Part 3. Physical conversion of biomass

3.1 Firewood

3.1.1 General scope

Firewood is a classic energy source, and is still important household energy source in many developing countries. In the latter half of the 20th century, firewood was deprived of many uses by petroleum, but firewood production occupies more than half of the harvested wood, and firewood covers 14% of the world energy consumption, and 36% of the energy consumption in the developing countries.

However, in some regions, the amount of wood is decreasing with the increasing population, and they have to travel far to get firewood. They have troubles even for getting firewood for cooking. In Asian countries, most of the forestry wood has difficulties in use, due to the troubles encountered for transporting wood from the forest of high slope area.

For the left side of Fig.1, which is the supply side of firewood from raw wood to the furnace, what matters now is not the amount of the resource, but the energy and cost for the transporting the wood from the forest. When external energy supply for this transportation *e and energy available from the product firewood E have the relationship

$$\sum{}^{*}e > E,$$

this system fails to be a net energy producing system. This aspect is also very important for the case where chipping or palletizing is made so that the fuel is easily handled at the furnace.

```
                *e transportation,etc.            ┌→[E]→cooker or heating
Raw wood   ——————————————————→   stove ———→ [flue gas]
                *e drying,cutting,etc.            └---—→[ash]
```

Fig.3.1.1. Material- and energy-flow around stove in firewood system
*e :energy supply from outside, E :useful energy

For the right side of Fig. 3.1.1, which is the user of the firewood, what matters is the low energy efficiency of the old heating devices similar to traditional kitchen stoves.

In addition, hygiene of the indoor air is to be considered when small stoves are used that often accompanies with incomplete combustion. The problems of soot, carbon monoxide (CO), tar, Non-methane volatile organic matter (NMVOC), and polyaromatic hydrocarbons (PAH, carcinogen) are pointed out.

Ash content of the firewood is lower than that of coal by one order, but ash removal is important from the view point of mass balance, although it usually does not cause a serious problem. Ash of wood has high content of potassium, which is an important fertilizer, and return of ash to the forest is essential for the sustainability of the system.

Herbaceous plants have higher ash content than wood by 5-20 times, and ash treatment is a large problem for production of artificial firewood from straw, husk, and bagasse.

Heating values of plant is about 20GJ/t-dry for various woody biomass (half of heating value of oil), and mostly decided by its water content. Woody biomass is not suitable for transportation of long distance due to its bulkiness. This is why utilization of firewood near the forest is insisted.

3.1.2 Firewood supply

The potential of firewood supply is discussed here. According to FAO (Food and Agriculture Organization), forest area of the world is 39,500 km^2 (3.95 Gha) and decreasing gradually (-0.2%/year). Although the primary growth rate of forest is estimated to be more than 5.1 km^3/year (5.1 billion m^3/year), annual lumber production is as small as 1.6 km^3/year (1.6 billion m^3/year) for industrial use, and 1.8 km^3/year (1.8 billion m^3/year) for fuel use. Even if forestry area is constant, artificial forest with high growth rate is increasing gradually, and supply increase with mild development of economy can be met.

For lumber production, production of forest residue and thinning wood is accompanied with. If proper development is made for transportation of these biomass, supply potential largely increases. However, transportation from steep mountain that is often found in Japan and Asian countries leads to very large value of *e-1 in Fig. 3.1.2, and the woody biomass cannot be effectively utilized. The value of *e-1 is expected to increase with distance proportionally, and increase with the slope with the exponent value of 2 to 3, but has not been studied in detail. The bulk density largely affects the transportability. Packing factor is 1/4-1/3 for twigs, 1/2 at maximum for chip, and 0.6 for pellets.

*e-1 transp.   *e-2 transp.   ┌→[E]
Raw wood ———→ village ——————→ stove
*e-3 gathering, ↓ *e-4 drying,*e-5 cutting ↑
Factory ——processing——→┘

Fig.3.1.2. Material- and energy-flow before stove in firewood system
*e1、*e 2、*e 3･･･ :energy supply from outside,

An experiment was made by a Japanese NPO to transport woody biomass from high-slope land forest to the foothills using a slider as shown in Fig. 3.1.3. Successful result was obtained for the thin wood, for the slope of around 20°. This system requires no mechanical power, and applicable to the sloped region.

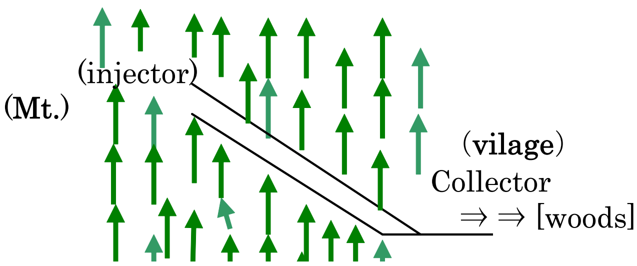

Fig. 3. 1. 3. Carrying-out system for mountain- fire woods

To convert raw wood to firewood, it is cut into the length of less than 50 cm, because of the furnace dimension. The improve the easiness of burning, change its form to have an aspect ratio of 10-20 by cutting into pieces so that surface area is increased. These requirement is troublesome, and recently, artificial firewood produced by pelletizing the crashed wood into a form of cylinder with empty core is developed (Ex: Ogaraito, See Chap. 3.2 Pelletizing). Order is given for some forms of woody biomass fuel in terms of high specific surface area and improvement in handling as follows, but higher treatment requires higher consumption of the process energy (*e-4、*e-5) and results in higher cost.

Raw wood ＞ fire wood ＞ chips, briquette ＞ pellet

Water content of firewood is 50% for raw material, and 15-30% for air-dried firewood. Both are combustible, but latent heat of water (2.26 MJ/kg-water) is lost. Generally, when water content exceeds 2/3, the fire gets extinguished because the remaining heat is not sufficient to achieve the flame temperature. Drying of firewood consumes process energy, but part of which can be partly recovered by the increase in the heat of combustion.

3.1.3 Utilization of firewood

Firewood can be used with simple equipment, but the mode of combustion changes as shown below. Char combustion is 10-20% of the whole combustion.

Drying → dry-distillation → flame combustion → char combustion
(～150℃,endothermic)
(250～400℃,endothermic) (main combustion) (solid combustion)

When air supply is in shortage, hazardous tar is produced in the dry-distillation stage. At the stage of flame combustion, CO and soot (carbon particles) are produced, and part of tar is converted into carcinogenic PAH by pyrolysis. To prevent these pollutant from getting in the flue gas shown in Fig.3.1.4, high temperature and oxygen content is to be maintained by using air amount a little bit in excess from stoichiometry.

For safe combustion of firewood, air ratio of 1.25-1.4 is usually employed. When the air ratio is too high, the flame is diluted, and the flame temperature is lowered, thus, supplying excess air as secondary air is recommended. A device to place combustion catalyst over the flame is available commercially, which aims at achievement of complete combustion even at the air ratio close to 1.0, but gas flow is deteriorated, and yearly exchange of the catalyst is needed.

[E]→cooker
↑ └→ heating
Fuel woods → stove ——→ [flue gas] —→ (chimney)
└→ ash pan ---—→[ash] ---→ fertilizer

Fig.3.1.4 Material- and energy-flow after stove in fire wood system
*e1、*e 2、*e 3･･･ :energy supply from outside,

At the upper part of Fig.4 is shown the use of heat. For air conditioning, heat loss can be small, but for cooking, effective use of heat is not always easy because heat transfer to the pot is needed. Development of an apparatus that works as both cooking stove and room heater requires elaborate work.

Generally, the top part of the stove, where the highest temperature is available, is used for cooking. For hot water supply which does not need boiling, lower temperature part is assigned.

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3.2 Pelletizing

3.2.1 What are Pellet and Pelletizing?

Pelletizing is to compress the materials into the shape of a pellet. A large range of different raw materials such as solid fuels, medicine, feed, ore, and more are pelletized. On the solid fuel, we call them the wood pellet, ogalite(wood briquette), coal briquette or composite fuel. The wood pellet shown in Fig. 3.2.1(a) is made of wood waste such as sawdust and grinding dust. A diameter of a pellet is 6-12 mm, a length is 10-25mm. Figure (b) and (c) show a large size pellet (wood briquette and rice husk briquette). A diameter of briquette s 50-80 mm, and a length is 300 mm. Figure (d) shows CCB that is a kind of the Composite fuel of Coal and Biomass. We call it Biobriquette.

(a)Wood pellet Japan (b) Ogalite Japan (c) Rice husk briquette Nepal (d) CCB Japan

Fig. 3.2.1. Various types of briquette.

(a) Wood pellet

Apart from a rice husk briquette, wood pellet and wood briquette are produced in the following manufacturing processes.

(1) drying process

Generally the original moisture content of wood is about 50%. It is necessary to dry the raw materials to moisture content 10-20% in order to obtain the optimum pulverizing and pelletizing conditions. Big particle size of raw material should be dried with the rotary kiln, and small particle size of raw material should be dried with the flash dryer.

(2) pulverizing process

The raw materials should be pulverized in accordance with size of the pellet. In case of whole wood or large size wastes, the raw materials should be crushed before drying process in order to prepare the moisture content uniformly. This process is needless in case of the raw material is rice husk.

(3) pelletizing process

Pelletizer consists of feeder, roller, dies as shown in Fig. 3.2.2-3.2.3. Fig. 3.2.2 shows the schematic drawing of pelletizer for wood pellet. This type of pelletizer is the most popular in the world. Fig. 3.2.3 shows the schematic drawing of briquetting machine for wood briquette and rice husk briquette.

(4) cooling process

Because the pellet of manufacture right after is high temperature and contains much moisture, it needs to cool off.

(5) screening process

Low quality pellets are removed in this process. They are utilized as energy for drying.

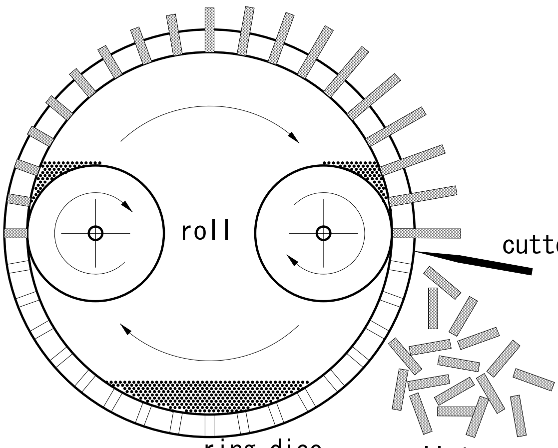

Fig. 3.2.2. Pelletizer for wood pellet.

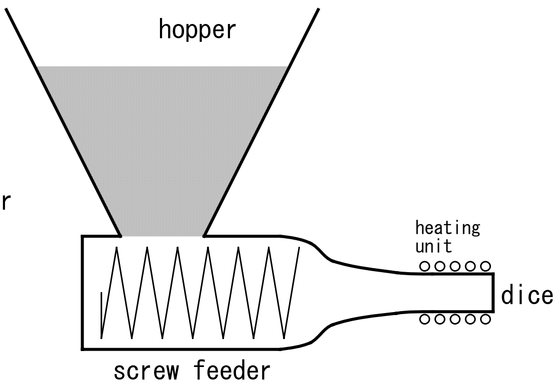

Fig.3.2.3. Briquetting machine for wood and rice husk briquette.

(b) CCB (Composite fuel of Coal and Biomass;Biobriquette)

In the second oil crisis, CCB was developed as kerosene substitute fuel in Japan. CCB is a kind of composite fuel of coal (<2 mm) and biomass (<2 mm) that is produced by the high pressure briquetting machine as shown in Fig. 3.2.4. The fundamental raw materials mixing ratio of CCB is coal 70-90%, biomass 10-30% by the weight. When coal includes sulfur content, slaked lime or lime stone of equivalence ratio 1-2 is added as a desulfurizer. Coal can be utilized from a lignite to smokeless coal, and wood waste, agricultural waste and something like that can be utilized as biomass. Because biomass is mixed with coal and the combustion efficiency of fuel is high, ignitability and flammability is good, there is a little emission of smoke, the effect of energy saving is high. In particular the reduction of the carbon dioxide is easy so that CCB includes 10-30% of biomass. The sulfurous acid gas of 50-80% can be reduced by adding a desulfurizer with fuel The technology of CCB is one of the clean coal technology and transferred to many countries as alternative fuels production technology of firewood, kerosene and charcoal In particular, the technical support requests for energy saving, reduction of carbon dioxide and prevention of acid are increasing rain from China.

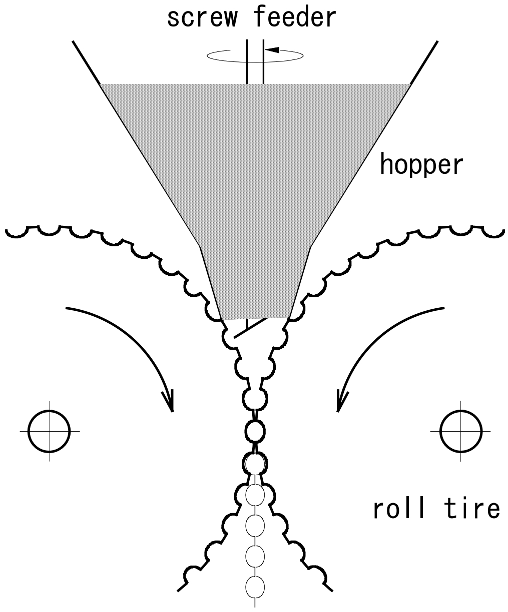

Fig. 3.2.4. Briquetting machine for CCB.

3.2.2 Characteristics of pellet and CCB

(a) Wood pellet

Characteristics of the wood pellet which compared with wood tip and fire wood are as follows; handling, igniting and burning are easy, shape and characteristics of fuel are uniformly, there is a little emission of harmful gas during burning, transportation efficiency is high, energy density is high.

(b) CCB

CCB includes 10-30% of biomass. Generally biomass has the defect that heat quantity is low.

On the other hand, it has superior characteristics such as good ignitability, good flammability, little smoke emission, low ash content. These characteristics are not in coal and make the utilizing of low quality coal possible. These characteristics make the use of low-grade coal possible.

3.2.3 Fundamental test for briquetting

(a) Wood pellet

It is thought that the factors that affect on pelletizing condition are pressure, temperature, compression time, particle size of raw materials, moisture content and chemical composition of wood. As for the boundary condition on pelletizing, it is not clear yet. It is actual that pellet is produced on the basis of experience of operator. It is different with a kind of wood material, but the experience value of pelletizing pressure and temperature is 70MPa and 100-150 degrees. However, there is no doubt that lignin, glucide and pectin play as a binding agent.

(b) CCB

We use a high pressure roll type briquetting machine for production of CCB. Tablet tests are carried out to obtain the optimum blending ratio of the raw materials and indispensable as a preliminary step in briquette manufacturing. The blended material is compressed to tablet of 25 mm diameter. A steel ball with a diameter of 20 mm is placed on a tablet and the ball is forced down onto the tablet until the tablet breaks. The breaking strength is measured as the criteria of quality. Fig. 3.2.5 shows the breaking strength of the tablets prepared from coal and biomass. The breaking strength becomes increasingly higher as the content of the biomass increases. Heating the raw materials under briquetting is an effective way to increase the breaking strength. Fig. 3.2.6 shows that a higher temperature of molding increases the breaking strength of tablet. This is attributable to the enhancement of the plastic deformation of the biomass by heat. The blending ratio of coal and biomass that achieves a breaking strength of briquette of 1 kN is 20% of biomass content and molding temperature 50 degrees. Based on these results, the standard blending ratio of coal and biomass is determined. When a CCB was produced with high pressure roll press machine, the shearing stress occurs between roll tire and raw materials, and raw materials is heated in about 70-80 degrees. Therefore heating control of raw materials is not done in briquetting process.

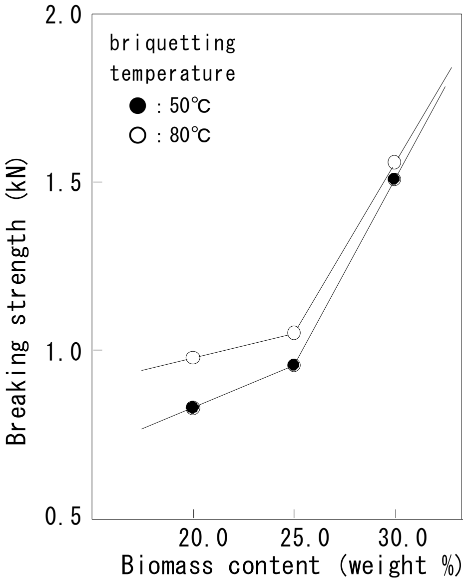

Fig.3.2.5 Effect of biomass content

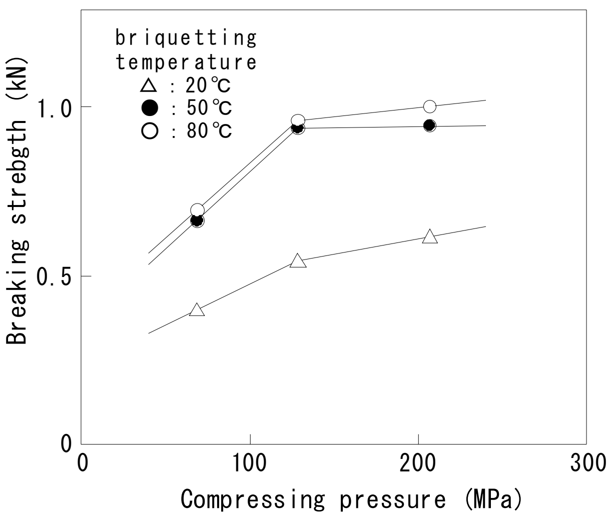

Fig.3.2.6 Effect of compressing pressure

3.2.4 Energy efficiency

In China, the effects of CCB use for an economy and an environment are estimated as follows; As for the consumption of coal decrease 20%, because CCB includes a biomass of 20%. And, by improvement of flammability of fuel, about 25% heat efficiency becomes higher than a present coal boiler. When CCB were consumed 1,000,000 t/year in China, it is estimated that 400,000 t/year of coal consumption, 5,000 t/year of smoke emission and 15,000 t/year of sulfur dioxide are decreased.

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3.3 Particleboard Production

3.3.1 Particleboard

Composition board has many names and definitions. Particleboard is a general term for a panel manufactured from lignocellulosic materials (usually wood), primarily in the form of discrete pieces or particles, as distinguished from fibers, combined with synthetic resin or other suitable binder. The particles are bonded together under heat and pressure in a hot press by a process in which the entire interparticle bond is created by the added binder; other materials may be added during manufacture to improve certain properties (ASTM D 1554). Classification of particleboard varies, depending on country. For example, Japanese Industrial Standard (JIS) A 5908 classifies particleboard into five categories on the basis of: 1) surface condition, 2) bending strength, 3) adhesive, 4) formaldehyde release amount, and 5) flame resistance. Fiberboard is a general term for a panel manufactured from lignocellulosic fiber. This chapter does not cover fiberboard.

Products made from comminuted woody materials in the shape of fiber, shavings, and particles can be made from woodworking waste, noncommercial or low-value wood, and agriculture waste. Bark, forest slash, and industrial waste can be included in the products. The manufacture of composition board is a conversion of previously unused natural resources to useful products. Thus, particleboard production is considered a technology for recycling woody cellulosic biomass resources for sustainable forestry.

3.3.2 Particleboard Production and Consumption

There are 16 factories that manufacture particleboard in Japan (April, 2006). In October, 2006, total domestic production was 1,234,000 m^3 and imported particleboard production was 391,000 m^3. Of this total (1,625,000 m^3), 60% was used for furniture and 37% was used for construction. To meet the goals of Japanese laws for recycling 60 % dismantled construction wood, 61% of raw materials for wood composite panel manufacturing was from dismantled waste in 2005.

3.3.3 Particleboard Manufacture

The process of particleboard manufacture is shown in Fig. 3.3.1. The first stage of the process is manufacturing raw particles from the mixture of waste wood, which is described as "particle formation process." Dismantled construction wood and industrial waste wood are processed on different lines in the particle formation process. Several processes are performed for reducing bulk wood to chip size and eliminating foreign materials. Raw materials are sent to a shear crushing machine for initial size reduction, metal is removed by magnets, and the material is then further reduced in a hammer crusher. Material is screened and sorted by airflow, eliminating sand and concrete. The remaining raw material is sent through a search-coil magnetometer, which eliminates non-metal foreign materials. The second stage of the process is to manufacture board from the raw particles created by the first process. To obtain uniformly thick particles, a ring flaker is used for particle size reduction. the particles are then dried and screened. Energy for the drying kiln is often supplied by burning dust produced in the plant. The particles are classified by size prior to blending them with adhesive. Separate surface and core blenders are used for three-layered particleboards. The blended furnish is moved to the three mat formers, hot-pressed, cured, and sanded. Nondestructive testing is sometimes performed to eliminate products that include defects, such as blisters. After sanding, products are inspected for shipping.

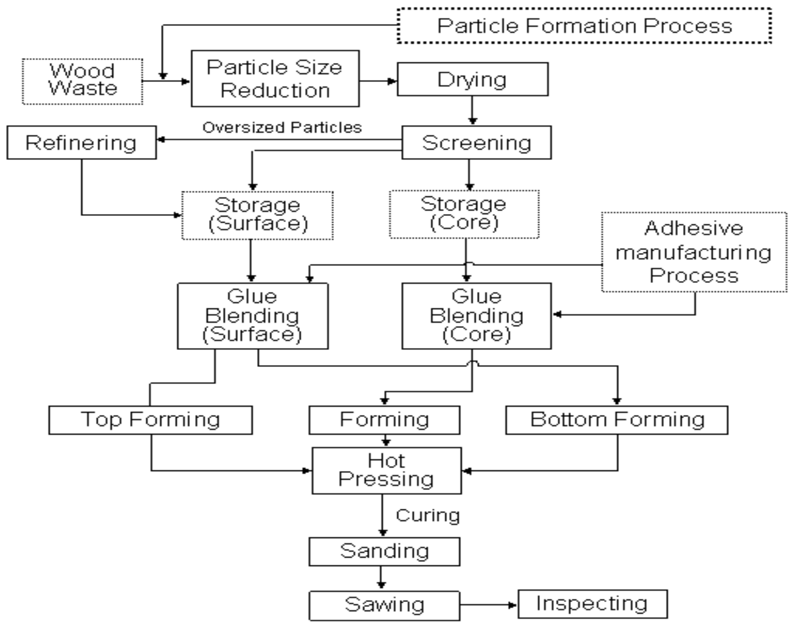

Fig.3.3.1. Particleboard Manufacturing Process. Courtesy of Saito, Y., Tokyo Board Industries, Co., Ltd.

3.3.4 Use of Particleboard for Material Recycling

Particleboard manufacture is a valuable process for recycling woody waste that might otherwise be landfilled or burned. The process permits blending recycled materials with fiber from other sources to achieve specific properties. For example, limiting shorter recycled elements to the core and using longer elements from other sources on the surface can improve strength. Particleboard manufacture is a mature industry in Japan, but there are opportunities for improving the efficiency of the process. As oil prices continue to increase, the costs for transportation, adhesives, and energy for plant operation continue to increase. Particleboard manufacturers must compete with other industries for woody raw materials. Some recent policies that focus on woody biomass for energy make the situation even worse. The Minister of Agriculture, Forestry and Fishery started a comprehensive program focusing on agricultural woody biomass resources, with clear goals for: 1) education, 2) technology development of transportation fuel such as bio-ethanol, 3) promotion and networking of local societies that use biomass resources, 4) research and development of technologies for using woody biomass and other potential natural resources, 5) initiatives for using biomass products and promoting recycling, and 6) technology transfer to other Asian countries. Most particleboard industries that use local woody wastes intend to improve efficiency by increasing their use of recycled material and supplementing energy for plant operation by burning material that is unsuitable for manufacturing particleboard.

3.3.5 Statistics of Woody Biomass Including Wood-Based Panels

Wood biomass includes bark, sawdust, and cut-offs from lumber, veneer, plywood, and engineered wood products. The total amount of woody biomass use in Japan was 10,782,000 m^3 in 2006. Almost all of this (10,197,000 m^3 (95%)) was used as a biomass resource, while the rest was discarded. Woody biomass is classified as: 1) wood chips, 4,408,000 m^3 (43%); 2) fuel, 2,330,000 m^3 (23%); 3) livestock bedding materials, 2,256,000 m^3 (2 %); 4) compost or soil improvement materials, 580,000 m^3 (5.7%); and 5) wood-based panels such as particleboard 258,000 m^3 (2.5%). Fuel (2,330,000 m^3) is classified as: 1) energy for operating drying kilns (1,550,000 m^3), 2) electric power (595,000 m^3), and 3) energy for manufacturing pellets (46,000 m^3).

3.3.6 Application in Asia

Kenaf grows faster than wood and is considered an environmentally friendly material. Panasonic Malaysia developed an environmentally friendly system for manufacturing kenaf (Hibiscus cannabinus) particleboard. The process decreased pollution, thus conserving Malaysia's rich coral reef ecosystem. The technique for manufacturing kenaf board was originally developed in cooperation with Kyoto University using kenaf grown in China. In 2005, Panasonic succeeded in developing a process for growing kenaf in Malaysia that was suitable for manufacturing high quality kenaf particleboard. This process produces 30% waste, but the fiber is burned to provide electric power for the manufacturing plant and the ash is returned to fields to fertilize kenaf (see http://panasonic.co.jp/ism/kenaf/index.html).

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