW), while a 180 kW plant for the smaller mill would cost $429,358 ($2,385/kW). The calculated internal rate of return (IRR) was 21.7% for the system at the larger mill and 16.7% at the smaller mill; payback periods were 6.2 and 5.7 years. These systems were considered acceptable candidates for investment, but the energy self-sufficiency option would be more attractive if capital costs were reduced through the purchase of used equipment.

- A low capital, grid-connected option assumed a minimum-cost power plant large enough to use all of the mill's residues and the sale of surplus power to the grid. The plant would have an air-cooled condenser and would operate with a turbine exhaust pressure high enough to return condensate to the feedwater storage tank without using condensate pumps. Such a system minimizes capital cost but sacrifices turbine efficiency and substantially reduces the power output per tonne of residues. The estimated cost of a 500 kW plant for the larger mill was $775,384 ($1,550/kW), while a 200 kW plant for the smaller mill would cost $456,750 ($2,383/kW). The analysis indicated that the increase in capital cost would be more than offset by the earnings from energy sales. The IRR for this option was 54.4% at the larger mill and 32.2% at the smaller mill; payback periods were 4 and 5 years. The team concluded that the low-capital option with energy sales would provide very attractive investments for sawmills that expect to operate at least though the end of the decade.

• An energy-efficient, grid-connected option would substitute a surface condenser for the air-cooled condenser and allow the operation of the turbine with a vacuum exhaust. This modification nearly doubles the electrical output per tonne of residues, and provides much more power for sale to the grid. Under this option a 825 kW plant for the larger mill would cost $1,020,853 ($1,237/kW), while a 325 kW plant for the smaller mill would cost $588,913 ($1,812/kW). The IRR for this option was 75% at the larger mill and 40% at the smaller mill; payback periods were 3.4 and 4.4 years. The analysis indicated that the energy efficient option with energy sales would provide extremely attractive investments as well as substantial contributions to the national power supply in Honduras.

Operating Costs

Because developing countries have few large industrial wood energy systems and residue-fired power plants, there is a very limited basis for estimating the operating costs of such systems under typical conditions in developing countries. The operating costs are dependent on the type of system, the extent of the mechanical equipment, and the reliability and durability of the components.

All wood energy systems are more labor intensive than most systems that burn fossil fuels. Even systems in the USA with mechanical fuel handling and automatic stoking devices require closer monitoring than systems fired with oil or gas. Wood residue energy systems in developing countries would need a larger labor force due to greater use of manual techniques for the handling, preparation, and stoking of the residues.

Wood energy systems with mechanical equipment for fuel handling and stoking have higher costs for maintenance, repairs, and replacement parts than oil- or gas-fired systems.

Notes

1. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras: Industry Overview*, Office of Energy Report 91-05 (Washington, D.C.: USAID/Honduras and U.S. Agency for International Development, 1991), 12.
2. ESMAP, *Ghana*, 1:67.
3. Bioenergy Systems and Technology, *A Prefeasibility Assessment of the Potential of Wood Waste Power Systems for the Indonesian Wood Products Industry*, Office of Energy Report 88-17 (Washington D.C.: U.S. Agency for International Development, 1988), 27.
4. P.V. Bawagan, *Wood Based Energy System in Rural Industries and Village Applications: Philippines* (Bangkok: FAO, 1989), 37.
5. Bioenergy Systems and Technology, *Prefeasibility Assessment*, 45.
6. Wisconsin Energy Bureau, "Walnut Hollow Farm Wood Waste Cogeneration Plant" (n.p., n.d.).
7. M.A. Kuzel and T. Miller, "Power Produced for Captive Use in a Wood Waste Fueled Cogeneration Plant" (Chicago: Council of Great Lakes Governors, n.d.)
8. Gregory Morris, unpublished draft for report on Winrock International Honduras study, 26 October 1990.
9. ESMAP, *Ghana*, 1:63.
10. Marcia M. Gowen, "The Industrial Wood Energy Initiative" (Winrock International, unpublished draft, 1989), 80.
11. Ibid, 80, 82.
12. Ibid.
13. Suvit Khalaisang and Kyi Lwin, "Energy From Woodwastes in Sawmilling Industry," *Agricultural Wastes and Solar Technologies for Energy Needs in Farms* (Bangkok: FAO, 1983), 149.
14. ESMAP, *Costa Rica*, 1:56.
15. Bioenergy Systems and Technology, *Prefeasibility Assessment*, 45.
16. Gregory Morris (Future Resources Associates), unpublished draft research report, 8 October 1990.
17. Meridian Corporation, *Case Studies of Biomass Energy Facilities in the Southeastern U.S.* (Muscle Shoals, Alabama: Tennessee Valley Authority, 1986), 9.
18. Wisconsin Energy Bureau, "Walnut Hollow Farm Wood Waste Cogeneration Plant" (n.p., n.d.)
19. Mike Sturbrugg, "Pellets Possible Sawdust Solution," *Joplin* (Missouri) *Globe*, 25 February, 1990.
20. ESMAP, *Ghana*, 1:37.
21. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras*, 43.
22. Meridian Corporation, 14.
23. S. M. Brock, D.W. Patterson, and J.O. Ruark, *Economic Feasibility of Cogeneration at Sawmills in West Virginia* (Morgantown: West Virginia University, 1987), 7.
24. Jane Turnbull (Pacific Gas and Electric), telephone conversation with author, 20 September, 1990.
25. Ibid.
26. Pacific Northwest and Alaska Region Biomass Energy Program, *Biomass Energy Project Development Guidebook, Supplement* (Portland, Oregon: Bonneville Power Administration, 1989), CS1-1.
27. Peter Jezek (member of BST Project team in Indonesia), telephone conversation with author, 17 September, 1990.
28. ESMAP, *Ghana*, vii.
29. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras*, 32-34, 42-43.

6. ENVIRONMENTAL IMPACTS OF WOOD RESIDUE DISPOSAL AND UTILIZATION

Impact on Air Quality

Until the early 1970s, many sawmills in the USA used fossil fuels to meet their energy requirements and burned unmarketable wood wastes in cone-shaped "teepee" burners without energy recovery. The burning of wet residues in these incinerators often required co-firing with some fuel oil in order to sustain combustion. Air quality standards established pursuant to the National Environmental Policy Act of 1969 precluded the continued use of most of these incinerators. In many areas of the U.S., environmental protection regulations now prohibit the burning or uncontrolled dumping of green sawdust. But the large piles of unused sawdust at many sawmills pose a serious fire hazard, often in areas with a high risk of forest fires in dry seasons.[1] Along with the rapid rise in fossil fuel prices of the mid-1970s, these environmental concerns provided additional incentive for the forest products industry to use wood residues as fuel.

In some managed forests in the U.S., the "slash" remaining after timber harvesting is burned to reduce the danger of forest fires and to prepare the site for regeneration. Smoke from the burning of slash contributes significantly to air pollution, and a wood energy journal noted recently that such burning may eventually be banned in the U.S.[2] Air pollution would undoubtedly be reduced if the slash were burned in wood-fired power plants operating with a high rate of combustion efficiency and with effective pollution control devices.[3]

Burning wood residues in a properly designed industrial wood energy system or power plant results in substantially less air pollution than is caused by the open burning of the residues in such facilities. A modern wood energy system provides for the efficient combustion of the biomass and minimizes the generation of particulates and other undesirable emissions. Most of the particulates that leave the combustion chamber are easily removed from the stack gas by pollution control devices. The burning of wood fuels does not produce significant quantities of certain pollutants, notably sulfur dioxide and nitrous oxide, which are generated in the combustion of fossil fuels.

Federal legislation in the USA has established a number of national ambient air quality standards, and the individual states are free to set more stringent standards. The Federal standards measure the concentration in the air of seven pollutants: carbon monoxide (CO), nitrogen oxide (NOx), sulfur dioxide (SOx), ozone, total suspended particulates, nonmethane hydrocarbons, and lead.[4]

In the design and operation of wood energy systems, the primary air quality problem is particulate emissions. The carryover of particulates into the gas stream can be limited by the proper design and operation of the furnace. The fuel feeding rate and the control of the amount and distribution of air in the combustor influence particulate emissions.[5]

Several types of devices can be used to remove particulates from the gas stream.[6]

• Cyclones: In a cyclone separator (Fig. 20) particulates are unable to follow a sudden change in direction of the gas stream and are separated out by centrifugal force. A multiple cyclone (sometime called a "multiclone") contains a number of cyclones operated in a series for particulate removal. The multiclone is the most widely used device for the removal of particulates from the stack gas of wood-fired furnaces and boilers.

• Wet scrubbers: A wet scrubber removes particulates by spraying a fine mist of water into the exhaust stack. It is used to remove fine particles that are not precipitated out in the cyclones. The principal disadvantage of the wet scrubber is the problem of treating or disposing of the contaminated water.

• Dry scrubbers: A dry scrubber filters the gas stream through a bed of gravel or other filtering medium.

• Baghouse: A baghouse filter contains a number of fabric bags that function like the bag of a home vacuum cleaner to trap particulates. They are efficient, but have a limited lifetime and are susceptible to fires and explosions caused by hot particles.

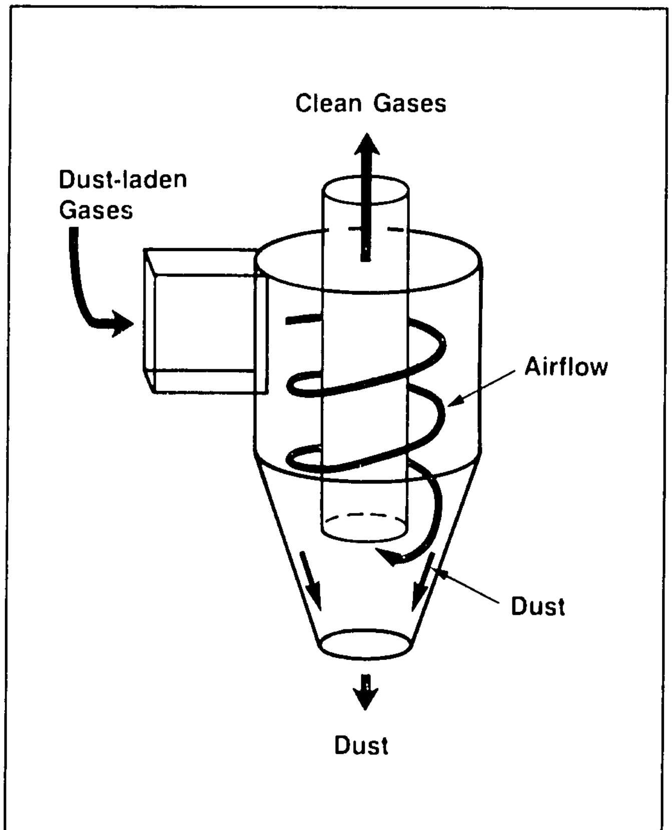

Fig. 20. Cyclone particulate separator. (Source: Southeastern Regional Biomass Energy Program)

- Electrostatic precipitators: Particles entering electrostatic precipitators are negatively charged by a suspended electrode. The gases pass by a positively charged plate that attracts the negatively charged particles. The particles are then removed by a shaking or scraping device.

Wood is virtually a sulfur-free fuel, and sulfur dioxide emissions from wood combustion are usually too low to measure.[7] However, an USAID study in Indonesia noted that emission control devices may be required to limit sulfur dioxide emissions from the combustion of tree bark.[8]

In developing countries a large percentage of the wood residue generated by land clearing, timber harvesting, and operations of forest products industries is burned for disposal in open piles or pits without energy recovery. Most of the residues are rather wet and these fires produce considerable smoke.

The USAID study in Indonesia noted that the burning of some wood wastes in primitive boilers at plywood factories and the disposal of other wastes in smoldering heaps create serious air pollution problems around the factories.[9] Present disposal methods create serious health and safety problems including potential explosions from sawdust and respiratory diseases due to airborne sawdust and smoke from the open burning of residues.

In Honduras, the Winrock International team reported almost constant ground level smoke and haze from the open burning of sawmill wastes near the mills or at other disposal sites. The team concluded that the use of these wastes as fuel in sawmill power plants would significantly reduce air pollution by reducing the amount of particulate emissions (compared with the present open burning of the wastes) and by eliminating the carbon monoxide, nitrogen oxide, particulates, and other contaminants generated by the diesel engines used for power generation at the sawmills.[10]

Impact on Water Quality

Present methods of disposal of wood residues in developing countries contribute significantly to water pollution. Leachates from large piles of dumped or landfilled wood residues and from the ashes of burned residues contribute to groundwater pollution. In many areas the residues are dumped into rivers or the ocean. The USAID team in Indonesia noted that much of the wood residue from plywood mills is dumped into rivers, creating serious problems of floating debris and other harmful effects on water quality, and that power generation with the residues would significantly improve water quality downstream from the plywood factories.[11] The Winrock International team in Honduras reported that nearby streams are contaminated by runoff from piles of unburned and partially burned wood waste and that groundwater may be contaminated by tannic acids resulting from the biological degradation of sawmill waste.[12]

Wood energy systems can also contribute to water pollution in several ways. These include leachate from uncovered storage piles of pulverized wood fuels, residual ash in the water used for ash removal in some systems, and minerals in blowdown water used to w scale from boilers and cooling towers.[13]

Wood Ash Disposal and Recycling

Most wood fuels contain from as little as 0.2% to about 2.5% ash. Some bark fuels have higher ash contents (3 to 5%). The composition of the ash varies with the species and with the conditions under which the trees were grown and harvested. The ash usually contains about 10 compounds; the most important are calcium oxide (CaO) and silicon dioxide (SiO_2).[14] Logs transported by water may have a lower ash content than those transported by land, because the water tends to remove grit accumulated during harvesting.[15]

The *Wood Ash Disposal and Recycling Sourcebook*,[16] prepared for a U.S. Department of Energy program, states that only 15% of the wood ash from wood-fired power plants in the northeastern USA is landfilled. Some plants send their ash to public landfills, paying "tipping fees" to the firm or municipality operating the landfill. Others such as International Paper's Androscoggin Mill at Jay, Maine, operate special lined landfills for wood ash on company property under permits from state environmental agencies.

The landfilling of ash requires careful management. If the ash is not properly watered and covered, blow ash can cause skin, eye, and respiratory irritations. Leachate from wood ash is highly alkaline (pH 11) and can cause serious ground water pollution.[17] The use of liners is now required by Federal regulations at all landfills in the USA Due to transportation costs and the cost of compliance with Federal and state environmental regulations, ash disposal in a landfill can be quite expensive. The disposal of wood ash in a landfill with a liner, allowing recovery and treatment of leachate, cost $44 to $50 per tonne ($40 to $45/ton) in 1987 in the states of Maine and New Hampshire.[18] In some areas, total landfilling costs including transportation have exceeded $100/t. The high cost of landfilling has increased incentives to find less expensive options for ash disposal.

In 1988 approximately 80% of the wood ash generated in the northeastern USA was applied to agricultural lands as a substitute for lime. Many soils in the region are naturally acidic, and the application of lime to reduce acidity is a common practice. Wood ash has high concentrations of calcium and magnesium, the primary neutralizing agents in lime. Several researchers have found wood ash to have an effect on soil pH that is nearly equivalent to that of commercial lime. If the ash contains a significant fraction of unburned carbon, however, the "lime equivalency" of the ash is reduced. Several companies have indicated that the costs of spreading of ash on land were only 25% to 50% of the costs of landfilling.[19]

One environmental concern relates to dioxins in the ash. The sourcebook states that "testing indicated concentrations of dioxins to be less than 15 parts per trillion (ppt), less than the 27 ppt concentration triggering regulator restrictions, and well below the 250 ppt level above which landspreading is prohibited. Dioxins in ash are deemed to be sufficiently well understood and related potential environmental and health effects to be sufficiently small that proposed [Maine] regulations will discontinue dioxin analysis requirements for boiler wood ash. Dioxins do not appear to be a serious impediment to the disposal of boiler wood ash."[20]

Many wood-processing plants in developing countries are located in coastal areas. Ash from wood fuel that has been exposed to seawater may contain chlorinated organic compounds.[21] The USAID study in Indonesia noted that wood ash contributes to stability and nutrient level of the soil, if the soil has not been previously exposed to salt.[22]

Some research has been conducted in Europe and initiated in the USA on the benefits and logistics of applying wood ash to forest lands. Ash is being spread on some forest lands in Sweden, Finland, and Germany. Due to rugged terrain and the lack of roads, spreading ash in forests is usually more difficult than on agricultural lands.

The sourcebook reviewed several other possibilities for the use of ash:

- Wood ash has been used as a binding agent at two charcoal plants in the USA
- The Tennessee Valley Authority has applied for a patent on a process incorporating wood ash into commercial fertilizer.
- Several research projects have examined the use of wood ash to treat or absorb various types of wastes including sewage sludge, oil spills, hazardous wastes, leachate from landfilled urban solid wastes, and potato processing wastes.
- A recent patent covers the use of wood ash in a solution for scrubbing air pollutants from a coal-fired cement kiln.
- At a power plant in Wisconsin, the ash has been used as a base material for a parking lot; the ash is covered with 1.2 meters (4 ft) of gravel and other roadbase materials. Wood ash is used as an insulator

and stabilizing layer under asphalt in road construction in northern Finland.[23]

Impact on Global Climate Changes

The U.S. Environmental Protection Agency recently noted that "a growing body of scientific evidence suggests that the addition of greenhouse gases (carbon dioxide, carbon monoxide, methane, nitrous oxide, nitrogen oxide, volatile organic compounds and chlorofluorocarbons) to the earth's atmosphere is altering the global climate .... Carbon dioxide appears to be the principal contributor to global warming. Among the numerous potential methods of reducing carbon dioxide emissions is the development of alternatives to fossil fuel combustion for energy production. One alternative viewed favorably by EPA is the use of biomass to replace fossil fuels." [24]

The use of wood residue fuels to replace fossil fuels eliminates the carbon dioxide emission that would have been produced by burning the fossil fuels. Although burning wood fuels to produce energy releases carbon dioxide, the amount released is no greater than would have been released if the residues had not been used to produce energy. Most unused wood residues are oxidized through the burning of the wastes for disposal or through the decomposition of residues dumped in uncovered piles. As the EPA noted, the conversion of biomass to energy "will release no new carbon dioxide to the atmosphere as does the use of fossil fuels."

In the USA, large quantities of wood residues, notably sawdust, have been placed in sanitary (covered) landfills. The decomposition (anaerobic digestion) of organic matter in the absence of oxygen produces "biogas" or "landfill gas," which contains about 60% methane and 40% carbon dioxide. An EPA report states that methane is the second most important greenhouse gas accumulating in the atmosphere. The agency has been studying ways of reducing methane emissions from landfills.[25]

In testimony before an energy subcommittee of the U.S. Congress, a spokesman for the National Wood Energy Association noted that "much of the biomass used for energy in this country is waste wood that would otherwise rot in the forest or be hauled to a landfill. The decomposition of biomass produces an acid runoff and methane, both harmful to the environment. Methane ... is one of the strongest contributors to the greenhouse effect. Burning the biomass for energy eliminates the methane release and results in no net increase in atmospheric carbon dioxide."[26]

In many developing countries, rapid deforestation has severely reduced the capacity of forests to absorb carbon dioxide from the atmosphere. The increased use of available logging residues and mill residues for fuel would reduce the cutting of trees for fuel, reduce deforestation, and reduce carbon dioxide in the atmosphere by sustaining the capacity of forests to absorb carbon dioxide.

Research funded by the U.S. Department of Energy suggests that forests managed on a sustained yield basis to produce both wood products and fuel would absorb more greenhouse gases than unutilized forests. Mature forests absorb little additional carbon dioxide from the atmosphere, but fast-growing young trees absorb substantial quantities of carbon dioxide. A summary of this research funded noted that "the harvest of a mature forest will result in a net discharge of carbon dioxide to the atmosphere even if it is replaced by a young growing forest. On the other hand, a young vigorous forest that is used for fuel to replace fossil fuels will result in no net carbon dioxide release so long as it is managed on a sustained-yield basis."[27]

Notes

1. L.A. Grace and W.B. Stuart, "Sawdust Utilization Technology," *Biologue*, September/October 1989, 32.
2. D.C. Hemphill, "The Economics of Forest Residue Recovery in the Inland West," *Biologue* (National Wood Energy Association), September/October 1989, 35.
3. A.A. Moslemi, "Tree Biomass," *Energy From Forest Biomass* (New York: Academic Press, 1982), 63.
4. Pacific Northwest and Alaska Regional Biomass Energy Program, *Biomass Energy Project Development Guidebook* (Portland, Oregon: Bonneville Power Administration, 1987), 5-18.
5. D.A. Tillman et al., "Airborne Emissions From Wood Combustion," *Wood Combustion: Principles, Processes, and Economics* (New York: Academic Press, 1981), 118-151.
6. J.L. Easterly and M.Z. Lowenstein, "Environmental Regulations and Issues," *Cogeneration From Biofuels: A Technical Guidebook* (Muscle Shoals, Alabama: Tennessee Valley Authority, 1986), 8-1 to 8-11.
7. Tillman et al., 119.
8. Bioenergy Systems and Technology, *A Prefeasibility Assessment of the Potential of Wood Waste Power Systems for*

the Indonesian Wood Products Industry, Office of Energy Report 88-17 (Washington D.C.: U.S. Agency for International Development, 1988), 52.

9. Ibid, 51.
10. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras: Industry Overview*, Office of Energy Report 91-05 (Washington, D.C.: USAID/Honduras and U.S. Agency for International Development, 1991), 21.
11. Bioenergy Systems and Technology, *Prefeasibility Assessment*, 51.
12. Biomass Energy Systems and Technology Project, *Energy from Sawmill Wastes in Honduras*, 21.
13. Pacific Northwest and Alaska Regional Biomass Energy Program, 5-12.
14. Tillman et al., 4.
15. Ibid, 52.
16. Omni Environmental Services, *Wood Ash Disposal and Recycling Sourcebook* (Washington, D.C.: Coalition of Northeast Governors, 1988).
17. Pacific Northwest and Alaska Regional Biomass Energy Program, 5-12.
18. OMNI Environmental Services, 11, 37.
19. Ibid, 9.
20. Ibid, 11.
21. Bonneville Power Administration, *Pacific Northwest and Alaska Bioenergy Program Yearbook* (Portland, Oregon, 1989) 27.
22. Bioenergy Systems and Technology, *Prefeasibility Assessment*, 52.
23. OMNI Environmental Services, 17.
24. U.S. Envirc imental Protection Agency, "Biomass Into Energy Solicitation," *Commerce Business Daily*, 24 April, 1990.
25. "EPA Expected to Craft Policy to Limit Landfill Gas," *Sludge Newsletter*, 29 March, 1989.
26. Scott Sklar, "Industry Image: Is it Environmental Friend of Foe?," *Biologue*, April/May 1989, 3.
27. Gregg Marland, "Reforestation: Pulling Greenhouse Gases Out of Thin Air," *Biologue*, April/May 1989, 15.

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