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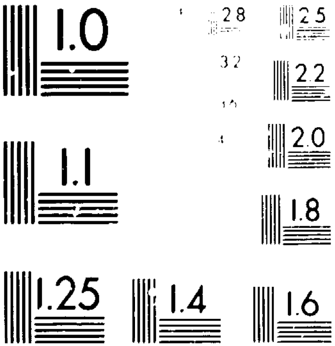
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Distr.
LIMITED
UNIDO/IS.437
6 February 1984
ENGLISH

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

THE USE OF RESIDUES FOR ENERGY PRODUCTION IN THE MECHANICAL WOOD PROCESSING INDUSTRY

Sectoral Working Paper Series

No. 16

Secto-al Studies Branch
Division for Industrial Studies

2276

V.84-81257

SECTORAL WORKING PAPERS

In the course of the work on major sectoral studies carried out by the UNIDO Division for Industrial Studies, several working papers are produced by the secretariat and by outside experts. Selected papers that are believed to be of interest to a wider audience are presented in the Sectoral Working Papers series. These papers are more exploratory and tentative than the sectoral studies. They are therefore subject to revision and modification before being incorporated into the sectoral studies.

Preface

The wood and wood processing sector has a particularly important role in the industrialization process of many developing countries. This has been reflected in the decision by the Industrial Development Board of UNIDO to organize the first global consultation on the wood and wood processing industries, which was held in 1983.

An analytical appraisal of the wood and wood processing industry has been carried out in UNIDO's first world-wide sectoral study of this industry. The main study document has been issued in draft form under the title "First world-wide study of the wood and wood processing industries" (UNIDO/IS.398). Some of the material contained in the present paper was summarized in the main study, however, this paper contains a more detailed treatment of the subject and contains material prepared since the main study was released. This paper is based on material prepared by Swedforest Consulting AB for the world-wide study, on several studies carried out for FAO, and on material presented at the ECE seminar on the topic, which was held in Bonn in 1982. However, none of these organizations have reviewed this synthesis of their work.

The following UNIDO documents (including the present paper) have been prepared in the context of the world-wide study:

1. "First world-wide study of wood and wood processing industries", prepared by the UNIDO Secretariat, (UNIDO/IS.398).

2. "Wood resources and their use as raw material", prepared by the Food and Agriculture Organization of the United Nations, (UNIDO/IS.399).

3. "A review of technology and technological development in the wood and wood processing industry and its implications for developing countries", prepared by J.F. Brotchie, (UNIDO/IS.413).

4. "Environmental aspects of the wood and wood processing industry", prepared by K.M. Strzepek, (UNIDO/IS.394).

5. "Health and safety problems in wood and wood processing industries", prepared by the secretariat of the International Labour Organization, (UNIDO/IS.410).

6. "Potentials and requirements of increasing the degree of wood processing in developing countries of Asia and the Pacific", prepared by H.P. Brion, (UNIDO/IS.395).

7. "Tariff and non-tariff measures in world trade of wood and wood products", prepared by the Secretariat of the Secretariat of the United Nations Conference on Trade and Development, (UNIDO/IS.396).

8. "The USSR forest and woodworking industries", prepared by N.A. Burdin and V.A. Sylantyev, (UNIDO/IS.406).

9. "The use of residues for energy production in the mechanical wood processing industry", (UNIDO/IS.437).

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INTRODUCTION

In most wood processing facilities in developed countries there is a high degree of utilization of raw materials. Residues such as scraps, bark, and sawdust are used either as raw materials for producing fibreboard, particle board, or other products, or are burned to produce energy. Wood residues which are not used at the location where they are produced are sometimes sold to other firms which use them. Overall for the developed countries about 50 per cent of wood delivered to the mill is recovered in primary products and of the remaining residues about 75 per cent are used in some form either for energy production or as raw material (see Table 1 and FAO 1982). Of the total wood volume delivered to the mill about 85 per cent is used in some form or other.

In developing countries the situation is typically quite different. While mill recovery rates are lower than in the developed countries, the main factor accounting for the differences in total utilization of the wood brought to the mill is the much lower utilization of wood processing residues in the developing countries. One reason for this fact is that the developing countries produce very little kiln-dried sawnwood, reconstituted board or paper. It is in the production of those products that the developed countries use most of their wood residues. The use of residues for energy production and as raw material has an additional advantage: it eliminates the problem of disposing of such wastes. In fact, waste disposal can represent a significant cost if carried out in an environmentally acceptable way. Environmental aspects of the wood processing industry are discussed in another background paper prepared for the world-wide study (UNIDO 1983a).

The use of wood for energy production in developing countries is mainly in the form of the direct use of forest material as fuelwood. This is an important use of the forest resource in developing countries. FAO forecasts that there will be severe shortages of fuelwood facing a large proportion of the world's population in the year 2000 (FAO 1982). While to some extent waste in the form of solid wood pieces (cut-offs and slabs) from milling and secondary processing plants can be used directly for fuelwood, the most promising use of industrial residues is for use in producing energy for the wood sector itself.

In this paper the focus is on the mechanical wood processing sector. It is convenient to subdivide this sector further into the primary and secondary processing industries and by various types of products within both of these latter categories. These categories are shown in figure 1 which shows also the flow of wood in the mechanical processing sector. The figure is meant as a simplification and is not necessarily exact in every detail (not shown in the figure are the secondary processing industries producing decorative items, tool handles, and miscellaneous articles made of wood; also not shown is the tie between the mechanical wood processing sector and the pulp sector, mainly in terms of pulpwood for the production of fibreboard and particle board or the use of residues from the mechanical processing sector for pulping). This chart shows the main places where wood residues are being generated with the mechanical wood processing sector.

While this paper deals only with waste materials generated in the mechanical wood processing industries, there are implications for the entire wood sector including forestry. This broader context is more thoroughly developed in the "First world-wide study of the wood and wood processing industries" (UNIDO 1983b).

The relationship between the economic use of residues and forestry has practical importance. For example, the amount of residues available to use either as fuel or raw material for producing reconstituted boards or pulp should not be thought of as necessarily fixed by the amount of waste currently generated in the mechanical wood processing sector. In fact, only a small proportion of the available volume (especially in the tropical forest) is felled and of that felled less than half, in terms of biomass, is brought to the mill site. This is a question of economics. Only the material that can justify the cost of getting it to the mill will be brought to the mill. If the value of residues from industrial processing increases then the amount of industrial residues available will increase. The use of lower grade logs (e.g. smaller diameter, more defects, dead or diseased trees, less easily worked species, etc.) results in more wastes being generated in processing. The more valuable are these wastes, the more advantageous it will be to harvest, transport and process these lower quality logs and so the larger the proportion of the total forest biomass that can be economically utilized.

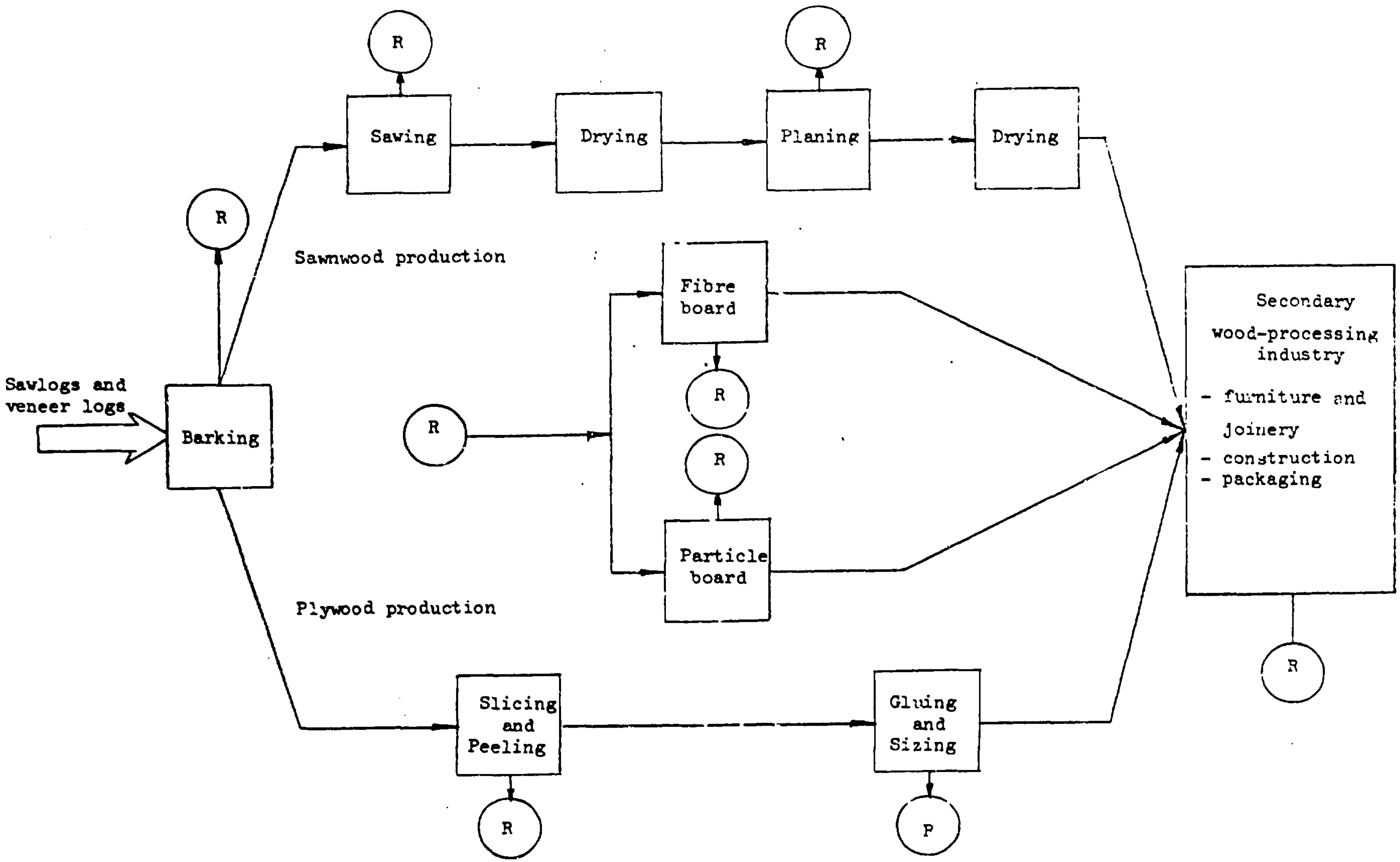

Fig.1 Flow of wood in the mechanical wood-processing sector.

R - production residues

Utilizing a larger proportion of the forest biomass will tend to increase the amount of forest management activity that can be economically justified. This should be an important consideration in developing countries, where only a small amount of forest land is presently under management (FAO 1983a).

The ability to convert wood residues into useful energy at the location where they are produced is relevant to the practical considerations for their use. In developing countries especially, processing facilities may be located in remote areas where cheap energy is not available. The issue of potential energy self-sufficiency is of special interest in these instances. Energy self-sufficiency is also of interest in those facilities where other energy is available if energy can be produced more cheaply using wood residues. In case of thermal energy, the use of residues is often the cheapest source, but only if the thermal energy is produced and used where the residues are created so that transport cost is not a factor.

The first chapter of this paper first establishes the basic energy requirements of the typical plant in each of the various branches of the wood processing industry. Estimates are given for the total amount of energy required for various types of products and various phases of the operation. Energy requirements are further broken down by type of energy (thermal, electrical and motor fuel). Chapter 2 describes the energy content of wood and the various processes by which wood residues can be converted into energy. Chapter 3 contains some observations on energy self-sufficiency and the extent to which it might be feasible and/or advisable to utilize residues on an operational basis to supply the energy requirements of the wood sector in the developing countries.

1. ENERGY REQUIREMENTS IN THE MECHANICAL WOOD PROCESSING INDUSTRY

It is economically feasible in some cases to transport residues from the location at which they are produced to another location for use as fuel or raw material, however, the most efficient use of wood residues normally requires that they be used where they are produced. Therefore, in order to assess the possibilities for using wood residues to produce energy, it is necessary to know what the energy requirements are in various types of wood processing facilities.

The figures concerning energy consumption that are contained in this chapter are not precise. They are typical for the situation in the regions from which they are taken (Scandinavia), and are believed to adequately represent the situation found in the developing regions as well. For the immediate needs of this paper the data as presented are adequate, but as data which are more representative of the developing countries become available, it will be possible to provide more precise information to develop further the results presented here.

1.1 Primary processing

The primary mechanical processing industries typically require energy for mechanical processes like sawing, planing and peeling, for thermal processes like drying, glueing, and for transport inside the plant.

Sawmilling

Electrical energy requirements in sawmilling processes include those for sawing, planing, and for fans used in drying. The electrical energy consumption of fans used in drying is, in fact, greater than the combined electrical energy consumption of sawing and planing (see Table 1). Also, the energy requirements (for all types of energy) associated with hardwood sawmilling are significantly higher than those for softwood. Thermal energy requirements per cubic meter for artificial drying are nearly 70 per cent higher for hardwood. This mainly results from the higher density of hardwood.

The single largest consumer of energy in the sawmilling industry is the kiln. Since in developing countries wood is not commonly kiln-dried it is important for planners there to recognize that as industrialization proceeds and kiln drying becomes commonplace there will be larger energy requirements in the sawmilling industries. And, second, since kiln drying is not presently widespread, there will be opportunities to implement kiln design and operation innovations. Also mills can be designed to make efficient use of energy produced from wood residues.

Because of the importance of the drying process in this subsector, it is dealt with separately at the end of this chapter, including a discussion of solar-powered kilns.

Example: A softwood sawmill and planing mill in Sweden with a production of 20,000 cubic meters per year which consists of a circular saw line, a reducer line for small logs, a kiln with 3 chambers (heated by burning bark), a planing mill with 2 moulders, 2 band saws and one multi-rip saw. Total energy consumption is 10.7 Gigawatt-hours per year. 92 per cent of this total is thermal and 8 per cent is electrical energy. Of the total thermal energy, 70 per cent is consumed by the kiln, 25 per cent is lost in the boiler, and 5 per cent is used for space heating. For electrical energy, 42 per cent is consumed by the kiln, 28 per cent by the circular saw line, 13 per cent by the planing mill, 6 per cent by the reducer line, 5 per cent by sorting and debarking, 5 per cent by the chipping station, and finally 1 per cent for lighting.

Plywood and veneer production

Energy requirements per cubic meter of output are significantly higher in the production of plywood and veneer than sawnwood (as of course is, value added). In plywood production there is no option such as in sawnwood production for reducing energy requirements by cutting out the use of drying. Thermal processes are an integral part of plywood production and cannot be skipped, as can be kiln-drying in the production of sawnwood.

Table 1. Energy requirements by sector and type of energy[a/]

Product	Electrical kWh	Thermal GJ	Motor fuel litres
	---	per cbm	---
Primary processing			
Sawnwood			
Air dried			
Hardwood	30.0	--	5.0
Softwood	20.0	--	4.0
Kiln dried			
Hardwood	75.0	2.5	5.0
Softwood	45.0	1.5	4.0
Veneer			
Hardwood	170.0	5.3	3.0
Softwood	110.0	3.3	2.5
Plywood			
Hardwood	230.0	6.0	4.0
Softwood	150.0	4.0	3.0
Particle board[b/]			
Hardwood	160.0	3.0	3.0
Softwood	120.0	2.0	3.0
Fibreboard			
Medium density			
Low capacity, 60 tons/d	450.0	5.3	3 - 5
High capacity, 180 tons/d	400.0	4.6	3 - 5
Hardboard			
Low capacity, 60 tons/d	525.0	10.4	3 - 5
High capacity, 180 tons/d	475.0	9.0	3 - 5
	---	per ton	---
Secondary processing			
Furniture	350.0	4.0	3.0
Joinery	260.0	2.4	3.0
Packaging	120.0	-	2.0

Sources: Swedforest: "Wood and wood processing as a consumer and supplier of energy", consultant report prepared for UNIDO. Information on particle board and fibreboard was supplied by Fahrni Institute, Zurich and Sunds Defibrator, Stockholm.

a/ These figures are for energy consumption in more or less typical well functioning plants. They are not meant to be absolute since plant design, raw materials used and other factors will cause significant variations in energy requirements among different plants.

b/ These figures are for capacities of between 100-500 cbm per day.

1.2 Secondary processing

Wooden furniture

It is assumed in this discussion that raw materials consist of 65 per cent sawnwood and 35 per cent panels. This is typical for shelving, chairs, and tables. Raw materials are assumed to have a moisture content of about 20 per cent for sawnwood and 8-10 per cent for plywood. For processing in this industry, it is necessary that the moisture content of the sawnwood be reduced to between 8 and 10 per cent. In addition to moisture reduction of the sawnwood raw materials it is typical to have a drying line for surface drying of finishing treatments. These two drying processes use a little less than half of the electrical energy and all the thermal energy (see Table 2).

Examples: A furniture factory in Scandinavia produces 23,000 units per year of mainly massive pine beds. The equipment consists of a kiln with one chamber, 7 saws, 9 milling and drilling machines, 3 moulders, 6 sanders, lacquering equipment, 2 spraying chambers, and 2 boilers fired by residues.

Total energy use for this facility is 1.8 Gigawatts per year. Electrical energy accounts for 18 per cent and the rest is thermal. For thermal energy the distribution of uses is 31 per cent for boiler losses, 28 per cent for drying, 21 per cent for ventilation and 20 per cent for space heating. For electrical energy the percentages are 28 per cent for operating machinery (saws, drills and milling machines), 17 per cent for transporting sawdust, 14 per cent for ventilating, 10 per cent for kilning, 8 per cent for lighting, and 23 per cent for various other uses (Sweden 1982).

A second example is provided by a factory, also in Scandinavia, which produces book shelves, cupboards, drawers and other similar items. Annual output is 250,000 units per year. The main raw material is particle board. Equipment consists of a machine shop with automated sheet, box and joinery lines. Surface treatment consists of a staining line and a drying line. There is also equipment for curtain coating and a car dryer, 3 spraying chambers and various sanding machines. There are three boilers.

The total energy used per year is 5.3 Gigawatt-hours, of which electricity is 18 per cent and the rest is thermal (the same as in the previous example). For thermal energy, 31 per cent is used for heating of premises, 18 per cent for glue pressing and surface treatment, 20 per cent boiler loss and 31 per cent for other uses. For electricity, 21 per cent is used for illumination and air compression, 21 per cent for fans (used for sawdust transport, ventilation, and surface drying), 17 per cent for process machinery (drills, saws, etc., excluding sanders), 16 per cent for sanding, 3 per cent for the glue press and 22 per cent for various unspecified uses.

Joinery and packaging production

Raw material inputs are assumed in this case to be the same as in the furniture industry described above, namely 65 per cent sawnwood and 35 per cent panels. It is assumed that the products produced will be for indoor use (windows, kitchen fittings, floorings, mouldings, etc.). The required moisture content is the same as for furniture, and again for sawnwood raw material drying is assumed necessary in order to reduce the moisture content from around 29 per cent down to 8-10 per cent. However, typically no surface treatment is done (meaning that surface drying is not required); this accounts for the main difference between the energy requirements for this industry and those for furniture (see Table 1).

Packaging production requires much less energy per unit of output than joinery. It requires significantly less processing (and produces less value added per ton). Normally, neither surface drying nor wood drying are required (sawnwood is sufficiently dry when delivered to satisfy production requirements and surface treatment is normally not a part of the production process). It requires less electrical energy and no thermal energy.

1.3 Kiln drying

In developing countries sawnwood is typically not artificially dried. It is either air-dried or delivered green to the user. For example, in China today 15-20 per cent of sawnwood is kiln-dried (UNIDO 1982). For some purposes green wood or air-dried wood is satisfactory and the techniques could be developed further. However, there are significant advantages associated with the use of kiln-dried wood. First, lower ultimate moisture content levels can be achieved and a greater level of control can be exercised over the drying process resulting in greater stability of the wood during and after drying. Second, it is faster and more predictable than air seasoning, and in this respect can significantly reduce storage costs and the cost of working capital.

In developed countries sawnwood is typically kiln-dried to a moisture content of 15-20 per cent; for wood that will be used inside of buildings it is dried further to 8-10 per cent. In some cases this is completed via a two-stage process with the first stage being completed at the sawmill and the second stage at the joinery or furniture factory. A medium-sized furniture or joinery factory in a developed country can operate its own kiln, but small secondary processing plants do not use a sufficient volume of raw material to be able to justify the expense of the kiln. There are thus some advantages for drying to take place at the sawmill where sufficient scale can be maintained to make the operation efficient. In order to promote the development of the secondary processing industry it is useful to take steps to ensure the availability of a supply of satisfactorily dried raw material.

Types of kilns vary considerably in different parts of the world. A batch kiln is one in which the timber is placed in a stationary position in the kiln and left there till it is dry. A progressive kiln is used for pre-drying timber to a moisture content of 15-20 per cent (further drying would be necessary for interior applications). The progressive kiln with longitudinal air circulation is specially designed for pre-drying of softwood timber on a relatively large scale; it is used in Scandinavia and to an increasing extent in the USSR. The advantage of the progressive kiln over the batch kiln are:

- less heat consumption
- less power consumption
- lower capital costs
- potentially better drying schedule in the early stage of drying
- greater potential for continuous operation and more easily automated.

Kiln drying accounts for up to 70 per cent of energy consumption in sawmilling--virtually all thermal energy use is for kiln drying. Depending on the design and degree of heat recovery, a drying kiln uses about 3.2-5 MJ of thermal energy per kg of evaporated water. An ordinary progressive kiln equipped with a conventional heat exchanger consumes on an average 0.94 GJ of thermal energy per cubic meter of dried wood (or 1.25 GJ without heat exchanger) and 22 kWh of electrical energy (Sweden 1982).

Factors affecting the energy consumption of the kiln include:

- thickness of the sawnwood and the size of the pile
- kiln design (size, configuration, insulation)
- outside temperature, and
- efficiency and skill of operators.

Increased costs for oil and gas have led to efforts to substitute other fuels for firing the kiln and to search for ways to make the kiln more energy efficient. The major development in this direction is the increased use of residues as fuel. This aspect is discussed elsewhere in this report. Other developments include the design of more energy efficient kilns and the use of solar energy to provide heat for the kiln. There are a number of operational units in various locations in developing and developed countries, and there is experimental work taking place throughout the world toward making this technology cheaper and more reliable (see, for example, UNIDO 1981 and World Wood 1982).

Future developments in solar kiln processes may involve two-stage drying where initial drying is via a solar powered kiln with final drying in a conventional kiln. One study suggests that it might be optimal to use the solar kiln for complete drying of some timber and partial drying of the remainder with final drying again taking place in a conventional kiln (Klamecki 1978).

Development work in this area relates to the use of solar ponds to heat water and overnight storage of water heated in solar ponds, the production of low pressure steam using solar radiation concentrators, and the use of the greenhouse type facilities.

Apart from solar energy there are developments to make kilns more energy efficient. One such device is the heat pump, which uses the same principle of the expansion and condensation of a fluid as in a refrigerator to remove heat from the ambient air and place it inside the kiln. The main disadvantage of such a system is that it relies on electrical energy for (indirectly) producing heat, which is normally not very efficient. However, in areas where cheap electricity is available, this may be an economically efficient system (Parachini 1982).

2. THE USE OF WOOD RESIDUES FOR ENERGY

2.1 The energy content of wood

Wood consists of combustible materials and non-combustibles which form ash when the wood is burned. The combustibles are carbon, hydrogen and oxygen. While wood has a lower heat value than coal, it has the advantage of being an environmentally more acceptable fuel. Specifically, it can be burned without producing significant amounts of air pollutants. Its sulphur and ash content are much lower than for coal, which makes it possible to burn wood without using the sort of pollution control devices necessary when coal is burned. There is, however, the potential for significant particulate and carbon monoxide emissions from burning wood if it is not done properly. Carbon monoxide emissions can be reduced to acceptable levels through measures to ensure complete combustion. This requires the maintenance of proper air flow to the combustion chamber and ensuring that combustion temperature is high enough. For particulates, air pollution control standards in the developed countries usually require that additional measures be taken. These typically include the use of multi-cyclone collectors, wet and dry scrubbers, or electrostatic precipitators (for more information see Rydin 1979, Wird 1979 and Leman 1976).

The chemical composition of dry wood varies over species, but would typically fall in ranges:

Carbon	48 - 55 per cent	Nitrogen	0.0 - 0.6 per cent
Hydrogen	6 - 7 per cent	Sulphur	0.02 - 0.06 per cent
Oxygen	38 - 43 per cent	Ash (wood)	0.1 - 2.0 per cent
		(bark)	2.0 - 4.0 per cent

This distribution of chemicals is for dry wood. Wood also contains water. The moisture content (mc) of wood is normally (and always in this paper) expressed as the ratio of the weight of water contained in wood to the total weight of water and wood. Sometimes moisture content is expressed as the ratio of the weight of water contained in wood to the weight of completely dry wood. The first definition is called the wet basis moisture content and the latter the dry basis moisture content.

There is very little variation in the heat value of wood per unit of weight, however, because there is a wide variation in the density of wood there is a correspondingly wide variation in heat value per unit of volume. The heat value of wood is customarily expressed in terms of net calorific value, which deducts from the heat content the amount of heat required to vaporize water contained in the wood. The variation in the heat content of wood as a function of its moisture content is small. Table 2 summarizes these relations and shows some typical density ranges for wood of various species. The densities shown there are for oven-dry wood; volumes are measured in terms of solidwood equivalents.

Table 2. Net calorific value for different densities and moisture contents of wood
(GJ/cbm of solidwood)

Species and density (kg/cbm)	Moisture content (per cent) 0	30	50
Cedar, Obeche 300-500, average 400	7.6	7.18	6.62
Iroko, Mahogany 500-650, average 575	10.93	10.32	9.52
Oak, Maple, Ash 650-725, average 690	13.06	12.34	11.38
Afzelia, Keroing 725-100, average 860	16.39	15.48	14.38
Ekki, Greenheart 1000	19.00	17.95	16.55

The figures shown in Table 2 are valid for residues from wood under bark, net calorific values for bark would be somewhat higher.

2.2 Combustion of wood residues

There are a number of ways of extracting the energy content of wood. It can be used to produce charcoal, producer gas and alcohol. However, the method of direct combustion is the most common way. The main factors affecting the way wood burns are:

- moisture content
- the size and shape of the pieces
- the presence of various types of impurities (e.g. soil).

Moisture content affects burning in two ways. First, surface moisture inhibits ignition by preventing the contact of air with the wood. Second, any water contained in the wood must be vaporized, and expelled through the flue. This latter property affects net calorific value as shown above (Table 2). It also affects the way in which a furnace for a boiler is constructed (as discussed below).

The moisture content of fuels varies from less than 10 per cent for sander dust to perhaps 75 per cent for sawdust from water cooled saws. The typical moisture content for green logs would be 40-55 per cent (Corder 1976).

The size and shape of the pieces being burned are important factors governing the rate of combustion. The greater the ratio of surface area to volume the faster will be the rate of combustion. There are some important advantages of converting wood to pieces of uniform size. This has to do with the ease of regulating the flow of fuel to the combustion chamber and controlling the rate of combustion and heat generated via the flow of air to the combustion chamber. If the fuel properties are constant then the burning process can be more closely controlled.

Impurities in the supply of fuel can present major problems for the continuous effective operation of the combustion equipment. They may also affect the predictability and regularity of the burning process and complicate it to the point where it needs constant supervision and adjustments.

2.3 Equipment for direct combustion

The procedures for direct combustion normally involve burning in a furnace of some type--normally a boiler is involved for producing hot water or steam.

For generating electricity a boiler would be combined with a steam engine or turbine. In addition to the boiler there would be fuel conditioning and handling equipment and in some cases water treatment equipment.

The boiler

The furnace in which the fuel is burned must be designed to suit the type of fuel and rate of combustion needed for the particular application. Typically the fuel is burned on a grate with combustion air coming from below the grate. Complete combustion is an important objective from the perspective of environmental considerations and is also important in terms of the maintenance of the boiler and associated equipment.

The moisture content of wood fuel affects the size and performance of the furnace. There are two reasons for this. First, the volume of fuel which must be burned in order to generate the same heat output increases with moisture content. Second, when wood with a moisture content is burned, it is necessary to line the furnace with refractory brick in order to maintain sufficient combustion temperature. It is not generally possible to burn fuel with a low moisture content in a furnace designed for fuel with high moisture content, since the hotter combustion of the drier fuel could exceed the limit for the refractory brick.

Another factor in furnace design is the grate type. Grates may be stationary or moving (travelling grates). Flat grates are normal for burning logs; for wet fuel conic grates are typical. Generally, the type of grate will depend on the characteristics of the fuel to be burned. Another type of furnace of more recent origin and more complex design is the suspension burning furnace. In this type of furnace wood or bark, hogged to a small size, is blown into the combustion chamber and burns in suspension. (Koch 1980).

Combining a boiler with a generator

For producing electricity superheated steam (steam under high pressure) is used to turn a turbine or, in the case of a steam engine, to push a piston.

When process steam is needed it can be taken from the exhaust of the turbine or steam engine. Typical efficiencies for converting wood wastes into electricity are in the neighbourhood of 15-20 per cent. The efficiency of conversion of wood into thermal energy is much higher. Typical efficiencies for thermal conversion are between 75 and 85 per cent.

2.4 Conversion of wood residues into other fuels

Producer gas

Producer or generator gas is a low-calorie gas obtained by partial combustion of organic carbon fuels. Gas made from wood can be used to power internal combustion engines. It can be burned in either spark or diesel engines after they have been modified to use it. Such fuel might be of most interest in those areas where other fuels have to be transported to the site at high expense.

Gas generators are available for converting both charcoal and wood chips. The process can be used for a wide variety of different types of biomass, but for any given plant, the range of material which can be handled is limited. The gasification plant must be geared to the chemical and physical properties of the fuel. Charcoal is a good fuel for a gasification plant in that it has a high energy content and burns clean. However, a great deal of energy is lost in the production of charcoal. In fact, the production of charcoal can in many instances be combined with a gasification operation so that the two products are charcoal and producer gas. However, while charcoal and liquid distillates are relatively simple for the small producer to transport to market, gas is not.

Charcoal

From the figures given above it is clear that the energy value of wood fuel used in charcoaling can be increased if it is possible to recover some of the by-products of the charcoaling process (both gases and liquids are produced). The main constraint in small-scale charcoaling operations is being able to preserve sufficient temperature in the kiln for pyrolysis while taking off the gas and oil. These units, however, have the significant advantage of requiring only low capital and technology while adding significant value to the raw material. And further, while efficient high quality charcoal production requires a kiln operator well versed in the art, it is possible to set-up and operate a small-scale kiln with gradually improving efficiency and quality of output using unskilled labour that is trained on the job. (For a comprehensive manual which describes simple charcoaling techniques see FAO 1983b).

Typically, recovery in a small-scale kiln (2 to 3 tons per day) would be between 40 and 60 per cent. In a large-scale kiln with provision for recovery of volatiles and oils efficiency can be as high as 90 per cent.

Not all forms of forest and processing waste can be charcoaled. The size of the pieces should be in the range of 5 to 15 cm in diameter, further the pieces in a single batch should be of about the same size. Best results will be achieved by carbonizing small and large pieces separately. High density raw material produces charcoal of a higher quality.

One of the advantages of charcoaling is that it increases heat value per unit of bulk and weight so that transport costs become acceptable relative to the value of the product. This increases its marketability not only as fuel but also for non-energy industrial applications.

Densification

Another method for converting residues into useful fuel is through densification. The advantage of densified wood is that the material is easy to handle and burn due to the more uniform size and composition of the pieces. Densified wood is normally either briquetted or pelleted. In recent years a lot of densified wood has been sold in the form of small logs for household use, to be burned in the livingroom fireplace. Densified wood requires that the raw material have a moisture content of 15 per cent or less.

An important advantage of densified fuels over simple wood wastes is the increased value of the product in relation to transportation costs. Densified fuels have a fairly high heat content to bulk ratio and their convenience of use gives them a high value for some applications (especially for household use). The improvement of transport economics is normally a necessary condition for densification being a cost-effective procedure. Where the fuel will be shipped a long distance or handled several times during distribution (such as would typically be the case for household distribution), densification is a good way to reduce these costs in relation to the market value of the product.

3. ENERGY SELF-SUFFICIENCY AND SOME PRACTICAL CONSIDERATIONS

Possibilities for self-sufficiency by sector

As stated in the previous chapter, the net calorific value of different types of wood residues depends on their density and moisture content (see Table 2). So the energy content of residues generated in different types of plants can be calculated on the basis of assumptions concerning the typical values of these parameters (see Table 3). Then based on assumptions on the energy requirements in the typical plant and the efficiencies involved in converting residues into the two types of energy, i.e. thermal and electrical, it is possible to determine the degree of self-sufficiency possible in each type of plant (or industry).

3.1 Meeting thermal energy requirements

In general, the most efficient use of wood residues is for replacing petroleum based fuels used for producing thermal energy. This is true because there is a high efficiency for converting wood into thermal energy and because a large part of the energy requirement in the sector is for thermal energy. Thus, the calculations in this chapter first deal with thermal energy requirements.

The difference between thermal energy available and thermal energy required is positive in each sector (in Table 4, this is shown as the difference between columns 2 and 3). Thus, in principle, for thermal energy each sector could be self-sufficient.

Table 4 is based on the figures for waste as a share of input presented in Table 3. These ratios are converted to waste per unit of output by the formula:

$$\text{waste per unit output} = (\text{input required per unit of output}) \div (\text{waste per unit of input})$$

Table 3. The energy content of wood residues

Product	Waste per unit of input	Waste per unit of output	Moisture content of waste	Oven dry density kg/cbm	Energy content GJ/cbm
Sawnwood					
Softwood	0.50	1.20	0.50	400.0	6.60
Hardwood	0.50	1.20	0.50	575.00	9.50
Plywood					
Softwood	0.45	1.10	0.50	400.00	6.60
Hardwood	0.45	1.10	0.50	575.00	9.50
Veneer					
Softwood	0.40	0.80	0.50	400.00	6.60
Hardwood	0.40	0.80	0.50	575.00	9.50
Furniture	0.50	1.10	0.10	500.00	9.20
Joinery	0.45	0.90	0.10	500.00	9.20
Packaging	0.35	0.60	0.20	500.00	9.00

Table 4. Surplus or deficit of energy from available residues

Product	GJ waste per unit output	Thermal		kWh surplus a/	Electrical	
		GJ required	GJ Surplus		kWh required	kWh surplus
Sawnwood						
Softwood	7.90	2.00	5.90	245.00	55.00	190.00
Hardwood	11.40	3.30	8.10	340.00	90.00	250.00
Plywood						
Softwood	7.30	5.30	2.00	85.00	150.00	-65.00
Hardwood	10.50	8.00	2.50	105.00	230.00	-125.00
Veneer						
Softwood	5.30	4.40	0.90	35.00	110.00	-75.00
Hardwood	7.60	7.10	0.50	20.00	170.00	-150.00
Furniture	20.20	3.20	17.00	710.00	260.00	450.00
Joinery	16.60	3.20	13.40	550.00	260.00	290.00
Packaging	10.80		10.80	450.00	120.00	330.00

Sources: Swedforest "The wood and wood processing industry as a consumer and supplier of energy" - an unpublished report prepared for UNIDO, 1983.

a/ Assuming 15 per cent efficiency in converting wood to electrical energy.

Energy content per cubic meter of waste (measured in terms of net calorific value) is taken directly from Table 2 and reproduced here as the last column of Table 3. Multiplying this figure times waste per unit of output then gives the energy content of waste generated per unit of output. This is the figure shown in the first column of Table 4.

3.2 Electrical energy requirements

The issue of economic efficiency is discussed in the next section. The use of wood residues to produce electrical energy is typically not a very cost efficient operation, although under some circumstances it may be. Here the focus is on self-sufficiency, not economic efficiency.

The conversion of calorific value to electrical energy is based on the assumption that only about 15 per cent of the energy content of the wood residues can be realized as electrical energy (i.e. the efficiency of conversion is 15 per cent). The secondary sector and sawmilling are in principle able to produce all of the electrical energy they require from residues. Plywood and veneer production are not energy self-sufficient (see Table 4, column 6). Taken as a whole, the sector could be considered energy self-sufficient with respect to thermal and electrical energy; motor fuel is not considered in the self-sufficiency analysis. That is, the surpluses of energy available in the self-sufficient branches are more than ample to off-set the deficits in the plywood and veneer sectors. Thus, an integrated sawmill and plywood operation producing the two commodities in approximately the same amounts would be able to meet all of its electrical and thermal energy requirements from its wood residues.

No attempt is made here to include an analysis of self-sufficiency of the sector with respect to motor fuel. In fact, while it would be possible to convert wood wastes into producer gas or alcohol to use as motor fuel, the issue of self-sufficiency is not so interesting for motor fuel, since the cost of transport is not high relative to the value of the product. It is thus not especially useful, for this type of energy, to analyze the potential for the energy to be used at the same place where it is produced (i.e. firm self-sufficiency).

3.3 Practical considerations

While the above discussions show that self-sufficiency is a possibility for much of the sector, this does not necessarily mean that it is practical. There are economic and technical considerations. The discussion in this section concerns these practical aspects. Two examples are considered; the first concerns an actual installation and the second is based on a number of hypothetical installations.

First example: Karl Richtberg GmbH & Co. KG

An installation in the Federal Republic of Germany which converts wood residues into thermal and electrical energy is described in World Wood magazine. (Fraser 1982).

The unit is located at the Bingen mill of the Karl Richtberg GmbH & Co. KG, which produces sawnwood, sleepers, and utility poles. As originally planned, the company would have sold about half of the power plant's 10.5 million kWH/yr output to the national grid, but as it has turned out, sales to the national grid have been only a small proportion of this figure.

The mill's annual roundwood consumption is 100,000 cbm/year of which about 35,000 cbm of waste material can be recovered as fuel for their boilers. Wastes include slab, sawdust, bark and trim; larger sized material is hogged before burning. In addition, noxious phenolic condensate waste from the creasote impregnation operation can be burned. Reduced waste disposal costs, for noxious and other waste material, were a consideration in the decision to build the plant.

The power plant itself consists of two boilers capable of producing 8.5 tons of steam each when operated at a fuel consumption of 6 tons of wood residues per hour. Each boiler is also equipped with an auxiliary oil burner which is capable of producing one half of rated capacity when burning oil alone. These oil burners are used when the plant is burning wastes containing phenol.

The turbine installation consists of a single-stage dc turbine with double row Curtis-wheel and connected turbo-generators. It is connected in series to the two boilers. Turbine No. 1 works as a back-pressure machine reducing steam pressure from 26 bar to 6 bar. Combined capacity is 2,400 kW. Turbine No. 2 works as a condensing machine reducing pressure from 6 bar to 0.26 bar. Exhaust steam at 310 degrees centigrade is bled off for process steam and to turn turbine 2. This steam is used for space heating, heating the kiln and heating creosote for the impregnation operation. The complex has been increasing its kilning operations since installing the power plant. Sleepers had formerly been air dried for between six months and a year b t are now dried in a low temperature kiln, which reduces drying time by two thirds.

The initial investment cost for the complete power plant was US$1.75 million (or US$3.5 million including modification of the existing mill to make use of the power and heat produced). The plant went into operation around the beginning of 1980. Because of economic considerations, the company has operated the power plant at only about half its capacity. The price offered by the utility which operates the grid is less than one third the price which the mill pays the same company for the electricity it purchases. Under these conditions the firm has chosen to produce power mainly for its own use and has sold only a small amount of power to the national grid. The company gains not only from supplying its own energy needs but also from reduced waste disposal costs. Its gains in the future would be greater if rising energy prices result in increased prices for the electricity it sells to the national grid.

Second example: hypothetical plants

Several hypothetical examples of waste wood utilization for energy production in the mechanical wood processing sector are presented in a report prepared for FAO by Ekono Oy, Helsinki (Ekono 1980). The approach used in their report has the merit of making it possible to produce a consistent set of engineering and economic data concerning the conversion of wood waste to energy across a spectrum of firms producing several different products. This sort of detailed information seems not to be available for very many actual installations.

There are four power plants considered in the report, two thermal plants and two electrical plants (which also produce thermal energy as a co-product, as in the first example, above). The main results for all the mills are summarized in table 8 at the end of this section. The two sawmills which use artificial drying are presented in more detail here. All of the production facilities considered are smaller scale and simpler in design than typical mills in developed countries.

The plants are assumed to be operated in the Philippines and their designs take into account the costs there in the fourth quarter of 1979; all monetary values are expressed in terms of real US dollars (in fourth quarter 1979 prices, and are thus comparable to the figures in the previous example). The two sawmills differ in terms of scale: Mill A produces 50 cbm per day and Mill B produces 100 cmb per day (see also table 5). The mills are equipped with chamber-like kilns which are heated with hot water entering the kiln at a temperature of 110-120 degrees Celsius. Kiln air is circulated by fans.

The main result of the Ekono report is a set of estimates of energy costs per unit of output for the various products and energy sources considered. These estimates are, of course, based on certain assumptions. A key assumption concerning the production of electricity is that it is possible to sell the surplus output to the public grid. It is thus possible to run the generators on a twenty-four hour schedule. It is assumed that it is possible to sell electricity for $34/MWh which is over two-thirds of the price of electricity purchased from the grid (in the first example this ratio was less than one-third). Other key assumptions are that wood fuel is available for either mill at zero cost, fuel oil costs $300/metric ton, and the interest rate is 10 per cent. Free disposal of wood wastes (and certain other wastes) is assumed, e.g. the reduction in disposal costs which results from burning wood wastes is not reflected in these figures.

Table 5. Characteristics of the two mills

	Mill A	Mill B
Output per day(cbm)	50	100
Output per year (cbm)	13,500	27,000
Installed capacity (kW)	240	480
Consumption		
Electrical (kWh/cbm)	40	40
(MWh/yr)	540	1080
Thermal (KWh/cbm)	420	420
(MWh/yr)	5,625	11,250
Energy yield of waste wood (MWh/cbm)	1.7	1.7

Source: Ekono "Power and heat plants: study prepared for the FAO portfolio of small-scale forest industries for developing countries" 1980, Helsinki.

Investment costs for the two power plants are US$320,000 for the thermal plant and US$1,452 million for the co-generation (electrical) plant (see Table 6).

The costs of energy per cubic meter of sawnwood output for the smaller mill are significantly higher than for the larger firm (see table 7). In part, this is because the power plant for the smaller mill is not optimized for the lower level of output. While this cost estimate should not be taken too seriously, recall that the facility in the first example was in fact operated at only half its design capacity.

More important than the higher energy costs for the smaller facility, is the significantly cheaper unit energy cost in both cases when wood wastes are used to produce thermal energy while electrical energy is purchased from the grid. Thus, the total energy required to produce one cubic meter of sawnwood in the larger plant costs US$5.90 when thermal energy is produced from wood residues and electrical energy is purchased from the grid. If wood wastes are also used to produce electrical energy, costs per cubic meter rise to US$8.50.

The results are similar for those other wood processing facilities where an electrical power production alternative was examined (see table 8). Ekono also reports unit costs for some of the mills for the case of a co-generation plant fired by fuel oil. These figures show that if it is not possible to purchase electricity from the grid, as might be the case in some remote facilities, then it is cheaper to produce it with wood wastes than with fuel oil.

These results depend, of course, on the assumptions of the study; a higher price of electricity and a lower rate of interest, for example, would favour the use of wood wastes for electricity production. Also if the estimates were to reflect the savings in disposal costs associated with the use of wood wastes for energy production they would have been more favourable to the use of wood. Generally, however, it must be concluded that except for those situations where a public grid is not available, the economic considerations do not favour the use of waste wood for producing electricity. In addition to the higher cost of electricity produced with waste wood, it should also be noted that generating facilities are capital-intensive--the initial investment for a co-generation facility is five to ten times that for a thermal plant. Too, in most cases, a large part of the plant and equipment would have to be imported requiring that foreign exchange be diverted from the purchase of other imports. Both of these latter considerations are important for developing countries.

Table 6. Investment costs

(thousands of US$)

	Thermal		Electrical	
Equipment		214		939
Boiler	127		340	
Steam engine			175	
Fuel handling	87		89	
Other			335	
Construction		11		45
Freight & insurance		15		66
Assembly		43		241
Other costs		37		161
Total investment		320		1,452

Source: Ekono "Power and heat plants", op.cit.

Table 7. Calculation of total and unit energy costs

(per year and per cbm of output in US$)

	Mill A		Mill B	
	Thermal	Electrical	Thermal	Electrical
Wages	4,900	8,800	4,900	8,800
Maintenance	6,400	16,400	7,200	23,500
Fuel oil	9,600	14,100	19,100	28,100
Auxiliary power	6,750	9,563	13,500	19,125
Miscellaneous	2,250	3,337	4,500	6,775
Capital	52,000	133,700	59,000	190,900
Electricity	25,900	-21,900	51,800	-44,000
Consumption (MWh)		(540)		(1080)
Generation (MWh)		(470)		(940)
Purchased US$48/MWh		(70)		(140)
Sold US$ 34/MWh		(745)		(1490)
Total energy cost	108,000	148,500	160,000	229,500
Unit energy cost	8.00	11.00	5.90	8.50

Source: Ekono "Power and heat plants", op.cit.

Note: The negative entries for electricity reflect the revenues generated from selling electricity.

Table 8. Unit energy costs for different energy sources
(in US$)

Type of mill and level of output	Type of energy supply and cost				
	Thermal plants		Electrical plants		Fuel oil
	Small	Large	Small	Large	
Sawmill (without kiln)					
50 cmb/d	1.00				
100 cbm/d	1.00				
Sawmill (with kiln)					
50 cbm/d	8.00		11.00		11.00
100 cbm/d	5.90		8.50		10.80
Plywood mill					
30 cbm/d		27.30			45.40
Fibreboard mill					
20 tons/d		67.70			96.50
Particle board plants					
25 cbm/d		41.80			50.80
50 cbm/d		26.60			36.70
Integrated plant 1					
sawnwood: 100 cbm/d		5.80		7.00	11.30
plywood: 30 cbm/d		23.00		24.90	39.60
particle board: 50 cbm/d		21.30		22.10	34.80
Integrated plant 2					
plywood: 30 cbm/d		27.30		33.30	41.60
veneer: 30 cbm/d		22.10		29.10	36.40
particle board: 25 cbm/d		30.10		32.60	40.90

Source: Ekono "Power and heat plants", op.cit.

Note: The small thermal and small electrical plants are described in the text in relation to sawmills A and B. The energy production potentials and initial investment costs for the wood-fired plants are:

Small thermal 1 MW thermal, US$320,000
Large thermal 2.5 MW thermal, US$588,000
Small electrical 2 MW thermal, 250 kW electrical, US$ 1,452,000
Large electrical 8 MW thermal, 1 MW electrical, US$2,511,000.

4. CONCLUSIONS

There are large amounts of wood processing residues in developing countries which are not currently being used. One reason is that the uses of particle board and fibreboard are not well-developed. Another reason is that sawnwood is not yet extensively kiln-dried.

Increased use of wood residues for energy production has much potential in the developing countries. The possible methods of converting wood wastes to energy range from simple techniques such as direct combustion combined with a boiler to produce thermal energy to more complex methods such as gasification or the production of electricity. The energy efficiencies of conversion vary widely, for example, direct combustion to operate a boiler typically has an efficiency of 70-80 per cent, while for electricity production it is usually between 15 and 20 per cent.

Mainly because of higher efficiency and lower investment costs the use of wood wastes is generally an economically efficient source of thermal energy. In the sawmilling and furniture industries the main use of thermal energy is usually for the kiln. Since artificial drying provides better control of inventory and scheduling and results in a higher quality product, the trend in developing countries toward increasing use of artificial drying can be expected to continue or even accelerate. This is then likely to be an important use of wood residues in the developing countries in the future.

The extent to which the production of electrical energy will become more practical depends on the future prices of competing sources of electrical energy. It is reasonable to conclude that in many cases small-scale co-generation facilities can produce energy more cheaply using wood residues than using fuel oil. This assumes that wood residues are available at little or no cost. This is the case for many mechanical wood processing establishments in developing countries where otherwise wood residues create a disposal problem. One factor which limits the use of wood residues is the cost of transporting them over any great distance. If they cannot be used close to where they are created they normally will not be used.

While it depends on individual conditions, typically the price of electricity would not need to increase substantially in order for wood fired co-generation facilities to become the cheapest source of thermal and electrical energy co-generation. For the hypothetical case presented in this study the increase in the price of electricity which would cause the co-generation option to be the cheapest was quite small for some of the facilities. One implication of this is that, for the most part, the sector can insulate itself from large shocks (on the cost side) which could result from dramatically increased energy prices. This is one way to measure the degree of self-sufficiency of the sector.

Considering the concept of self-sufficiency as relating strictly to the match between the energy requirements and energy available, the wood products sector could be energy self-sufficient when taken as a whole. Specifically, it would be possible for an integrated facilitiy producing several primary and secondary products to supply all of its energy requirements from its residues. In fact, it is almost always possible to inrease the amount of wood recovered from the harvest site if the economic requirements can be met. Thus, self-sufficiency may be attainable even though the energy content of current residues are insufficient to cover all requirements.

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