

The Asian Biomass Handbook

A Guide for Biomass Production and Utilization

**Support Project for Building Asian-Partnership for
Environmentally Conscious Agriculture, Entrusted by
Ministry of Agriculture, Forestry, and Fisheries**

The Japan Institute of Energy

This handbook was edited as a part of a project entrusted by the Ministry of Agriculture, Forestry, and Fisheries, Japan, with the help of Asia Biomass Association.

Preface

It is a great pleasure and honor for me to give some words for this Biomass Handbook. In 2002 we had already published Biomass Handbook in Japanese edition with the help of more than 60 contributors who are distinguished specialists in this field. This time English version has been issued with the cooperation of scientists and engineers of Asian countries in addition to domestic contributors.

As we are aware, negative impacts of global warming has been remarkably coming out. Carbon dioxide discharged from fossil fuel combustion has been accumulated in the atmosphere as far as we consume coal, petroleum, and natural gas. On the other hand, it is clear that the life of fossil fuels is limited, for example, the life, the ratio of reserve divided by the production, of petroleum, coal, and natural gas will be about 41, 160, 65 years, respectively. I believe that we are at the gateway to the new age independent on the fossil fuels and biomass is a key resource to open up a new vista of the future.

Biomass means, in general, a substantial amount of bioorigin resources which can be utilized in the form of energy and materials. Wood, grass, marine algae, micro algae, agricultural wastes, forestry wastes, and municipal wastes fall into this category. Energy crops are one of promising biomass which could make energy plantation possible in a large scale, though it has not yet been commercialized at the present.

One of the strong countermeasures to suppress carbon dioxide emission is the introduction of renewable energies. Renewable energies mean biomass, photovoltaics, geothermal, wind, hydro, tidal, and wave energies. How does differ biomass from other renewable energy?

Biomass forms own body by photosynthesis. The concentration of carbon dioxide in the atmosphere remains unchanged as far as carbon dioxide, which is emitted by combustion of biomass after energy utilization, is refixed by, for example, reforestation. It is called the carbon neutrality of biomass. Energy which replaces fossil fuels can be derived from the cycle, that is, biomass combustion, carbon dioxide emission, and carbon dioxide refixation. Thus, the carbon dioxide emission can be reduced by replacing fossil fuels by biomass.

Biomass is only organic or carbonaceous among renewable energies. In other words, ethanol, methanol, dimethyl ether, and hydrocarbons can be produced only from biomass among renewable energies. It has the same meaning that biomass can be transportable and storable in the form of material. It should be emphasized that wind, photovoltaic, tidal, wave, and geothermal energy can produce heat and power but not chemicals and fuels. However, carbon dioxide emitted from biomass utilization will be accumulated irreversibly into the atmosphere in a similar manner with fossil fuel utilization unless otherwise reforestation is made. Sustainable forestry management is essential to the long and stable supply of bioenergy.

This Biomass Handbook deals with the characteristics and resources of biomass, thermochemical and biochemical conversion of biomass, and system development of sustainability. However, the most important aspect is the contribution of many specialists of Asian countries, that is, Brunei, Cambodia, China, India, Indonesia, Korea Malaysia, Myanmar, Philippines, Singapore, Taipei Chinese, Thailand, Viet Nam. I should like to appreciate all the people who contributed this Handbook. Also I appreciate the Ministry of Agriculture, Forestry and Fisheries which gave an opportunity to enable us to issue this Handbook by financial support.

January 2008
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Part 1. Benefit of biomass utilization

1.1 Benefit of Biomass

1.1.1 What is biomass?

Generally biomass is the matter that can be derived directly or indirectly from plant which is utilized as energy or materials in a substantial amount. “Indirectly” refers to the products available via animal husbandry and the food industry. Biomass is called as “phytomass” and is often translated bioresource or bio-derived-resource. The resource base includes hundreds of thousands of plant species, terrestrial and aquatic, various agricultural, forestry and industrial residues and process waste, sewage and animal wastes. Energy crops, which make the large scale energy plantation, will be one of the most promising biomass, though it is not yet commercialized at the present moment. Specifically biomass means wood, Napier grass, rape seed, water hyacinth, giant kelp, chlorella, sawdust, wood chip, rice straw, rice husk, kitchen garbage, pulp sludge, animal dung etc. As plantation type biomass, eucalyptus, hybrid poplar, oil palm, sugar cane, switch grass etc. are included in this category.

According to Oxford English Dictionary, it was in 1934 that the term “biomass” appeared first in the literature. In Journal of Marine Biology Association, Russian scientist Bogorov used biomass as nomenclature. He measured the weight of marine plankton (*Calanus finmarchicus*) after drying which he collected in order to investigate the seasonal growth change of plankton. He named this dried plankton biomass.

Biomass is very various and the classification will be reviewed in 2.(1). Biomass specifically means agricultural wastes such as rice straw and rice husk, forestry wastes such as sawdust and saw mill dust, MSW, excrement, animal dung, kitchen garbage, sewage sludge, etc. In the category of plantation type, biomass includes wood such as eucalyptus, hybrid poplar, palm tree, sugar cane, switch grass, kelp etc.

Biomass is renewable resource and the energy derived from biomass is called renewable energy. However, biomass is designated as new energy in Japan and this naming is a legal term peculiar to our country. Law concerning promotion of the use of new energy was enforced in April of 1997. Though biomass was not approved as one of new energies at this moment,

biomass was legally approved when the law was amended in January of 2002.

According to the Law, power generation by photovoltaics, wind energy, fuel cell, wastes, and biomass as well as thermal use of waste are designated as new energy. Legally new energy is provided by the law what should be the production, generation, and utilization of petroleum alternatives, what is insufficiently infiltrated by the economic restriction, and what is specially prescribed in order to promote the use of new energy by the government ordinance. In foreign countries, biomass is usually called and designated as one of renewable energies.

Many studies have suggested that biomass-derived energy will provide a greater share of the overall energy supply as the price of fossil fuels increase over the next several decades. The use of biomass a source of energy is very attractive, since it can be a zero net CO₂ energy source, and therefore does not contribute to increased greenhouse gas emission. It is carbon neutrality of biomass, which is precisely described in 1.(2). The combustion of biomass energy results in the emission of CO₂, however, since nearly all of the carbon in the fuel is converted to CO₂, just as it is during the consumption of fossil fuels. The zero net CO₂ argument relies on the assumption that new trees, or other plants, will be replanted to the extent that they will fix any CO₂ released during the consumption of biomass energy. This may well be true for the properly managed energy plantations, but is not likely to pertain in many developing countries where most of the biomass energy is obtained from forests which are not being replanted, at least not to the same degree that they are being harvested.

The widespread expansion of biomass energy use may result in significant concerns about availability of land, which may otherwise be used for food production, or other commercial use such as timber production. Recent reports showed that a wide range of estimates of future biomass energy potential, ranging from the current level of approximately 42 EJ to nearly 350 EJ close to the current level of total energy production by the year 2100. Consequently, it is desired that biomass energy should be wisely utilized in accordance with the food or valuable material production as well as environmental preservation.

Biomass is quite various and different in its chemical property, physical property, moisture content, mechanical strength etc. and the conversion technologies to materials and energy are also diversified. Researches which make it possible to develop cost effective and environmentally friendly conversion technologies have been done to reduce the dependence on fossil fuels, to suppress CO₂ emission, and to activate rural economies.

1.2 Characteristics of Biomass

1.2.1 General scope

Biomass resource can be utilized substantially in endless number of times, on the basic rail of carbon circulation by photosynthetic process. On the other hand, a fossil resource is limited to a transitory use in principle. Additionally the irreversible emission of CO₂ caused by fossil combustion gives serious influence on global climate (Fig. 1.2.1). R.= resource.

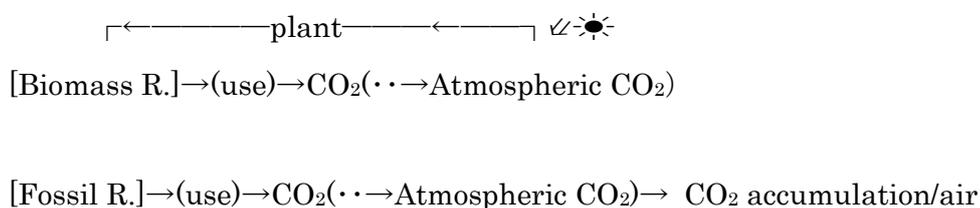


Fig. 1.2.1. Comparison of biomass and fossil system on Carbon cycling.

But the words “renewable” and “sustainable” are not always same meaning. The recycling power of plants is founded on a very delicate base of ecosystem.

The conditions for the bio-system are, maintaining the balance of harvest vs.growing speed, and the environment protection of the farming land. If not, long term sustainability of the biomass system will be fading out.

1.2.2 Renewable

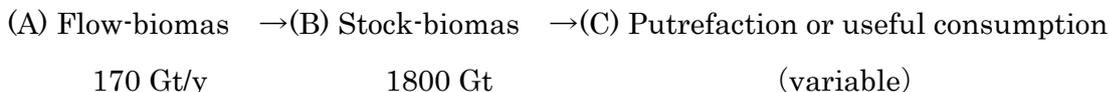
There are two kinds of energy resource: (1)exhaustible resource (=stock type) and (2)renewable resource(flow type; such as solar-,wind-, hydraulic power and biomass). A flow stock is infinitely large, but it should be limited within a given period of time. Excessive utilization such as a deforestation cannot sustain a renewable production system. Biomass has both types of resources.

(A) Flow type Biomass. The net primary productivity 170 Gt/yr (about 7 times as much as world energy demand)

(B) stock type Biomass. Mainly in forest; 1800 Gt (about 80 times as much as world energy demand/yr)

Biomass consumption (C) has two variations, putrefaction and utilizing consumption. In

natural forest, there are nearly equal amounts of growing and the putrefaction, the equilibrium (A)=(C) would be established.



Although we cannot realize (C)>(A), it is capable to get a bigger share of biomass utilization in the distribution among (C), by our policy and technology.

1.2.3 Carbon neutral

Biomass fuel also emits CO₂ by the combustion. But people permit a CO₂ indulgence for biomass, because of the CO₂ absorption during the growing process.

That is, [CO₂ emission] = [CO₂ fixation by the growing process]. However, coal also has a biomass-originated history, the carbon is circulating in long term, several hundred million years. Then under the consideration of term of CO₂-repayment, CO₂ immunity rate should be estimated.

Just after the biomass combustion, none can pay back its CO₂. Therefore, it is estimated that a temperate forest (about 25 years for regeneration time) acquires [CO₂ immunity rate=1], as a standard. At subpolar forest, the regeneration time =100 years case, the immunity rate becomes [25/100=0.25]. In the case of brown coal (the origin was 25 million years before), this immunity rate is only 1 ppm. So fossil fuel has no hope to get the effective CO₂ indulgence.

1.2.4 Sustainable agriculture

At the fuel production from biomass resource, much energy input (E_i) from outside is necessary for the producing process. In addition, a part of biomass becomes biomass waste (E_w) (Fig. 1.2.3). For a energy production system, [E_z-E_i-E_w] should be higher than zero at least. E_z: the gained bio-fuel energy.

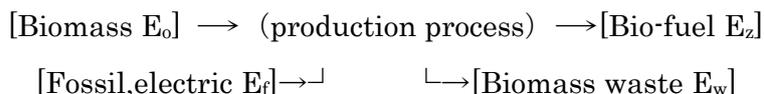


Fig. 1.2.3. Biomass energy balance for the income and expense.

Total energy yield in this system is shown as $E_z/[E_o + E_f]$, if the value is lower than 0.5, the biomass is merely auxiliary fuel. But even small part of biomass can contribute to new energy system if energy balance ratio (products/invested fossil fuel) is over than 1, in the case of coal-biomass mixed combustion generation. When biomass waste can substitute a fossil fuel in the system, the E_f is so decreased that the energy balance ratio is much improved. The typical success example is found at cane sugar industry which uses bagasse as an alternative fossil fuel. Biomass production system with inferior energy balance ratio often loses its carbon-neutral sustainability. In agriculture, production of grain and potatoes, the energy balance ratio is about 1.5~5 (neglected man-power calculation), while lower than 0.5 in almost vegetables that is on loss-making railroad line. In this point, forestry is more excellent than agricultural crops because of a little cultivation energy.

(a) Man-power investment. Increasing of man-power is often able to cut down a fossil and/or electric energy consumption, causing an improvement of apparent energy balance ratio. However, man-power and fossil energy has a trade-off relation. Energy unit for man-power is estimated by 0.073 toe/yr/man (biological standard)~1 toe/yr/man (total life consuming). Labor intensive production often gives a faked saving energy system.

(b) Cycling of N,P,K. N (nitrogen), P (phosphorus), and K (potassium) are main components of fertilizer. They so often disappear by exploitative production that a recycling system is necessary to hold N,P and K in soil. At a woody thermal power station, it is necessary to return the ash for sustaining P and K. Component N cannot stay in the ash, so another N-supply route is indispensable to restore the system. Exceptionally, traditional forestry need not any fertilizer because there is sufficient nitrate-N from rain. But future energy forestry will demand N-fertilizer because the N-balance will collapse.

(c) Conservation of biodiversity. Biodiversity is often fragile by enhancing a biomass production according to the uniformity, the large scale farm, and the intensive process. For example, mixed cropping like agroforestry, is hopeful to have a sustainable soil conservation.

Further information

Sano,H.in “Biomass Handbook”, Japan Institute of Energy Ed., Ohm-sha, 2002, pp.311-323. (in Japanese)

UN Energy “Sustainable Bioenergy: A Framework for Decision Maker”, 2007.

1.3 How to Use Biomass

1.3.1 General scope

For the utilization of biomass, a raw biomaterial is selected among various kinds of biomass by taking into consideration of its utilization purpose, demand and availability. Then, the raw material is converted to new material or energy.

Biomass as bioresource comes mainly from plants and their debris. Animals and microorganisms as well as their organic matters are also important. Many species of plants are useful as biomass. Land biomass mainly consists of herbal biomass from major farm crops, and woody biomass from forest. Many of them are cultivated, converted and utilized for specific purposes. Aquatic biomass from oceans, lakes and rivers can also be cultivated in such a case as kelp. Biomass which is cultivated on farm land or felled from forest for specific purposes is called virgin biomass, whereas the discarded biomaterials in production, conversion and utilization processes are named waste biomass and used for other purposes. For example, bagasse which is the waste of sugarcane processing is used as excellent fuel for the sugar extraction and ethanol distillation processes. Utilization of waste biomass is also important for avoiding the conflict of bioenergy utilization with food and feed. Bagasse is also considered as one of the major raw materials for “the second-generation biofuel”.

Transportation and storage of biomass is not easy because of its bulkiness and degradation. It is, therefore, reasonable to use biomass in the areas where it is produced. For this reason, biomass is used in or nearby regions where biomass supply and demand are balanced. However, when biomass is converted into more transportable form like densified pellet or liquid fuels, it can be utilized in distant regions.

Biomass can be used either as materials or energy. Biomass is utilized as diversified materials such as food, feed,

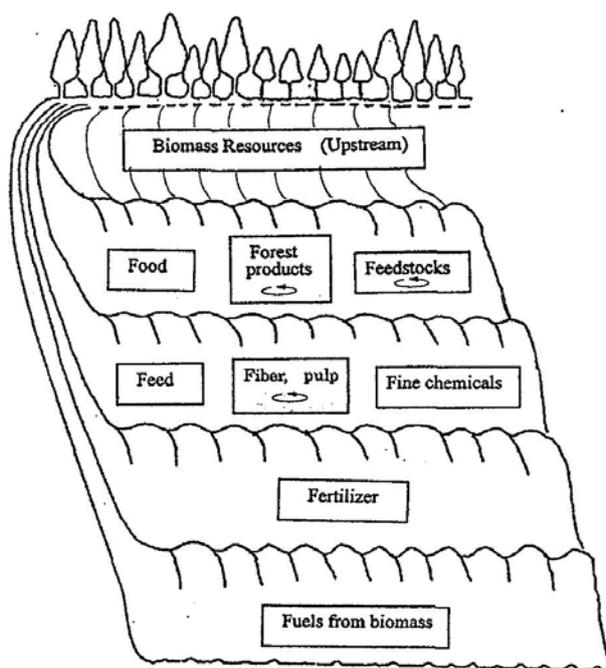


Fig. 1.3.1. Cascade use and recycling of biomass.

fiber, feedstock, forest products, fertilizer and fine chemicals. Utilization as energy in the form of biofuels occurs on the final stage and biomass is decomposed into carbon dioxide or methane and emitted in the air. The diversified use can be called "8F Use" of biomass.

Biomass can be used stepwise like a cascade as its quality is degraded. Fig. 1.3.1. illustrates examples of cascade use of food to feed and then to fertilizer.

Food waste can be treated into good feed. Feed changes into livestock manure which can be fermented into methane. The digested sludge can be used as fertilizer. Forest products such as wood from pulled down houses can be utilized as particleboard or pulp, and as the final step, it can be converted into energy through the combustion of bio-solid fuel.

Recycling is made for paper, fiber, some feedstock and wood products as shown with round-arrows in Fig. 1.3.1. So far as biomass is used as material, its carbon is kept in the material and does not emit any greenhouse effect gas contributing to reduce the ill effect of global warming.

1.3.2 Conversion and utilization

There are many conversion technologies available for changing the quality of biomass to match its utilization purposes. They are physical, chemical and biological techniques. Fig. 1.3.2 illustrates typical conversion technologies.

Physical conversion includes milling, grinding and steam explosion to decompose the biomass structure for increasing its surface areas to accelerate chemical, thermal or biological processes. It also covers separation, extraction, distillation etc. for obtaining useful ingredients of biomass as well as densification, drying or moisture control for making biomass more suitable for transportation and storage. Physical conversion technologies are also often used for the pretreatment to accelerate the main processes.

Chemical conversion includes hydrolysis, partial oxidation, combustion, carbonization, pyrolysis, hydrothermal reactions for decomposing biomass, and also synthesis, polymerization, hydrogenation for constructing new molecules or reforming biomass. Generation of electrons in oxidation process of biomass can be used for fuel cells to generate electricity.

Biological conversion is mainly composed of fermentation processes such as ethanol fermentation, methane fermentation, acetone-butanol fermentation, hydrogen fermentation, and enzymatic treatments which will play more important role to bring the second-generation bioethanol on the practical stage. Application of photosynthesis and photolysis processes will be important to improve biomass systems.

Combustion heat of biomass is converted to mechanical power by means of such heat cycles as Otto cycle (for gasoline engine), Diesel cycle (Diesel engine), Rankine cycle (steam engine), Brayton cycle (gas turbine) and others. Electric generator with electromagnetic induction is used to convert mechanical power into electricity.

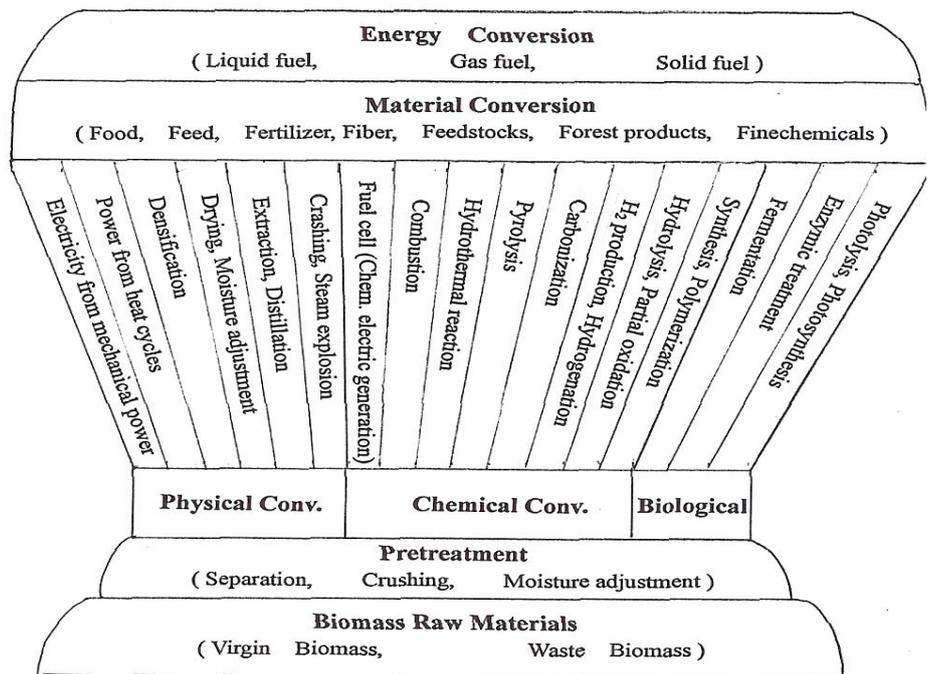


Fig. 1.3.2. Various conversion and pretreatment technologies.

Such pretreatments as separation, extraction, milling, grinding, moisture regulation etc. are often performed before the main conversion processes. Fig. 1.3.2 illustrates so-called a magic box in which biomass is put on the bottom and converted by using various techniques to match its utilization purpose.

Evaluation of the conversion processes is done in terms of product quality, energy efficiency, yield and system economy.

Planning of conversion and utilization system should take the following items into consideration: fluctuation of biomass supply, means and cost of transportation & storage, managing organization and rules which are in harmony with the relevant regulations, as well as the economy of the total system.

1.4 Benefit of Biomass Utilization

1.4.1 General scope

Though energy from biomass is generally not cost-competitive with fossil fuels under current technology and market conditions in many of developed economies, the production of biomass

for materials and energy will produce a variety of benefits. These benefits vary from case to case, however, some noticeable ones include, among others, offsetting greenhouse gas emissions from the combustion of fossil fuels, creating jobs and income through the development of a new industry and the utilization of locally produced raw materials, and enhancing energy security by reducing dependence on imports. Yet, the values of these benefits are far less understood than biomass and bioenergy production costs. Assessing these benefits will provide a more comprehensive picture about the overall competitiveness of biomass and bioenergy, offering implications for bioenergy development and policy formulation.

1.4.2 Oil depletion

Forests and coal resources were in abundance and were sufficient to meet energy demands. However, as human creativity exceeded expectations, producing a more efficient energy technology based on coal and then on oil was needed.

World ultimate conventional oil reserves are estimated at 2000 billion barrels. The global daily consumption of oil equals 71.7 million barrels. It is estimated that around 1000 billion barrels have already been consumed and 1000 billion barrels of proven oil reserves are left in the world (Asifa and Muneer, 2007). The price of petrol and other fuels will rocket with potentially disastrous economic consequences unless people have moved to alternatives to fossil fuels. Increased use of biomass will extend the lifetime of diminishing crude oil supplies. For instance, Carpentieri *et al.* (2005) shows the important environmental advantages of biomass utilization in terms of reduction of natural resource depletion, although an improved impact assessment methodology may better highlight the advantages due to the biomass utilization.

1.4.3 Global warming

Globally, increase in emission rates of greenhouse gases, *e.g.*, CO₂, present a threat to the world climate. As an estimate in the year 2000, over 20 million metric tons of CO₂ were expected to be released in the atmosphere every year (Saxena *et al.*, in press). If this trend continues, some extreme natural calamities are expected such as excessive rainfall and consequent floods, droughts, and local imbalances. Biomass is a carbon neutral resource in its life cycle and the primary contributor of greenhouse effect. Biomass is the fourth largest source of energy in the world after coal, petroleum, and natural gas, providing about 14% of the world's primary energy consumption (Saxena *et al.*, in press). Biomass is being considered as

an important energy resource all over the world.

In order to reduce greenhouse gas emissions from energy consumption, several policy alternatives such as emission taxes and tradable emission permits have been proposed. These mitigation policies are likely to enhance the competitive advantage of biomass energy over fossil fuels as the former can displace CO₂ emissions from the latter. However, it is well understood that the conversion of biomass to bioenergy requires additional energy inputs, most often provided in some form of fossil fuel. The life cycle energy balance of a biomass compared to conventional fossil fuel should be positive, but depending on the processing choices, the cumulative fossil energy demand might, at times, only be marginally lower or even higher than that of liquid fossil fuels. Bioenergy systems should be compared to conventional fuel ones from a point of view of a life cycle basis, or using LCA.

1.4.4 Improving standard of living

Since agriculture is of much importance for the economies under development, it is desirable that sustainable agriculture leads to improvement of farmers' standard of living as well as their income. Education of people is important, since the literacy rate in the rural area of developing countries is expected to be not so high. In this sense, it is important to supply proper information on this technology to the farmers. What is important for the biomass utilization for farmers to be effective is the accessibility of the biomass plant or biomass collecting site from farmers. Even if farmers possess or produce biomass feedstock, it is nothing if they do not have access to the sites where it can be made use of.

1.4.5 Increasing farmers' income

There are mainly two ways to support farmers (The Japan Institute of Energy, 2007). One is to supply energy so that they have the access to useful fuels. In Thailand, small-scale biomethanation provides cooking gas to farmers, so they need not to buy propane gas for cooking. This support to farmers is also effective for sustainable agriculture due to the reduction of fossil fuel utilization. The other support is by cash. When they grow feedstock for ethanol production and sell it at a higher price, they can get money for buying electricity. Since those who use ethanol as fuel are richer compared to farmers, this mechanism can be considered as 'redistribution of wealth.'

1.4.6 Energy security

The economies of all countries, and particularly of the developed countries, are dependent on secure supplies of energy. Energy security means consistent availability of sufficient energy in various forms at affordable prices. These conditions must prevail over the long-term if energy is to contribute to sustainable development. Attention to energy security is critical because of the uneven distribution of the fossil fuel resources on which most countries currently rely. The energy supply could become more vulnerable over the near term due to the growing global reliance on imported oil. Biomass is a domestic resource which is not subject to world price fluctuations or the supply uncertainties as of imported fuels.

1.4.7 Foreign currency

There are opportunities for developing countries to get foreign currency by exporting bioenergy. In the case of cassava production in Thailand, for instance, the cassava production for food and that for ethanol are balanced now. However, the future use of cassava should be carefully determined. In the future, the amount of cassava production for ethanol may increase, while it is often said that bioenergy utilization may be in conflict with food production, i.e., the international growing demand for ethanol may threaten the stability of domestic supply of food.

Further information

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Part 2. Biomass resources

2.1 Classification of biomass

2.1.1 Definition of biomass

As stated in Chapter 1.1, “What Is Biomass?,” the word “biomass” consists of “bio” + “mass”, and originally used in the field of ecology simply referring to amount of animal and plant. After the oil shocks, the meaning of the word was widened beyond ecological field and came to include the meaning “biological resources as energy sources”, since it was vigorously proposed that alternative (new) energy sources should be promoted. There is still no strict definition of biomass, and the definition differs from one field to another. From the perspective of energy resources, a common definition is “a general term for animal and plant resources and the wastes arising from them, which have accumulated in a certain amount (excluding fossil resources)”. Accordingly, biomass encompasses a wide variety including not only agricultural crops, timber, marine plants, and other conventional agriculture, forestry, and fisheries resources, but also pulp sludge, black liquor, alcohol fermentation stillage, and other organic industrial waste, municipal waste such as kitchen garbage and paper waste, and sewage sludge. Because some countries do not classify municipal waste as biomass, care is needed in the use of statistical data.

2.1.2 Definition of biomass (energy) in Law

As an example of definition in law, Japanese case is shown below. On January 25, 2002, the Law on Special Measures for Facilitating the Use of New Energy Sources (New Energy Law) was partially amended, and biomass was for the first time recognized as a new energy source in Japan. Fig. 2.1.1 shows the position of biomass among other “new energies”. Formerly, biomass had been considered as merely a kind of renewable resources, but the amended law now sees it as an independent category of new energy. However, some wastes, such as paper waste, food waste, demolition waste, and black liquor, are considered to be recyclable resources as well according to circumstances, and they are not strictly classified.

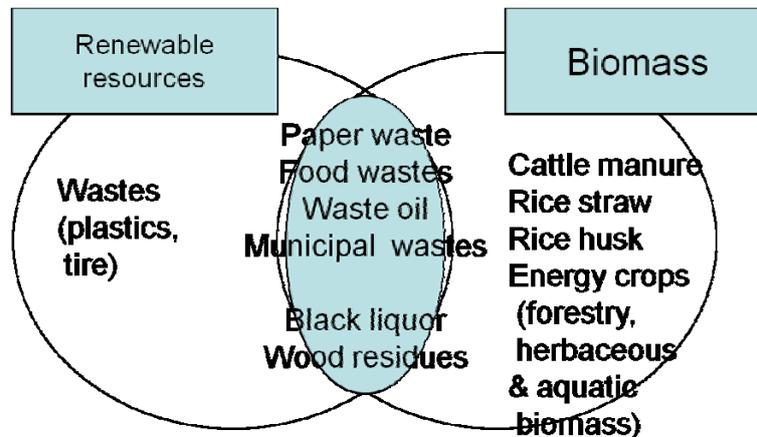


Fig. 2.1.1. Definition of biomass energy in Japan.

2.1.3 Characteristics of biomass energy

Up to the 19th century, biomass in the form of firewood and charcoal was the main source of energy, but these were replaced by coal and oil in the 20th century. In the 21st century, however, biomass shows signs of being revived because of the following characteristics: it is renewable, it is storable and substitutive, it is abundant, and it is carbon neutral.

2.1.4 Biomass categories

There is no established way of categorizing biomass, which is defined differently according to the field; categorization changes depending on the purpose and application. Generally there are two ways to categorize biomass: one is biological categorization based on types of existing biomass in nature (such as categorization according to ecology or type of vegetation), and the other is based on the use or application as resources. The latter is highly significant in terms of making effective use of energy (resources).

2.1.5 An example of biomass categorization (in terms of use and application)

An example of biomass categorization appears in Fig. 2.1.2. In this categorization, biomass includes not only the conventional product and waste from agriculture, forestry, and fisheries, but also plantation biomass. Categorization according to source is important for designing biomass usage systems.

Biomass

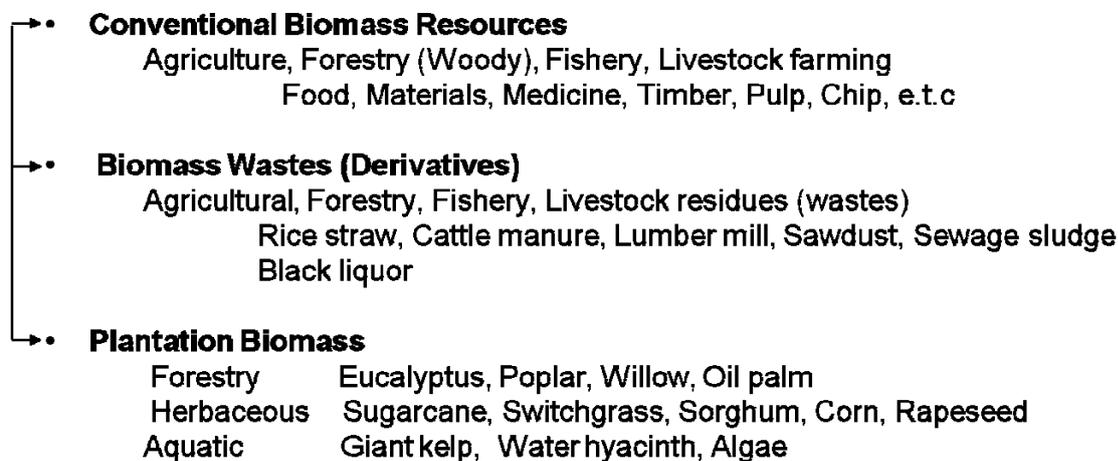


Fig. 2.1.2. Biomass categorization (in terms of use and application).

Moisture content is a major factor to consider when using biomass, especially as energy. Because moisture content is defined differently in each field, care is needed in reading indications of moisture content. In the energy field, moisture content is often defined as follows.

$$(\text{moisture content}) = (\text{moisture weight}) / (\text{total weight}) \times 100 [\%] \quad (2.1.1)$$

$$(\text{total weight}) = (\text{biomass dry weight}) + (\text{moisture weight}) \quad (2.1.2)$$

Using this definition, moisture content never exceeds 100%. In the forestry and ecology fields, moisture content is often defined as follows:

$$(\text{moisture content}) = (\text{moisture weight}) / (\text{biomass dry weight}) \times 100 [\%] \quad (2.1.3)$$

As a rule, this handbook employs Eq. (2.1.1) for definition of the moisture content. Biomass comprises natural macromolecular compounds such as cellulose, lignin, and proteins, and many kinds of biomass have high moisture content, because the origin of biomass is living organisms. Fig. 2.1.3 shows the moisture content of various biomass types. There is a wide range, from biomass types like dry wood and paper waste with about 20% moisture content, to those with over 95% moisture content, such as microalgae, fermentation residue, and sludge. For the purpose of energy conversion, one must choose a process adapted to the moisture

content.

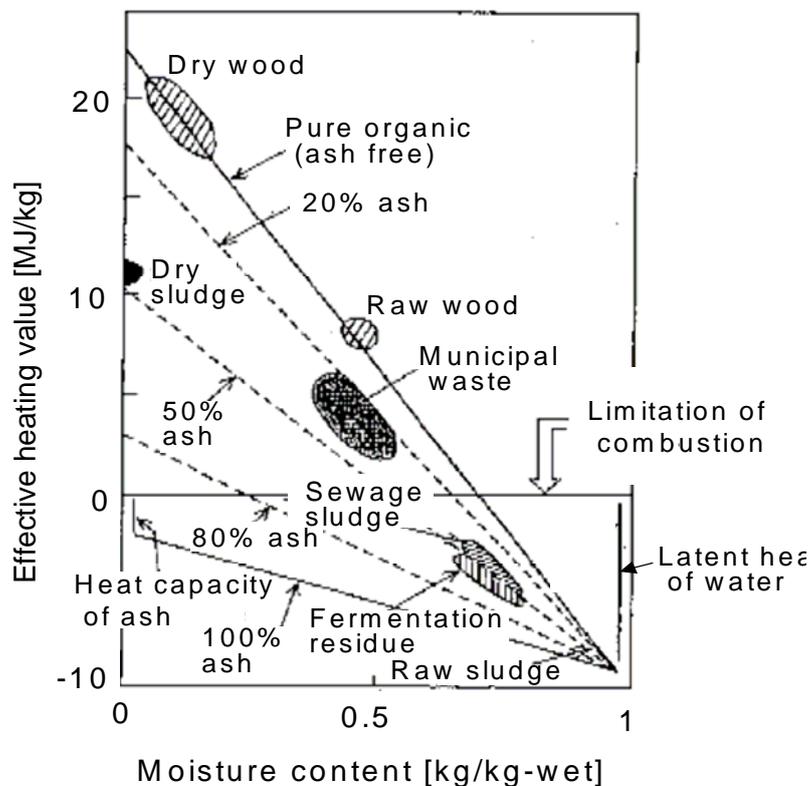


Fig. 2.1.3. Relation of moisture contents and heating value.

Further information

Ogi, T. in "Biomass Handbook", Japan Institute of Energy Ed., Ohm-sha, 2002, pp.2-6 (in Japanese)

2.2 Availability of Biomass

The earth has a huge stock biomass covering wide regions including forests and the ocean. The total biomass of the world is 1,800 billion tons on the ground and 4 billion tons in the ocean, and a comparative amount of biomass exists in the soil. The total biomass on the ground is 33,000 EJ on the energy basis, which corresponds to 80 times or more of the annual energy consumption of the world.

However, some part of the biomass is used as food by living things including humans, and

also for uses other than foods, which are necessary for the human living. Therefore, it is important to estimate quantity of biomass resources, which can be used for energy source.

2.2.1 Estimation of potential for waste biomass

Waste biomass includes wastes and residues discharged from our living. Quantity of this production is now referred to as “waste biomass production”. Waste biomass has a variety of uses, not only for energy but also for feed or fertilizer. On the other hand, biomass currently not being utilized but convertible to energy is referred to as "energy potential of biomass."

In this section, a method of estimating the quantity of resource will be shown, referring to waste biomass generated in association to production in agriculture, forestry, and livestock industry

(a) Amount of waste biomass production

It is necessary to know the waste biomass production to estimate current stock of waste biomass, but it is difficult to know the amount of waste biomass production in each country and region of the world. Therefore, the waste biomass production is often estimated typically by assuming ratio of waste production relative to the biomass resources production. An example of the parameters for the estimation of waste biomass production is shown in Table 2.2.1 Note that these parameters are generalized on the global basis, and that it is desirable to set parameters adapted to each region, in a study of a limited region.

Fig. 2.2.1 shows the current stock of waste biomass estimated using the above parameters by the following procedure:

- Amounts of production of agricultural waste and forestry waste were estimated by adjusting agricultural (2000) and forestry (1999) productions using statistics of the FAO, multiplied by ratio of waste production.
- Amount of production of livestock waste was estimated by determining the number of head of livestock (2000), and using amount of dung per head.
- The current stock of biomass was estimated based on waste biomass production multiplied by a coefficient of energy conversion.

The current stock (annual value) of waste biomass was estimated as approximately 43 EJ for livestock biomass, approximately 48 EJ for agricultural biomass, and approximately 37 EJ for forestry biomass, totals approximately 128 EJ. Approximately 22 EJ of dung of cattle accounts for the largest part of resources, which is followed by an approximately 20 EJ of log residue.

Table 2.2.1. Parameters used for estimating waste biomass production and amount of resources

Biomass species	Ratio of waste production (t/t)	Coefficient of energy conversion (GJ/t)
Rice	1.4	16.3
Wheat	1.3	17.5
Maize (corn)	1.0	17.7
Roots and tubers	0.4	6.0
Sugarcane residue (tops and leaves)	0.28	17.33
Cattle	1.10 (t/y/head)	15.0
Swine	0.22 (t/y/head)	17.0
Poultry	0.037(t/y/head)	13.5
Horses	0.55 (t/y/head)	14.9
Buffaloes and camels	1.46 (t/y/head)	14.9
Sheep and goats	0.18 (t/y/head)	17.8
Industrial logs	1.17	16.0
Fuel logs	0.67	16.0
Wood waste	0.784	16.0

*dung production rate, dry tons basis

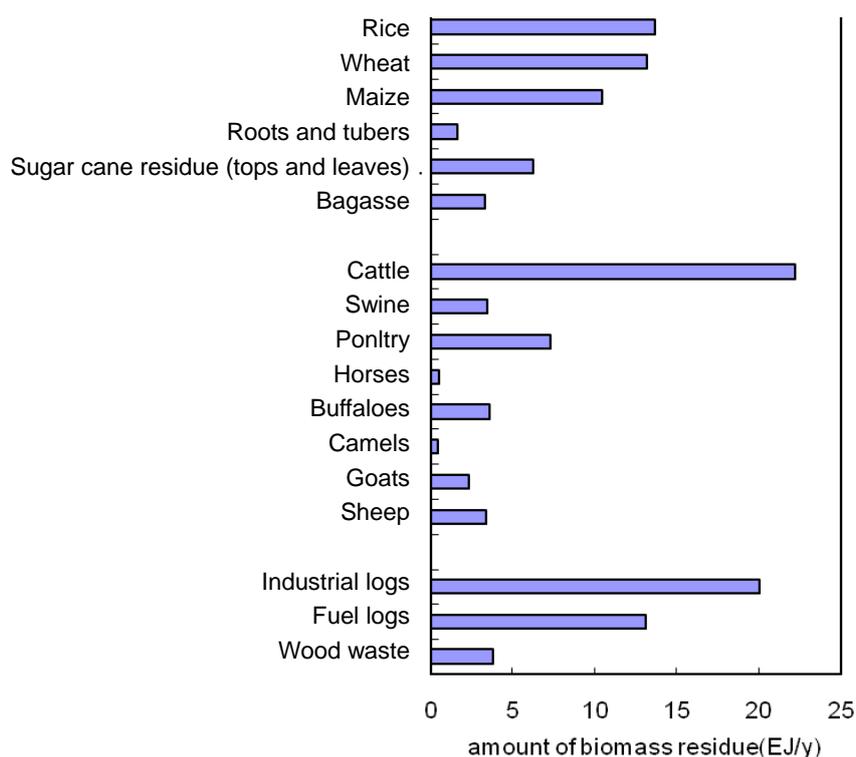


Fig. 2.2.1. Amount of biomass residue in the world.

(b) Energy potential of waste biomass

Part of current stock of waste biomass has already been used for other applications, so that it may supposedly be difficult to efficiently recover the complete mass, and to reuse it as an energy source, even if it is reserved unused. For example, some of rice straw is used as feed for livestock at present. It may be almost impossible to collect dung of cattle in pasture, and it is not always possible to completely collect dung of cattle even if they are fed as being tried. Whenever current stock of biomass quantity is estimated, it is necessary to consider such availability, so that energy potential of the waste biomass is given as a portion actually available as an energy source out of the entire current stock. Ratios of availability proposed by Hall et al. are shown in Table 2.2.2.

Table 2.2.2. Biomass species and availability ratio of energy

	Biomass species	Availability ratio of energy (%)
Agricultural waste	Rice, Wheat, Maize, Roots and tubers, Sugarcane (crop residue)	25
Livestock waste	Cattle, Sheep and Goats, Swine, Horses, Buffaloes and Camels, Poultry	12.5
Forestry waste	Industrial log	75
	Fuel log	25
	Wood waste	100

[Hall et al., 1993]

Energy potential of waste biomass estimated using ratio of availability is shown in Fig. 2.2.2. The largest portion of the energy potential of waste biomass (annual value) is contributed by forestry waste biomass, which accounts for approximately 22 EJ on the worldwide basis. Especially, log residue accounts for approximately 15 EJ, which is about two-thirds of the waste forestry biomass, and accounts for as much as approximately 36% of the total biomass resources. There is approximately 15 EJ of agricultural waste biomass on the worldwide basis. The individual items of the agricultural biomass in concern exist to as much as 1.5-3.5 EJ on the average. On the other hand, livestock biomass is about 5.4 EJ on the worldwide basis, where the largest contribution is approximately 2.8 EJ of cattle dung.

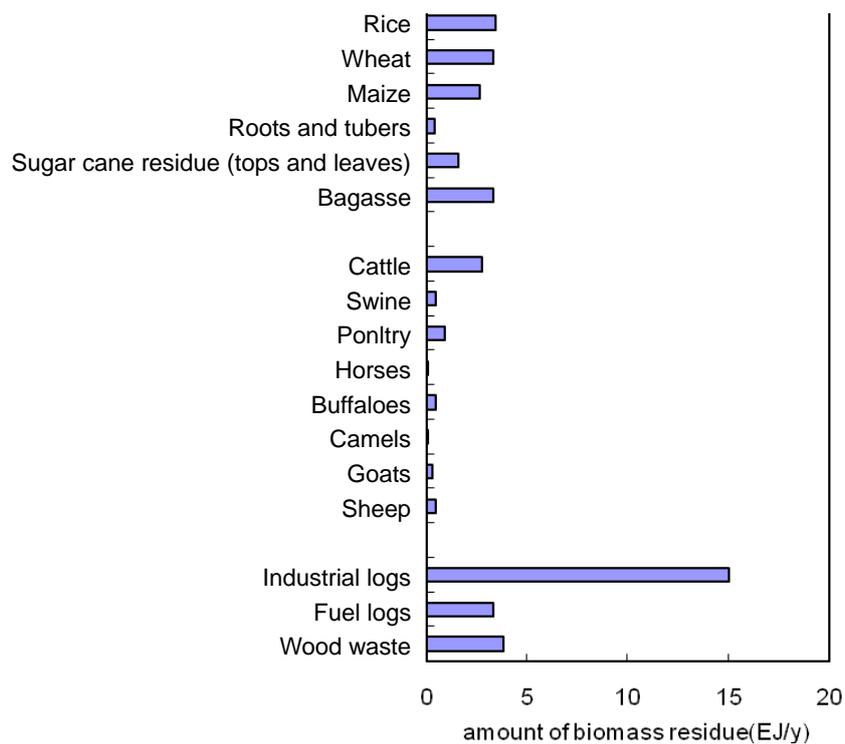


Fig. 2.2.2. Availability of biomass residue in the world.

Further information

FAO (The Food and Agriculture Organization of the United Nations), FAO Statistical Database, (<http://www.fao.org/>)

Hall, D. O. et al. (1993), “Biomass for Energy: Supply Prospects”, In: *Renewable Energy*, Johansson, T. B. eds., pp.594, Washington, Island Press.

2.3 Biomass Composition

2.3.1 Overview of biomass composition

There is a wide variety of biomass, and composition is also diverse. Some primary components are cellulose, hemicellulose, lignin, starch, and proteins. Trees mainly consist of cellulose, hemicellulose, and lignin, and so herbaceous plants, although the component percentages differ. Different kinds of biomass have different components: grains have much starch, while livestock waste has many proteins. Because these components have different

chemical structures, their reactivities are also different. From the standpoint of energy use, lignocellulose biomass, which consists mainly of cellulose and lignin such as trees, exist in large amounts and have great potential.

2.3.2 Typical biomass components

(a) Cellulose

A polysaccharide in which D-glucose is linked uniformly by β -glucosidic bonds. Its molecular formula is $(C_6H_{12}O_6)_n$. The degree of polymerization, indicated by n , is broad, ranging from several thousand to several tens of thousands. Total hydrolysis of cellulose yields D-glucose (a monosaccharide), but partial hydrolysis yields a disaccharide (cellobiose) and polysaccharides in which n is in the order of 3 to 10. Cellulose has a crystalline structure and great resistance to acids and alkalis. Fig. 2.3.1-a shows the structural formula of cellulose.

(b) Hemicellulose

A polysaccharide whose units are 5-carbon monosaccharides including D-xylose and D-arabinose, and 6-carbon monosaccharides including D-mannose, D-galactose, and D-glucose. The 5-carbon monosaccharides outnumber the 6-carbon monosaccharides, and the average molecular formula is $(C_5H_8O_4)_n$. Because the degree of polymerization n is 50 to 200, which is smaller than that of cellulose, it breaks down more easily than cellulose, and many hemicelluloses are soluble in alkaline solutions. A common hemicellulose is xylan, which consists of xylose with 1,4 bonds. Figure 2.3.1-c shows the structural formula of xylan. Other hemicelluloses include glucomannan, but all hemicelluloses vary in amounts depending on tree species and the part of the plant.

(c) Lignin

A compound whose constituent units, phenylpropane and its derivatives, are bonded 3-dimensionally. Its structure is complex and not yet fully understood. Figure 2.3.1-d shows a constituent unit. Its complex 3-dimensional structure is decomposed with difficulty by microorganisms and chemicals, and its function is therefore thought to be conferring mechanical strength and protection. Cellulose, hemicellulose, and lignin are universally found in many kinds of biomass, and are the most plentiful natural carbon resources on Earth.

(d) Starch

Like cellulose, starch is a polysaccharide whose constituent units are D-glucose, but they are linked by α -glycosidic bonds. Owing to the difference in the bond structures, cellulose is not water-soluble, while part of starch (see Figure 2.3.1-b) is soluble in hot water (amylose, with a

molecular weight of about 10,000 to 50,000, accounting for 10%–20% of starch) and part is not soluble (amylopectin, with a molecular weight of about 50,000 to 100,000, accounting for 80%–90% of starch). Starch is found in seeds, tubers (roots), and stems, and has a very high value as food.

(e) Proteins

These are macromolecular compounds in which amino acids are polymerized to a high degree. Properties differ depending on the kinds and ratios of constituent amino acids, and the degree of polymerization. Proteins are not a primary component of biomass, and account for a lower proportion than do the previous three components.

(f) Other components (organic and inorganic)

The amount of the other organic components vary widely depending on specie, but there are also organic components with high value, such as glycerides (representative examples include rapeseed oil, palm oil, and other vegetable oils) and sucrose in sugarcane and sugar beet. Other examples are alkaloids, pigments, terpenes, and waxes. Although these are found in small amounts, they have very high added value as pharmaceutical ingredients. Biomass comprises organic macromolecular compounds, but it also contains inorganic substances (ash) in trace amounts. The primary metal elements include Ca, K, P, Mg, Si, Al, Fe, and Na. Substances and their amounts differ according to the feedstock type.

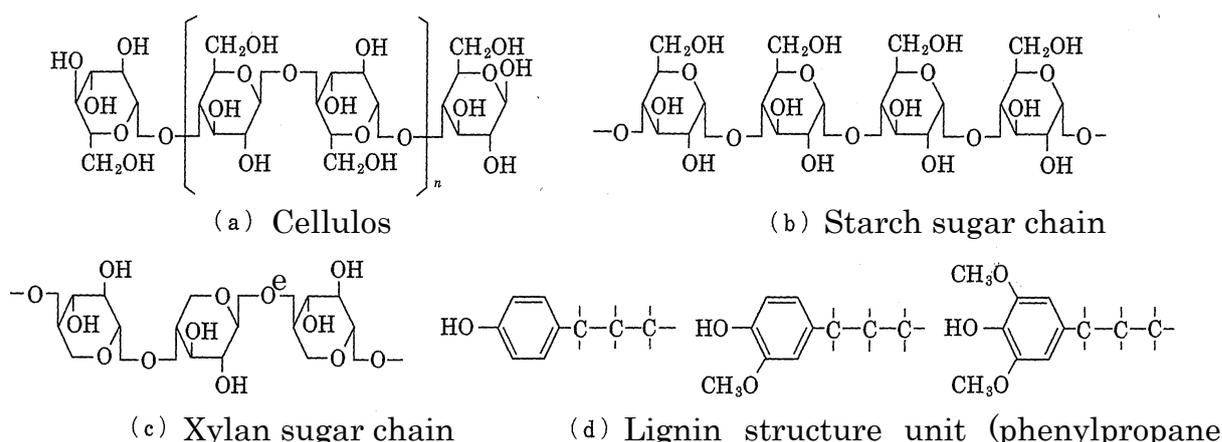


Fig. 2.3.1. Chemical structures of major biomass components.

2.3.3 Constituent analyses of representative biomass types

Table 2.3.1 presents representative compositions of major biomass types. Although there are

exceptions, the main components of terrestrial biomass in order of amount from high to low are cellulose, hemicellulose, lignin, and proteins. Aquatic biomass has different compositions. While Table 2.3.1 shows plant biomass, Table 2.3.2 gives the compositions of sludge and other waste biomass types with high moisture content. Tables 2.3.1 and 2.3.2 use a different composition classification. Cellulose and lignin in Table 2.3.1 are represented by fiber in Table 2.3.2, while hemicellulose in Table 2.3.1 comes under carbohydrates in Table 2.3.2.

Table 2.3.1. Typical chemical analyses of representative biomass (Part 1) (wt%)

Category of biomass	Marine	Freshwater	Herbaceous	Woody	Waste
	Giant brown kelp	Water hyacinth	Bermuda grass	Hybrid poplar	Refuse-derived fuel (RDF)
Cellulose	4.8	16.2	31.7	41.3	65.6
Hemicellulose	—	55.5	40.2	32.9	11.2
Lignin	—	6.1	4.1	25.6	3.1
Mannitol	18.7	—	—	—	—
Alginin	14.2	—	—	—	—
Crude protein	15.9	12.3	12.3	2.1	3.5
Ash	45.8	22.4	5.0	1.0	16.7
Total*	—	112.5	93.3	102.9	100.1

* Totals may not necessarily be 100 because each component was measured with a different method.

Table 2.3.2. Typical chemical analyses of representative biomass (Part 2: Waste biomass with high moisture content). (wt%)

Feedstock biomass	Alcohol fermentation stillage (rice)	Alcohol fermentation stillage (sweet potato)	Starch sludge	Microalgae (<i>Dunaliella</i>)	Aquatic (Water hyacinth)	Sewage Sludge
Moisture content	76.7	88.6	82.2	78.4	85.2	76.7
Ash a)	1.3	4.4	23	23.6	19.6	16.4
b)						
Fat	8.3	1.8	0.7	20.5	2.5	12.9
Protein	56.5	28.5	59.6	63.6	24.4	42.3
Crude fiber	2.1	11.9	5.4	1.2	20.6	18.1
Carbohydrates	33	57.8	34.3	14.7	52.5	26.7
b)						
C	47.9	47.3	44.6	53.3	47.6	51.4
H	6.7	7	7.2	5.2	6.1	7.9
N	7.5	4.2	9	9.8	3.7	6.5
O	37.9	41.5	48.2	31.7	42.1	40.7

a) Based on dry weight.

b) Based on organic content.

Further information

Ogi, T. in "Biomass Handbook", Japan Institute of Ed., Ohm-sha, 2002, PP.12-15 (in Japanese)

2.4 Biomass Energy Content

2.4.1 Indicators of biomass energy content

In order to establish biomass energy systems, the energy content of each type of biomass feedstock should be determined at first. Heating value is often used as an indicator of the energy that biomass contains. Heating value is the amount of heat generated when a substance

undergoes complete combustion, and is also called the heat of combustion. Heating value is determined by the ratio of components and the kinds and ratios of elements (especially carbon content) in biomass.

(a) Higher and lower heating value

Biomass comprises organic substances composed mostly of carbon, hydrogen, and oxygen, and when it is completely combusted, it produces water and carbon dioxide. The generated water and water vapor contain much latent heat that is given off upon condensation. The heating value which includes latent heat is the high heating value (HHV), while that from which latent heat is subtracted is the low heating value (LHV).

(b) Available heat

Heating value Q_0 is the amount of heat that arises from complete combustion per unit material under standard conditions. Actual biomass contains much moisture and ash, which must be taken into consideration when energy is producing. Merely evaluating low heating value is inadequate as an indicator whether biomass in its natural state will sustain combustion. The energy to raise ambient air to the temperature that maintains the fire and the endothermic energy of ash should also be taken into account. The heat amount that takes them into account is the available heat, and is expressed with this equation:

$$\text{Available heat } Q = Q_0 (1 - w) - 1000 w - [\text{flue heat absorption}] - [\text{ash heat absorption}]$$

(w: moisture content)

Fig. 2.1.3. uses values calculated for available heat Q at 900°C. A positive (+) value for available heat Q is the condition for combustion to occur.

2.4.2 Heating values of various kinds of biomass

Table 2.4.1 gives the data for moisture content, organic matter content, ash content, and heating value of representative types of biomass.

Table 2.4.1. Typical analyses and heating values of representative types of biomass, coal, and peat.

Category	Biomass	Moisture content* [wt%]	Organic matter [dry wt%]	Ash** [wt%]	High heating value [MJ/dry-kg]
Waste	Cattle manure	20—70	76.5	23.5	13.4
	Activated biosolids	90—97	76.5	23.5	18.3
	Refuse-derived fuel(RDF)	15—30	86.1	13.9	12.7
	Sawdust	15—60	99.0	1.0	20.5
Herbaceous plant	Sweet sorghum	20—70	91.0	9.0	17.6
	Switch grass	30—70	89.9	10.1	18.0
Aquatic plant	Giant brown kelp	85—97	54.2	45.8	10.3
	Water hyacinth	85—97	77.3	22.7	16.0
Woody plant	Eucalyptus	30—60	97.6	2.4	18.7
	Hybrid poplar	30—60	99.0	1.0	19.5
	Sycamore	30—60	99.8	0.2	21.0
Derivatives	Paper	3—13	94.0	6.0	17.6
	Pine bark	5—30	97.1	2.9	20.1
	Rice straw	5—15	80.8	19.2	15.2
Coal	Illinois bituminous	5—10	91.3	8.7	28.3
Peat	Reed sedge	70 —90	92.3	7.7	20.8

* Moisture content is determined from the weight loss after drying for at 105°C under atmospheric pressure.

** Ash content is determined from the weight of residue (metal oxides) left after heating at about 800°C.

Moisture content differs considerably depending on the kind of biomass, for example, 3% in paper and 98% in sludge. With most biomass types, water content exceeding two-thirds makes the available heat negative (-). Therefore, even if the heating value of the biomass itself is high, if it has a high moisture content in its natural state, it is not suitable for combustion. For example, water hyacinth and sewage sludge have high heating values, when they are dried, but moisture content is about 95% at the sampling, and they are unsuitable for combustion actually.

Total organic matter is left when the ash content subtract from total dry matter. Because the value of ash as energy is zero, a large amount of organic matter means a higher heating value, which is desirable as an energy source. Additionally, organic substances have different heating values depending on the kinds and ratios of their constituent elements (see 2.3 Biomass Composition). Table 2.4.2 presents the elemental analysis results and heating values of representative biomass types and other organic fuels. Because biomass contains more oxygen and less carbon and hydrogen than coal or petroleum, it has a lower heating value per unit weight. Woody and herbaceous biomass types have carbon contents of 45%–50% and hydrogen contents of 5%–6%, giving them an H:C molar ratio of about 2, with little variation. This is because they are affected by their composition, the main components of which are cellulose and lignin.

Table 2.4.2. Typical elemental compositions and heating values of representative types of biomass, coal, and peat.

Energy source	Cellulose	Pine	Giant brown kelp	Water hyacinth	Livestock waste	RDF	Sludge	Peat	Bitumen
Carbon [wt%]	44.44	51.8	27.65	41.1	35.1	41.2	43.75	52.8	69.0
Hydrogen [wt%]	6.22	6.3	3.73	5.29	5.3	5.5	6.24	5.45	5.4
Oxygen [wt%]	49.34	41.3	28.16	28.84	33.2	38.7	19.35	31.24	14.3
Nitrogen [wt%]	—	0.1	1.22	1.96	2.5	0.5	3.16	2.54	1.6
Sulfur [wt%]	—	0	0.34	0.41	0.4	0.2	0.97	0.23	1.0
Ash [wt%]	—	0.5	38.9	22.4	23.5	13.9	26.53	7.74	8.7
Heating value [MJ/dry-kg]	17.51	21.24	10.01	16.00	13.37	12.67	19.86	20.79	28.28

With respect to moisture content and other properties, elemental analysis results were all obtained in dried condition.

2.4.3 Estimating heating value by calculation

Heating values of biomass types shown in Tables 2.4.1 and 2.4.2 were all measured. Attempts are being made to estimate heating value by calculating it from information such as the values obtained by elemental analyses of the materials. A number of equations have been proposed, one of which is given here.

High heating value (HHV) [MJ/dry-kg] = 0.4571 (%C dry standard) – 2.70

Table 2.4.3 compares the heating values calculated with this equation and those obtained by measurement. Except for sludge, biosolids, the results coincide closely.

Table 2.4.3. Comparison of the measured and calculated heating values of biomass.

Feedstock biomass	High heating value: measured	High heating value: calculated	Error [%]
Cellulose	17.51	17.61	+0.59
Pine	21.24	20.98	-1.23
Giant brown kelp	10.01	9.94	-0.70
Water hyacinth	16.00	16.09	+0.54
Cattle manure	13.37	13.34	-0.19
Biosolids	19.86	17.30	-12.90
Bitumen	28.28	28.84	+1.98

Further information

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2.5 Carbon Cycle

2.5.1 Global carbon budget

Carbon on the earth is stored in the atmosphere, oceans, biosphere and lithosphere and carbon components are exchanged among these stores in gas phase (CO₂), and in organic or inorganic phase. According to the IPCC 4th Assessment Report, 2007, the global fossil-fuel emission including fossil-fuel use and cement industry is 6.4 GtC/yr in 1990s, and emission by land use changes is 1.6 GtC/yr. On the contrary, the estimated accuracy of net land and ocean uptakes are 2.6 GtC/yr and 2.2 GtC/yr, respectively. The net carbon balance of the atmosphere

in 1990s is 3.2 GtC/yr (=8.0–2.6–2.2) as shown in Table 1. These values of carbon balances have been assessed thorough comparative check of many results related carbon cycle. The global fossil-fuel emissions of CO₂ and the net carbon balances of the atmosphere are now rather well established, the others in the Table 2.5.1 are less accurate. And also, there are carbon cycles in the land and ocean-biosphere, the net carbon balances are related to the activities of them. The status of carbon cycle in each store is controlled by forest management and climatic changes. The Kyoto Protocol, which accounts for offsetting reduced targets of CO₂ emission by carbon sequestration in forests through forest management, became effective in February 2005. The rules for the effective management have focused attention on the role of the terrestrial biosphere in global scale carbon cycles. Therefore, accurate data are required for carbon stocks and cycle over various terrestrial ecosystems. However, uncertainty remains about the change in carbon stock from forest management and the response of the ecosystem CO₂ exchange to climate change.

Table 2.5.1. Global carbon budget. by convention, CO₂ fluxes leaving the atmospheric reservoir. (i.e. “CO₂ sinks”) have a negative sign. Numbers in parentheses are ranges. Units: GtC/yr. NA: No information available to separate. (IPCC 4th assessment report, 2007)

	1980s	1990s	2000-2005
Atmospheric increase	3.3±0.1	3.2±0.1	4.1±0.1
Emissions (fossil fuel + cement)	5.4±0.3	6.4±0.3	7.0±0.3
Ocean-atmosphere flux	-1.8±0.8	2.2±0.4	-2.2±0.4
Land use change flux	1.3 (0.3 to 2.8)	1.6 (0.5 to 2.8)	NA
Residual land sink	-1.6 (-4.0 to 0.3)	-2.6 (-4.3 to -1.0)	NA

2.5.2 Carbon cycle in forest ecosystem

Global amounts of carbon in forest ecosystems are 330 GtC in the forest biomass and 780 GtC in the soil after Dixon et al., 1994. Furthermore, uptake of carbon in net by forest ecosystem is regulated photosynthesis and respiration controlled by meteorological and

ecophysiological characteristics of forest trees and understory vegetation. Amount of carbon storage in the forest ecosystem classified into vegetation above ground, vegetation below ground, litter and woody debris, and also organic carbon in the soil. Forests and soils contain the largest stocks of organic matter globally, and organic carbon in the soil has a potential to release more CO₂ by increasing soil respiration and to increase atmospheric high concentration of CO₂ under the warm condition in the future. The trunk of tree is useful for timber and part of timber are reserved in the houses for long time. Plant growth can be stimulated by increased atmospheric CO₂ concentrations and nutrient deposition (fertilization effects). However, in the field studies, the fertilization effect is not clear for forest ecosystems.

2.5.3 Carbon cycle model

For the proper management of carbon budget in the future, land-ecosystem models that are truly useful for ecosystem monitoring and carbon budget evaluation are inevitably required. To extrapolate the results based on ground-observation data in a spatial and a temporal scale, more studies will be required to develop satellite remote sensing and statistical ecosystem models. Using a land-use model and land-ecosystem carbon cycle model, we can predict the fluctuations in carbon balance caused by human activities (i.e. terrestrial carbon management) and climate change in the future. And also, we can conduct the assessment of carbon management potential.

By Oikawa and Ito, a process-based carbon cycle model (Sim-CYCLE) was developed and validated with observational data at many measurement sites. The changes of carbon balances and stocks from present to future condition (after 70 years under twice time of CO₂ atmospheric concentration and higher air temperature by 2,1°C) was estimated using the Sim-CYCLE model. As shown in Fig.2.5.1 (T. Oikawa, 2002), carbon stocks in soil and vegetation of land-ecosystem will increase from 642.3, 1495.1 GtC at present to 835.1, 1559.0 GtC in the future, respectively.

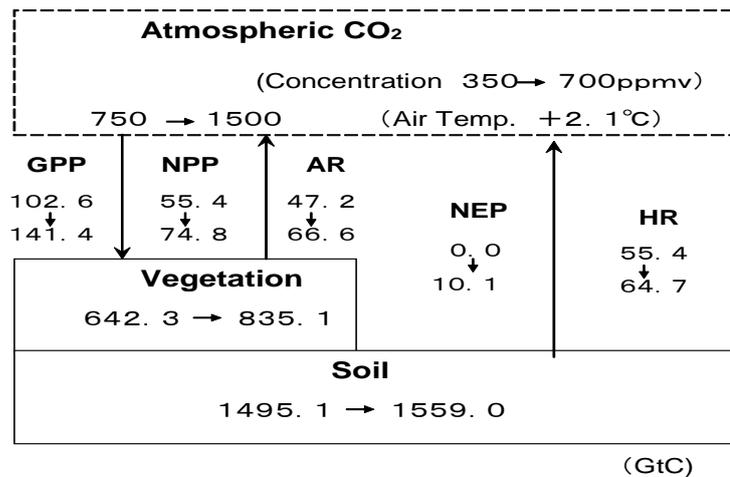


Fig. 2.5.1. The changes of carbon balances and stocks from present to future condition (after 70 years under twice time of CO₂ atmospheric concentration and higher air temperature by 2,1°C) estimate by Sim-CYCLE model. (T. Oikawa, 2002)

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2.6 Woody Biomass

2.6.1 Types of woody biomass material and its characteristics

Forest industry provides woody biomass material as by-products such as logging residues and as main-products which is cut directly from trees and forests. The planted forests are usually thinned out to maintain the growth space among stumps. These thinning trees are expected to utilize for biomass energy materials, because they have no commercial values and leave in a stand after thinning operation. A cutting cycle in the temperate zone is around 50 to 100 years and wood residues of 0.36 m³ branches and 0.22 m³ stumps are left after producing 1 m³ logs. These residues are utilized for modern and traditional biomass energy source in many countries.

Woodfuel accounts for about 53 percent of total round wood produced in the world. However woodfuel accounts for only several percent in industry countries at present, though industry countries used to depend on woodfuel until 1960s. In Japan case, hardwood forests located near rural communities used to be main resources for fuelwood and charcoal. Nowadays hardwood forests have not been utilized as woody resources, because hardwood timber value is cheaper compared with softwood. Though hardwood forests have not industrial values so far, they have high potential to provide renewable energy sources to mitigate global warming. Aside from this, fast growing species, such as willow (*Salix*), poplars (*Populus*), and birch (*Betula*), have been planted to produce biomass energy materials.

2.6.2 Growth rate

The use of woody biomass energy has grown in importance as part of the efforts to reduce dependence on non-renewable energy sources such as fossil fuels. Though woody biomass release carbon into atmosphere when it is burned to produce energy, replanted trees absorb the same amount of carbon from atmosphere into the forest ecosystem through photosynthesis which is in proportion to the growth rate of tree species. The growth rate is depended on temperature, precipitation, soil characteristics and other environmental factors. In general the growth rate is low in boreal zone and high in tropical zone respectively. Fast growing species such as eucalyptus (*Eucalyptus*), poplar and *Acacia mangium* in Southeast Asia capture from 5 to 15 ton carbon per hectare annually. Whereas Sugi (*Cryptomeria japonica*), one of representative plantation species in Japan, captures carbon from 2 to 3.5 ton per hectare annually.

The growth of forest biomass shows high rate in the early stage and fall down with getting mature. Table 2.6.1 expresses how man-made forest stores carbon in their biomass. Hardwood forests located close to rural communities in Japan used to be the main source to provide fuel wood. Table 2.6.2 shows annual increment of these forests. If we focus on only quantity and do not care timber quality, it is reasonable to adopt cutting rotation at the maximum annual increment which is generally younger than regular timber harvesting rotation.

Table 2.6.1. Accumulated biomass carbon of manmade forest.

age	Biomass weight (ton/ha)
10	13.5
20	59.2
30	105.8
40	145.9
50	172.0
60	189.5
70	198.0
80	203.0
90	206.5
100	208.6

Table 2.6.2. Accumulated biomass carbon of hardwood forest.

age	Biomass weight (ton/ha)	Mean annual increment (ton/ha)
10	18.3	1.8
20	41.6	2.1
30	59.9	2.0
40	74.0	1.9
50	85.2	1.7
60	93.7	1.6
70	100.0	1.4
80	104.9	1.3
90	109.2	1.2
100	112.0	1.1

2.6.3 Woody biomass resources

According to the FAO statistics, total forest area is 4 billion ha, corresponding to an average of 0.62ha per capita. This forest area accounts for one-third of total global land. However, deforestation is a significant problem and 13 million ha of forest land has annually disappeared. On the other hand, China and India have aggressively expanded new plantation every year, then net loss of world forests area in the period of 2000-2005 is estimated at 7.3 million ha per year. In addition to deforestation, there are about 1.6 billion ha of degraded forests. It is important to rehabilitate degraded forests for global environment and sustainable development. If woody biomass is limited to stem biomass, there is 350 billion tons of dry-biomass in the world forest ecosystem. One third of dried woody biomass is existed in South America.

The area of forest plantation is 140 million ha and has increased by about 2.8 million ha annually in the period of 2000-2005. Forest plantations in tropical countries consist primarily of introduced species which growth rates are 15-50 m³ per year of *Eucalyptus grandis*, 14-25 m³ of *Acacia mearnsii*, 12-35 m³ of *Pinus radiate*, and 20-50 m³ of *Pinus caribaea*. These annual growth rates are three times of Japanese species for forest plantation. The forest plantations in tropical countries have a big potentiality to provide woody biomass with short rotation and low costs. Though a large-scale of forest plantation is sometimes criticized for poor biodiversity, forest plantation can be harmonized timber production operation with other forest function and services if it will be well managed under a concept of sustainable forest management. This concept usually requests forest managers to take care not only forest plantation but also natural forest with indigenous species.

Further Information

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FAO, Forest Resources Assessment 1990, 7, FAO, 1995

2.7 Herbaceous Biomass

2.7.1 The herbaceous biomass means

Herbaceous biomass includes grasses and legumes growing on grasslands. It includes under utilized wild species as well as cultivated forages with higher forage quality. Broadly speaking,

food crops, such as rice, wheat, maize, and sugarcane represent sources of herbaceous biomass. By-products or residues, such as rice straw, are also considered herbaceous biomass; however, their use as herbaceous biomass is dependent on quality issues. Bamboos (*Phyllastachys* spp.) and sasas (*Sasa* spp.) are considered gramineous woody-type biomass species. Tropical grasses grow faster than trees and produce higher biomass in a shorter period. Grasses are classified into annual species, which include many cereals, and perennial species, which include many forage grasses. Legumes consist of shrubby, viny, and wood-types, of which the two former types are considered herbaceous biomass. An important component of legumes is their ability to fix nitrogen in symbiosis with *Rhizobium* bacteria located in root nodules. It is economically necessary that a reduction in the use of chemical nitrogen fertilizers will be a component of biomass production. By rotating or sowing a mix-culture of forage and leguminous species in biofuel production pastures, the application of nitrogen fertilizer can be minimized. Published biomass production of leguminous species is 8-17 t/ha/year for alfalfa (*Medicago sativa*) in temperate Aichi Prefecture and 5-19 t/ha/year for tropical legumes in the subtropical Ishigaki Island. This production level is much lower than that for tropical grasses.

2.7.2 C_3 species and C_4 species

Growth rates of plants are regulated by the photosynthetic ability and a multitude of environmental factors. Grasses are classified into C_3 species and C_4 species based on their unique photosynthetic pathway. It is important to note the anatomical differences in leaf and bundle sheath cells that occur between C_3 and C_4 grasses. Typically, the optimum light intensity for C_4 species is ca. 50,000-60,000 lux and is twice that for C_3 species (15,000-30,000 lux). The highest photosynthetic efficiency of the C_4 species generally reaches at high temperature and high light intensity which is characteristics of tropical regions. The C_4 species, however, cannot maintain their high photosynthetic efficiency under low light intensity and low temperature. Table 2.7.1 shows that napiergrass recorded a yield of 85 t/ha/year and the yield of sugarcane is 64 t/ha/year, with a mean of 232 kg/ha/day, and 176 t/ha/day, respectively. The yield of sugarcane and guineagrass in subtropical regions is 50 t/ha (140 kg/ha/day) and that of some tropical grasses is 25-30 t/ha (50-80 kg/ha/day). Since forage grasses generally exhibit rapid regrowth and persistency, they are utilized for low-input and sustainable biomass production. As one example, “Natsuyutaka” guineagrass has attained 40 t/ha (all are dry matter weight in the report) on a seven-year average in subtropical Ishigaki Island, Okinawa. In temperate regions, winter-hardy tropical grasses such as bermudagrass and bahiagrass

produce 20-30 t/ha/year (50-80 kg/ha/day) but go dormant in winter. On the other hand, temperate grasses produces 15-26 t/ha/year (40-70 kg/ha/day) but go dormant in summer. A primary advantage in utilizing perennial C₃ or C₄ grasses for biomass production is that less maintenance is required and stands can persist for 5-10 years producing stable amount of biomass following stand establishment.

Table 2.7.1. Biomass of perennial gramineous forages.

Species	DM yield (t/ha/y)	Daily DM (kg/ha)	site
C ₄ species			
Napierrgrass	84.7	232.1	Puerto Rico
Guineagrass ³	51.1	140.0	Ishigaki, JP
Sugarcane	49.5	135.6	Okinawa, JP
C ₃ species			
Perennial ryegrass	26.6	72.8	New Zealand
Orchadgrass	22.0	60.3	New Zealand
Tall fescue	15.0	41.1	Kumamoto, JP
Timothy	15.0	41.1	Hokkaido, JP

Table 2.7.2. Biomass of annual gramineous crops.

Species	DM yield (t/ha)	Total Days	Daily DM (kg/ha)	Site
C ₄ species				
Sorghum	46.6	210	221.9	California
Sorghum (green A)	28.8	190	151.6	Nagano, JP
Maize	34.0	140	245.7	Italy
Maize	27.2	104	261.5	Ohita, JP
C ₃ species				
Rice (Akihikari)	19.2	134	221.9	Iwate, JP
Wheat (Akiba-komugi)	14.3	219	65.3	Ibaraki, JP
Oat	16.4	193	85.0	Hyogo, JP
Rye	15.6	195	80.0	Tochigi, JP
Annual ryegrass	14.8	230	4.3	Chugoku,JP

In the annual C₄ species, such as maize, exhibiting superior seedling vigor following germination can produce a range, respectively from 13-34 t/ha to 132-260 kg/ha/day in 5 months. These yields are comparable to that of perennial napiergrass. These data suggest that the highest yield in tropical regions is achieved in the summer of temperate regions by using these C₄ crops. Although rice is C₃ plants, it can compete with C₄ species and produce high amount of biomass in temperate regions. However, winter cereals, such as wheat, annual forages, can produce lower yields per day, but can be cultivated during the winter month.

2.7.3 Primary production and existing amount of herbaceous biomass

Existing biomass of tropical savanna is lower than that of tropical rainforest. The primary production of the tropical savanna, which has rich rhizosphere and the grasses vigorously grow under heavy grazing of animals, is similar to that of tropical rainforest, whose rhizosphere is shallow, of poor quality. As such, tropical savanna greatly contributes to the reduction of CO₂ when compared to tropical rainforest¹. As advancements in fermentation and gasification techniques, the utilization of herbaceous biomass as a biofuel, has attracted much attention. Annual production of herbaceous by-products is estimated at 18.95 million tons (Mt) from rice straw and husks, 1.90 Mt from barley and wheat, 0.5 Mt from sugarcane. Furthermore, estimated data of forage production of 40 t/ha in 560,000 ha of abandoned fields, 40 t/ha in 79,000 ha of abandoned paddy field, 5-20 t/ha in un-utilized land comes to 32.08 Mt. The total of available herbaceous biomass comes at least to 53.43 Mt/year in Jpan. But these are utilized partly for forages of cattle now.

2.7.4 Switchgrass

(a) What is switchgrass?

Switchgrass (*Panicum virgatum* L.) is a perennial tropical grass (C₄ species) native to the Great Plains of the USA. The indigenous people of the region saw and called prairies consisting of switchgrass “Ocean of grass”. The plant height is ca. 90-150 cm, the leaf blade length is 15-45 cm, the width is 0.6-1.3 cm, with short rhizomes. Switchgrass exhibits adaptation to relatively wet and fertile soils and is also tolerant of



Fig. 2.7.1. Switchgrass Trial (USDA-ARS, El Reno, OK, USA, courtesy of Dr. B. Venuto)

both drought and flooding conditions. Annual dry matter yields are ca. 15 t/ha (Some data exhibit nearly 30 t/ha) and as with most forage species, its nutritious value lessens after the flowering. Seed yield is ca. 230 kg/ha from broadcasted stands and ca. 690 kg/ha from row-seeded stands. The 1,000-seed weight ranges 1.07-1.22 g.

(b) Advantages of switchgrass as a raw material for biofuel production

In the USA, Switchgrass has attracted the interest as a raw material for bioethanol production through cellulosic fermentation. The dry matter yield, however, is mostly similar to or less than some temperate and tropical forage grasses, it will not be very useful to use this grass for biofuel production in Japan. For example, if ca. 16t/ha of hay is harvested and 300 L of ethanol is produced from 1 t of hay, based on the price of raw materials, the cost of producing 1 gallon of ethanol from switchgrass is estimated at 0.51-0.89 USD, which is lower than the cost of 0.7-1.21 USD utilizing corn. This report suggests that the potential conversion of ca. 33 million ha of pasture, typically consisting of poorer soils and utilized for the production of a low quality hay crop for horses, to corn would lead to dramatic increases in soil erosion. If, however, switchgrass is sown to this area, ca. 520 million tons of hay can be produced and bypass the soil erosion problem caused by an annual corn crop. This point is very important for the USA, which maintains vast pasturelands and has a need to establish a cultivation system of perennial forage grasses, such as switchgrass, for biofuel production.

Once switchgrass pastures are established, a low-input, sustainable cultivation system for biofuel production may be practical. This system would be similar to the system in Japan that utilizes *Miscanthus* for a similar purpose. One deficit of the species is its seed dormancy. Seedlings germinate irregularly and more than 1 year may be required to achieve a full stand.

(c) Cultivar of Switchgrass

Some cultivars developed in the USA are explained below.

(1) Alamo

Soil Conservation Service (SCS) and Texas Agriculture Experiment Station (AES) selected from collection in Texas, and released in 1978. It is a “lowland type”, flowers 1 or 2 month later than cv. Blackwell, taller, wider leaves with medium saline tolerance and high productivity. It grows well on all soil types with 630 mm or more annual precipitation, from Iowa to Florida.

(2) Blackwell

The SCS in Kansas developed this cultivar from single plant collected in Blackwell, OK and released it in 1944. It is an “upland type” of medium height with rather large stems, good in seedling vigor, high in forage production, and grows well on wide range of soil types with 500

mm or more annual precipitation in Kansas, Oklahoma, southern Nebraska and north Texas.

(3) Cave-In-The-Rock

The SCS and Missouri AES developed from the collections of Cave-in-the-Rock, IL and released in 1973. It is a “lowland type” with high seedling vigor, resistance to lodging and diseases. It is tolerant to flooding and drought and grows well in Iowa, Kansas, and Missouri.

(4) Dacotah

The SCS and Northern Great Plains Research Laboratory selected 10 plants from collections of North Dakota and released the cultivar in 1989. It flowers 27 days earlier than cv. Forestburg, 45 days earlier than cv. Blackwell and cv. Pathfinder. It is shorter in height and exhibits high drought tolerance. It grows well in North Dakota, Minnesota, and Montana.

(5) Forestburg

The SCS in North Dakota and Northern Great Plains Research Laboratory developed this cultivar from collections obtained near Forestburg, ND and released in 1987. It has superior winter hardiness and persistence, seed production ability, and is of earlier maturity than other cultivars. Forage production at northern latitude exceeds that of cv. Dacotha, cv. Nebraska 28. It grows well in Montana, North and South Dakota, and Minnesota.

(6) Kanlow

The Kansas AES developed this cultivar from collections in Oklahoma and released in 1963. It is a tall and productive “lowland type”, especially adapt to lowlands where excess water problems occur; it also performs well on upland sites where soils are not too thin or dry.

(7) Pathfinder

The Nebraska AES originally released this cultivar as “Type-F” from a polycross and progeny test of collections in 1967. It is a late-flowering “highland type”, winter-hardy, vigorous, leafy, and resistant to rust and drought. It grows well in Nebraska and adjacent areas.

(8) Shelter

The SCS in New York developed this cultivar from collections made in West Virginia and it was released 1986. The cultivar exhibits thicker stems and fewer leaves than the other cultivars with the exception of cv. Kanlow. It is taller and flowers earlier by 7-10 days than cv. Blackwell but exhibits less seedling vigor during the 1st year of establishment. It grows well in a wide region ranging from the East Coast to Arkansas in the central USA.

(9) Trail Blazer

Nebraska AES developed this cultivar from collections made in Nebraska and Kansas and released in 1984. It is a “highland type” exhibiting both higher forage value and yield, flowers

at the same time of cv. Blackwell. It grows well in central Great Plains and eastern states.

Additional released cultivars not described are: cv. Sunburst, cv. Caddo, cv. Summer etc.

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2.8 Sugar and Starch Crops

2.8.1 General scope of sugar and starch crops

Starch and sugar can be fermented to biofuel such as ethanol, but fibrous saccharides such as cellulose and hemicellulose in the residual waste cannot easily be hydrolyzed to fermentable carbohydrates such as glucose.

Primary starch crops are rice (*Oryza sativa* and *Oryza glaberrima*), potato (*Solanum tuberosum* L.), sweet potato (*Ipomoea batatas* (L.) Lam.), corn (maize; *Zea mays* L.), wheat (*Triticum* L.), barley (*Hordeum spontaneum* C. Koch (wild-type two-rowed barley); *H. vulgare* L. (six-rowed barley); *H. distichum* L. (two-rowed barley)), cassava (bitter cassava, cassava, manioc, manihot, sweet-potato tree, tapioca, tapioca plant, yuca; *Manihot esculenta* Crantz),

and sago palm (*Metroxylon sagu* Rottb.). As primary sugar crops, sugar cane (*Saccharum officinarum* L.) and sugar beet (*Beta vulgaris* var. *altissima*) are widely known.

Yields of three primary cereals (corn, wheat, and rice) are increasing up to 725, 6.33, and 6.06 million tons, respectively, with a sum of 1,963 million tons, which is about 86% of total cereal production of 22.74 million tons (2004), being realized by novel cultivars and development of cultivation technology (Fig. 2.8.1). However, due to limitations of the conventional technologies, further extension of cultivation area will require novel technology such as genetic modification to cold-, drought-, or halo-resistant cultivars. Production of sugar cane has been increasing up to 1,332 million tons (2004), while that of sugar beet has been around 200 million tons (Fig. 2.8.2). Total production of sugar and starch crops (4,572 million tons (2004)) contributes to the high nutritional intake (2,808 kcal/capita/day (2003)) for 6,370 million population in the world (2004). However, around 800 million people, mainly in population explosion area of Asia and Africa, are still suffering from starvation. Therefore, it should be morally criticized if the crops would be further used as “non-food” energy crops. We have to increase the amount of the foodstuffs by increasing the cultivation area and crop yields with novel technology such as genetic modification, while promoting cultivation of energy crops and developing new technology to convert crop wastes to biofuel.

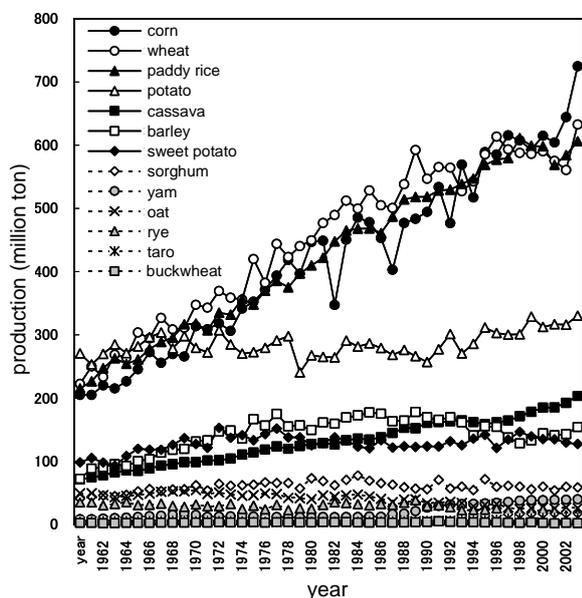


Fig. 2.8.1. World production of starch crops.

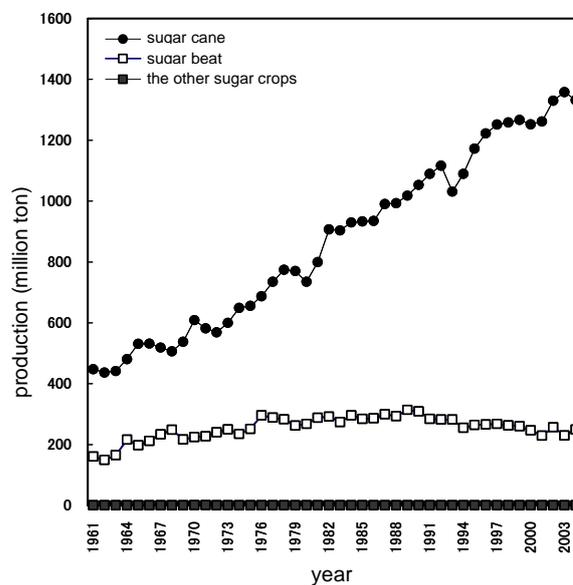


Fig. 2.8.2. World production of sugar crops.

(ref. FAOSTAT: <http://www.faostat.fao.org/default.aspx>)

2.8.2 Cassava

Cassava (*Manihot esculenta*) is a woody shrub and widely cultivated in tropical and subtropical regions in the world. In 2006, total production of the world was 226 million tons in 18.6 million ha of harvested area. The biggest cassava producer is Nigeria and followed by Brazil, Thailand and Indonesia (Fig. 2.8.3). The yield of cassava in Thailand is ranked first and about 21 ton/ha averaged over whole 1.1 million ha of harvested area (Fig. 2.8.4).

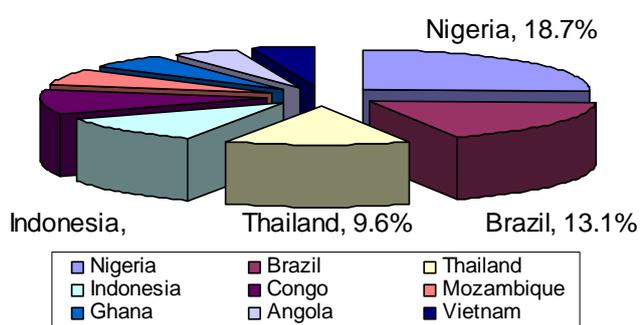


Fig. 2.8.3. World leading countries of cassava production in 2006.

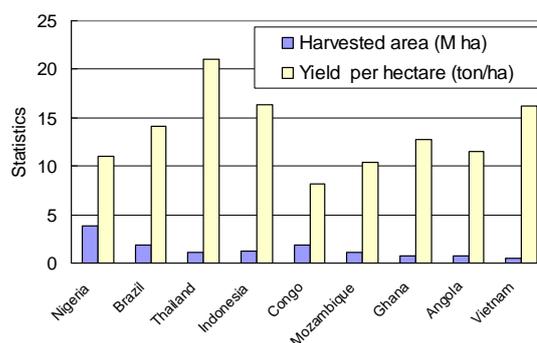


Fig. 2.8.4. Harvest area and yield of cassava.

Cassava is propagated by stem cutting, which is planted on a soil in a vertical and inclined position. It can grow well even on an infertile soil and is tolerant of drought. Starch-rich tuberous root is harvested by hand around 12 months after planting, but it can be harvested as early as 8 months or as late as 24 months. Starch content of tuberous root in Thailand is about 25%. In Thailand, yield of cassava gradually increases mainly due to the consistent development of better varieties (Fig. 2.8.5). Currently, Rayong 9 with up to 30 ton/ha yield has been distributed since 2006.

Tuberous roots of most varieties contain cyanide and it should be removed by soaking cassava flour. Cassava has been used as a staple source of carbohydrate for human consumption in many tropical countries, as an ingredient in animal feeds, and as a source of starch. Bio-ethanol production from cassava starch is developing. Cassava production of Thailand in 2007 was 27 million tons and the flow chart (Fig. 2.8.6) shows the breakdown of cassava applications in food, feed and fuel.

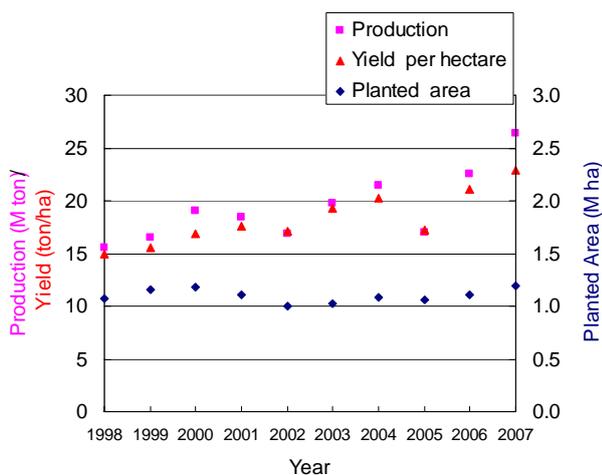


Fig. 2.8.5. History of cassava statistic in Thailand.

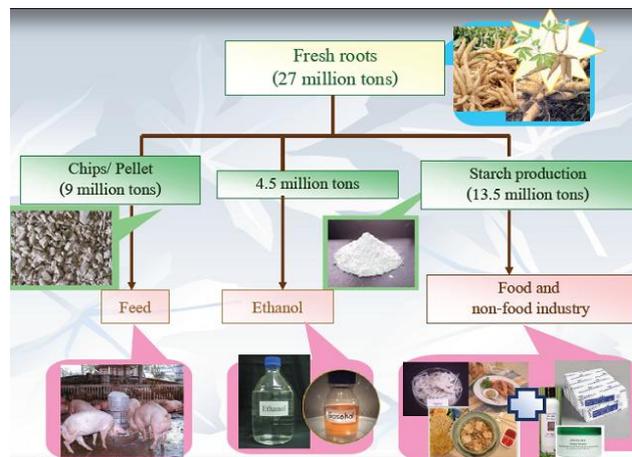


Fig. 2.8.6. Uses of cassava in Thailand.

2.8.3 Sugarcane

Sugarcane is a tall perennial grass and cultivated widely in tropical and subtropical regions of the world for sugar production. It belongs to genus *Saccharum* and most commercial varieties are hybrid with *S. officinarum*. In 2006, total sugarcane production of the world was 1,392 million tons in 20.4 million ha of harvested area. The biggest sugarcane producer is Brazil and followed by India, China, Mexico and Thailand (Fig. 2.8.7). The yield of sugarcane in Thailand is about 49.4 ton/ha averaged over whole 0.97 million ha of harvested area (Fig. 2.8.8).

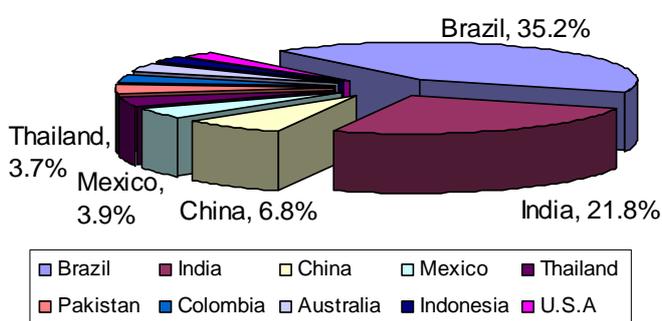


Fig. 2.8.7. World leading countries of sugarcane production in 2006.

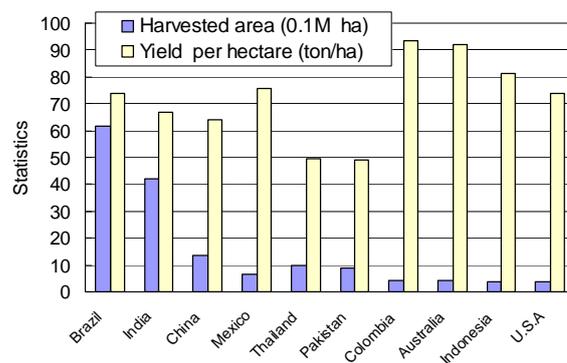


Fig. 2.8.8. Harvest area and yield of sugarcane.

Stem cutting with buds is used for planting. Sugarcane is C₄ plant with high photosynthesis

ability. Optimal temperature is between 20 and 35 °C and minimum requirement of rainfall is 1,200 mm/year. Stalks of sugarcane are harvested 9 to 14 months after planting by hand or by harvester. Once planted, sugarcane can be harvest several times, because new stalks, called ratoons, come from stubble. Top of sugarcane removed at harvest is used as animal feed in some areas. Over the past ten years of sugarcane cultivation in Thailand, sugarcane production unpredictably varies due to the weather from year to year (Fig. 2.8.9).

By-products from sugar mill are bagasse, filter cake (sugar juice residue) and molasses. Approximately, 1 ton of sugarcane gives 105 kg of sugar, 500 kg of water, 280 kg of bagasse, 30 kg of filter cake and 55 kg of molasses. Bagasse is a squeezed fibrous residue and usually fed back into the boiler to generate steam within the sugar mill. It makes sugar mill self-sufficient in energy. Filter cake is typically used as fertilizer. The most valuable by-product is molasses, which can

be further processed to ethanol or monosodium glutamate. About the half of sugarcane produced in Brazil are used to produce ethanol. Ethanol, which is made from not only molasses but also sugar juice, is blended with gasoline (gasohol) for transportation fuel. At the moment, sugarcane is the most economically and environmentally advantageous crop for bio-ethanol production.

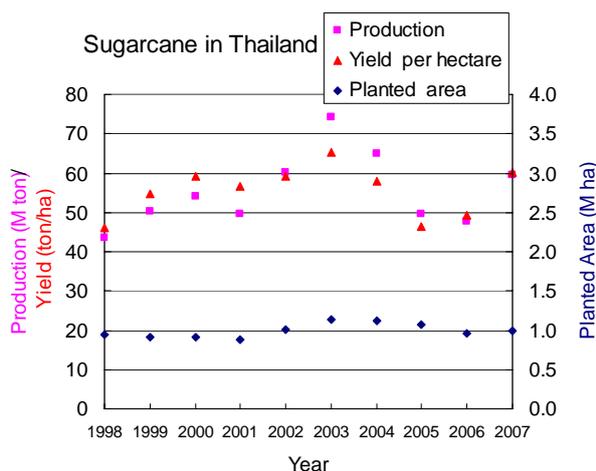


Fig. 2.8.9. History of sugarcane statistic in Thailand.

2.9 Oil Producing Biomass

2.9.1 What is oil producing biomass?

Oil producing biomass produces and accumulates fat & oil in its seed or fruit meat. The main component of fat & oil is tri-ester of fatty acid and glycerin. Fat & oil is widely used as food, industrial raw material and bio-diesel production as an alternative for mineral diesel oil.

Examples of oil producing biomass are as follows;

(a) Soybean (*Glycine max* Merrill)

USA, Brazil, Argentina and China are the main production country. Soybean oil contains oleic acid (20-35%), linoleic acid (50-57%) and linolenic acid (3-8%). It is widely used as edible oil and raw material for paints and varnish as an un-drying oil.

(b) Rape (*Brassica campestris* L)

Rape is cultivated in wide area from Asia to Europe because it can grow even in the cold district. Main production countries are China, Canada, India, Germany and France. Rape seed oil expressed from rape seed contains oleic acid (55-59%), linoleic acid (21-32%) and linolenic acid (9-15%). It is mainly used as food such as frying oil and salad oil.

(c) Palm Tree (*Elaeis guineensis* Jacq)

Main production countries are Malaysia and Indonesia. Palm tree has the highest oil productivity in oil producing biomass because palm fruits can be harvested several times in a year. Palm oil expressed from palm fruit contains saturated fatty acid such as palmitic acid (35-38%) and Stearic acid (3-7%), and it is used not only in food industry but also in detergent industry.

2.9.2 Production method of fat & oil

For the fat & oil isolation from seed/fruit expression process or solvent extraction process is applied.

(a) Expression process

Used for high oil content seed such as rapeseed by rough crashing by roll mill, flaking, heating at 75-85°C and expression by expeller.

(b) Solvent extraction process

Applied for low oil content seed such as soybean by extraction with hexane.

2.9.3 Production volume of oil producing biomass

World oil seed and fat & oil production (2005/06) are summarized in the following table.

Production volume of palm fruit was calculated by the palm oil production volume and oil content in palm fruit.

Table 2.9.1 World oil seed and fat & oil production (2005/06, million ton)

	Soybean	Rapeseed	Sunflower	Coconut	Palm kernel	Palm	Others	Total
Oil seed production	220	43	30	5.3 (Copra)	9.4	180 (Fruit)	78.3	566
Fat & oil production	34.8	17.7	10.5	3.3	4.1	35.2	16.3	121.9

2.9.4 Bio-diesel fuel

Fatty acid methyl ester produced by the trans-esterification of fat & oil with methanol has the similar physical properties as mineral diesel oil in terms of heating value, viscosity, cetane number etc., and it is used as bio-diesel fuel (Diesel oil alternatives).

As raw materials for bio-diesel production, rapeseed oil in EU, soybean oil in USA and palm oil in Asia are mainly used. In EU nation's, bio-diesel has been spreading since 2002 and its consumption reached to 4 million ton in 2005.

2.9.5 Oil palm

The oil palm tree (*Elaeis guineensis*) originated from West Africa. It was first introduced to Malaysia as an ornamental plant. In 1917, the first commercial planting took place in Tennamaran Estate in Selangor, laying the foundations for the vast oil palm plantations and palm oil industry in Malaysia. Later in the 1960s, the government introduced land settlement schemes for planting oil palm as a means to eradicate poverty for the landless farmers and smallholders. Now the oil palm plantations in Malaysia are largely based on the estate management system and small holders scheme. Today, more than 4 million ha of land in Malaysia is under oil palm cultivation producing 16 million tons of palm oil in 2006.

Oil palm is a crop that bears both male and female flowers on the same tree. Each tree produces 12-20 bunches per year (normally referred as fresh fruit bunches, FFB) weighing between 10-20 kg with more than 1000 fruitlets per bunch. Each fruitlet is spherical or elongated in shape. Generally the fruitlet is dark purple or almost black and the colour turns to orange red when ripe. Each fruitlet consists of a hard kernel (seed) inside a shell (endocarp) which is surrounded by the fleshy mesocarp. The oil palm produces two kinds on oil; crude palm oil from the mesocarp, and palm kernel oil from the kernel or seed. The trunks of young and adult plants are wrapped in fronds which give them a rather rough appearance. The older trees have smoother trunks apart from the scars left by the fronds which have withered and fallen off.

Oil palm trees start to bear fruits after 3 years old. Their most economic life is between 5-15 years, although palm trees continue to bear fruits until 25-30 years old. After that they are too tall (up to 20 m in height), generally they are fallen down for replantation with new trees or new clones. In Malaysia, the trees planted are mainly the *tenera* variety, a hybrid between the *dura* and *pisifera*. The *tenera* variety yields about 4 to 5 tons of crude palm oil (CPO) per ha per year and about 1 ton of palm kernels. The oil palm is most efficient, requiring only 0.25 ha to produce one ton of oil in comparison to soybean, sunflower and rapeseed which need 2.15, 1.50 and 0.75 ha, respectively.

2.9.6 Coconut

(a) Plant taxonomy

The coconut palm (*Cocos nucifera*) belongs to Plant Kingdom under Magnoliophyta Division, Class Liliopsida, Order Arecales, Family Areaceae and Genus *Cocos*.

(b) Origin

There are two contrasting views on to the origin of coconut. One is that it originated in America as several species in the genus *Cocos* are found only in America and the occurrence of coconuts in America antedates recorded history. On the other hand, others said that coconut originated in Asia as shown by the discovery of nuts of *Cocos* species in the Pleiocene deposit in North Auckland, New Zealand, the presence in Southeast Asia of a greater range of coconut varieties than in America and other reasons (Banzon, 1982).

(c) Description

Early Spanish explorers called it coco, which means "monkey face" because the three indentations (eyes) on the hairy nut resembles the head and face of a monkey. *Nucifera* means "nut-bearing." The coconut palm is generally described as a perennial tree. The coconut palm has long trunk of the tree, and several stems or leaves come from upper trunk, with green foliage, inconspicuous white flowers, and brown fruits. The greatest bloom is usually observed in the indeterminate, with fruit and seed production starting in the year round and continuing until year round. Leaves are retained year to year. The coconut palm has a moderate life span relative to most other plant species and a moderate growth rate. At maturity, the typical coconut palm will reach up to about 20 m high.

(d) Ecology

Coconut is a sun-loving plant requiring sufficient sunlight for photosynthesis and raising the

temperature of the air. It grows best at a mean temperature of 27°C and is sensitive to low temperatures. It is also observed that coconut does best at rainfall of 1,300 to 2,300 mm per year. It may even do well at 3,800 mm or more if the soil has good drainage. It does very well in humid climate. The best soil for coconut is a deep mellow soil such as sandy or silty loam or clay with granular structure.

(e) Fruiting

Different varieties come to bear fruits at different ages. The dwarf varieties start bearing fruits in 3-4 years after planting while the tall varieties start at 5-7 years. The complex of sunlight, rainfall and temperature result in periodicity of yield in the different months of the year. Results of studies showed that the heavier yields are obtained in March to June.

(f) The fruit

A coconut fruit is actually a one-seeded drupe. On the outside is the "husk", which is initially green but turns brown after being picked and dried. Inside the outer coat of the fruit lies the mesocarp, which is packed with vascular bundles. This fiber is called the "coir" and is used for making mats and rope. What we buy in the grocery store is the "stone" of this drupe, which has a hard "shell," the endocarp, and the seed, which is inside of the shell. The shell is used for containers and is widely employed by artisans to make ornaments and decorations. The thin seed coat is the next, and then there are the white flesh or "copra" and "coconut milk." Both the copra and the milk are the endosperm of this seed. Yes, coconut is unique among plants in having copious liquid endosperm, which bathes the young embryo. Initially the milk is fairly sweet and the copra is thin, but as the seed matures, the liquid is converted into solid endosperm rich in oils (triglycerides). The solid endosperm, copra, is harvested, dried, and then pressed to release the oil, widely used for chief ingredients of shampoo and hair conditioners.

(g) Product forms of coconut

Coconut is called the tree of life because of its many uses. Primary coconut products include coconut oil, desiccated coconut, fresh coconut, and copra (dried mature coconut meat). The major coconut products produced in the Philippines are copra, copra cake, coconut oil, desiccated coconut, fresh young coconut and coconut coir. From this list, desiccated coconut, "buko" fresh young coconut meat and coconut oil are the most in demand products in foreign markets.

Of the estimated 14 million nuts produced in the country per annum during 2001-2005, about 90% is processed into copra. Annual copra production is estimated at two million MT. The remaining portion (10%) of the total coconut production is devoted to the manufacture of

desiccated coconut (5%) and other coconut products namely coconut milk, “buko” and for household purposes. Out of the total amount of copra produced, 62% is processed into crude CNO – 60% of which goes to exports while 40% is left for domestic consumption. Copra cake or meal which is the by-product of copra production constitutes the remaining 34%.

Processing of coconut products produces other products such as detergent, bath soaps, shampoo, cosmetics, margarine, cooking oil, confectionery, vinegar, and nata de coco. Coconut intermediates include oleochemicals such as fatty acids and fatty alcohols

Recently, crude coconut oil is transformed into cocomethyl ester or more popularly known as cocobiodiesel. Throughout the conversion process, two by-products are generated namely copra meal and glycerin

(h) By-products of coconut

The major coconut by-products are coconut shell, coconut husk and coconut fronds. Coconut shell can be converted to activated carbon while coconut husk can be processed to produce coconut shell charcoal, coconut coir, and coir dust.

The following discussions are referring to the combination of the three prominent coconut by-products: coconut husks, coconut shells and coconut fronds.

The amount of residue generated annually in a country is equal to the product of residue-to-product ratio (RPR) value for any specific residue and the annual production of the crop or product. RPR values for major crops are given in Table 2.9.1.

Table 2.9.1. Residue-to-product ratios (RPR).

Agricultural Residues	RPR
Coconut shells	0.15
Coconut husks	0.33
Coconut fronds	0.33

Table 2.9.2 shows the heating values of common coconut residues used in the industry.

Table 2.9.2. Heating Values of coconut residues.

Type of Coconut residue	Heating Value, Kcal.kg
Coconut shell	4,436 (I. Cruz)
Coconut shell charcoal	6,540 (Lozada)
Coconut husk charcoal	6,320 (Lozada)

(i) Uses of coconut residues

Coconut shell is consumed mostly by commercial establishments for energy purposes due to its high heating value. Major users of coconut shells are by restaurants or food processors owners. Coconut shell is also used for drying of crops like copra and rubber. Other energy uses of coconut shells are in the ceramic industry and in heating.

Most of the coconut husk is used in drying of copra using the traditional method called “tapahan”. The rest of the coconut husk is used as fuel in bakeries, drying of fish, pottery, ceramics, brick making and in commercial food preparation.

Coconut frond is used as fuel for drying copra while others are in restaurants, bakeries, fish drying and others.

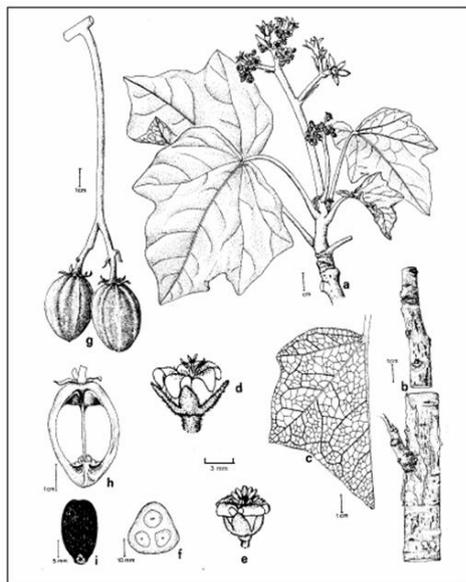


Fig. 2.9.1. Important parts of the *Jatropha Curcas*: a—flowering branch, b—bark, c—leaf veinature, d—pistillate flower, e—staminate flower, f—cross-cut of immature fruit, g—fruit, h—longitudinal cut of fruits;

Source: *Physic nut*, Joachim Heller, IPGRI. p.11.

2.9.7 *Jatropha*

The genus name *Jatropha* derived from the Greek *iatrós* (doctor) and *trophé* (food) which implies medicinal uses. *Jatropha curcas* L. belonging to the *Euphorbiaceae* or spurge family. *Curcas purgans* Medic. Vernacular/common names: English- *physic nut*, *purging nut*; Thailand - *sabudam*; Indonesia - *jarak pagar*; Chinese - *yu-lu-tzu*; the Philippines - *túbang-bàkod*; Brazil - *mundubi-assu*; Tanzania - *makaen*. By definition, it is a perennial small tree or large shrub which can reach a height of up to 6 m. The plant, originating in Central America, is mainly grown in Asia and in Africa, where it is known as *Pourghère*. It is cultivated in the tropics and semi tropics as a living fence. The seeds, however, are toxic to humans and many animals, and this species is a

resistant to a high degree of aridity and as such does not compete with food crops. It can grow without protection and can be used as a hedge to protect fields and farmer housings. Jatropha, the wonder plant produces seeds with an oil content of 37%. When the seeds are crushed, the resulting jatropha oil can be processed to produce a high-quality biodiesel fuel (between 30-35% of oil yield can be produced from one kg of seeds) without being refined and can be applied to a standard diesel engine. The by-products are press cake a good organic fertilizer, oil contains also insecticide. Glycerine byproducts from biodiesel production offer a valuable additional income stream to refiners.

Other uses :

Leaves - The young leaves may be safely eaten, steamed or stewed. Cooked with goat meat, they are said to advantageously counteract its smell.

Flowers - As honey plants.

Nuts - Sometimes roasted and eaten, although they are purgative. They can be burned like candlenuts when strung on grass. Used as a contraceptive in South Sudan.

Seed - The oil has been used for illumination, soap, candles, the adulteration of olive oil, and making Turkey red oil. Turkey red oil, also called sulphonated (or sulfated) castor oil, is the only oil that completely disperses in water. It is made by adding sulfuric acid to pure Jatropha oil. It was the first synthetic detergent after ordinary Soap, as this allows easy use for making bath oil products. It is used in formulating lubricants, softeners, and dyeing assistants. The seeds in particular area are very appreciated by the population as food once they have been boiled and roasted. It is unclear if this is due to the existence of a non-toxic variety of Jatropha in Mexico and Central America, or if the seeds become eatable once processed by cooking. It is also similarly reported that Jatropha seeds are edible once the embryo has been removed. Again it may be so because of these seeds coming from a local non-toxic variety.



Fig. 2.9.2. Flower of Jatropha.

Roots - Their ashes are used as a salt substitute. It can be used to kill molluscs, and has been listed for homicide, piscicide, and raticide as well.

Bark - Used as a fish poison.

Latex - Strongly inhibits the watermelon mosaic virus.

Sap - It stains linen. Sometimes used for marking.

Shrub - Mexicans grow the shrub as a host for the lac

insect, which is used in medicine as hepatoprotective and anti-obesity drug. Used for erosion control.

Further information

Banzon, J. A.; Velasco, J. R. Coconut: production and utilization. (1982)

2.10 Aquatic Plant Biomass

2.10.1 What is aquatic plant biomass?

Aquatic plant biomass is produced in freshwater and marine environments and has some potential human uses. Most current aquatic plant biomasses include seed plants, seaweeds and micro-algae, which are mostly produced naturally as well as some with man-made culture production.

Seed plant biomasses in freshwater are a water plant (*Eichhornia crassipes* (Mart.) Solms) and duckweeds. *E. crassipes* native to Brazil grows actively at 18-32 °C but shows no positive growth above 34 °C and below 0 °C. No duckweed species including about 30 species recorded has been selected as biomass utilization yet.

Within 60 species belonging 13 genera of 3 families (Hydrocharitaceae, Zosteraceae and Cymodoceaceae) as marine seed plants (sea grasses) in the world, eel grass (*Zostera marina* L.) and related species distributing at middle and high latitudes attract mostly for biomass uses (Hartog, 1970).

Algae include multi-cellular macro-algae (seaweeds) and unicellular micro-algae (phytoplankton). Seaweed inhabits, mostly in seawater and active biomass utilization is made with 220 species of red algae, 88 species of brown algae and 27 species of green algae in the world (Indergaard, 1982).

Micro-algae are distributed widely both in fresh- and marine waters although species are different. Current attractive species for biomass are green algae belonging *Chlorella*, *Scenedesmus* and *Dunaliella* and blue green alga of *Spirulina* in freshwater. Selected strains are cultured artificially for biomass uses, and some freshwater strains are cultured in seawater after acclimation treatment.

2.10.2 Productivity

Productivity of *E. crassipes* was recorded as 11-23 kgFW (fresh weight)/m².year (0.5-1.2 kgDW (dry weight)/m².year) during growing season in Japan, and reached 21.1 kgDW /m².year under sufficient light and nutrients. Eel grass productivity is 0.3-0.8 kgDW/m².year (120-320 gC/m².year), and that of *Thalassia* reached 5 gDW/m².day during 8 months in Florida, U.S.A.

Red alga, *Hypnea*, had productivity of 12-17gDW/m².day in outdoor tank (Slesser and Lewis, 1973). Productivity of micro-algae is 2-10 gDW/m².day in outdoor tank on average, and increases to 500 gDW/m².day under the optimum condition.

2.10.3 Current practical resource utilization

E. crassipes containing all essential amino acids supplies excellent livestock feed such as pig and chicken although heavy metals absorbed in the plant has to be eliminated for practical applications. For energy uses, 373 m³/tonFW bio-gas containing 60-80% methane and ca. 5,300 kcal/m³ for burning calorie was obtained by anoxic fermentation of *E. crassipes*. Since *E. crassipes* contains 3.2% of nitrogen, 0.7% of phosphorus and 2.8% of potassium in total DW, applications for fertilizer and soil amendment agent are now under considered.

Eel-grass biomass is used as a part of feed of sea pig and manatee in aquaria. Technology of artificial cultivation of eel-grass has not been established yet.

Seaweed biomass has been widely used in the world (Table 2.10.1). Yearly harvesting of attractive seaweeds is ca. 1.3 M (million) tonsFW for brown algae and ca. 0.81 M tonsFW for red algae. Most of them are natural, and artificial cultivation has increased recently. Seaweeds have been used for dried feed, human food, fertilizers, soil amendment agent and so on. Useful materials contained in seaweeds such as unique polysaccharides, iodine and so on are used for raw materials for extracting the useful substances (Indergaard, 1982). Kelp contains alginic acid in 13-45% of DW which is used for producing foods, medicines, cosmetics, dyes, paints, paper manufacturing, interior finishing materials, lubricating oil and so on. Some red algae contain agar and agar-like carrageenan.

Table 2.10.1. Yearly yield of seaweed production and potential productivity in the world.
(x10³ tons FW, Michanek 1975 (referred from Indergaard 1982))

Area	Red algae		Brown algae	
	1971-73		1971-73	
	Yearly yield	Potential productivity	Yearly yield	Potential productivity
18 Arctic sea	-	-	-	-
21 NW Atlantic	35	100	6	500
27 NE Atlantic	72	150	208	2,000
31 W central Atlantic	-	(10)	1	1,000
34 E central Atlantic	10	50	1	150
37 Mediterranean, Black Sea	50	1,000	1	50
41 SW Atlantic	23	100	75	2,000
47 SE Atlantic	7	100	13	100
51 W Indian	4	120	5	150
57 E Indian	3	100	10	500
61 NW Pacific	545	650	825	1,500
67 NE Pacific	-	10	-	1,500
71 W central Pacific	20	50	1	50
77 E central Pacific	7	50	153	3,500
81 SW Pacific	1	20	1	100
87 SE Pacific	30	100	1	1,500
Total	807	2,610	1,301	14,600

Regional numbers represent the FAO classification of world oceanic regions.

Micro-algae contain high percentages of protein reaching 50-70% of DW. Various utilizations of health care supplements, raw materials for extracting pigments such as carotenoids and phycobilins, and vitamins, and feed for aquatic organism are now in business for micro-algae. Due to micro-size and low biomass concentrations in natural, micro-algal biomass is prepared by artificial cultivation in tank, pool or channel on land in low or middle

latitudes suitable for year round cultivation. A business model has been proposed to culture filter feeder sea shells fed micro-algae cultured by nutrient rich deep seawater (Roels et al., 1979).

2.10.4 Standing stock of biomass resources

Actual standing stock of *E. crassipes* and duckweeds has not been estimated yet. Since *E. crassipes* is actively propagating due to acceleration of eutrophication in various places of low latitudes particularly serious in Africa where large rivers are dammed by the plant, attractive biomass utilization is urgently required.

Standing stock of biomass of natural sea grass bed is 0.1-0.5 kgDW/m² on average reaching to 2 kgDW/m² in a dense community. Sea grass bed is decreasing due to environmental changes and land reclamation in the world, and then artificial maintenance and recovery techniques are under challenged. Assuming 0.3 kgDW/m² of average density and 90% of water content of eel grass, it is expected more than a few 10 Mtons of eel grass biomass in the world.

According to the estimates based upon natural seaweed resources by Jensen (1978, after Indergaard, 1982), demand of alginic acid is 50,000 tons per year which requires 1.30 MtonsFW of seaweed. Yearly demands of carrageenan, agar, “*nori*”, “*wakame*” and kelp are 30,000, 20,000, 35,000, 30,000, 250,000 tons, respectively, and required seaweeds for respective those are 0.40, 0.50, 0.40, 0.20 and 2.00 MtonsFW. These are 1.1-3.0 times compared to the requirements made in the late 1970s. In addition, there are several M tonsFW to several 10 M tonsFW of seaweeds requested for seaweed meal, chemical industry, energy uses and high purity chemical industries, respectively. In order to meet with these large requirements of seaweed, a large increase of seaweed production is requested essentially in coastal areas as well as open seas in the future.

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2.11 Agricultural Residues

Agricultural residue refers to residue produced in fields or farm during harvesting and other activities. As energy resources, available agricultural residue includes those from cereals, rhizomic crops, and sugarcane. In addition, there is a huge amount and variety of vegetable residues could be produced that would not be considered as energy resources because it is difficult to collect them efficiently on a large scale.

2.11.1 *Types and features of agricultural residues*

(a) Rice and wheat

Residues from rice and wheat are mainly exemplified by chaff and straw. Of these, chaff generally refers to those derived from rice. This is because wheat chaff never drops in harvesting, and it can be processed without being removed. Rice chaff is almost uniform in shape and size, and is suitable for processing and transportation. Rice chaff, however, has a hard structure and less suitable for fermentation, due to its large amounts of lignin and silica (SiO₂). Most rice chaff is used as fuel for combustion. However, the silica contained in rice chaff as much as 10 to 20 wt%, which may damage incinerators during combustion, raising some considerations on its practical use. On the other hand, straw similarly contains lignin, silica and so forth, but may be more fermentable than the chaff, and it is used as energy sources both for combustion and fermentation.

(b) Corn and rhizomic crops

Corn residues are discharged not only as residues in fields (leaves, stems, etc.), but also as cobs after processing. Kernels of corn are abundant in starch, and it is used for ethanol production through fermentation in the USA.

Rhizomic crops may have leaves and stems as residues.

(c) Sugarcane

All parts of sugarcane other than the stems, such as cane tops (top portion with only a low sugar content), leaves and roots, are removed before the stems are transported to the sugar mill, leaving them as residues in the fields.

2.11.2 *Volume of production*

Although modes and volume of production of agricultural residues may differ by production

areas, rates of production of residues relative to crop yield are reported as 140% for rice, 130% for wheat, 100% for corn, and 40% for rhizomic crops (Hall et al., 1993). In this literature, the rate of production of sugarcane residue derived from stems, leaves and tops produced in the fields during harvesting is reported as 28% relative to the crop yield.

Annual production of agricultural residues estimated by determining production of each crop based on the FAO statistics (2000), and using the above-described rates of production of residues is shown in Fig. 2.11.1. About 3 billion tons of agricultural residues in total are produced around the world, in which rice residue accounts for a largest production of 836 million tons. Residue of rhizomic crops amounts 272 million tons, and wheat and corn residues, which not produced very much in Japan, amounts 754 and 591 million tons, respectively.

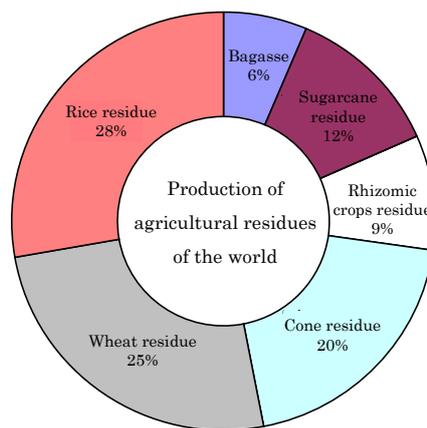


Fig. 2.11.1. Production of cereal residues and bagasse.

2.11.3 Bio-energy potential of the world

World's bio-energy potential of the agricultural residue in 2000 is shown in Table 2.11.1. These values were estimated based on production of residues multiplied by energy conversion factor, availability factor and so forth (Hall et al., 1993).

Rice residue was found to be as largest as 3.4 EJ, followed by bagasse and wheat residue as much as 3.3 EJ, respectively.

Table 2.11.1. Bio-energy potential from agricultural residues.

	Bio-energy potential (PJ/y)
Rice residue	3,407
Wheat residue	3,299
Corn residue	2,614
Rhizomic crops residue	407
Sugarcane residue	1,550
Total	11,277

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2.12 Wooden Residuals

2.12.1 Characteristics and environmental significance

Wood-based carbon from sustainable forestry, in which the amount harvested is less than or equal to the amount of growth, circulates in forests, human communities, and the atmosphere. Wood from sustainable forestry is called “carbon neutral” as it will not cause a rise of carbon dioxide concentration in the atmosphere. Fossil fuel consumption for forestry production is less than in agriculture or fisheries, and less energy is used for producing wooden products like sawn timber or wooden buildings than for producing steel products etc. The promotion of wood utilization could contribute to carbon dioxide reduction. However, only 30% of tree biomass carbon can be stocked in final wood products like wooden buildings. Thus, it is important to achieve a balance between resource saving through material-recycling and fossil fuel saving by consuming wooden residuals for energy.

Densities of wood and wooden composites vary from 0.2 to 1.0 g/cm³, and the weight of low-density wood can vary by up to 3-fold, depending on moisture content conditions. Thus in

most cases, wood statistics are listed using volume as the unit. Average oven dry density of wood used in Japan is estimated to be 0.42 g/cm³. Carbon content is 0.5. However, sometimes a carbon content value of 0.45 is used for wooden composites like particle board or medium density fiber board, which contain 10% weight ratio of adhesives, as a wood-derived portion.

2.12.2 Residuals from wood industries

Types and moisture content of wood residuals from wood processing plants like sawmills or plywood mills can vary widely. Larger residuals are chipped and sold for pulp or wood composites like log slabs from sawmills or peeled cores from plywood mills. Smaller residuals like bark, sawdust, planer dust, or veneer residuals are utilized as livestock bedding in nearby farms, as boiler fuel in the mill, or as compost. Only 7% of the estimated 12 million m³ of wood residuals produced in 2005 was uselessly burned or otherwise wasted.

In large scale mills, even zero emission production is possible by recycling residuals for electric power generation or steam for wood drying. But for small sawmills without drying facilities or precut mills, a residuals utilization system such as a small-scale round accumulation system, must be established. Recently, wooden pellet production from bark or sawdust, which is easy to handle and has higher energy density, has been increasing.

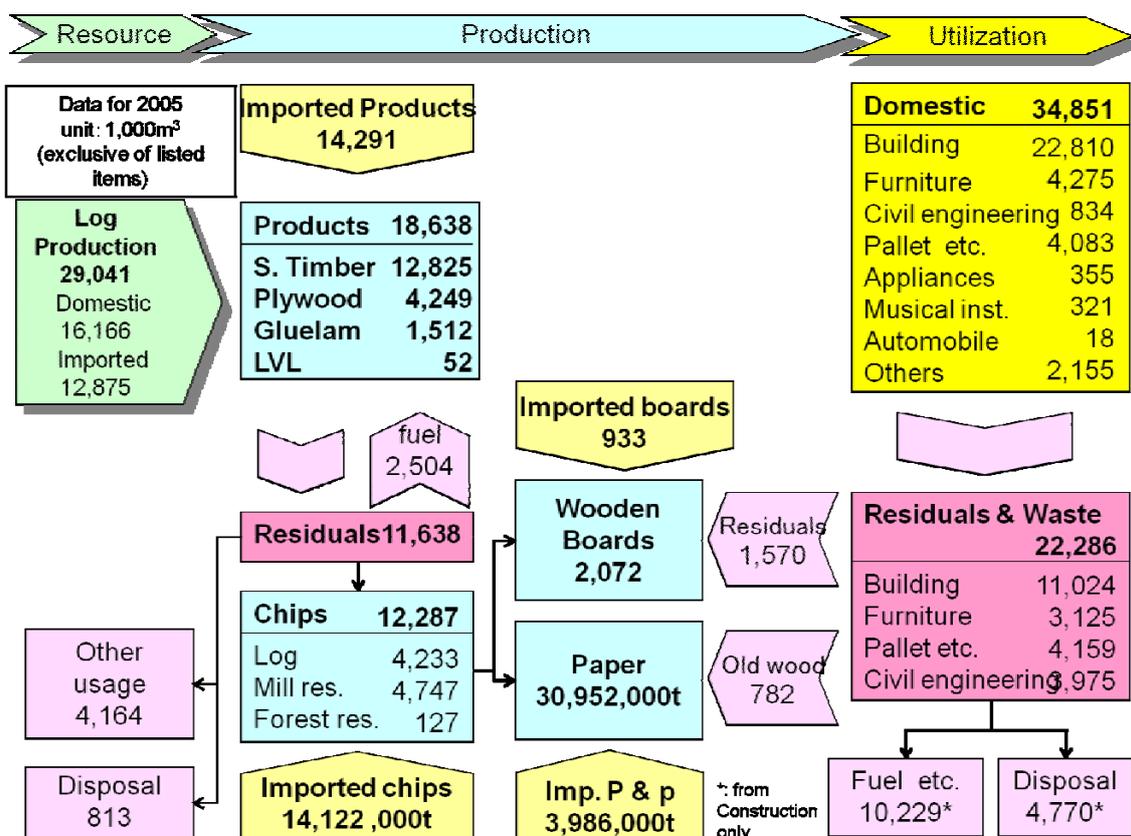


Fig. 2.12.1. Wood flow in Japan.

Table 2.12.1. Shipment of wooden primary products to utilization sectors (1,000m³) (2005).

	Building	Furniture & Fittings	Civil eng.	Pallets & Packaging	Home appliances	Musical Instr.	Automobile	Other	Total
Sawn timber	15,208	617	800	3,922				650	21,197
Plywood	4,393	2,000	33	134	192	318		1,297	8,367
Particle board	565	926			45	3		6	1,544
Laminated timber	1,581	145						110	1,836
LVL	390	114							504
Fiber board	Hard board	23	6	27	0		18	4	78
	MDF	561	224		118			26	929
	Insulation b.	90	245					61	396
Total	22,810	4,275	834	4,083	355	321	18	2,155	34,851

2.12.3 Residuals from wood utilization

In the 2005 estimates, 22 million m³ of residuals were produced in the construction, furniture, transportation, and civil engineering sectors. Residuals from civil engineering include trees felled during construction works.

Only 10% of residuals were recycled as materials; 1.6 million m³ for particle board etc., and 0.8 million m³ for pulp. The “Construction Recycle Law” mandates that construction-derived wood wastes from construction and civil engineering sectors are to be separated and recycled. In 2005, an estimated 62.8% of the 15 million m³ of residuals produced is recycled in some way, mostly, for energy generation, except for the volume reducing by incineration.

In the first commitment period of the Kyoto Protocol, the rise of petroleum prices has given many industries like power plants, steel mills, cement mills, and paper mills added incentive to start wooden residuals for energy production. Recycling companies also benefit easily, because they can collect a disposal fee for residuals from wood utilization. The objectives of the “Construction Recycle Law” will undoubtedly be achieved, and there may even be a shortage of wood residuals.

Material-recycling for conserving resources must have top priority. However, residuals with adhesives or paint cannot be used for pulp chips, and almost no waste wooden boards are material-recycled. Also small or composite wooden residuals, which cost much to be material-recycled, should be crushed and used as fuel chips. So, more than half of wood residuals could be energy-recycled without wasting, which in turn could reduce fossil fuel consumption by more than 1 million tons-C.

2.12.4 Technologies of energy utilization

Except for felled trees from civil engineering projects, the moisture content of residuals from wood utilization is considered to be 15% in dry base. Energy efficiency of direct burning as fuel chips is relatively high. There is also the possibility of gasification for electric power generation or for production of gas or liquid fuels. On the other hand, further consideration is necessary to utilize residuals from wood industries for energy production, because the moisture content may be nearly 100% in dry base and there are many types of residuals. Sawdust and bark, which requires little powdering energy, can be used as wood pellets.

The Japanese government is aiming to produce 2 million kL of bioethanol from wooden residuals by 2020. Lignin encloses cellulose etc. in the cell walls of wood, so saccharification

and fermentation are difficult without pre-processing. There is an opinion that automobiles should be powered by electricity rather than liquid fuel in future.

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2.13 Animal Waste

2.13.1 What is animal waste?

Livestock feces and urine are the major animal waste products and the amounts of livestock feces and urine account for the greatest portion of domestic organic waste in Japan. The feces and urine contain many easily degradable organic materials and many nutrient materials, such as nitrogen and phosphorus. The quantity and quality of feces and urine are very different depending on the kind of livestock, weight, feed, amount of drinking water, breeding system, season, and livestock conditions. According to their characteristics, feces and urine are processed and stored or used by suitable methods. Other animal waste products include slaughterhouse residue and other by-products of meat processing.

2.13.2 Characteristics of animal waste

Table 2.13.1 shows the amount of standard excretion for major livestock types. The amount of feces and urine excreted from each type of livestock is calculated under the conditions of standard feed conditions according to animal type and body weight. Generally, cow manure has a high carbon content (C/N ratio: ratio of carbon and nitrogen contents), but there are many organic materials that are relatively difficult to degrade, and poultry manure includes high concentrations of nutrient chemicals, such as nitrogen, phosphorus and potassium, and also contains many types of organic matters that are relatively easy to decompose. The category

“waste” in slaughterhouse residue includes substances that are not suitable as foods (inedible visceral, bone, fat, blood, skin, and feathers).

Table 2.13.1. The amount of standard excretion for major livestock.

Livestock type		Total weight (kg/head/d)			Nitrogen (gN/head/d)			Phosphorus (gP/head/d)		
		feces	urine	total	feces	urine	total	feces	urine	total
Dairy Cattle	lactating	45.5	13.4	58.9	152.8	152.7	305.5	42.9	1.3	44.2
	non-lactating	29.7	6.1	35.8	38.5	57.8	96.3	16.0	3.8	19.8
	heifers	17.9	6.7	24.6	85.3	73.3	158.6	14.7	1.4	16.1
Beef cattle	Breeding cows (under 2year old)	17.8	6.5	24.3	67.8	62.0	129.8	14.3	0.7	15.0
	Breeding cows (2year and older)	20.0	6.7	26.7	62.7	83.3	146.0	15.8	0.7	16.5
	Dairy breeds	18.0	7.2	25.2	64.7	76.4	141.1	13.5	0.7	14.2
Pig	Fattening pig	2.1	3.8	5.9	8.3	25.9	34.2	6.5	2.2	8.7
	Sow	3.3	7.0	10.3	11.0	40.0	51.0	9.9	5.7	15.6
Layer	Chick	0.059	-	0.059	1.54	-	1.54	0.21	-	0.21
	Adult	0.136	-	0.136	3.28	-	3.28	0.58	-	0.58
Broiler	Adult	0.130	-	0.130	2.62	-	2.62	0.29	-	0.29

2.13.3 Production of animal waste

Based on the data shown in Table 2.13.1, the annual production of livestock waste in Japan was calculated to be 60.7 million tons of feces and 27.7 million tons of urine (Table 2.13.2). Livestock waste in Japan contains 670 thousand tons of nitrogen and 108 thousand tons of phosphorus. Those amounts are very large considering that the amounts of nitrogen and phosphorus used as chemical fertilizer in Japan are 480 thousand tons and 250 thousand tons, respectively. Statistics for the total amount of slaughterhouse residue are not available, but the quantity (about 1.5 million tons) is less than 2% of the total amount of animal waste.

Table 2.13.2. The annual production of livestock waste in Japan.

Type	Number (Thousand)	Livestock Waste (thousand tons)			Organic materials, N and P in Waste (thousand tons)		
		Feces	Urine	Total	Organic matter	Nitrogen	Phosphorus
Dairy Cattle	1,683	21,206	6,261	27,467	3,424.2	134.9	18.8
Beef Cattle	2,805	18,990	6,872	25,862	3,452.5	130.9	15.9
Pig	9,724	7,857	14,586	22,443	1,644.3	151.5	32.3
Layer	174,550	7,698		7,698	1,154.6	154.0	29.3
Broiler	104,950	4,975		4,975	746.2	99.5	11.4
Total		60,725	27,719	88,444	10,421.9	670.8	107.6

2.13.4 General treatment and usage of animal waste

Dr. Haga (National Agriculture and Food Research Organization) summarized the main systems used for treatment of major livestock waste in Japan (Fig. 2.13.1). According to the results of an investigation by the Agricultural Production Bureau of the Livestock Industry Department, solid parts of manure were just piled or operated by a simple composting process and liquid parts of manure were stored and used on their own fields as fertilizer in most dairy cattle and beef cattle farms. In the case of pig breeding, composting with a forced aeration system was the main method used for processing of solid parts and wastewater purification systems were used on most farms for treatment of liquid parts. Moreover, after drying treatment, layer and broiler manure is sold and used in other farms in many cases. Generally, dairy and beef cattle farmers have their own land for cultivation but pig and poultry farmers do not. This is thought to be the major reason for the differences in livestock waste treatments. The slaughterhouse residue and other by-products of meat processing are treated by a process called “rendering”, and most of them are used as edible fat and oil, feed, or an industrial source.

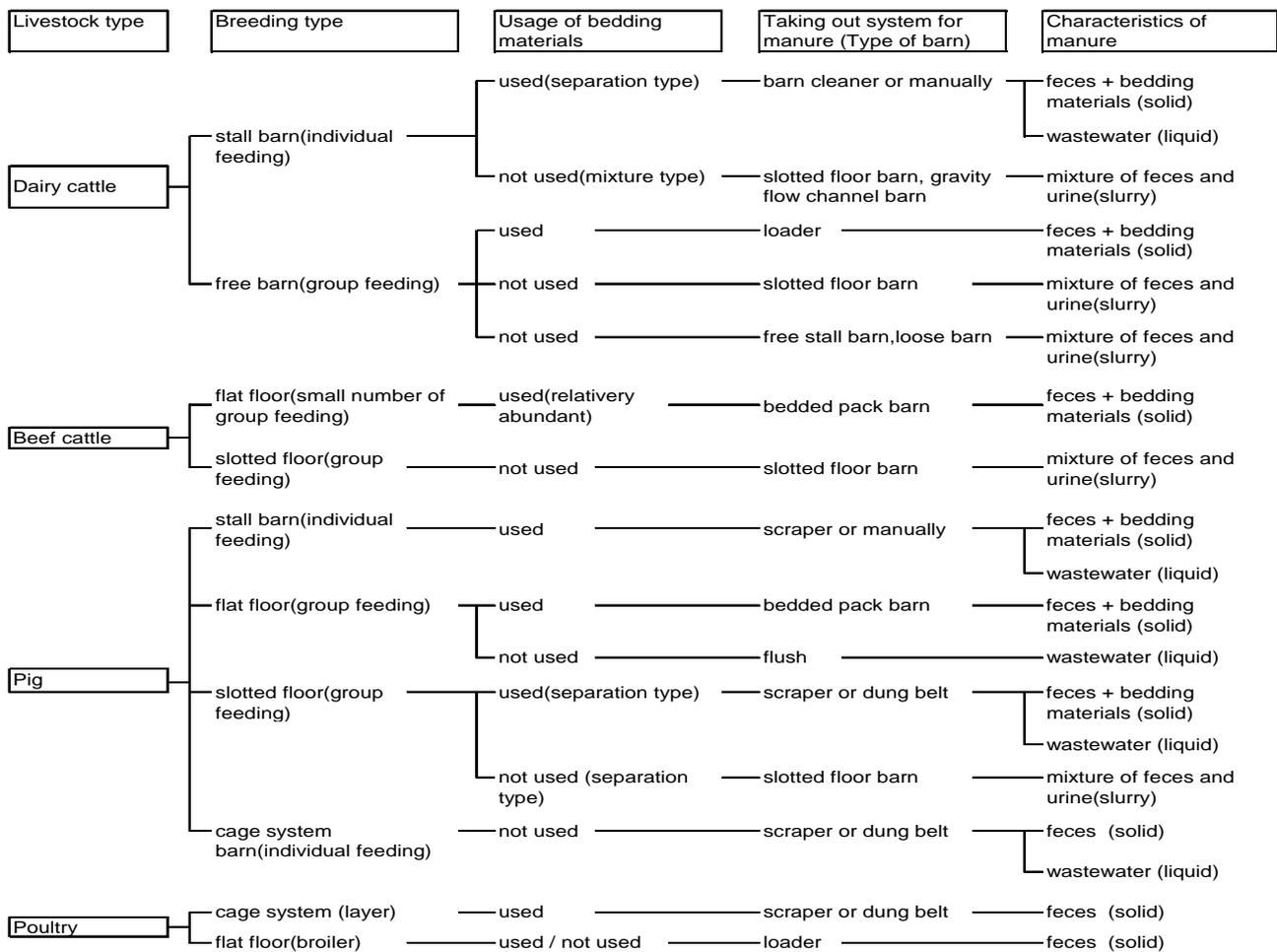


Fig. 2.13.1. Major breeding type and characteristics of manure of each livestock type.

2.13.5 Animal waste value and total amount in the world

To calculating the value of livestock waste as resources, consideration should be given to its value as 1) a source of plant nutrition (nitrogen, phosphorus, etc.), 2) a source of organic compounds with favorable effects on crop growth and 3) a source of energy. Because of the differences in breeding conditions, it is difficult to accurately calculate the amount of nutrients such as nitrogen and phosphorus in manure of all livestock throughout the world. Based on FAO statistics, total amount of nutrients in manure of all livestock in the world is estimated to be about 140-150 times greater than those in Japan.

2.14 Sewage Sludge

2.14.1 What is sewage sludge?

Sewage sludge is defined in this text as the solid matters discharged from an activated sludge wastewater treatment facility as the result of aerobic wastewater treatment. The sewage sludge, which is usually a mixture of settleable matters in sewage and reproduced microorganisms, is high in organic contents that are possibly considered as reusable biomass.

2.14.2 Types and characteristics of sewage sludge

The standard activated sludge process is depicted in Fig. 2.14.1 as a typical aerobic wastewater treatment process.

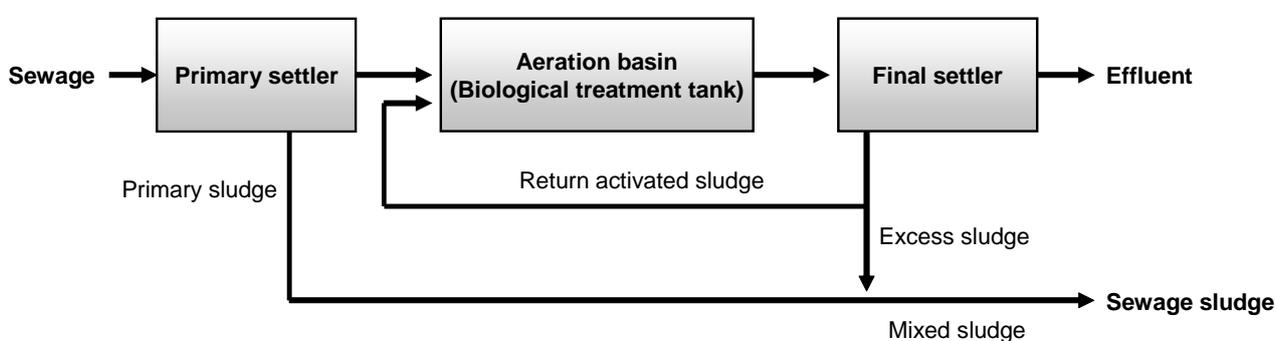


Fig. 2.14.1 Basic standard activated sludge process

In the activated sludge process, settleable matters contained in in-coming sewage are removed in the primary process and withdrawn as raw sludge. The sewage is then introduced to aeration basin(s) where the sewage is mixed with return activated sludge, aerated and vigorously agitated. The mixture of sewage and return activated sludge in the aeration basin is usually called mixed liquor. Most of the organic pollutants are removed from a liquid phase by bio-adsorption and eventually decomposed by microbial assimilation of the activated sludge. The mixed liquor is then introduced to the final settler where suspended solids (activated sludge) are settled and withdrawn as return activated sludge. A portion of return activated sludge is discharged from the facility as excess sludge and its quantity is approximately equivalent to the amount of microbes reproduced in the aeration basin. The sewage sludge is either a mixture of the raw sludge and the excess sludge, or each of the sludges discharged separately.

The discharged sewage sludge is thickened and dewatered, and is subjected to the final landfill disposal or recycled after an intermediate treatment such as incineration or

gasification-melting. Typical treatment/disposal processes for sewage sludge are shown in Fig. 2.14.2.

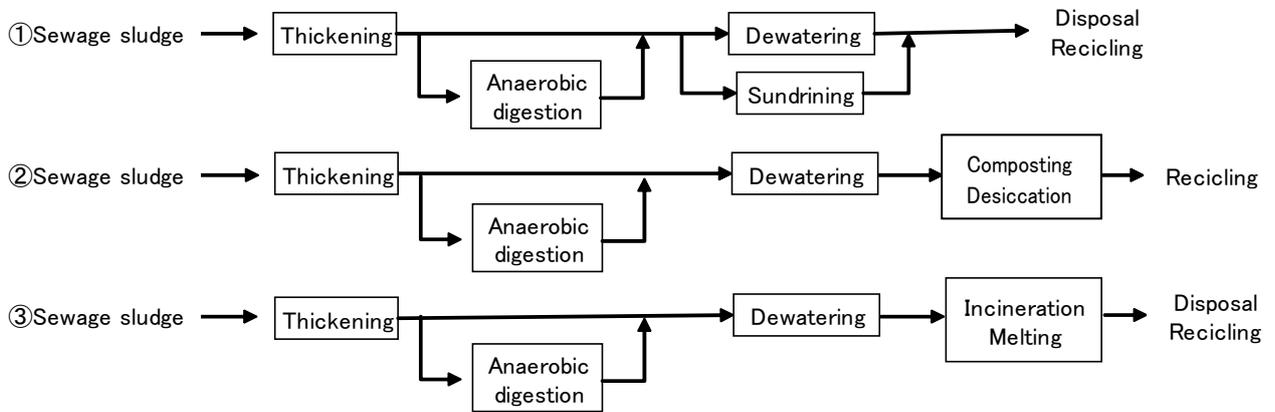


Fig. 2.14.2. Typical treatment process of the sewage sludge.

2.14.3 Utilization of sewage sludge

With various degrees of treatments including anaerobic digestion, dewatering, drying, incineration and/or melting, the sewage sludge is recycled and utilized as shown in Fig. 2.14.3.

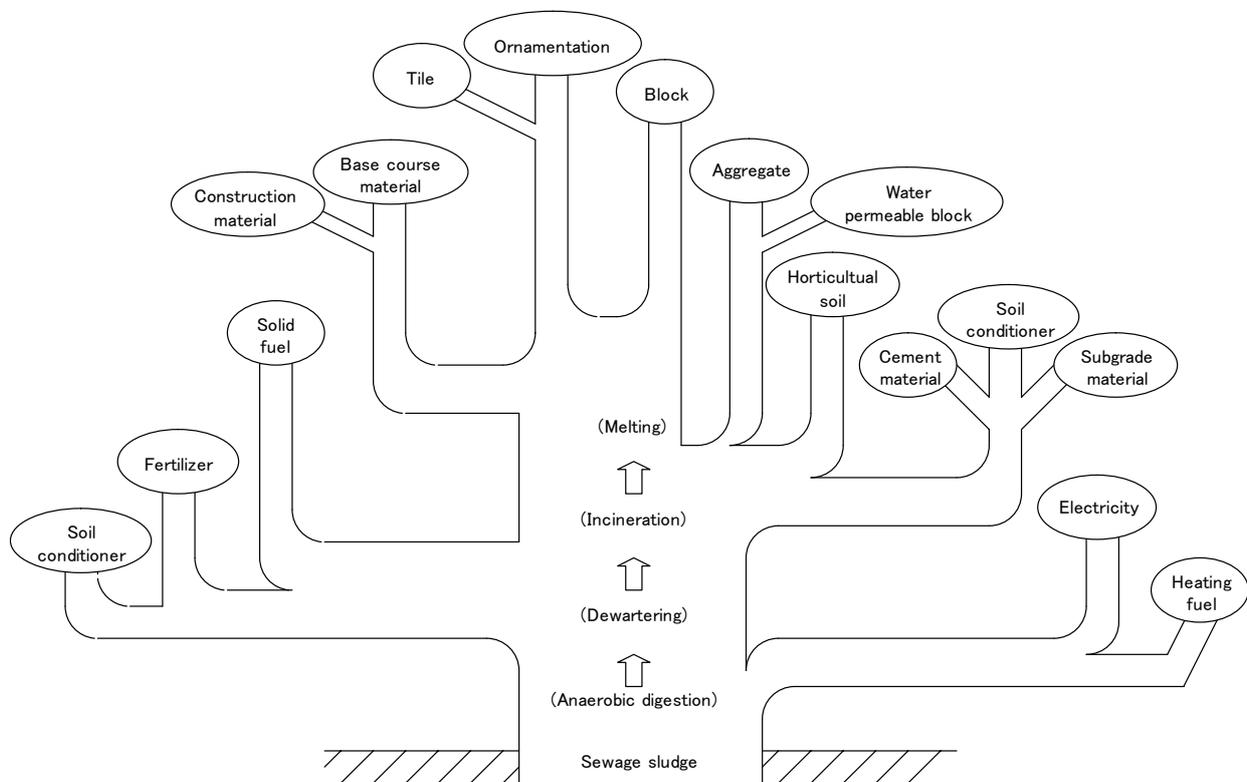


Fig. 2.14.3. Example of sewage sludge recycling.

By anaerobic digestion treatment, organic fraction of the sewage sludge is degraded by anaerobic microbes and converted to biogas. Since the biogas mostly consists of methane and carbon dioxide, it can be used as fuel for a gas engine or a gas boiler to generate electricity and/or steam/hot water, which, in turn, can be used at the wastewater treatment facility.

By-products of dewatering, incineration or melting treatment of sewage sludge can be utilized as a fertilizer/soil conditioner in agricultural applications, or as construction materials such as aggregates, tiles and water-permeable blocks in civil engineering applications. Rapid expansion of recycling and utilization of the by-products of sewage sludge treatments is expected to continue in the future.

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2.15 Municipal Solid Waste

The major biomass components in municipal solid waste (MSW) are food waste and paper, and thus biological (2.15.1 and 2) or thermal processes (2.15.3 and 5) are used to recover energy from the biomass fraction.

2.15.1 Methane recovery in landfills

In landfills containing organic waste, anaerobic biodegradation of biomass produces methane gas because oxygen diffused from the atmosphere is consumed near the landfill surface. Landfill gas can damage nearby plant growth and even cause neighboring buildings to explode. Therefore, gas control methods including flaring have been implemented since the 1960s. In large-scale landfills, vertical wells are installed to pump out the gas, which is used on-site for power generation or sold as fuel. Average gas recovery rates range from 120 to 150 m³/ton of dry MSW, equivalent to a heating value of 2500 MJ/ton (the methane concentration of landfill

gas is around 55%). Since the late 1990s, many American studies have investigated “bioreactor landfill,” in which moisture content is controlled to maximize biodegradation. Bioreactors also increase the rate of gas generation and consequently the rate of energy recovery.

In contrast, landfill gas is not recovered in Japan for two reasons: landfills contain little organic content due to the common practice of incineration, and landfills are aerated through the use of a semi-aerobic landfill structure, in which natural convection is allowed to form an aerobic zone around leachate collection pipes below the landfill. The Chuo-Botahei landfill in Tokyo Bay does recover methane, but its annual power generation (averaged over 20 years) is 3000 MWh, enough power for only 850 households.

2.15.2 Biogasification (methane fermentation)

Biogasification, a technology for recovering methane gas from organic matter in an anaerobic reactor, is also referred to as “anaerobic digestion.” This process was developed in the 1980s to treat organic wastewater. In 1997, 90 facilities operated worldwide (total throughput is 3.5 million tons/year). Japan has 12 facilities to treat human waste and food waste, and 3 of these treat only food waste. Fig. 2.15.1 illustrates the main processes of biogasification. Low solid concentrations (6 to 10%) are treated using a “wet system,” while high solid concentrations (25 to 40%) are treated using a “dry system.” Treatment systems are also classified by their dominant microorganisms: methophilic (used at 30 to 40°C) or thermophilic (used at 50 to 60°C).

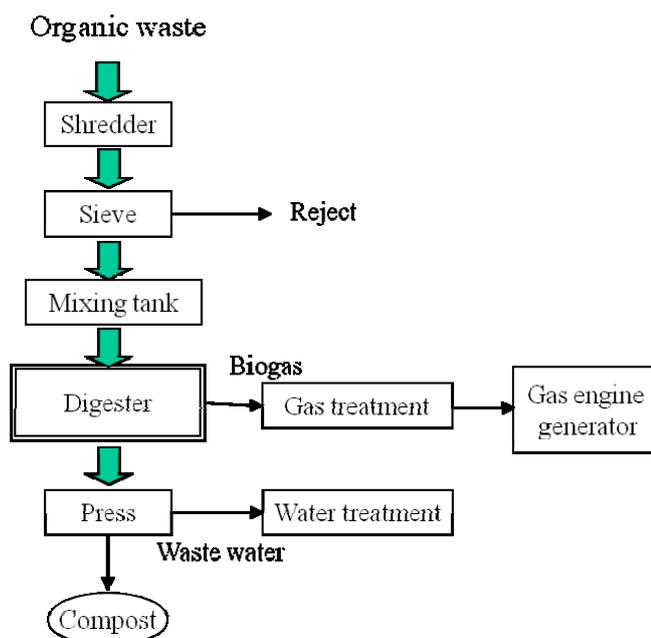


Fig. 2.15.1. Process flow of biogasification.

2.15.3 Incineration with energy recovery

MSW produces a heating value about one-third that of coal heat, and can burn at temperatures as high as 1000°C. When the combustion gas is cooled to between 200 and 300°C by gas control equipment, energy can be recovered by a boiler system. While even small-scale incinerators commonly reuse waste heat for heating and hot water supply, large-scale facilities can use high-temperature steam for power generation. In 2005, more than 60% of MSW incinerators reused hot water, and 20% generated power.

However, on average, MSW incinerators have a power generation efficiency of only 10%, much lower than coal power plants. They cannot be highly efficient because steam temperatures must remain low to prevent corrosion at temperatures of 320°C or higher; economic incentives are also low due to the low price of generated electricity and the high cost involved in generating power.

An incinerator of the 600 ton/day class can provide central heating service for 1000 to 1500 households. However, this is usually impossible because MSW incinerators are generally located far from residential areas. To increase energy efficiency, waste management systems should be incorporated into city planning.

2.15.4 Refuse-derived fuel production and power generation

Refuse-derived fuel (RDF) is fuel recovered from waste. It includes a wide range of fuel including gas and oil, but usually refers to shredded waste from which incombustibles have been removed. In Japan, RDF was first produced from uniform commercial waste, such as plastics or paper, and in the late 1980s, RDF production began to include household waste. Produced after a series of processes including separation of incombustibles, drying, shredding, and palletizing, RDF can be easily stored and transported, and therefore has been selected as an alternative method of incineration in small- and medium-sized cities. After problems related to dioxins limited RDF use as fuel for small-scale boilers, regional RDF power generation (in which RDF produced in member municipalities is used in a central power plant) became a promising option when decentralized small-scale incineration was not possible.

Compared to unprocessed waste, RDF provides a higher heating value and uniform composition, and yields improved power generation efficiency. Five RDF power generation plants have been in operation since 2001 in Japan. They were expected to yield throughput of 160 to 310 tons/day, power generation efficiency of 20 to 30%, and output of 3000 to 20,000 kW.

However, a RDF storage tank exploded at one plant in 2003, and extensive surveys revealed that similar accidents were not rare; a considerable fraction of RDF is now being sent to landfills. As of 2003, 43 RDF production facilities were in operation or under construction, but this technology has been discredited in Japan due to its poor safety record. The United States currently has 15 large RDF incinerators in operation, but in that country, RDF contains only shredded combustible waste, termed “fluff RDF” (or coarse RDF).

2.15.5 Pyrolysis

In the late 1990s, problems related to dioxin motivated incinerator manufacturers to develop a pyrolysis (or gasification) system in addition to a melting system. Solid waste is heated at around 500°C in a scarce- or low-oxygen atmosphere, and the resulting combustible gas and solid residue is burned at between 1200 and 1500°C to melt ash. This process was expected to yield benefits such as low dioxin emission, high power generation efficiency, and recycling molten slag, and 77 facilities were in operation by 2005. However, recent studies have found that these facilities require high consumption of supplemental fuel and electricity, and produce a low slag recycling rate. To minimize these drawbacks, the first part of the pyrolysis-melting system is used as carbonization. The product, char, can be used as a charcoal alternative, soil conditioner, and powdered coal for blast furnaces. In contrast, in the European Union, pyrolysis is used as an alternative technology for energy from waste, but its target is pyrolysis gas.

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2.16 Black Liquor

2.16.1 *Black liquor*

Black liquor, a mixture of organic wastes, is made from a wood as a by-product during the production of chemical pulp. And it's routinely burned as a liquid fuel in a recovery boiler in a pulp mill. Approximately 1.5 tones of black liquor are produced in the manufacture of 1 tone of pulp. Generally, a calorimetric heat value of black liquor is 12.6 MJ/kg and its energy is mainly used for pulp and paper making process.

2.16.2 *Process of black liquor generation*

There are a number of different processes which can be used for separating of the wood fibers. And their produced pulp is mainly divided into 2 types. One is mechanical pulp which is manufactured by a grinding process. The other is chemical pulp which is manufactured by a cooking process where the cellulose fibers are cooked out from the wood. Black liquor is produced during the cooking process. In this chapter, details of black liquor generation are described in terms of the kraft process so that the kraft process is nowadays the main stream for pulping (Fig. 2.16.1).

Wood, the raw material of paper, is composed by wood fibers which consist of cellulose, hemicellulose, and lignin which is an integral part between the fibers. The ratio of cellulose, hemicellulose and lignin is approximately 55: 20: 25.

The process to extract lignin from a wood chip by means of decomposition and dissolubilization is called cooking process. In the kraft process, Na₂S and NaOH are added as a chemical to cook and the mixture is heated to 140 - 170°C and it keeps several hours. Although it's important not to damage to the cellulose and the hemicellulose fibers during the process, indeed, a part of the cellulose and most of the hemicellulose fibers are decomposed and dissolved. Generally, the half of the organic materials in the wood turns to pulp and the other turns to black liquor.

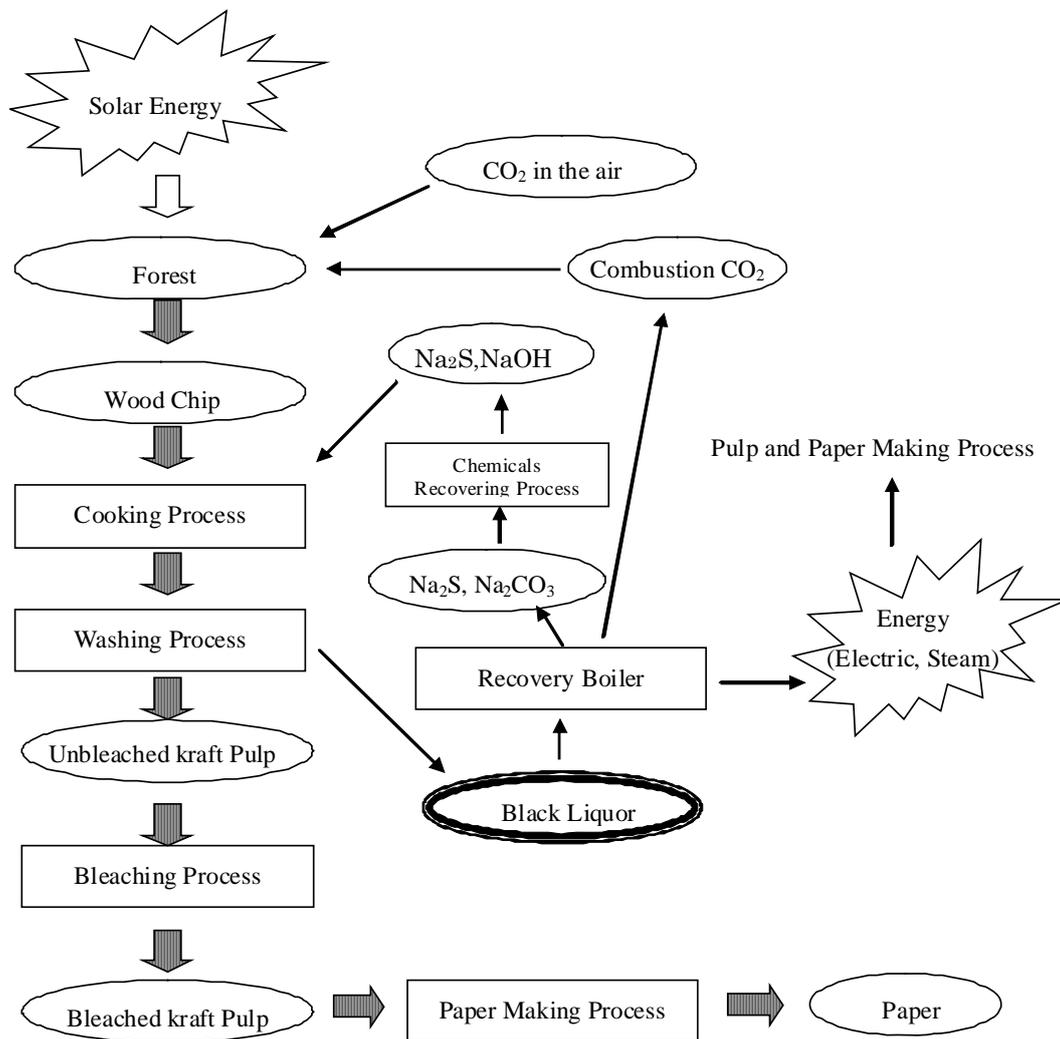


Fig. 2.16.1. The main stream for pulping.

Black liquor contains decomposed and dissolved lignin, hemicellulose, and Na and S. After the cooking process, the concentration of black liquor is usually 15 to 20%. Then the liquor is concentrated to approximately 70 to 75%. Finally, it's burned in a boiler called recovery boiler. As for a hard wood chip, 1 tone of the pulp turns to 1.5 tons of black liquor. Generally, a calorimetric heat value of black liquor is 12.6 mJ/kg.

During the process, melted Na and S which were contained in the liquor are extracted and then dissolved into hot water. After that, they're reproduced to Na₂S and NaOH in the causticizing process, and then used in the cooking process again. On the other hand, separated wood fibers turn to pulp through the washing process and the bleaching process. Finally, they're used as a raw material of paper.

2.16.3 Characteristics and significance of black liquor

As described, burning black liquor in a recovery boiler is a process to get energy. At the same time, it reproduces the chemicals for pulp production. It's necessary to use black liquor in a kraft pulp manufacturing plant. Therefore, all kraft pulp plants have a process to burn black liquor.

2.0 tones of black liquor are produced as a by-product from 1 tone of a hard wood pulp or 1.5 tones of a soft wood pulp. Generally, almost all amount of black liquor is used as biomass energy. The production of the kraft pulp in Japan is about 9,000,000 tones a year and 14,000,000 tones of black liquor are produced during the process. And the amount of the liquor is equal to 4,710,000 kiloliters of crude oil in terms of energy.

In 1999, the production of chemical pulp in the world was 119,000,000 tones. In consequence, the production of black liquor was calculated to be about 200,000,000 tones. And it's equal to 60,000,000 kiloliters of crude oil (Table 2.16.1).

Pulp and paper industry in Japan and Asian countries has been using planted woods as a material of pulp in these days and the production has been increasing. The industry is able to be developed by means of producing both material and energy from sustainable forest management which produces the resources for pulp. The utilization of black liquor is surely the foundation for the management.

Now that the utilization of black liquor is limited to the energy source in pulp and paper mills, however, various kinds of materials are produced such as lignosulfonic acids by dividing lignin from black liquor and nucleic acids by culturing of the yeast using sugars in the black liquor. It's expected that biorefinery of black liquor utilization will be more and more developed in the future.

Further information

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Table 2.16.1. The pulp production.
(1000 tones)

	1989	1994	1999
World	113,803	111,304	119,260
Europe	19,381	20,219	22,502
North America	58,053	62,714	61,934
Asia	17,490	13,755	17,252
Latin America	5,517	7,527	9,652

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2.17 Food Processing Waste

2.17.1 *Potential of food processing waste*

In this chapter, the example of Thailand is given to show the utilization of food processing waste. As one of the agricultural based countries, food industry sector plays an important role in Thai economy and also is worth a great fraction of Thai export value each year. The processing of food and its related commodity often involves thermal, mechanical and chemical treatment, which reluctantly poses environmental problems on proper treatment of the food processing waste. Broadly, food processing waste can be categorized into two types, according to its physical states, namely solid and liquid wastes. Solid waste varies from empty oil palm bunches, baggase, rice straw/stubble/husk, waste from cassava starch factory and corncob. On the other hands, liquid waste mainly comes from any food processing that involves washing, cleaning, extracting with water or any other solvents.

Conventionally, solid wastes have often been thrown back into the boiler in order to generate steam for the plant processing itself or power generation. With biomass technology like gasification, solid wastes find higher efficiency conversion to energy than simply uncontrolled burning. On the other hand, since liquid wastes are regulated for environmental concern, processing plants are required to install wasted water treatment system. Often such system is of an anaerobic digestion technology, from which biogas can also be produced and used as energy source in the plants.

From the Ministry of Energy evaluation back in 2000, the first nine industries of high potential for biogas production are of cassava, sugar, palm oil, canned seafood, frozen product,

slaughterhouse, canned pineapple, carbonated soda and liquor, respectively. Recent investigation on the wasted water from cassava, sugar, oil palm, canned pineapple and ethanol plants to assess the biogas potential was conducted by TRF (<http://www.trf.or.th>). The results are shown in Table 2.17.1. Cassava plant has the highest potential to produce biogas, more than twice the runner-up ethanol plant. Some reasons for seemingly low potential of biogas production in certain industries are the better management of waste water treatment system and also better by-product utilization.

Table 2.17.1 Potential biogas production from different industries.

Industries	Biogas data in 2005		MW _e	Energy substituted by biogas		
	Production (Mm ³ /y)	Energy equiv. (ktoe/y)		Plant capacity (GWh/y)	%Plant capacity	Fuel oil equiv. (ML)
Cassava	344	167	57	413	82.2	158
Ethanol	149	97	20.5	179	100	69
Oil palm	84	39	14	100	82.2	39
Canned pineapple	13	6	3.7	16	50	6
Sugar	4.2	0.7	3.6	5	27.4	0.3
Total	594.2	309.7	98.8	713		272.3

Source: TRF (Thailand Research Fund) final project report, 2007

Remarks: Fuel oil equivalent is calculated based on methane content in biogas with the following conversion factors: 1 m³ of CH₄ = 33.8 MJ, 1 m³ of biogas = 0.46 L of fuel oil equiv. = 1.2 kWh

2.17.2 Baggase

Baggase is the fibrous solid waste produced after stalks of sugarcane are crushed to extract sugar juice in the sugar mill. Typically, about 25-30% of sugar cane production is baggase, contributing to about 10.9-22.3 Tg/year (Mt/year) from the sugarcane production of 43.5-74.3 Tg/year (Mt/year) over the period between 1998 and 2007 in Thailand. Currently, almost all of baggase from the sugar mills in Thailand are used up as biomass fuel to generate energy partially for the sugar processing within the mills, leaving negligible amount for other applications. As shown below, more than half of grid biomass power plant in 2007 uses baggase as the fuel.

Since 1994, there are 37 SPPs (Small Power Producers) and VSPPs (Very Small Power

Producers) operating on baggase with installed capacity over 780 MW with almost 300 MW of which are sold back to the grid. The recent rapid increase in the baggase power plants are due to governmental strong support on electricity generation.

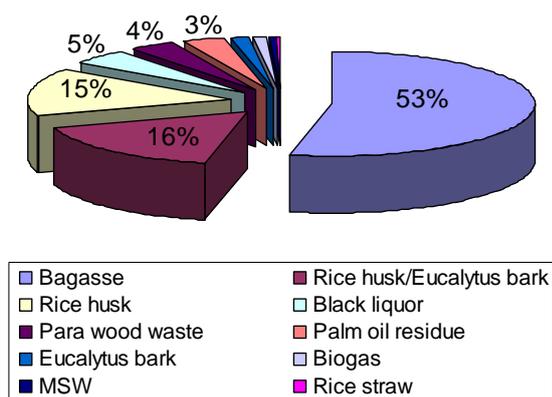


Fig. 2.17.1. Breakdown of biomass power plants by fuel type in 2007.

Source: Adapted from Energy for Environment Foundation (<http://www.efe.or.th>)

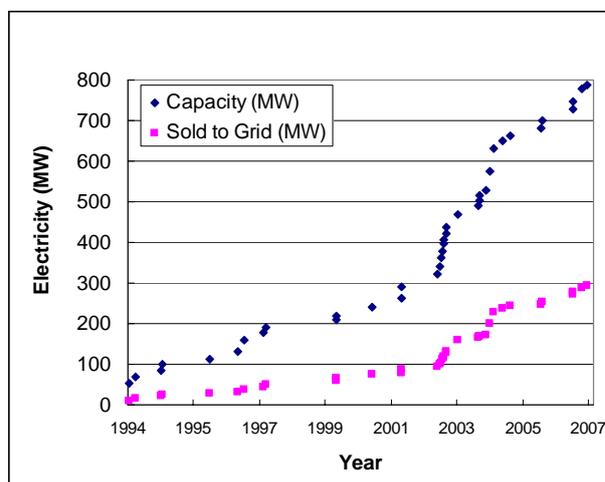


Fig. 2.17.2. History of baggase power plants in Thailand.

Furthermore, baggase can only be used to produce other value-added products like biodegradable food container (as shown below) and particle board. The baggase residue & ash from power plants can also be compressed to make a construction brick that weighs 3.2 kg/brick, sustains 80-90 kg/cm² load and costs only 4 Baht/brick (compared to typical construction brick of 5.8 kg, 70 kg/cm² strength and 8 Baht/brick cost).



Fig. 2.17.3. Biodegradable food container from baggase fiber.

2.17.3 Corn cob

Even though corn or maize is not one of the most economic crops in Thailand, there has been an increasing utilization of corn cob in power generation and solid fuel in order to achieve zero-waste philosophy in corn processing industry. The figure below shows the 2006 production of maize around the world, where USA is accounted for almost half of the world

production and also with the highest yield in the world. Although China has a similar amount of land for maize plantation to USA, the lower yield in China makes its production only half of the USA figure.

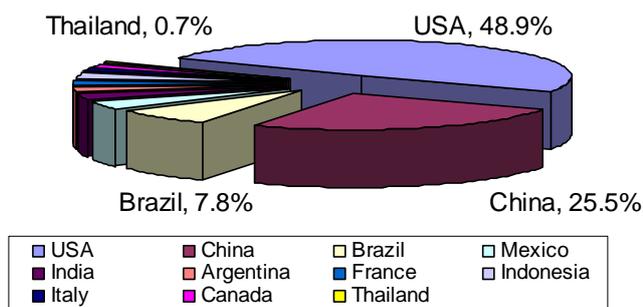


Fig. 2.17.4. World leading countries in maize production in 2006.

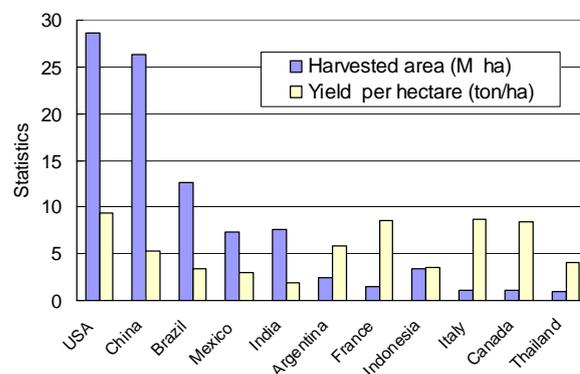


Fig. 2.17.5. Harvested area and yield of maize in 2006.

For the past 10 years in Thailand, the yield has been gradually increasing but not fast enough to compensate the decreasing plantation land, resulting in a decreasing maize production, as shown in Fig. 2.17.6. In 2006, the yield is 411 g/m² (4.11 t/ha) averaged over whole 9,000 km² (0.9 million ha) harvested area. Most of maize production in Thailand goes to food and feed industry; both of which corn cob is left as solid waste in the plants. In 2006, 33 Gg (0.33 Mt) of corn cob is reported, where 200 Gg (0.2 Mt) comes from the lower North part in Thailand especially Phetchabun (76 Gg (0.076 Mt)), Tak (35 Gg (0.035 Mt)) and Nakorn-sawan (33 Gg (0.033 Mt)). This corn cob is usually dried before putting in the boiler to generate steam for power generation, e.g. 10 MW power generation unit in the ethanol plant Pornvilai International Group Co.

Another value-added product for corn cob is corn charcoal, where corn cob is first heated to about 900-1000°C before being palletized with proper binder. Then, the final drying at 120°C for 12 h is conducted to obtain charcoal with less than 5% moisture.

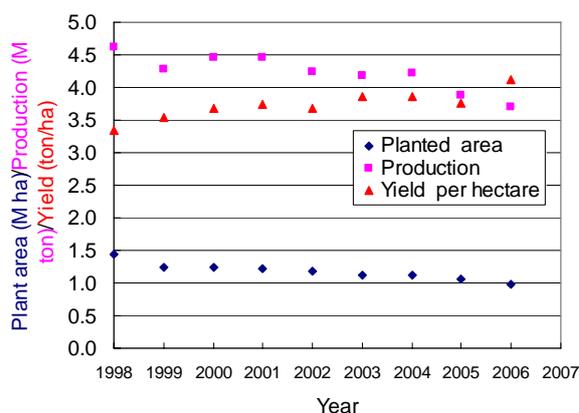


Fig. 2.17.6. History of maize statistic in Thailand.

2.17.4 Molasses

Molasses is a by-product of sugar processing from sugarcane. This black thick syrup remains after sugar has been extracted from sugar juice. In Thailand, sugar industry is closely regulated by OCSB (Office of the Cane and Sugar Board) via the Cane and Sugar Act of 1984. The OCSB has an important role in ensuring fair distribution of the revenue between the sugar mills and sugarcane growers.

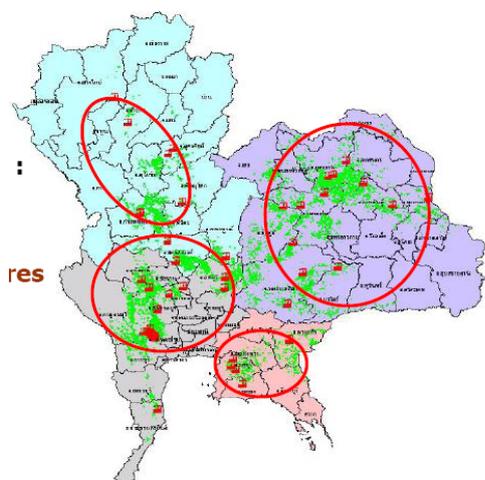


Fig. 2.17.7. Sugarcane plantation (green) and sugar mills (red) in Thailand.

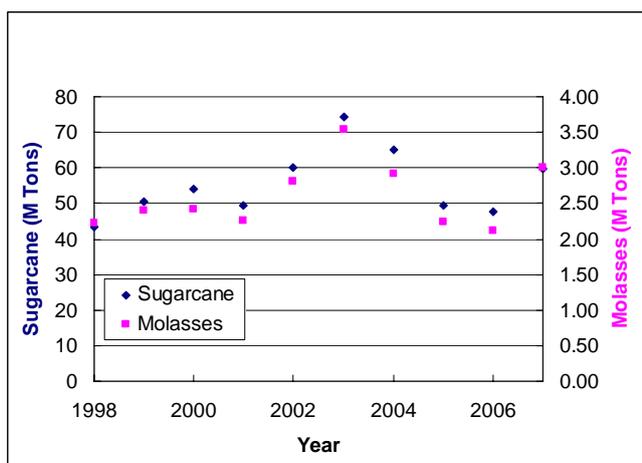


Fig. 2.17.8. Production of sugarcane and molasses in Thailand.

As shown above, about 10,000 km² (1 million ha) of sugarcane plantation area (green) is clustered in four regions (spanning 49 provinces) showing all 45 sugar mills (red). The molasses production strongly depends on sugarcane production. In general, 1 Mg (1 t) of sugarcane would yield molasses by about 45-50 kg, and 1 Mg (1 t) of molasses can be processed to produce 260 dm³ (L) of ethanol. For 60 Tg (Mt) of sugarcane production in 2007, 3 Tg (Mt) of molasses is produced. Of this 3 Tg (Mt), 1 Tg (Mt) is used among liquor, yeast, cooking sauce, MSG (mono sodium glutamate), vinegar and animal feed industries while 2 Tg (Mt) can be used to produce ethanol totaling about 520 dam³/year (million L/year) or 1.4 dam³/d (million L/day).

Initially, Ministry of Energy required licensing for a fuel ethanol plant but later on it was not required. At the moment, there are 7 total fuel ethanol plants (6 from molasses/sugar and 1 from cassava) operating at the capacity about 1 dam³/d (million L/day). About 12 more plants are currently being constructed with half using cassava as a feedstock. The total additional

capacity is 1.97 dam³/d (million L/day). This drive for ethanol capacity building is a result of the governmental initiative on using 10% ethanol-blended gasoline or so-called “gasohol E10” for both 91 & 95 octane rating. Recently, gasohol E20 (octane rating of 95) or 20% ethanol-blended gasoline will be commercially available at selected gas station from January 1, 2008 onwards.

For molasses export market, Thailand has recently become the largest molasses exporter (value at \$41.6 M in 2004), where the second and third largest are USA and Guatemala. About 37% of the export goes to ASEAN countries, and other 53% goes to other countries in Asia. Other molasses exporting countries nearby are Philippines, Indonesia and Australia.

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 \sum^*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.

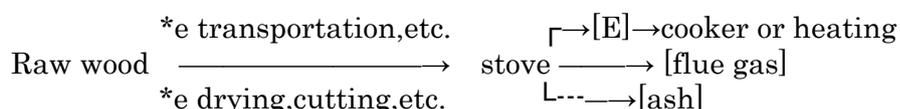


Fig.3.1.1. Material- and energy-flow around stove in firewood system

\sum^*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 km² (3.95 Gha) and decreasing gradually (-0.2%/year). Although the primary growth rate of forest is estimated to be more than 5.1 km³/year (5.1 billion m³/year), annual lumber production is as small as 1.6 km³/year (1.6 billion m³/year) for industrial use, and 1.8 km³/year (1.8 billion m³/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 α in Fig. 3.1.2, and the woody biomass cannot be effectively utilized. The value of α 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.

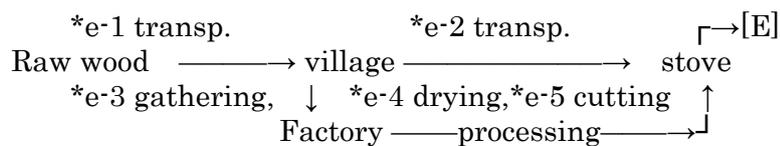


Fig.3.1.2. Material- and energy-flow before stove in firewood system
 *e1、 *e 2、 *e 3... :energy supply from outside,

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.

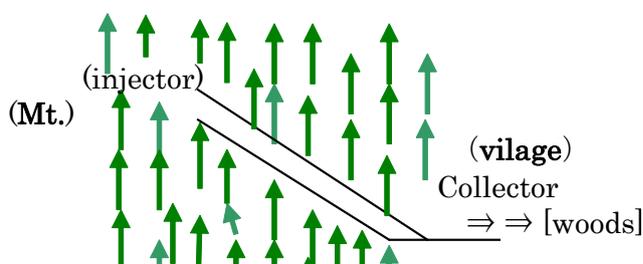


Fig. 3. 1. 3. Carrying-out system for mountain- fire woods

To convert raw wood to firewood, it is cut into the length of less than 50 cm, because of the furnace dimension. To 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 requirements are troublesome, and recently, artificial firewood produced by pelletizing the crushed 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°C, endothermic) (250~400°C, 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.

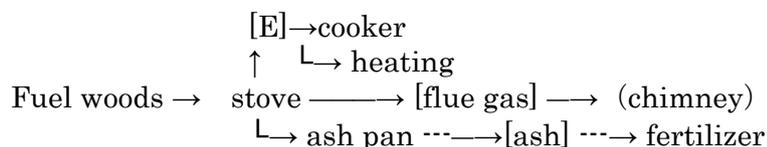


Fig.3.1.4 Material- and energy-flow after stove in fire wood system
 *e1、*e 2、*e 3... :energy supply from outside,

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.

Further Information

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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.

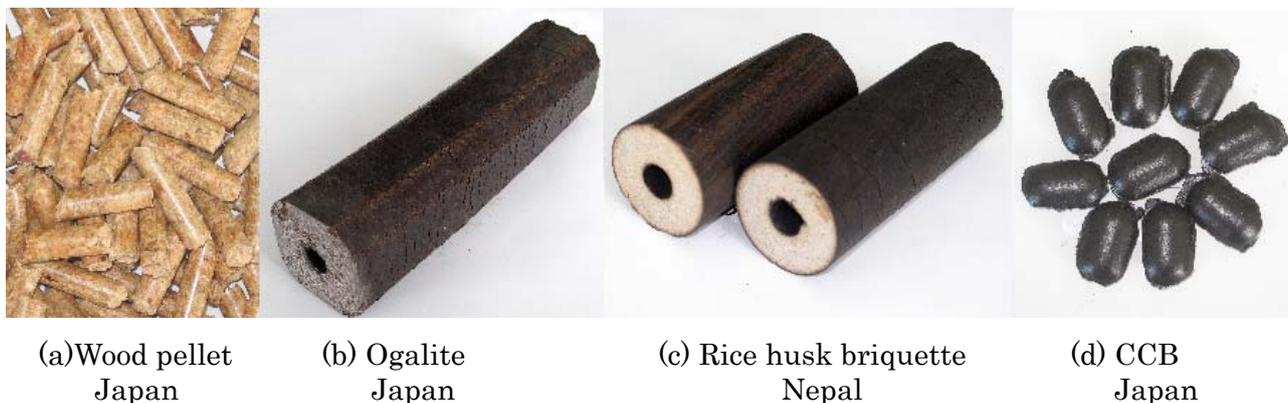


Fig. 3.2.1. Various types of briquette.

(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.

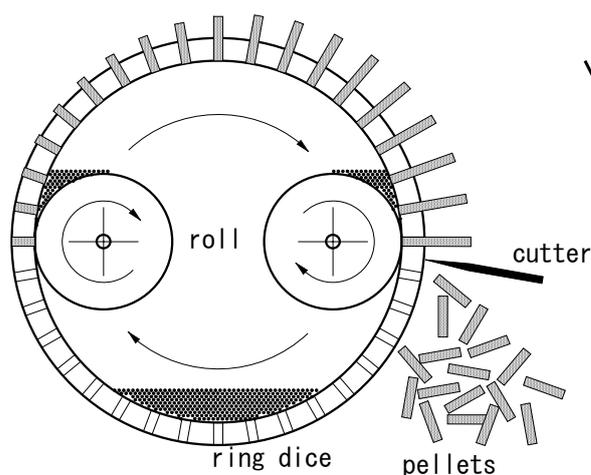


Fig. 3.2.2. Pelletizer for wood pellet.

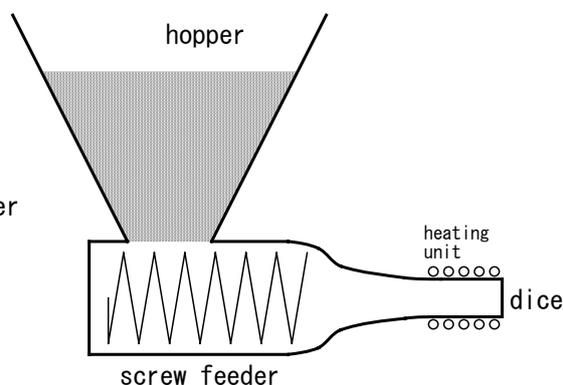


Fig.3.2.3. Briquetting machine for wood and rice husk briquette.

(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.

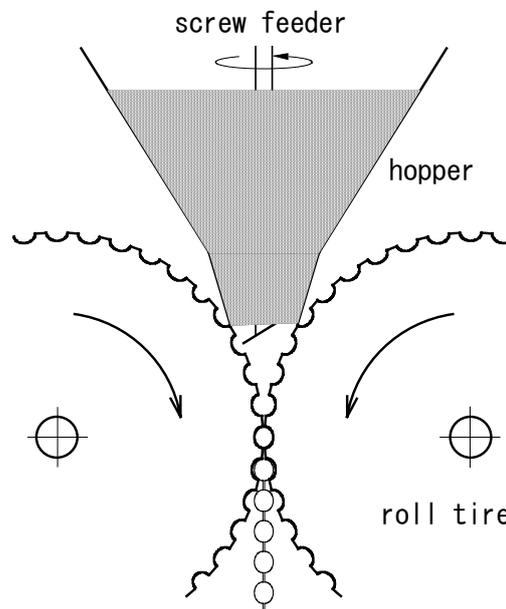


Fig. 3.2.4. Briquetting machine for CCB.

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.

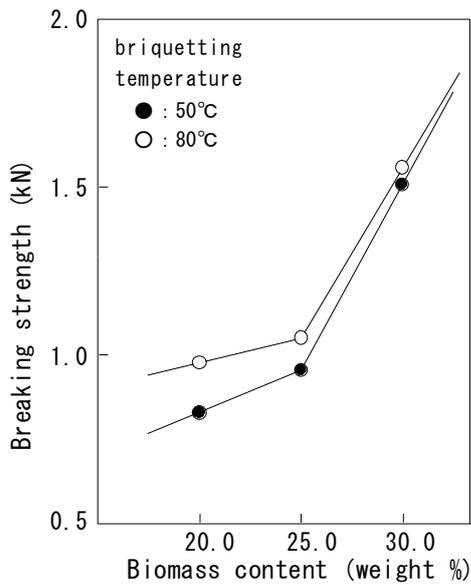


Fig.3.2.5 Effect of biomass content

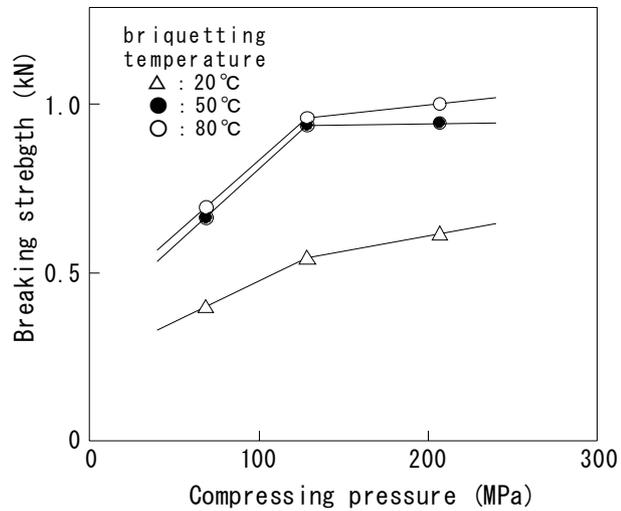


Fig.3.2.6 Effect of compressing pressure

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 m³ and imported particleboard production was 391,000 m³. Of this total (1,625,000 m³), 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.

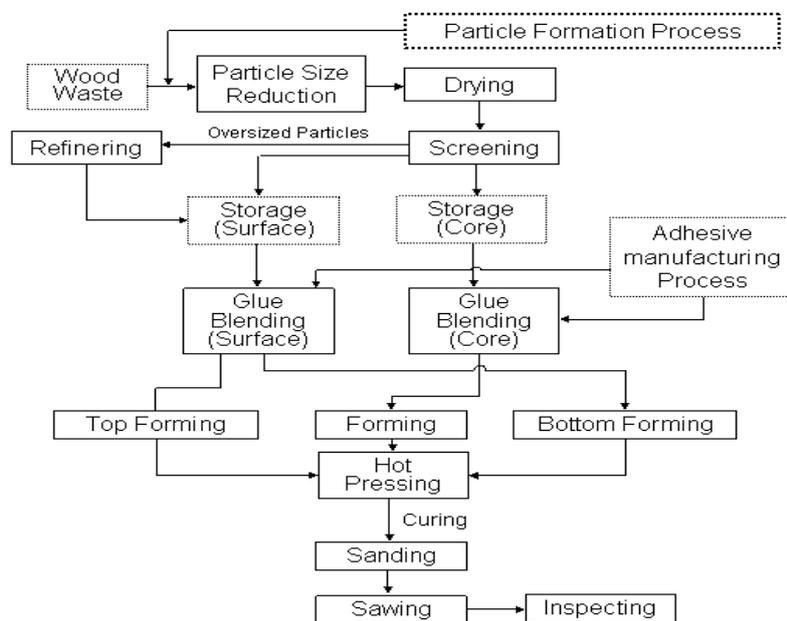


Fig.3.3.1. Particleboard Manufacturing Process. Courtesy of Saito, Y., Tokyo Board Industries, Co., Ltd.

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 m³ in 2006. Almost all of this (10,197,000 m³ (95%)) was used as a biomass resource, while the rest was discarded. Woody biomass is classified as: 1) wood chips, 4,408,000 m³ (43%); 2) fuel, 2,330,000 m³ (23%); 3) livestock bedding materials, 2,256,000 m³ (2 %); 4) compost or soil improvement materials, 580,000 m³ (5.7%); and 5) wood-based panels such as particleboard 258,000 m³ (2.5%). Fuel (2,330,000 m³) is classified as: 1) energy for operating drying kilns (1,550,000 m³), 2) electric power (595,000 m³), and 3) energy for manufacturing pellets (46,000 m³).

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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Part 4. Thermochemical conversion of biomass

4.1 Combustion

4.1.1 General scope

(a) What is combustion?

Combustion is an exothermic chemical reaction accompanied by large heat generation and luminescence, and is a phenomenon in which the reaction is spontaneously continued by the heat generated by the reaction. When using biomass as fuel, the heat-generating oxidation reaction, where carbon, hydrogen, oxygen, combustible sulfur, and nitrogen contained in biomass react with air or oxygen, is known as combustion, industrially. Combustion process proceeds by gas phase reaction, surface reaction, or both, following processes such as fusion, evaporation, and pyrolysis. In actual combustion reaction, complicated phenomena such as evaporation, mixture, diffusion, convection, heat conduction, radiation, and luminescence advance complexly at a very high velocity. Gas fuel burns directly in gas phase as premix combustion or diffuse combustion. Liquid fuel burns as inflammable gas in gas phase after surface evaporation, which is called evaporation combustion., Heavy oil etc. burns in evaporation combustion but decomposition combustion also proceeds, where decomposing the fuel portion occurs by the produced heat.

(b) Forms of combustion

The combustion forms of direct combustion of biomass, which is in solid form, include evaporation combustion, decomposition combustion, surface combustion, and smoldering combustion. In evaporation combustion, the fuel containing simple component and molecular structure with comparatively low fusing point fuses and evaporates by heating, and reacts with oxygen in gas phase and burns. In decomposition combustion, gas produced from thermal decomposition by heating (H_2 , CO , C_mH_n , H_2O , and CO_2) reacts with oxygen in gas phase, forms flame, and burns. Usually, char remains after these forms of combustion and burns by surface combustion. Surface combustion occurs in the case of the component composed of only carbon

containing little volatile portions such as charcoal, and oxygen, CO₂, or steam diffuses to pores existing inside or on solid surface of the component, and burns by surface reaction. Smoldering combustion is the thermal decomposition reaction at temperature lower than the ignition temperature of volatile component of the reactive fuels such as wood. If ignition is forced to smoke or temperature exceeds ignition point, flammable combustion occurs. In industrial direct combustion of biomass, decomposition combustion and surface combustion are the main forms of the combustion.

(c) Combustion method

Industrially, combustion surplus air is supplied in addition to the theoretical amount required for biomass combustion. If surplus air rate is too high, it causes decrease in combustion temperature and thermal efficiency. As the combustion method of biomass, grate combustion (fixed grate and moving grate), fluidized bed combustion, rotary hearth furnace combustion, and burner combustion are used. The features of each combustion method are shown in Table 4.1.1.

Table 4.1.1 Combustion type and feature of biomass

Combustion method	Combustion type	Features
Fixed bed combustion	Horizontal/Inclined grate Water-cooling grate Dumping grate	Grate is level or sloping. Ignites and burns as surface combustion of biomass supplied to grate. Used in small-scale batch furnace for biomass containing little ash.
Moving bed combustion	Forward moving grate Reverse moving grate Step grate Louver grate	Grate moves gradually and is divided into combustion zone and after-combustion zone. Due to continuous ash discharge, grate load is large. The combustion obstruction caused by ash can be avoided. Can be applied to wide range of fuels from chip type to block type.
Fluidized bed combustion	Bubbling fluidized bed combustion Circulation fluidized bed combustion	Uses sand for bed material, keeps fuel and sand in furnace in boiling state with high-pressure combustion air, and burns through thermal storage and heat transmission effect of sand. Suitable for high moisture fuel or low grade fuel.
Rotary hearth furnace combustion	Kiln furnace	Used for combustion of high moisture fuel such as liquid organic sludge and food residue, or large waste etc. Restricted to fuel size on its fluidity.
Burner combustion	Burner	Burns wood powder and fine powder such as bagasse pith by burners, same as that for liquid fuel.

(d) Application

The combustion of biomass is the simplest use of biomass to obtain heat, and is widely used because experiences of fossil fuel technology can be applied, because generation of NO_x, SO_x,

HCl, and dioxin is low, which is the advantage of biomass combustion, and because flammability is excellent. Combustion heat is used for power generation and heat production by recovering heat through heat transfer media such as steam and hot water using boilers and heat exchangers. In district heat supply and in energy centers of industrial complexes, cogeneration fueled by waste wood and agricultural waste is widely used. There are many power plants and heat utilization plants regardless of scale using paddy husk, bagasse, waste wood, oil palm waste and poultry chicken droppings, etc. as fuels.

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4.1.2 CHP

(a) What is CHP?

Production of electricity and heat from one energy source at the same time is called Combined Heat and Power (CHP). Because the energy efficiencies are higher than the cases to produce only electricity, attention is paid to CHP by the viewpoint of effective use for energy.

(b) Energy conversion in CHP

To generate electricity from biomass, the energy of the biomass is changed into the kinetic energy, the dynamo is turned by it, and the electrical energy is obtained. The main method of changing the energy of the biomass into the kinetic energy is as follows: 1) Steam is made by heat of combustion of the biomass and the steam turbine is turned, 2) The combustible gas is made by pyrolysis or microbial degradation of biomass and the gas engine or the gas turbine is turned using the gas. In any case, the heat obtained by the combustion is converted into the kinetic energy. As all thermal energy cannot be converted into the kinetic energy, a part of the heat is discharged. The energy efficiency of the biomass utilization can be improved if this heat is collected and supplied with the electricity. The CHP has the advantage of raising the energy conversion efficiency in this way.

(c) Possibility of a large-scale plant

CHP can be applied even in a large-scale power plant. The reason for locating a thermal power plant and a nuclear plant near the coast or the big river is to use a large amount of seawater or river water to throw away heat. On the other hand, there is a case to sell the heat that occurs from the power plant to the nearby factories. It would be desirable to consider heat

supply when a large-scale power plant is planned.

(d) Applicability of factories and housing complexes

The CHP facilities can be designed and be set up in a factory or a housing complex according to the demand for the electric power and heat. There are various specifications for the obtained heat from the steam of high temperature and high pressure to the warm water. The collections and supplies of the heat are easier at low temperature and low pressure. The steam and the hot water can also be supplied by combining the CHP facilities with the existing boiler. When the biomass is used as fuel, the generation efficiency decreases when the scale of the facilities gets smaller. In case of the boiler and turbine processes, the scale of 2,000 kW or more in electrical output is necessary and in case of the gasification and gas engine process, the scale of 50 kW or more in electrical output is also necessary.

(e) Examples

An example of the small-scale CHP facility using woody biomass is shown below. In this facility, the wood scrap from the factory is used as fuel, pyrolysis and gasification is performed and electricity, hot air, hot water and cold water are supplied to the factory. The process flow diagram is shown in Fig. 4.1.1.

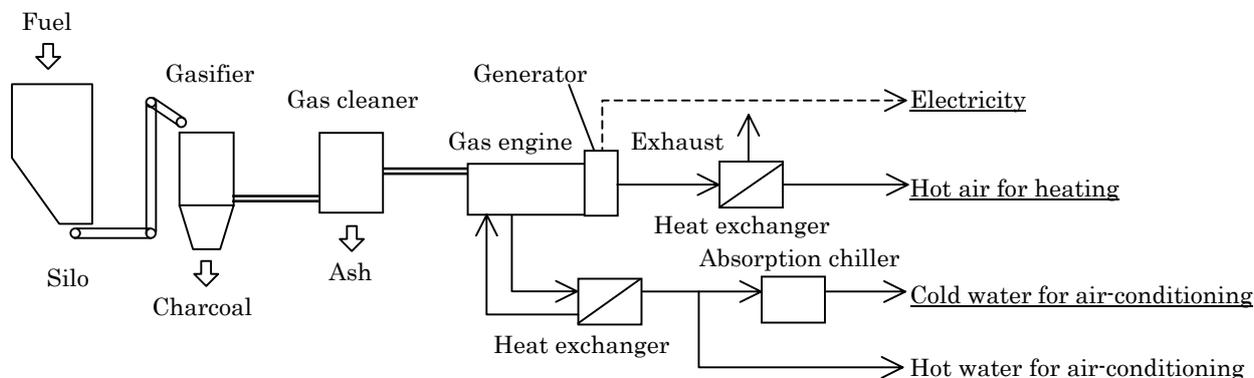


Fig. 4.1.1. Outline flow diagram of a small CHP using woody biomass

Gross power output of electricity is 175 kW and net power output is 157 kW. Heat outputs are 174 kW (150 Mcal/h) as hot air (67°C), 116 kW (100 Mcal/h) as hot water (80°C) and 70 kW (60 Mcal/h) as cold water (7°C). The energy efficiency in the facility can be raised by using heat that is originally thrown away as exhaust and cooling water.

4.1.3 Co-Firing

(a) What is co-firing?

Co-firing refers to the technology whereby biomass is fired with fossil fuels at thermal power stations and so on. The advantage of this technology is that, simply by making some minor revisions to existing equipment to enable biomass treatment, it becomes possible to fire biomass in highly efficient large-scale combustion facilities. Here, an introduction is given to research and development of coal and woody biomass co-firing technology that has been jointly implemented by The Chugoku Electric Power Co., Inc., Hitachi Ltd. and Babcock-Hitachi K.K.

(b) Goals

Upon burning around 5-10% of woody biomass in a coal fired power station (hereafter the proportion of mixed fuel is shown in terms of the calorific base), they aimed to secure stable operation and to clear environmental standards while at the same time minimizing any reduction in generating efficiency. Aiming for generating efficiency equivalent to approximately 40% the level in the existing coal fired power station, they held the reduction in efficiency at the sending end to within 0.5% when the mixed fuel firing rate was 5% (and within 0.8% when the mixed fuel firing rate was 10%).

(c) Feedstock

Based on component analysis of pine, cedar, cypress and bamboo, etc., woody biomass has greater volatile content than coal (bituminous coal), its fuel ratio (ratio of fixed carbon content to volatile matter content) is approximately 1/10 of that of coal, and its ash content is low. Upon conducting tests in a small hammer mill, etc., grinding power consumption for woody biomass was at least 10 times higher than that for the same weight of coal and simultaneous grinding testing of coal and woody biomass revealed that the grindability of coal is reduced a lot when the mixing ratio of wood is increased.

(d) Process flow

Figure 4.1.2 shows the flow diagram of the biomass pretreatment equipment. The woody biomass consisted of thinned timber and bamboo chips procured from the Chugoku region with a size of no more than 50 mm and water content of 50wt%. The chips were crushed to a size suitable for drying (no more than 20 mm) and dried to a water content of 20% or less. Next, two types of pulverizer were combined to regulate the pieces to a top size of 1~5 mm, and the materials were blown into the furnace by fixed quantity feeder. The mixed fuel firing rate was a maximum of 15%. Two types of burner were used: a coaxial coal and biomass mixed burner and a biomass dedicated burner (separately installed).

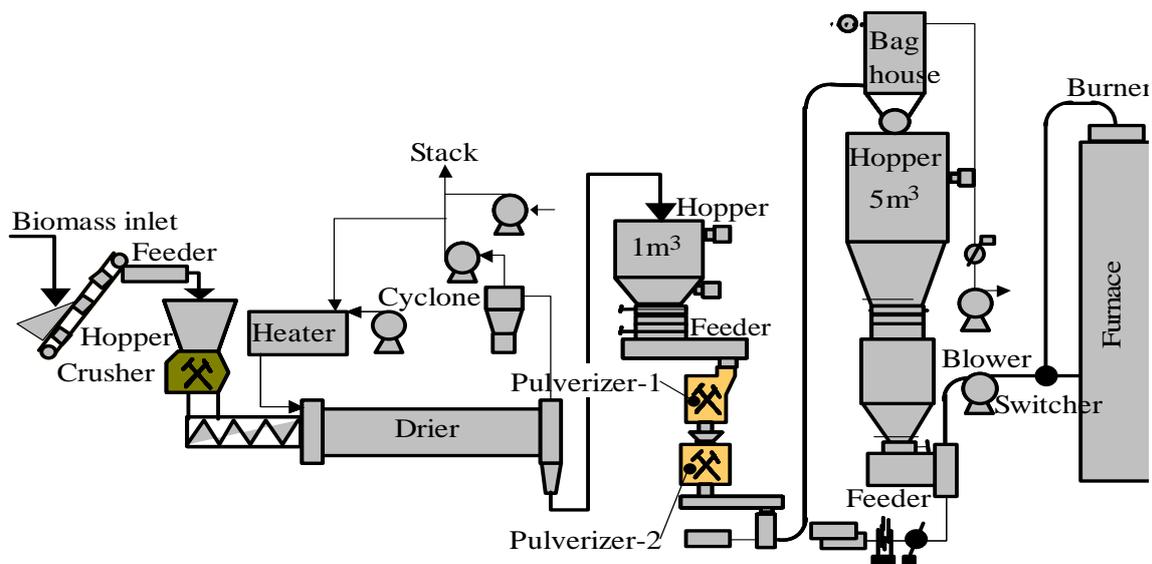


Fig. 4.1.2 Schematic of the Pretreatment Flow

(e) Results

Figure 4.1.3 shows some of the test results. As the proportion of mixed fuel was increased, the unburned matter and relative value of NO_x fell in both the coaxial burner and separately installed burner. The reduction in the unburned matter indicates that mixing of the highly volatile biomass caused the ambient temperature to rise and the combustion efficiency of the fuel itself to increase. The rate of decline in NO_x was lower than the value forecast from the rate of decline in the N content of fuel .

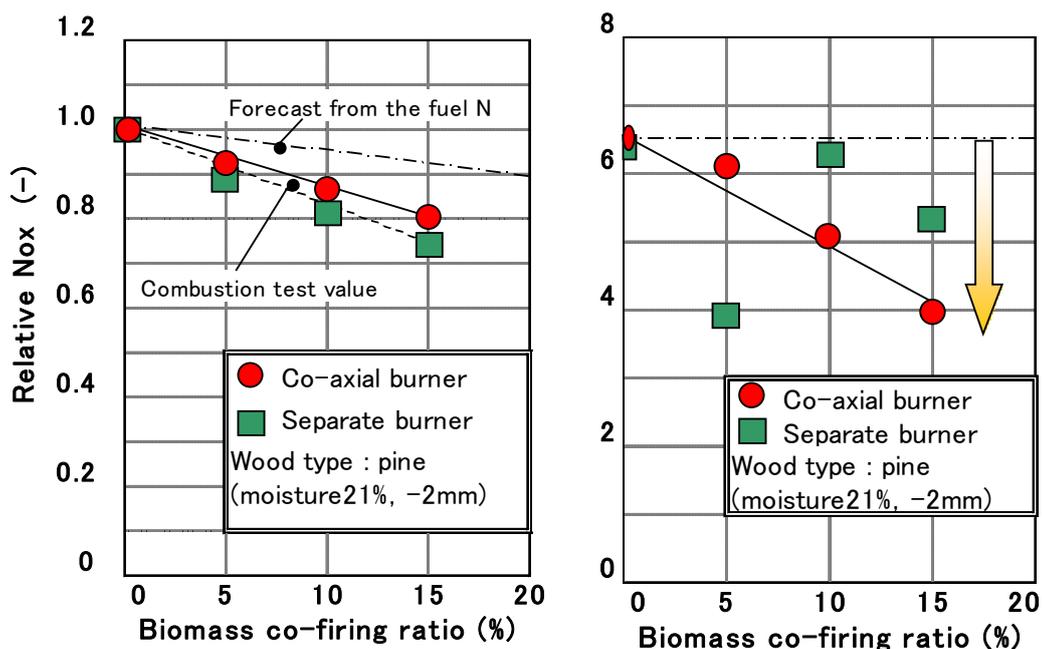


Fig. 4.1.3 Mixed Fuel Firing Test Results

(f) Efficiency

Based on the results of the combustion tests, the basic equipment and system composition in the case of application to the existing coal fired power station (selecting three units of 75-500 MW) was examined and the power generating efficiency and generating cost were assessed. Factors that cause the mixed fuel firing to affect power generating efficiency are thought to be changes in boiler efficiency and auxiliary power. In the case where thinned wood chips having water content of 30% and chip size of 50 mm or less following natural drying of the forest land, etc. are introduced to the power station, this wood is converted to crushed biomass of 20% water content and 2-mm particle size following pulverization and conveyance, and this is combusted in the boiler, whereas the unburned matter of ash is lower than in the case of firing only coal, the boiler efficiency drops slightly due to the water content of the woody biomass. As for auxiliary power of the plant, from the pilot test findings and based on estimation of the crushing power in the case where a two-stage shock crusher is used, the drop in overall sending end efficiency is 0.44% and 0.77% when the proportion of mixed fuel is 5% and 10% respectively, and these values are within the respective targets of 0.5% and 0.8%. Furthermore, upon comparing costs between woody biomass-only firing (10 MW) and mixed fuel firing, since the mixed fuel firing was less expensive than dedicated firing (11.3 yen/kWh), the superiority of mixed fuel firing was confirmed.

4.2 Gasification

4.2.1 Definition

The process to convert biomass solid raw material into fuel gas or chemical feedstock gas (syngas) is called gasification or thermochemical gasification.

4.2.2 Classification of gasification method

Gasification methods are classified according to combinations of conditional factors shown in Table 4.2.1..

Table 4.2.1 Classification of Gasification Method

Classification	Conditional factor
Gasification pressure	Normal pressure (0.1-0.12 MPa), High pressure (0.5-2.5 MPa)
Gasification temperature	Low temperature (700°C and below), High temperature (700 °C and above), High temperature decomposition (ash fusion point and above)
Gasification agent	Air, oxygen, steam and combination of them, carbon dioxide for particular time
Heating (Temperature zone formation)	Direct gasification (heat generation from reaction of partial gasification raw material and oxygen) Indirect gasification (heating raw material and gasification agent by external heat)
Gasifier types	Fixed bed, flow bed, circulating flow bed, entrained bed, mixing bed, rotary kiln, twin tower, molten furnace

4.2.3 Examination of biomass material properties

Examination of biomass material properties is necessary before planning gasification.

(a) Element analysis

Carbon (C), hydrogen (H), oxygen (O), sulfur (S), nitrogen (N) and chlorine (Cl) are observed through element analysis (HCN coder etc.). Excessive sulfur and/or chlorine can cause corrosion of plant equipment. The abbreviated molecular formula $C_nH_mO_p$ can be determined by obtaining the mol ratios for carbon (C), hydrogen (H) and oxygen (O). For biomass consisting of grass and wood, $n=1.2-1.5$ and $p=0.8-1.0$ when $m=2$.

(b) Ash composition and fusion point

The ash softening point, fusion point and flow point are to be measured in both oxidizing and reducing atmospheres. Problems with plant equipment occur more easily when the fusion point temperature is low.

(c) Technical analysis

Technical analysis is to be performed on raw material biomass to determine surface moisture, inherent moisture, volatile matter content, fixed carbon content and ash content, as well as high and low calorific content. These material property values are essential for gasification analysis.

4.2.4 Gasification agent

In order to convert solid biomass into inflammable gas, a substance to promote the chemical reaction is necessary. This substance is called the gasification agent, and mainly air (N_2 , O_2), oxygen (O_2), H_2O , or CO_2 are applied as an appropriate mixture. Air (only O_2 reacts) and O_2

generate heat by oxidation, and increased O₂ decreases the effective amount of inflammable gas.

4.2.5 Fundamental phenomenon of biomass gasification

Fundamental gasification processes are as follows:

(a) Evaporation of surface moisture

Surface moisture evaporates from the raw material at the water boiling point (depends on pressure). Inner moisture remains when the raw material is large.

(b) Evaporation of inherent moisture

Following surface moisture evaporation, inherent moisture evaporates at 110-120°C.

(c) Volatilization

Thermal decomposition of biomass begins at 200-300°C, and CO, CO₂, H₂ and H₂O are vaporized as gas. Thermal decomposition is a heat generating reaction which is a characteristic phenomenon of biomass (C_nH_mO_p).

(d) Volatilization and gasification reaction

The temperature is raised further during volatilization, and the volatile matter of the lightweight hydrocarbons (C_xH_y; where *x* and *y* are integers of at least 1; a low value of *x* indicates lightness and a high value of *x* indicates heaviness) is transformed into heavy C_xH_y with a high boiling point. Subsequently, the C_xH_y reacts with the gasifying agent for conversion to lightweight molecule clean gas, although tar and soot can form when diffusion of the gasifying agent is slow and the C_xH_y condenses.

(e) Char gasification

Following volatilization of the volatile content in the raw material biomass, the fixed carbon and ash become char, and the char is heated to the surrounding temperature. The subsequent reaction with the gasifying agent transforms the carbon into CO and CO₂. However, in cases where the gasifying agent contains excess steam and the surrounding temperature is over 750°C, a wet gas reaction occurs (C+H₂O (CO+H₂) producing gas composed mainly of CO, CO₂ and H₂.

(f) Char residue

The reaction rate of the wet gas reaction is slow, and char residue can easily form. The formation of tar, soot and char tends to reduce efficiency, as well causing equipment trouble.

4.2.6 Characteristics of gasification product gas

Gasification generally adopts the direct gasification method with partial combustion of raw material to raise the temperature. Raw materials are mainly wood chips and corn stalks. Most gasification furnaces use normal pressure and a direct gasification process. To keep the reaction temperature at 800°C and above for direct gasification, air, oxygen and steam (as appropriate) are required for the gasification agent. For this purpose, approximately 1/3 of the oxygen required for complete combustion (known as the oxygen ratio) is supplied, with partial combustion (partial oxidation) causing gasification. The calorific value of product gas depends on the percentage of inflammable gas (CO, H₂, C_xH_y) contained. Generally, gas can be divided into low calorie gas (4-12 MJ/m³), medium calorie gas (12-28 MJ/m³) and high calorie gas (above 28 MJ/m³). For the most part, direct gasification of biomass yields low calorie gas. Fig. 4.2.1 presents composition of the product gas from rice straw when steam and oxygen is employed as gasifying agent. The ratio between the calorific content of the biomass and that of the product gas (at room temperature) is called cold gas efficiency.

4.2.7 Gasification equipment and a practical example

Here is shown a fixed bed gasifier, based on the combustion or gasification of solid fuel, and featuring a comparatively simple structure and low equipment cost. Fig. 4.2.2 shows a concept diagram of the gasifier. Wood chips of about 2.5-5 cm are generally used as the raw material. They are supplied from the upper feed port, and layered in the furnace. The gasifying agent (air, oxygen, steam or a mixture thereof) is supplied from the bottom in a rising flow (some systems

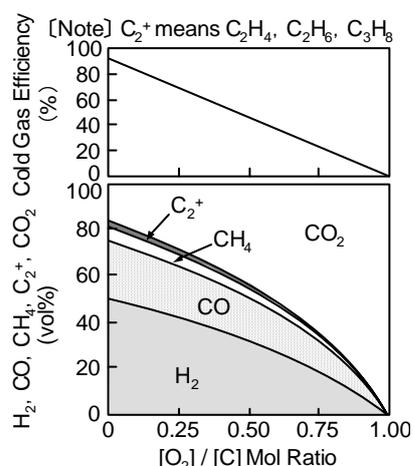


Fig. 4.2.1 Changes in product gas composition due to oxygen ratio

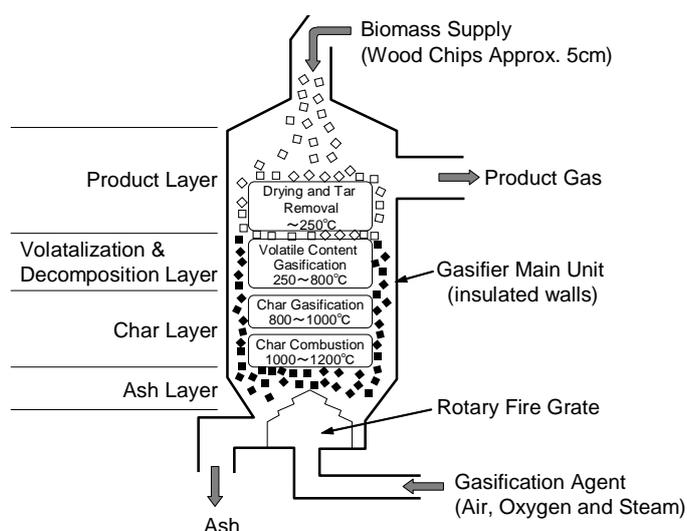


Fig. 4.2.2 Concept diagram of a fixed bed gasifier

use a descending flow). The gasification reaction proceeds from the bottom towards the top. From the bottom upward, individual layers are formed due to the changes accompanying gasification of the raw material, in the order of ash, char, volatilized and decomposed material, and product. The product gas is obtained at the top.

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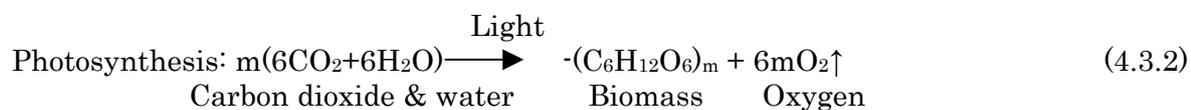
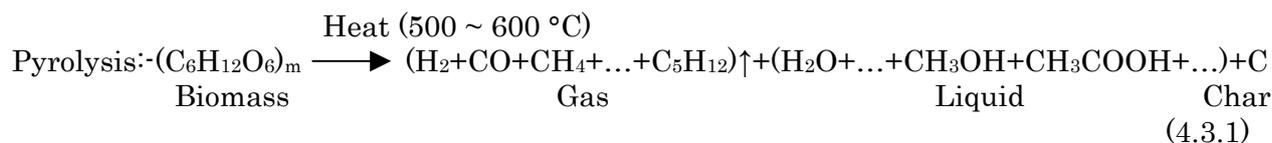
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4.3 Pyrolysis

4.3.1 What is pyrolysis?

Biomass is consisted mainly of carbon, hydrogen and oxygen. The photosynthesis and pyrolysis can be simply described as the following formulas,



The main chemical components of biomass are cellulose, hemicellulose and lignin. Fig. 4.3.1 shows the composition changing during pyrolysis. The cellulose, hemicellulose and lignin are decomposed with temperature increase. Solid residue is char in the yield of 10 to 25%.

4.3.2 Characteristics of pyrolysis

During pyrolysis, moisture evaporates at first ($\sim 110^{\circ}\text{C}$), and then hemicellulose is decomposed ($200\text{--}260^{\circ}\text{C}$), followed by cellulose ($240\text{--}340^{\circ}\text{C}$) and lignin ($280\text{--}500^{\circ}\text{C}$). When temperature

reaches 500°C , the reactions of pyrolysis are almost finished. Therefore, at the heating rate of 10°C/s , the pyrolysis finishes in 1 min, while it finishes in 5 s at 100°C/s . Higher heating rate results in the more rapid generation of vapor product, increasing pressure, shorter residence time of vapor product in the reactor, and higher liquid yield; named fast pyrolysis or flash pyrolysis. Dynamotive (Canada) and BTG (Netherlands) have developed fast pyrolysis reactors, which show high liquid yield of 60 to 80%. Since heat conductance of wood is $0.12\text{--}0.42\text{ W/(m K)}$, which is around $1/1000$ of copper, heat transfer is important for fast pyrolysis, and the milling to small particles is required.

4.3.3 Reactors at laboratory scale

Thermobalance is most commonly used at laboratory for the fundamental study. Very small amount of sample, around a few mg to 10s mg, is heated up from room temperature to the desired temperature at the desired heating rate to measure the weight changing. However, it is difficult to recover the products.

A few g to 10s g of sample is used at laboratory scale reactor to recover the products. Sand bath or molten salt bath are used as the heater for the batch type reactor. Infrared rays heater is usually used for the continuous reactor. At these reactors, mass balance and product analysis are studied.

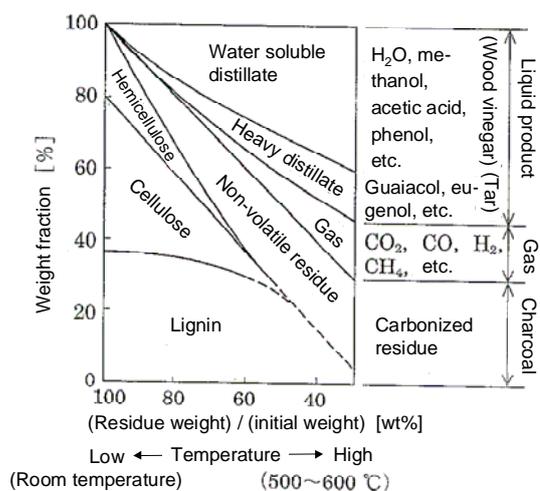


Fig. 4.3.1 Composition changing during pyrolysis.

4.3.4 Reactors at R&D

NREL, USA, has developed a vortex reactor, in which wood particle slides on the hot reactor wall by the circled hot gas flow. By the revolution, fresh surface is always appeared on the wood particle, and then the flash pyrolysis is realized. BTG, Netherlands, has developed a rotary corn type reactor, in which hot sand is used as the heat transfer medium and the sand fluids by the centrifugal force of the rotated reactor.

Many type of fluidized bed (FB) reactor have been developed by Dynamotive-RTI, Pasquali-ENEL (Italy), Ensyn,(Canada), RedArrow-Ensyn (USA), Union Fenosa-Waterloo (Spain), VTT (Finland), etc. The small particle of wood is introduced in FB with hot gas or hot heat transfer medium, and it is rapidly pyrolyzed for high liquid yield. Since smooth feeding of the wood particle is difficult, tar trouble occurs easily.

AIST, Japan, had developed the pyrolysis using microwave. Microwave can heat wood from inside, and big size wood, log, is directly used. The same result is obtained as the flash pyrolysis of 200°C/s. Bigger size is better for the energy efficiency, and around 1.4 MJ (0.4 kWh) is used for the completed pyrolysis of 1-kg wood. In addition, in this pyrolysis, tar trouble is small.

4.3.5 Products

The liquid, gas and char are obtained by pyrolysis. The liquid has high moisture from original moisture (8-40%) and produced water (14-17%), and it is a mixture of water and polar organics. Its higher heating value is around 12.5-21 MJ/kg. The relationship between the viscosity and heating value of the liquid is shown in Fig. 4.3.2. Higher moisture content results in lower viscosity and lower heating value. In addition, the liquid is unstable, and any improvement is required.

The pyrolysis gas has much CO₂, and CO, H₂, C₁₋₅ hydrocarbon as combustible gas. The char has the higher heating value of 32 MJ/kg, and it is suitable as a feedstock for activated carbon.

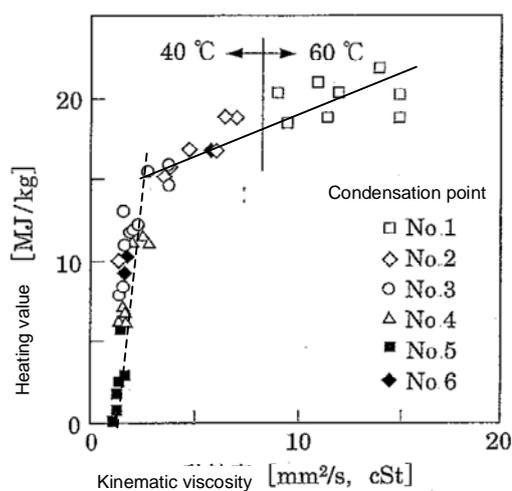


Fig. 4.3.2 The relationship between the viscosity and heating value of pyrolysis liquid.

However, all of the char is usually used as heat resource for the pyrolysis system.

4.3.6 Status of technology

The pyrolysis liquid can not be mixed with the transportation fuel, and any improvement is required. There is tar trouble, but the know-how to operate the reactor is not opened. To get liquid at high yield, rapid heating and cooling are needed, and heat loss and recovery is an important issue. Merit and demerit should be considered.

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4.4 Carbonization

4.4.1 What is carbonization?

Carbonization is the method or technology to obtain charcoal as the main product by heating such solid biomass as wood, bark, bamboo, rice husks, etc. at 400-600°C in the almost or complete absence of air or oxygen. It can afford tar, pyroligneous acid, and combustible gases as by-products. In case of discrimination from 'dry distillation' aiming at the recovery and utilization of liquid products, 'charcoal making' is used as the terminology. Carbonization customarily means charcoal making, although it is the general term including dry distillation.

4.4.2 Characteristics of carbonization

Carbonization is a classical energy conversion means of biomass, similarly to combustion. While the main objective is increase in the calorific value of the solid product charcoal, it has two sides of liquefaction and gasification. As liquefaction means corresponding to ordinary pyrolysis (see Chapter 4.3), commercial operation was early examined together with high pressure (direct) process (Chapter 4.6). However, the obtained tar (oil) was in a low yield (< 30%) with poor quality (high viscosity, high oxygen content, low heating value, low pH, etc.), so that the process was given up after the appearance of rapid pyrolysis (Chapter 4.3) yielding a

large quantity of oil. As gasification means (Chapter 4.2), it is inferior to current processes in the production of combustible components, due to lower reaction temperature. In the utilization of product gas for generation, a considerable amount of tar must be removed. Nevertheless, carbonization that has industrial advantages of inexpensive apparatus and easy operation is still important for cheaply producing solid fuels with high heating value. The features making a certain proportion of organic carbon stably fixed and the features making the volume of municipal wastes, garbage, sewage sludge, cow dung, etc. effectively reduced contributes to the control of CO₂ emission and serves as a practical measure to dispose of various wastes, respectively.

4.4.3 Reactions in carbonization

Carbonization reactions are basically the same as pyrolytic reactions in an inert gas like nitrogen. For wood, after most water is evaporated at below 200°C, three main constituents of cellulose, hemicellulose, and lignin are decomposed to produce liquid fraction and gaseous fraction, consisting mainly of CO and CO₂, at 200-500°C, thereby occurring a rapid weight decrease. In this region, each wood constituents undergo dehydration and depolymerization to repeat intermolecular and intramolecular fission and re-bonding, and the resulting low molecular weight fragments are cracked into liquid and gaseous products, whereas high molecular weight fragments formed by condensation are charred together with non-decomposed portion. Although the weight loss becomes smaller at above 500°C, polycondensed aromatic carbon increases with the evolution of H₂ to reach about 80% C in char up to 700°C. By further increasing the temperature, the polycondensed carbon structure develops to increase the content of C without prompt production of H₂. The overall scheme of carbonization is represented in Fig. 4.4.1. This signifies that product distribution depends on both steps of the decomposition of 'melt' resulted from wood constituents into gas, liquid, and solid fractions (first stage) and subsequent decomposition of the liquid fraction (second stage), and the ratio of rate constants for first stage to that for second stage. The distribution is also influenced by moisture and size of feed, heating rate, operating temperature, etc. The latter three are particularly important, and the yield of liquid (tar) is increased with decreasing the size and increasing the rate.

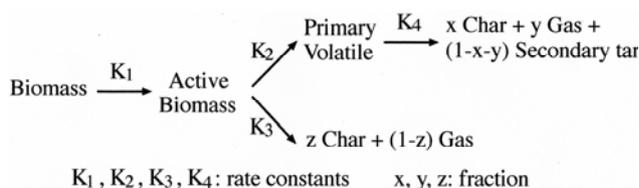


Fig. 4.4.1. Modified Broide-Shafizadeh scheme

Higher temperature makes the yield of charcoal lower and that of tar higher at below 500°C. Pressure is likewise important, and the yield of tar becomes higher at the lower value.

4.4.4 Energy efficiency of carbonization

Continuous carbonization of a mixture of pine bark and sawdust by Tech-Air pyrolysis system (Fig. 4.4.2) is described as an example. This is an internal heat supply process with a vertical fixed bed reactor. The raw material is fed at the top of the reactor after reducing the initial moisture of 25-55% to 4-7%. Heat for carbonization is provided by partial combustion of the feed with air introduced from the bottom of the reactor. Charcoal produced is drawn out with a screw from another bottom section, while the product vapor passes through a cyclone where fine solid particles are removed to enter a condenser for tar (oil) recovery. The non-condensable gas is then combusted in a burner, and the discharged gas (204-316°C) is used for drying the raw material. The reactor temperature that is

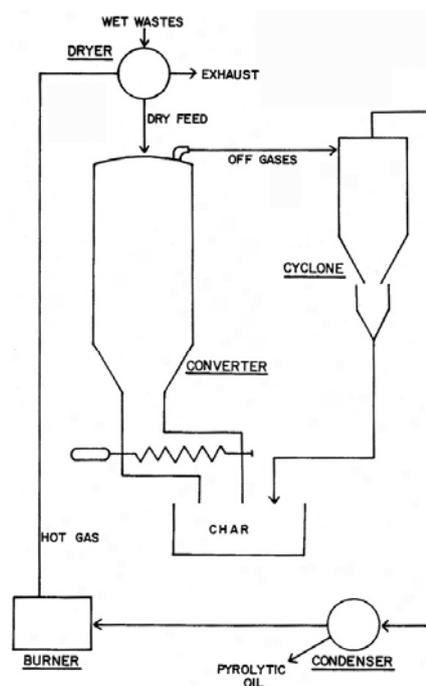


Fig. 4.4.2. Tech-Air pyrolysis system

variable from 430° to 760°C is so controlled as to allow the heating value of the pyrolytic gas to have the energy necessary for drying the feed. Table 4.4.1 summarizes product distribution and two process efficiencies, which are defined as Net Thermal Efficiency (NTE, %) calculated as $[\{\text{heating value of products} - \text{heat of process (gas for drying)}\} / \text{heating value of raw material}] \times 100$, and Energy Benefit Ratio (EBR, %) obtained as $[\text{energy of products} / \text{energy consumed}] \times$

Table 4.4.1. Product energy yields and process efficiency

Case	Feed [GJ]	Char [GJ]	Available Gas ^d [GJ]	Oil [GJ]	Dryer Gas [GJ]	NTE [%]	EBR [-]
Maximum char	9.18	4.54	1.72	0.63	1.85	75.0	3.71
Maximum oil	9.18	2.85	1.84	2.21	1.85	75.2	3.72
Maximum gas	9.18	3.48	2.16	1.26	1.85	75.1	3.72

^d (Total gas produced) – (Dryer gas)

100, respectively, in terms of energy for the maximum yield of each product. Because of no great difference for all of the operations, the optimal conditions are decided by quality, use, cost, and so on for charcoal and oil.

4.4.5 Products of carbonization

In Japan, charcoal is widely used as soil improver, fodder, moisture conditioner, etc. by making use of the adsorption capacity (so-called 'charcoal for new uses'), in addition to solid fuel for cooking and heating. For liquid products, low boiling point fraction, pyrolygneous acid, is on the market as agricultural materials, deodorant, etc. In contrast, high boiling point fraction, tar, has a limited practical utilization, like creosote as medicine. In a laboratory scale, the production of phenolic resin adhesive, the recovery of wood preservatives, conversion into electroconductive carbon, etc. has been reported. The use of gas fraction is a supplementary fuel for process.

4.4.6 Status-quo of the technology

A variety of reactors in scale and shape are developed in response of the diversification of material, and they are commercially operated, although the current system does not greatly differ from the earlier one. Nickel-catalyzed carbonization of wood at 900°C, which was conducted in a laboratory scale to obtain a functional carbon with conductivity and liquid phase adsorption in concurrence with hydrogen-rich gas, has attracted considerable attention.

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4.5 Hydrothermal Gasification

4.5.1 What is hydrothermal gasification?

Hydrothermal gasification is treatment of biomass in hot compressed water, usually above 350°C and above 20 MPa to obtain combustible gas. Figure 4.5.1 shows phase diagram of water, where gas-liquid equilibrium line starts from the triple point and ends at the critical point. Hydrothermal condition is located around the critical point. When both temperature and pressure is higher than

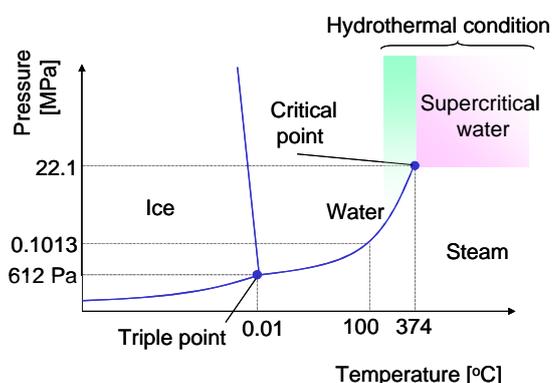


Fig. 4.5.1. Phase diagram of water

critical temperature and critical pressure, respectively, the state is called supercritical water, and gasification in supercritical water is called “supercritical water gasification”. This hot compressed water enjoys high reactivity, and when biomass is placed in this water, it is gasified by hydrolysis and pyrolysis reactions.

4.5.2 Characteristics of hydrothermal gasification

Hydrothermal gasification is suitable for wet biomass treatment. When wet biomass is to be gasified, usual thermochemical gasification is not employed due to its high moisture content. Hydrothermal gasification, on the other hand, uses water as reaction medium, and thus wet biomass can be treated without costly, energy-consuming drying pretreatment. Since reactivity of water is high under these conditions, hydrothermal gasification enables quick and almost complete gasification of biomass. Biomethanation is employed to obtain methane gas from wet biomass, but usually it takes a few weeks for the reaction to complete, and treatment of unreacted fermentation sludge and waste water can be a large problem. Reaction time as long as a few weeks results in bulky reactor. Fermentation sludge can be converted to compost, but when sufficient land is not available for the use of the compost, it is just a waste to be treated. In hydrothermal gasification, reaction is completed in a few minutes at longest, and almost complete gasification is possible when reaction condition is properly adjusted. Sometimes, addition of catalysts such as alkali, metal, or carbon catalysts enhances the reaction.

4.5.3 Reactors for hydrothermal gasification

To investigate the reactions taking place in hydrothermal gasification, tube-bomb reactors of the volume of several mL and autoclaves are often used. However, when you want to develop a commercial plant, a continuous reactor such as is shown in Fig. 4.5.2 is a must. Biomass is fed to the reactor at a high pressure, and then heated to the reaction temperature. In the reactor, biomass is gasified under hydrothermal condition, and the effluent is cooled down to the room temperature. Heat released at this time is recovered by the heat exchanger, and used to heat up the feedstock. After reaching the room temperature, the effluent is depressurized to atmospheric pressure, and the product gas is recovered. The continuous reactor is needed because of the large amount of heat needed to attain the hydrothermal condition. This heat sometimes matches the heat of combustion of the biomass to be gasified, and thus heat recovery using a heat exchanger is needed. Only flow reactors allow this heat recovery. In Fig. 4.5.2, heat balance for the ideal case is also shown. Combustion heat of biomass is maintained in the product gas while heat required to attain hydrothermal condition is recovered so that no heat is added from outside during gasification operation. In practice, the efficiency of the heat exchanger cannot be unity, and endothermic reaction results in necessity of additional heat supply to the reactor.

4.5.4 Energy efficiency of hydrothermal gasification

For the ideal process as shown in Fig. 4.5-2, the energy efficiency of hydrothermal gasification is unity. This is to be noted since misunderstanding that energy efficiency of hydrothermal gasification is low due to the large amount of heat required to attain hydrothermal condition. When heat recovery is properly made, a high energy efficiency is possible.

Energy efficiencies higher than 70% including electricity and heat loss at the heat exchangers have been shown by a detail process calculation.

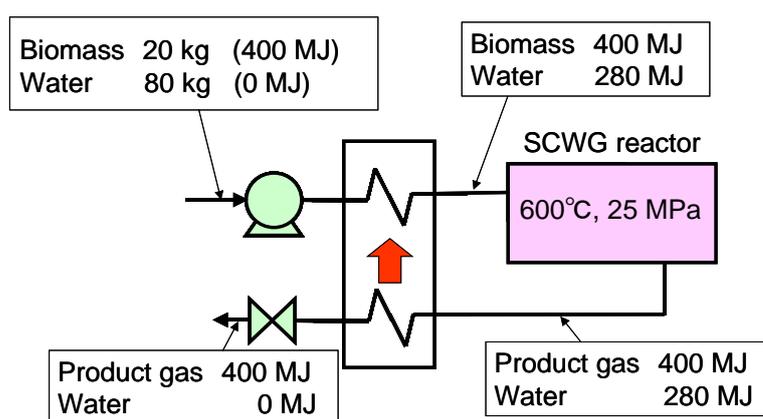


Fig. 4.5.2. Heat balance of hydrothermal gasification.

4.5.5 Products of hydrothermal gasification

The product gas is automatically separated from liquid phase when the reactor effluent is cooled down to the room temperature. Tar free gas is available, which is a benefit over usual thermochemical gasification of biomass. The main component is hydrogen, carbon dioxide, and methane. Due to the water-shift gas reaction the yield of carbon monoxide is negligible. The high temperature, low pressure, and dilute feedstock favors high hydrogen content. The heating value of the product gas depends on reaction condition, and usually varies from 12 to 18 MJ/m³-N.

4.5.6 Status-quo of the technology

Many reports on experiment with laboratory scale reactors exist. There are three pilot plants in operation: Energia Co. plant in Japan; VERENA Plant in Germany; and TEES Process in USA. The capacity ranges from 1 to 2.4 t-wet/d. Feedstocks tested are many including chicken manure, corn silage, and cheese whey. No commercial plants have been built mainly due to the high plant cost at present.

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4.6 Hydrothermal Liquefaction

4.6.1 What is hydrothermal liquefaction?

Hydrothermal liquefaction is pyrolysis in hot compressed water of around 300°C and 10 MPa. Biomass is converted into gas, liquid and solid, like common pyrolysis in gas phase. The light tar fraction, such as pyroligneous, can be dissolved in water, and the heavy tar fraction can be obtained in the mixing with char. That is, products are gas, aqueous, and oily material.

4.6.2 Characteristics of hydrothermal liquefaction

Since hydrothermal liquefaction proceeds in water, drying process of feedstock is not needed. Therefore, it is suitable for high moisture content biomass, such as aquatic biomass, garbage, organic sludge, and so on. In addition, many kinds of reaction can occur at different reaction temperatures, and many application is possible. Fig. 4.6.1 shows the reactions which occur in the hot compressed water. At around 100°C,

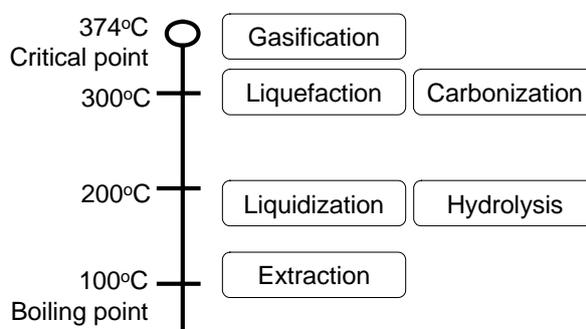


Fig. 4.6.1. Reactions which occur in the hot-compressed water

aqueous soluble fraction is dissolved, and extraction is applicable. At above 150°C, hydrolysis occurs, and biomass polymers, such as cellulose, hemicellulose, protein, and so on, are degraded into monomer. At around 200°C and 1 MPa, solid like biomass is changed to slurry (liquidization), and oily product, however, is not obtained. At severer condition of 300°C and 10 MPa, liquefaction occur, and oily product is obtained. When reaction condition is changed such as reaction time or catalyst, main product can be changed to char (hydrothermal carbonization). At around critical point and with catalyst, biomass can be gasified (see Chapter 4.5).

4.6.3 Reaction scheme of hydrothermal liquefaction

Fundamentally, hydrothermal liquefaction is pyrolysis, and therefore degradation and polymerization occur. Simple reaction scheme is shown in Fig. 4.6.2. At first step, biomass can be degraded into water-dissolved materials. Then the water-dissolved materials are

polymerized to form oil. When reaction is prolonged, the formed oil is polymerized into char.

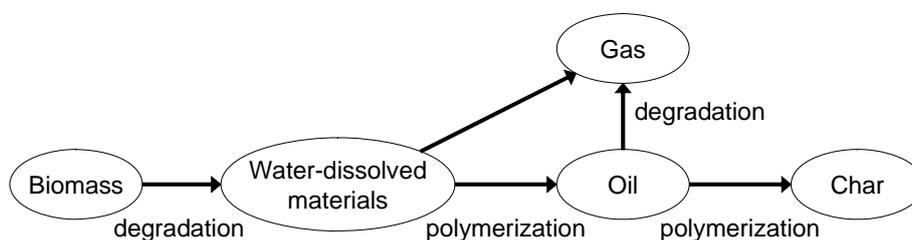


Fig. 4.6.2. Simple reaction scheme of liquefaction

4.6.4 Product oil from hydrothermal liquefaction

Properties of obtained oil by liquefaction are shown in Table 4.6.1. The reaction was conducted without reducing gas, such as hydrogen and carbon monoxide, and with alkali catalyst for wood and without catalyst for sewage sludge. The obtained oil has oxygen content of around 20 wt%, and therefore, its higher heating value is lower than that (around 42 MJ/kg)

of heavy oil from petroleum. In addition, its viscosity is very high. The obtained oil from wood has much amount of acid fraction, and it can corrode and polymerize during storage. On the other hand, the obtained oil from sewage sludge has nitrogen originated from protein, and NO_x treatment is needed at its combustion. As chemical fraction, pyridine derivative, pyrazine derivative, and amid compounds are detected. If they can be separate, they might be used as chemicals.

Table 4.6.1. Properties of obtained oil by liquefaction

Biomass	Wood	Sewage sludge
Elemental composition [wt%]		
Carbon	72	71
Hydrogen	6	9
Nitrogen	-	6
Oxygen	22	16
H/C	1.00	1.52
Higher heating value [MJ/kg]	29 - 30	33 - 34
Viscosity [mPa.s]	> 10 ⁶	10 ³ - 10 ⁴

4.6.5 Energy efficiency of hydrothermal liquefaction

The energy yield (= calorie in the obtained oil / calorie in the feedstock biomass) is around 70%. As for energy efficiency of hydrothermal liquefaction process, the effective calorie of the obtained oil almost balances or is surplus a little with the required heating energy of feedstock biomass from room temperature to reaction temperature. The moisture content affects it strongly, and at below around 85% of moisture content, it is calculated that the process can

produce energy.

4.6.6 Status-quo of the technology

There are many reports on laboratory scale and pilot scale, and no commercial plants have been built. About pilot scale R&D, US Bureau of Mines had developed PERC process and US DOE had developed LBL process in 1960 to 1970s, NIRE and Organo Co. in Japan had developed a sewage sludge liquefaction plant in around 1990, and Biofuel Co. and Shell Co. in Netherlands had developed HTU process in around 2000.

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4.7 Biodiesel Production

4.7.1 What is biodiesel production?

Compared with other biomass resources, oils and fats are high in heat capacity, and their majority is liquid at an ambient temperature. Although these characteristics are preferable for automobile fuel, viscoelasticity ($>30\text{mm}^2/\text{s}$ at 40°C) and flash point ($>300^\circ\text{C}$) are so high that it cannot be used without modification. Therefore, by transesterifying triglycerides of the oils and

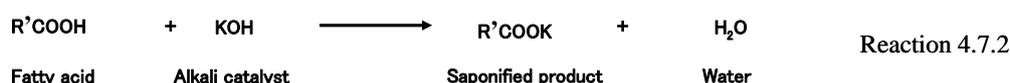
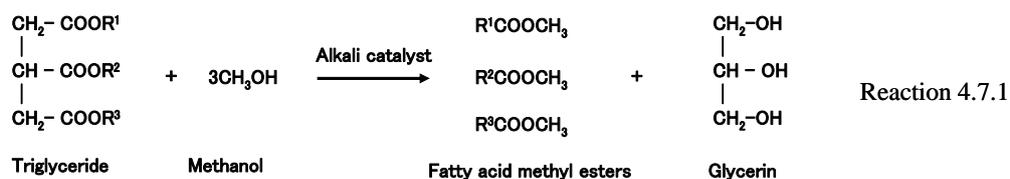
fats, its viscoelasticity and flash point are reduced respectively down to 3~5mm²/s and 160°C which would be appropriate with cetane number of 50-60 to substitute for the diesel fuel. This fatty acid methyl ester is called biodiesel fuel (BDF).

4.7.2 Characteristics of biodiesel production

Biodiesel is low in SO_x, dark smoke and particulate matters, compared with diesel. Therefore, its exhausted emission is relatively clean. Additionally, there exists an advantage to keep carbon balance on the earth due to its biomass-derived product. Furthermore, it contains oxygen as an ester to be 11% low in heat capacity. However, due to its lubricity and less dark smoke emission, biodiesel is almost comparable to diesel in practical engine performance.

4.7.3 Reactors for biodiesel production

For biodiesel production, transesterification is applied for vegetable oils (Reaction 4.7.1) in which triglycerides, the esters of glycerin with fatty acids, and free fatty acids exist. Generally, oils are mixed with methanol using alkali catalyst such as potassium hydroxide or sodium hydroxide, and its mixture is stirred at 60-70°C for 1 h. After the reaction, the lower and upper portions are phase-separated with glycerin in the lower and esterified products in the upper which is washed to be fatty acid methyl esters as biodiesel. Since free fatty acids are contained in the waste oils, they can react with a catalyst to produce saponified products (Reaction 4.7.2), thus reducing the yield of biodiesel.



R¹, R², R³, R⁴; Hydrocarbon residues

Due to such a disadvantage of the alkali catalyst method, it is reported that free fatty acids are first esterified by acid catalyst, followed by alkali catalyst method. As non-catalytic methods, ion-exchanged resin catalyst method, lipase catalyst method and supercritical

methanol method are proposed. In addition, to promote efficiency of esterification, the two-step supercritical methanol method is also proposed by hydrolyzing triglycerides with subcritical water followed by esterification of fatty acids with methanol in its supercritical state (Reactions 4.7.3 and 4.7.4, Fig. 4.7.1). This process is the only one to handle the low-grade waste oils with

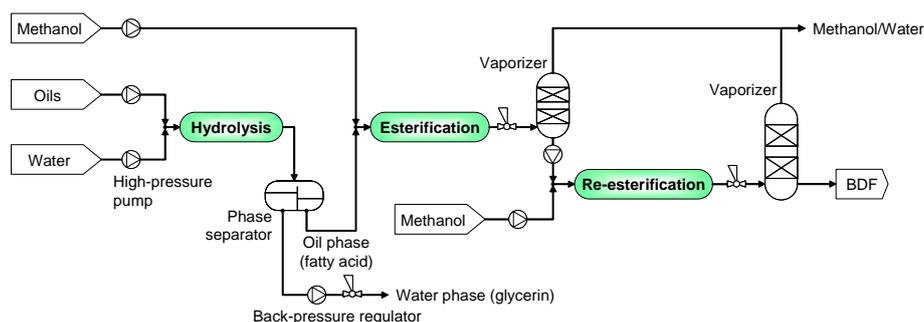
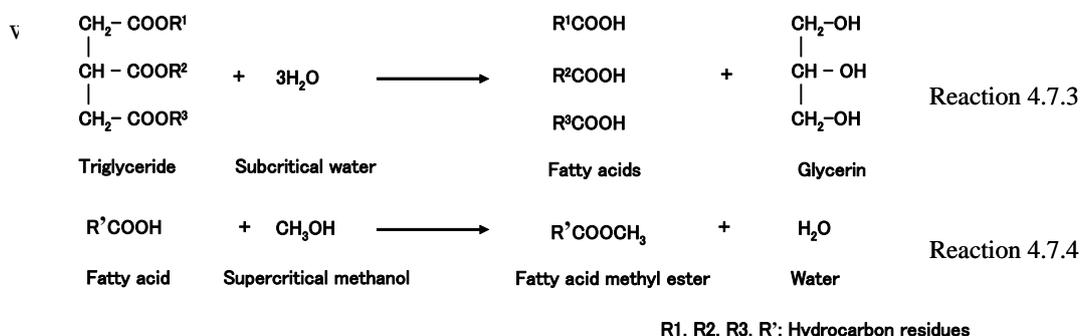


Fig. 4.7.1. Two-Step supercritical methanol process adopting the re-esterification step.

4.7.4 Energy efficiency of biodiesel production

Transesterification of triglycerides and esterification of fatty acids are both exothermic reactions but their heat capacity is small. In alkali catalyst process, energy to increase the system to 60-70°C, energy for a methanol, and energy for the whole reaction process are essential. Furthermore, additional energy is required after the reaction for purifying the glycerin as a by-product. In the biodiesel production with 2.2 kg/s (70,000 t/year) capacity, energy efficiency is reported to be 62% on higher heating value basis.

4.7.5 Status-quo of the technology

Biodiesel production has been commercially developed in Europe and North America, and their production is mainly based on alkali catalyst method. However, for the low-grade waste

oils, a combined process with acid catalyst has been developed with their own non-disclosed technologies. Due to the limited raw materials in Japan, new development of the technology will be expected to handle the low-grade waste oils to be converted into high-quality biodiesel.

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Part 5. Biochemical conversion of biomass

5.1 Biomethanation

5.1.1 What is biomethanation?

“Methane fermentation” or “anaerobic digestion” is usually used to indicate “biomethanation”. Biomethanation is a complex microbial process in which organic compounds are degraded into methane and carbon dioxide by variety of anaerobes. This biogas has a low heating value of 20-25 MJ/m³-N (5,000~6,000 kcal/m³-N) and can be used for fuel after desulfurization of hydrogen sulfide. Biomethanation is used as a technique of biofuel recovery from biomass and treatment of waste biomass. Fermented residue can be used for liquid fertilizer and raw material of compost.

5.1.2 Feature of biomethanation

First of all, organic compounds are decomposed to organic acid or hydrogen by variety of anaerobes. At the final stage, acetate or hydrogen and carbon dioxide are converted to methane. Biomethanation takes place under anaerobic conditions, especially, methanogens require absolute anaerobic conditions for methane production. Biomethanation is a microbiological process; therefore, this process proceeds under normal temperature and pressure. Biomethanation can be applied for variety of biomass compared with ethanol fermentation due to activities of complex microflora.

5.1.3 Mechanism of biomethanation

When organic compounds are maintained at 5-70°C and neutral pH under anaerobic conditions, spontaneously biomethanation will happen. Biogas is often produced from underground of landfill. Kitchen garbage and sewage sludge have been used as substrates of biomethanation. Organic wastewater from food factory containing sugars and starch has been also used as substrate for biomethanation.

Biomethanation is composed of hydrolysis, acetogenesis and methanogenesis. Fig. 5.1.1

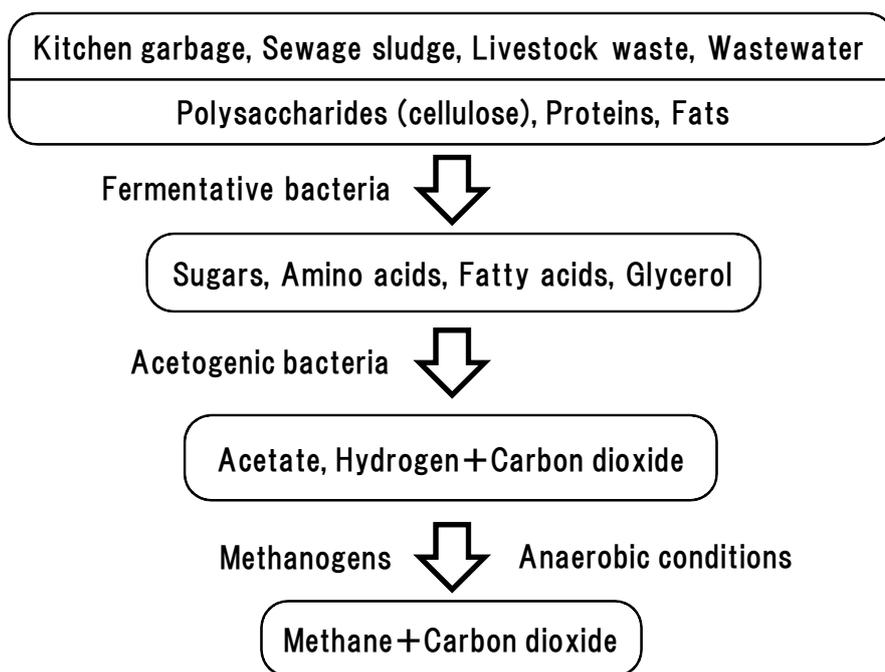
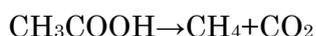
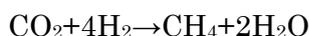


Fig. 5.1.1 Schematic diagram of biomethanation

indicates an outline of biomethanation. Polysaccharides are decomposed to monosugars, proteins are to amino acids, and fats are to fatty acids and glycerol. Fermentative bacteria are for example *Bacteroides* spp. and *Clostridium* spp. Sugars and amino acids are decomposed to acetate and propionate by acidogens. Finally, methanogens convert acetate or hydrogen and carbon dioxide to methane. Acidogenesis is a complex process in which microflora of anaerobes collaboratively decomposes organic compounds to low molecular organic acids. Acetate, lactate, succinate, ethanol, butanol, acetone and etc. can be produced from glucose by acidogens. In wastewater treatment, 70% of methane is produced from acetate, and 30% is produced from hydrogen and carbon dioxide. Formula of acetoclastic reaction is as follows;



Formula of hydrogenotrophic reaction is as follows;



Methanogens are anaerobes which can grow using acetate or hydrogen and can produce methane. Representative methanogens are *Methanobacter* spp. and *Methanosaeta* spp.

Methanogens are killed by exposure to oxygen; therefore, methane formation requires obligate anaerobic conditions. Phylogenetic analyses indicate that methanogens are placed in Archaea group, distinguished from eukaryote and prokaryote. Methanogens can only use hydrogen, formate, acetate, 2-propanol, 2-buthanol, methylamine, methanol, methylmercaptan to produce methane.

5.1.4 Current status

Biomethanation is commercialized for food waste, cattle waste, sewage sludge, and wastewater. European countries have developed biomethanation technology. Biogas plants have been gradually increasing in Japan. The reaction takes place at high, moderate, or low fermentation temperature, and organic content classifies biomethanation into wet and dry fermentation. High temperature systems reveal high gasification performance compared with other temperatures. Disadvantageous points of biomethanation are low digestion ratio, low removal ratios of ammonium and phosphate, long treatment time, and necessity of heat. Fermented effluent and residue should be recycled for agriculture as an organic fertilizer since treatment cost is high. Technological developments is being conducted to overcome these issues.

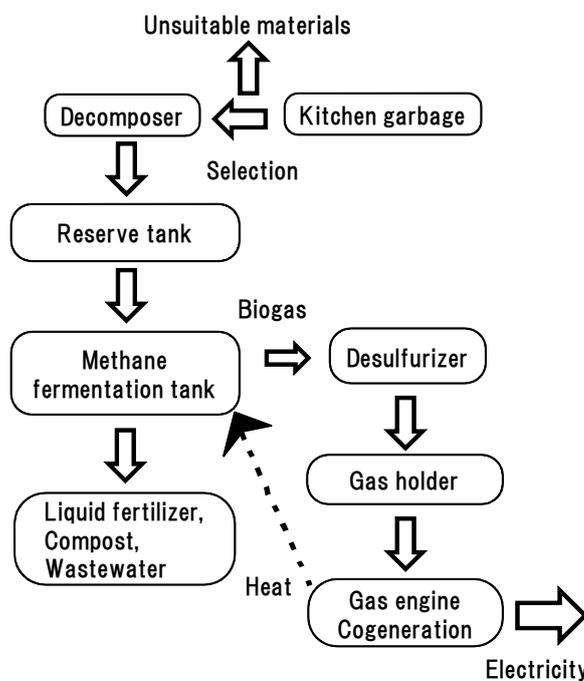


Fig. 5.1.2. Biomethanation flow of kitchen garbage.

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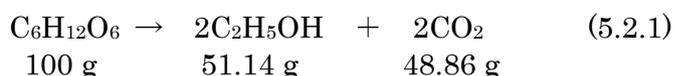
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5.2 Ethanol Fermentation

5.2.1 General scope

In ethanol fermentation saccharine materials like glucose, fructose, and sucrose are metabolized by yeast strains through glycolysis pathway (Embden-Meyerhof Pathway) to produce ethanol and carbon dioxide in anaerobic condition (Eq. (5.2.1)). In this reaction two molecules of ATP are generated from one molecule of glucose and are used as energy for growth of yeast cells. Mankind has long known and utilized ethanol fermentation for brewery of alcohol drinks, manufacture of fermented food, bakery and so on for several thousands years. In the medieval period, people came to know how to make distilled liquor. Ethanol became available in the field of various chemical industries, beverage and food industry, medical use, as well as fuel, since great progress was achieved with technologies of fermentation and distillation in 19-20th century. Large amount of fuel ethanol has been produced from corn in the USA and from sugar cane in Brazil for the purpose to alternate fossil fuel and to prevent global warming, particularly after two times of oil crisis in 1970's. Extensive research and development are undergoing in the world on technologies for ethanol production from various cellulosic materials which are available in large amount and do not compete with food utilization.



Ethanol fermentation is a biological reaction at room temperatures and under atmospheric pressure. *Saccharomyces cerevisiae* is the yeast which is widely used for industrial and fuel ethanol production, and has excellent ethanol fermenting ability and ethanol tolerance. Yeast strains produce 51.14 g of ethanol from 100 g of glucose according to Eq. (5.2.1). In this reaction nearly 50% weight of glucose is lost as carbon dioxide, but about 91% of energy

contained in glucose (2.872 MJ/mol) is retained in ethanol. Therefore, ethanol fermentation is an excellent biological process to convert biomass to liquid fuel ethanol. Yeast cells were first isolated from beer as pure cultures in 1883 in Denmark and a great deal of work were carried out on their metabolic pathway of ethanol fermentation. *S. cerevisiae* can ferment many sugars including glucose, fructose, galactose, mannose, sucrose, maltose, except pentoses like xylose and arabinose. *Pichia stipitis* and *Pachysolen tannophilus* are known as yeasts capable of fermenting pentoses, but they are not so tolerant to ethanol as *S. cerevisiae* is. Strain improvement research to construct strains of *S. cerevisiae* having pentose fermentability is undergoing in many laboratories.

Next to *S. cerevisiae*, *Zymomonas mobilis* is excellent bacterium to ferment a limited range of sugars of glucose, fructose and sucrose to ethanol. Fermentation yield and fermentation rate of *Z. mobilis* are supposed to be better than those of yeast *S. cerevisiae*, but *Z. mobilis* is not so tolerant to ethanol as *S. cerevisiae* is. *Zymobacter palmae*, isolated in 1980's in Japan, has ethanol fermenting ability similar to that of *Z. mobilis* and its genome base sequence has been determined recently. Strain improvement of *Z. mobilis* and *Z. palmae* regarding pentose and mannose fermentation has been successfully made in Japan. Pentoses are contained at relatively high concentration in hard woods and herbaceous plants, and mannose is a characteristic component of soft woods.

DNA recombinant strains of *Escherichia coli* and *Corynebacterium glutamicum* having ethanol fermenting ability have been constructed through biotechnology. Other ethanol fermenting bacteria like hetero-lactic acid bacteria (*Lactobacillus*), cellulose degrading *Clostridium* bacteria, and anaerobic thermophilic bacteria *Thermoanaerobacter* have been known so far, but they can produce ethanol at relatively low concentration and with byproducts like organic acids. Therefore, these bacteria are considered difficult for the industrial use at least for the present.

5.2.2 Ethanol fermentation of saccharine materials

Saccharine materials used for ethanol production at a large scale are juice and molasses of sugar cane and sugar beet. Molasses is a byproduct which is concentrated mother liquid after sugar crystallization. Sugar concentration of molasses is around 50% and contains glucose, fructose and sucrose as main sugar components. These saccharine materials are good substrate for ethanol fermentation by yeast and *Zymomonas*. A lot of cane juice is used for ethanol production in Brazil and India.

Popular ethanol fermentation process in Brazil is continuous or semi-continuous fermentation process called Melle-Boinot process in which yeast cells are recovered from beer through centrifuge and recycled to fermentation tank after sterilization of contaminated bacteria with dilute sulfuric acid at pH 3. Ethanol fermentation at high concentration of yeast cells can make beer containing 6 to 8 % of ethanol from cane juice (11-17% sugar concentration) in about 15 h of fermentation period. Molasses is used for fermentation after two-times dilution or mixing with cane juice or beet juice.

When fermentation yield is 82% (based on total sugar), and sugar concentration of molasses is 55%, the amount of molasses required to produce 1 m³ (kL) of 95% ethanol is 3.3 t-wet.

Unique saccharine materials are milk whey and citrus molasses. In dairy industry of New Zealand, for example, a large amount of milk whey containing about 4% lactose is discharged. They use the waste whey for ethanol fermentation to recover value-added byproduct and to reduce BOD.

A large amount of citrus peel is discharged in citrus juice manufacture. Secondary juice from citrus peel containing about 8% sugar and bitter components is concentrated to citrus molasses of sugar concentration of over 40% for ethanol production.

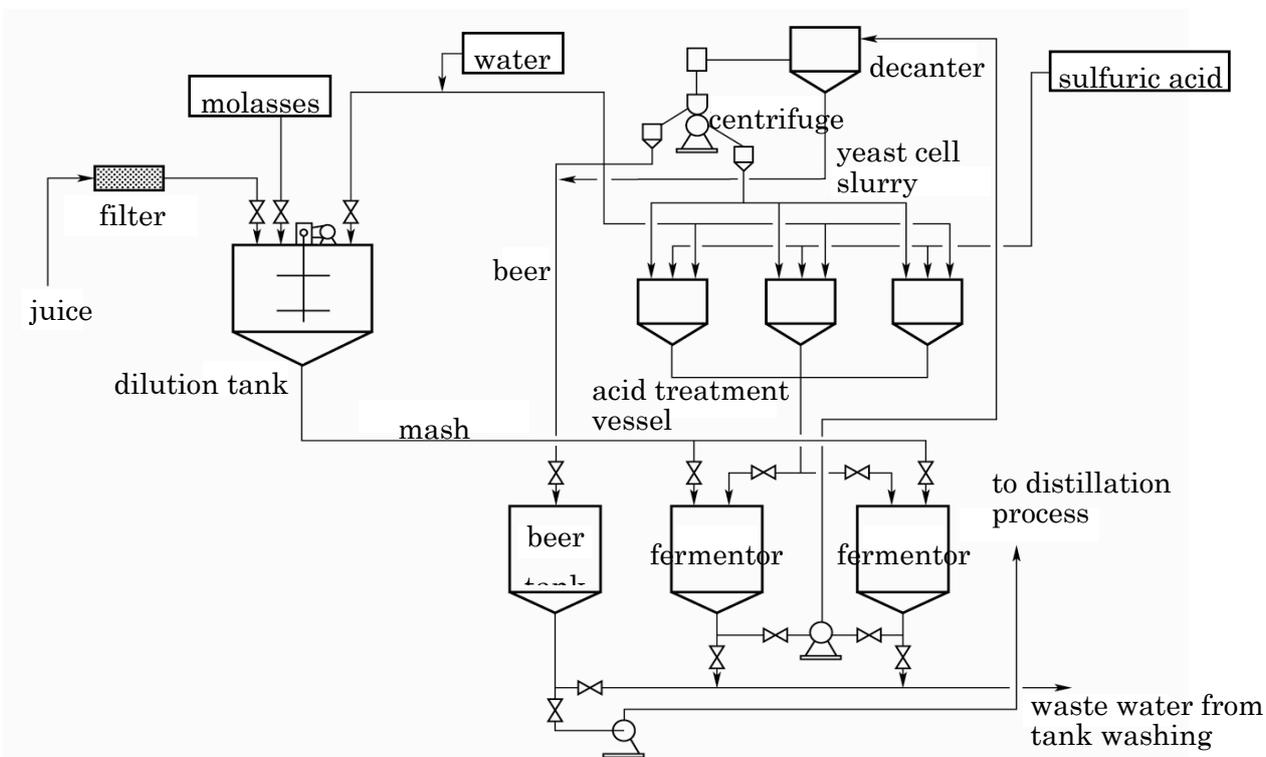
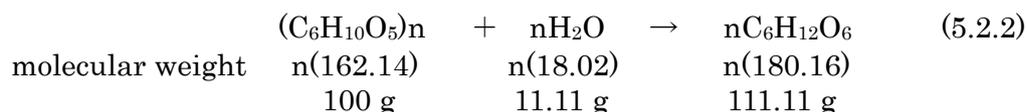


Fig. 5.2.1. Ethanol Fermentation by Melle-Boinot Process (Saiki, 2007).

5.2.3 Ethanol fermentation of starch

Starch is a polymer of glucose in which glucose units are linked with each other via α -1,4 and α -1,6 linkages. Starchy materials are first hydrolyzed to glucose using amylase enzymes (Eq. (5.2.2)).



Starchy materials are first cooked at temperatures between 100 and 130°C and then hydrolyzed to glucose by using α -amylase and gluco-amylase.

A large amount of ethanol is produced from corn in USA and from sweet potato in China.

Low temperature cooking procedure for ethanol production from sweet potato which was the practice in Japan until 1990's is described below. Raw sweet potato is first crushed by hammer-mill, cooked at 80-90 °C for 60min, added with α -amylase to liquefy starch and to reduce viscosity, and then cooled to temperature of about 58°C. Liquefied starch is hydrolyzed to glucose in two hours of hydrolysis by gluco-amylase. Glucose concentration of mash is adjusted at about 15%. Fermented beer of about 8 vol% ethanol is obtained after four days of batch-wise fermentation at 30-34°C. When starch value of raw sweet potato is 24.3% (27% glucose equivalent), and fermentation yield is 92%, the amount of raw sweet potato required to produce 1 m³ (kL) of 95% ethanol is 6.03 t-wet.

Fuel ethanol is produced mostly from corn in USA. In a wet mill process corn is immersed in dilute sulfite solution, fractionated into starch, germ, gluten, and fiber. Starch fraction is hydrolyzed to glucose by the amylases after cooking and then fermented by yeast. One of the popular fermentation process is a continuous fermentation process with several fermentation tanks connected in series in which yeast cells are recycled via centrifuge resulting in high fermentation rate. Traditional batch-wise process is also the practice in some of ethanol plants. Final ethanol concentration of fermented beer is 8 to 11 vol% on average. Wet-mill process of corn to ethanol conversion is indicated in Figure 5.2.2. When starch value is 63% (70% glucose equivalent), and fermentation yield 90%, the amount of corn necessary to produce 1 m³ (kL) of 95% ethanol is about 2.4 t-wet.

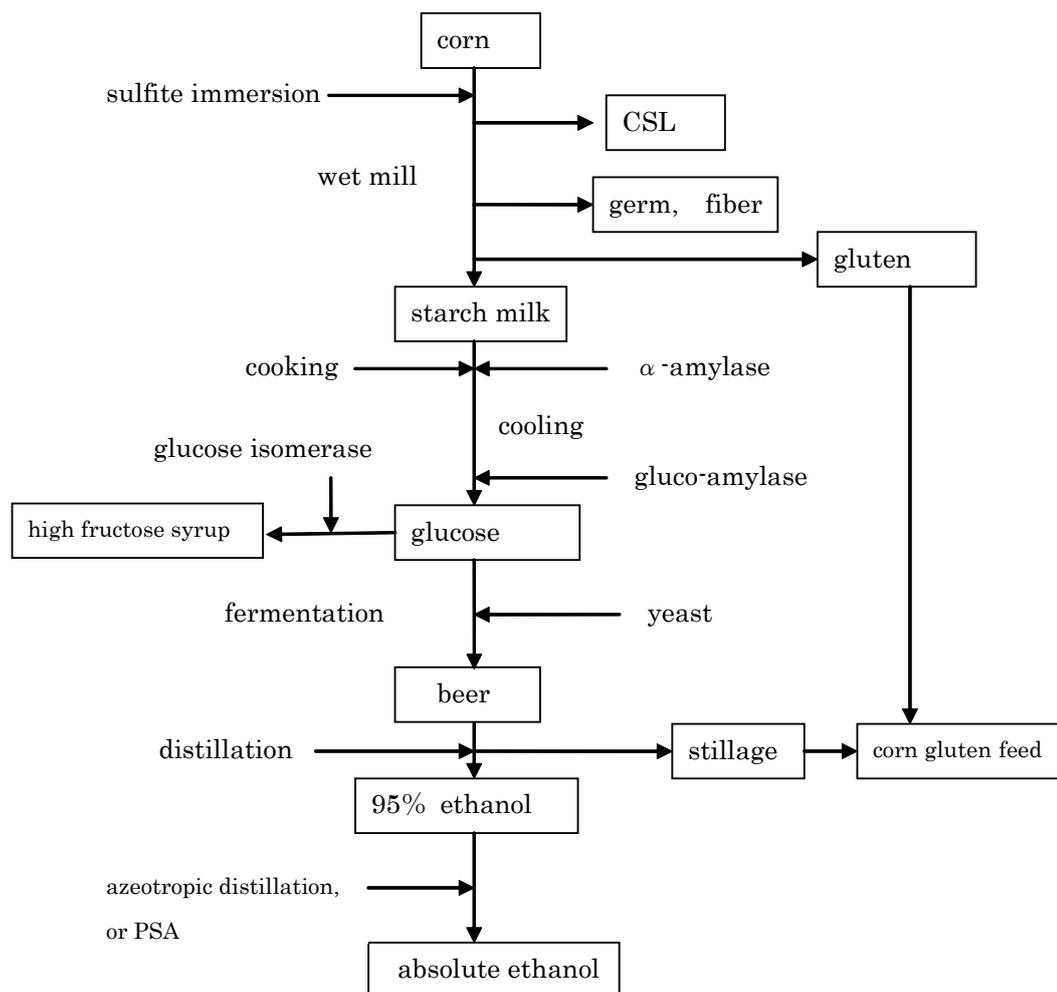


Fig. 5.2.2. Production process of ethanol and high fructose syrup from corn.
(Modified from (Elander, 1996))

5.2.4 Ethanol fermentation of lignocellulosics

Lignocellulosic biomass is generally composed of cellulose, hemicellulose and lignin (Table 5.2.1). Before ethanol fermentation, biomass has to be pre-treated with acid or alkali, and/or with cellulases to be hydrolyzed into sugar solution.

Table 5.2.1. Compositions of Various Biomass (%).

	cellulose	hemicellulose	lignin
Soft wood	43	28	29
Hard wood	43	35	22
Rice straw	38	25	12
Office paper	69	2	11

(a) Concentrated Sulfuric Acid Process

The process of Arkenol Co. Ltd. (USA) was modified and improved in NEDO project between 2001 and 2005. Concentrated sulfuric acid is sprayed on to wood chips (moisture of about 15%) which is then kneaded well at room temperature. During the kneading the structure of cellulose is decrystallized. Concentration of sulfuric acid is then adjusted at 20 to 30% by adding water, and the wood material is kept at around 90°C for 10 to 15 min for hydrolysis. After solid fraction is removed through filtration, sugar components are separated from the acid on ion-exchange chromatography. Sugar solution containing hexoses and pentoses are fermented by yeast or *Zymomonas* strains genetically modified. Sulfuric acid is concentrated again to reuse.

(b) Dilute Sulfuric Acid Process

Hemicellulose fraction is degraded into sugars composed of mainly pentose and some hexoses through first dilute sulfuric acid (0.5-1.0%) treatment at 150-180°C, and at about 1 MPa (10 atm). Residual fraction containing cellulose and lignin is again treated with similar concentration of the dilute acid at 230-250°C and at 3-5 MPa (30-50 atm) to produce glucose. Sugar yield in first and secondary treatments are reported to be about 90%, and 50-60%, respectively. In the ethanol plant of “Bioethanol Japan Kansai” (Osaka, Japan), which has been operated since January, 2007, sugar solution only from hemicellulose fraction of wood is reported to be converted to ethanol through fermentation by genetically modified *E. coli*.

In the United States, research groups including NREL have been challenging to improve cellulase activity for industrial use in dilute sulfuric acid process. Their target is, reportedly, to start production of bioethanol from biomass like corn stover in 2013.

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5.3 Acetone-Butanol Fermentation

5.3.1 What is acetone-butanol fermentation?

Acetone-butanol fermentation is a reaction in which acetone and butanol are produced from glucose using *Clostridium*, a strictly anaerobic bacterium. Further, ethanol is also produced. Therefore, acetone-butanol fermentation is also called as ABE fermentation. *Clostridium* is widely distributed in soil, and secretes amylase, xylanase, protease and lipase out of cells. There are two types of strain in acetone-butanol fermentation. One is Weizmann-type which produces butanol from starch, and the other is Saccaro-type which produces butanol from sucrose.

5.3.2 Characteristics of acetone-butanol fermentation

Acetone-butanol fermentation has a long history and is industrialized technology. Acetone-butanol fermentation was utilized to produce acetone as a raw material of smokeless powder in WWI and butanol for fuels of fighter planes in WWII. After WWII, acetone-butanol fermentation fell out of use due to development of petroleum chemistry. Recently, butanol is reviewed as biofuel.

5.3.3 Reactions of acetone-butanol fermentation

The strains of bacteria utilized for industrial production of butanol were acetone-butanol producing bacteria and butanol-isopropanol producing bacteria which produce butanol and isopropanol, a reduced product of acetone. The reaction pathway is shown in Fig. 5.3.1. Glucose is decomposed to pyruvate, acetyl-CoA, and acetoacetyl-CoA via EMP pathway, and finally acetone, butanol, isopropanol and ethanol are produced. The stoichiometrical equation of acetone-butanol fermentation is shown in Eq. 5.3.1.



In acetone-butanol fermentation, butanol is gradually accumulated and cause production

inhibition at more than 3 kg/m³ (g/L) of the butanol concentration. When the production inhibition occurs, the growth of bacteria cells, consumption of substrates, and accumulation of products are suppressed. Final concentration of butanol reaches about 30 kg/m³ (g/L). After fermentation, the culture solution is distilled and products are separated by the difference in their boiling points, e.g. acetone (BP 56.3°C), ethanol (BP 78.3°C) and butanol (BP117°C).

5.3.4 Energy efficiency of acetone-butanol fermentation.

From Eq. 5.3.1, 60 mol butanol (170 MJ), 30 mol acetone (54 MJ), 10 mol ethanol (14 MJ) and 120 mol hydrogen (34 MJ) are produced from 95 mol glucose (273 MJ) in acetone-butanol fermentation. Almost all energy in glucose can be moved to butanol, acetone, ethanol and hydrogen.

5.3.5 Products of acetone-butanol fermentation

Acetone-butanol fermentation was industrialized for supply of raw materials of smokeless powder and fighter planes. Presently, acetone and butanol are synthesized in petroleum industry. Biofuels, renewable gasoline or diesel additives are now paid much attention throughout the world. Butanol can be added to both gasoline and diesel fuels and has more affinity for gasoline than ethanol. Therefore, butanol will be promising biofuel.

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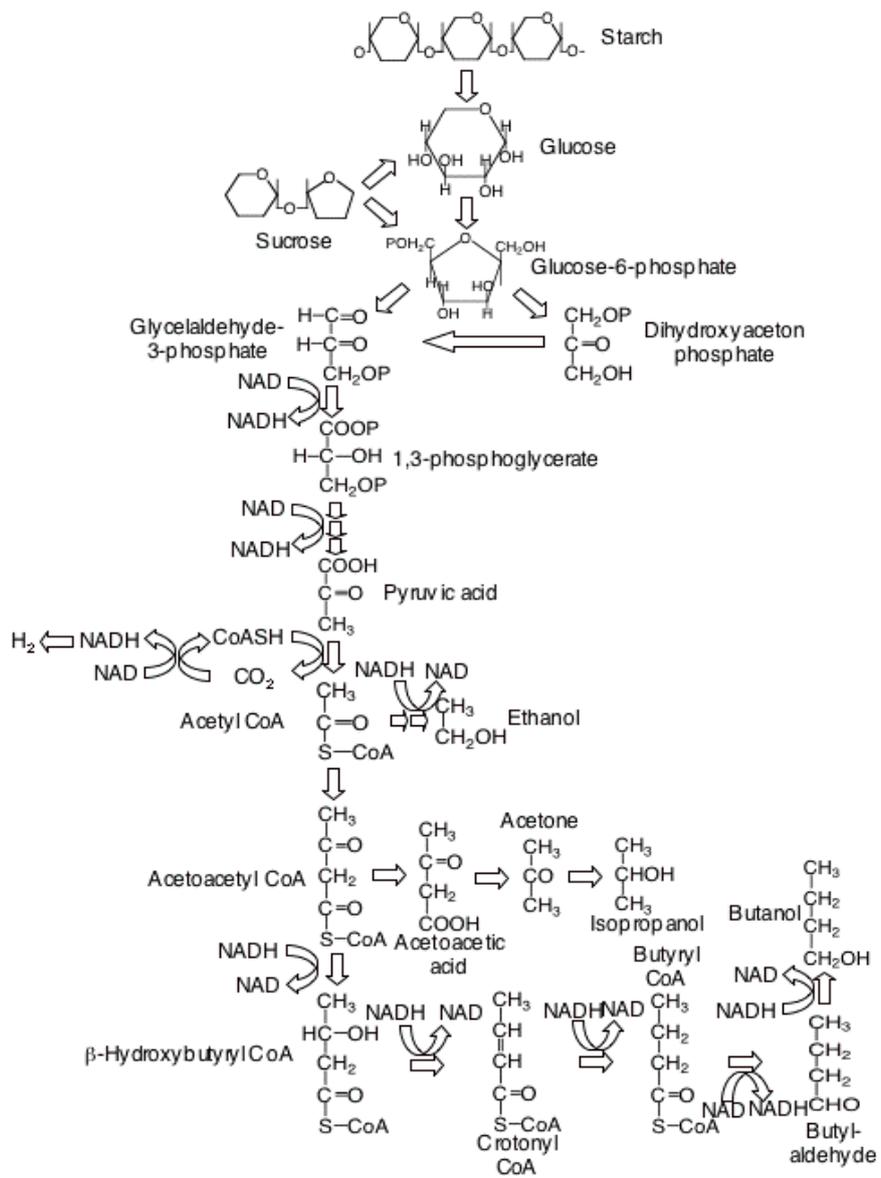


Fig. 5.3.1. Reaction pathway of Asetone-Butanol fermentation.

5.4 Hydrogen Fermentation

5.4.1 What is hydrogen fermentation?

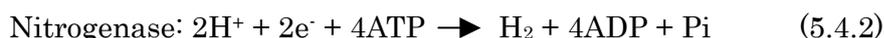
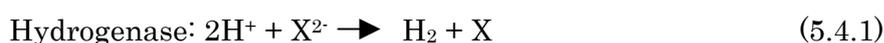
Anaerobic fermentation is a reaction in which anaerobic microorganisms oxidatively decompose organic materials to get energy under anaerobic conditions. We call fermentative reactions in which hydrogen is the final product as hydrogen fermentation. In hydrogen fermentation, some organic materials and alcohols are produced with hydrogen. Although final electron acceptor is oxygen or inorganic materials in respiration, oxidatively degraded organic materials and carbon dioxide etc. from substrate materials are final products in fermentation. For example, final products are ethanol and carbon dioxide from glucose during ethanol fermentation. While ATP synthesis is coupled with electron transfer chain in respiration, ATP is produced in reactions at substrate level in fermentation. Energy gained from fermentation is smaller than that from respiration for the same amount of substrate.

5.4.2 Characteristics of hydrogen fermentation

The role of hydrogen production is to regulate oxidation-reduction level in bacterial cells by converting excess reducing power to hydrogen. There are bacteria which can take in and utilize such hydrogen. In order to increase hydrogen yields, the reverse reactions consuming hydrogen should be suppressed. Generally, it is needed to treat waste water from hydrogen fermentation, since hydrogen fermentation includes the production of some organic materials.

5.4.3 Reactions of hydrogen fermentation

Hydrogen-producing bacteria are classified into 2 types by the difference in reaction enzymes. One is bacteria with hydrogenase, and the other with nitrogenase.



X: electron carrier, Pi: inorganic phosphate

As shown in above reactions, hydrogenase catalyzes a reversible reaction of evolution and uptake of hydrogen. On the other hand, the reaction by nitrogenase needs energy (ATP). In anaerobic fermentation, the reaction by hydrogenase is mainly investigated. Representative

hydrogen fermentation reactions are as follows:



Figure 5.4.1 shows the pathway of hydrogen fermentation. Hydrogen is formed from hydrogenase via both NADH and ferredoxin, via only ferredoxin, or via formate-lyase. In hydrogen fermentation, hydrogen is produced from oxidative decomposition of organic substrates. Therefore, hydrogen fermentation is utilized as treatment of wastes and waste water. In such cases, the following treatment such as methane fermentation or activated sludge method is needed, since hydrogen fermentation accompanies the production of organic acids. The reaction rate of hydrogen fermentation is fast compared with methane fermentation. It may be promising pre-treatment method of methane fermentation.

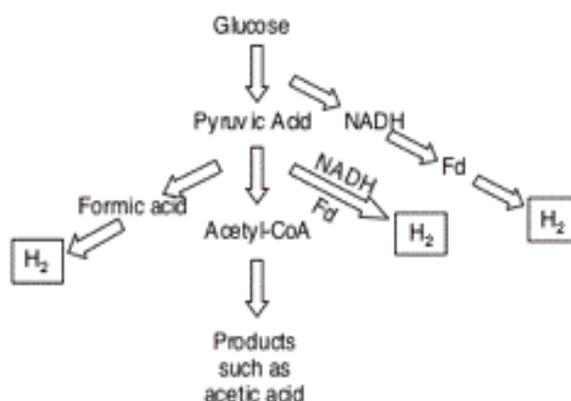


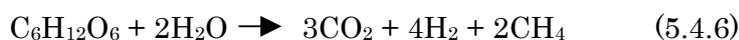
Fig.5.4.1. Pathway of hydrogen fermentation

5.4.4 Energy efficiency of hydrogen fermentation

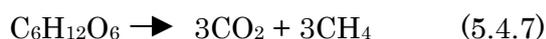
Since hydrogen fermentation accompanies organic acids production, it is needed to consider total system combined subsequent treatment methods such as methane fermentation. In hydrogen fermentation, 4 mol of hydrogen is theoretically produced from 1 mol of glucose (Eq. (5.4.3)). When subsequently formed acetate is utilized for methane fermentation and converted to methane, the reaction is shown as follows:



Total reaction of hydrogen-methane two-stage fermentation is shown as follows:



The sum of high heat value of these products is 2.924 MJ (2,924 kJ). On the other hand, in only methane fermentation, the reaction is shown as follows:



High heat value of the product from Eq. (5.4.7) is 2.671 MJ (2,671 kJ). It is obvious from these results that the energy yield of hydrogen-methane fermentation increases 10% compared with that of only methane fermentation.

5.4.5 Products of hydrogen fermentation

The product gas evolved from hydrogen and methane fermentation might be utilized to fuel cells which have higher energy conversion efficiency than those of gas turbine and gas engine. Methane from methane fermentation has to be converted to hydrogen for fuel cells.



Since Eq. 5.4.8 is an endothermic reaction, supply of energy is needed to proceed the reaction. Generally, methane gas is converted to hydrogen gas under nickel catalysts at 650-750°C. On the other hand, in hydrogen fermentation, energy yield is higher than that of methane fermentation and the catalytic conversion of methane is not needed to provide hydrogen gas to fuel cells.

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5.5 Lactic Acid Fermentation

5.5.1 What is lactic acid fermentation?

Lactic acid has alcohol (OH) and carboxylic (COOH) sites inside the molecule. Since it includes chiral carbon, it has two chiral isomers, D-lactic acid and L-lactic acid. Recently, demand of poly-lactate, a biomass plastic, is increasing, and demand of lactic acid is also increasing as a raw material of poly-lactate. Then the lactic acid with almost 100% of the optical purity is strongly requested. Generally, lactic acid is produced by chemical syntheses or by microbial fermentations. In the chemical syntheses, a method using hydrolysis of lacto-nitrile is usually adopted, yielding D-lactic acid and L-lactic acid half by half of which the optical purity is nul. Thus lactic acid for the production of poly-lactate is always produced by fermentation. Lactic acid can be produced by either bacteria or fungi. Here the lactic acid fermentation with bacteria is focused on.

5.5.2 Lactic acid bacteria

Lactic acid bacteria produce a lot of lactic acid from several types of sugars. They are gram-positive rod-type or spherical bacteria which can grow under an anaerobic condition. They show no mobility and negative in a catalatic reaction. They form no spores. They use only sugars as an energy source to yield lactic acid, and convert more than 50% of the consumed sugars. There are the following four groups in the bacterial species to satisfy the above-mentioned conditions: *Lactobacillus*, *Leuconostoc*, *Pediococcus*, and *Streptococcus*. Lactic acid bacteria can grow with higher growth rates and produce lactic acid with higher productivities. Since they request a lot of nutrients including amino acids and vitamins, the composition of the fermentation broth is not simple. We can classify lactic acid fermentation into two groups, homo-lactic acid fermentation and hetero-lactic acid fermentation. In the

homo fermentation two moles of lactic acid and two moles of ATP can be produced from one mole of mono-saccharides with almost 100% of the lactic yield. On the other hand, in the hetero fermentation, lactic acid and other compounds are produced; it is classified into two groups: 1) one yielding lactic acid, ethanol and carbon dioxide. 2) one yielding one mole of lactic acid and 1.5 moles of acetic acid from one mol of mono-saccharides. Lactic acid bacteria possess both D type and L type or either D type or L type of lactate-dehydrogenases. Thus D-lactic acid and (or) L-lactic acid can be produced by the bacteria. Most of lactic acid bacteria has enzymes which racemize the produced lactic acid, affecting the chiral quality of lactic acid. *Lactobacillus rhamnosus* can produce only L-lactic acid with almost 100% of the optical purity, which is used as a raw material for the poly-lactate production.

5.5.3 Biomass resources for lactic acid fermentation

Glucose is a major substrate for lactic acid fermentation, which is usually obtained by hydrolysis of starch. Starch is now obtained from crops. However, we sometimes worry about competition between energy or materials and food, as claimed in the ethanol production from biomass resources. Thus soft cellulosic biomass like rice husk which has been currently not used is expected for biomass resources. Anyhow such unused biomass has less quality and that is why it has not yet been used. Then some conditions must be considered for its utilization in fermentation. First, constant and stable supply of the biomass is required. Next, sugars should be obtained easily with energy as least as possible. Of course, more effective and sophisticated technology for the fermentation is needed, and moreover, it is also important to solve the issues accompanied by transportation and storage of biomass in terms of energy, cost, etc.

5.5.4 Utilization of unused biomass from palm oil industry

Palm oil is one the three major vegetable oils in the world. It can be harvested throughout a year only around the equator. In the mill operation to produce oil, more than 10 Tg (Mt) of unused biomass is obtained as business as usual. Since the palm oil mills are very large, more than a few tens Gg (thousand tones) of uniform unused biomass can be collected constantly throughout a year. Moreover, the replanting season of oil palm trees is arriving currently and a large amount of oil palm trunks shall be wasted. Recently, it was found that there exists a lot of glucose inside the trunks and that glucose syrup can be easily obtained by pressing them like sugarcane processing.

5.5.5 Lactic acid fermentation from kitchen garbage

Japan is a narrow country and has higher population density. That is why we cannot use a simple dumping method for the garbage treatment in Japan. Thus we have around two thousand incinerators for burning the garbage. Every day, garbage is collected in the incinerators and burned to get heat energy, part of which is used for power generation. Therefore, unused steam with lower pressure is available. Kitchen garbage comprises

30% in the total garbage in Japan. Especially, kitchen garbage from business sectors including supermarket and convenience stores can be easily separated from the others. Japanese kitchen garbage should be a good resource for sugars because half of the solid in the kitchen garbage is composed by starch, even though the compositions of the kitchen garbage should be changed every day. Then kitchen garbage contains a variety of nutrients including vitamins and it is good for the lactic acid fermentation. Fig.5.5.1 shows the lactic acid yield from kitchen garbage in the lactic acid fermentation after enzymatic treatment with glucoamylase using *Lactobacillus rhamnosus*. Generally, kitchen garbage contains 80% of moisture and indicating that around the 10% of the lactic acid yield shown in the figure should be quite high.

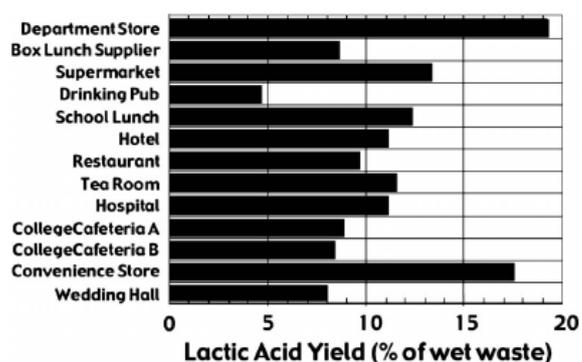


Fig.5.5.1 Lactic acid yield from lactic acid fermentation with kitchen garbage

5.5.6 Purification of lactic acid

Lactic acid for poly-lactate is requested to guarantee not only quite high optical purity but also its quite high purity as lactic acid. In lactic acid fermentation, any higher class purification technology to yield pure lactic acid is required because the fermentation broth contains a variety of compositions. Usually distillation technology is adopted for this purpose: In the purification of lactic acid from fermented kitchen garbage, butyl-lactate is separated by distillation after esterification of lactic acid with butanol. Moreover, ammonia can be recovered in the esterification reaction, which can be again used for pH adjustment in the fermentation. However, in this process more energy would be required to remove water to encourage the esterification reaction. When the energy would be supplied from fossil resources, it is neither ecologically nor economically suitable. Utilization of unused heat energy from incinerators should be an acceptable solution.

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5.6 Silage

5.6.1 What is silage?

Silage is now the most commonly preserved cattle and sheep feed in many countries. It is produced by the controlled fermentation of crops with high moisture. Silage is a fermented and stored process which ensilages with forage crops and grasses in a silo (Fig. 5.6.1). The types of silo in which the farmer may choose to ferment their crop are greatly varied. For convenience, commercial silos can be classified into the main categories: stack or clamp without retaining walls, tower, bunker, vacuum, plastic sausage and roll bale. Compared with the hay, the feed intake, digestibility and nutritive value of silage are excellent. Silage can be made of many other by-products of field crops and food, and other materials.



Fig. 5.6.1. Forage cutting (left) and stack silo (right).

5.6.2 Silage making

Silage originated in ancient Egypt. The silage research on the fermentation mechanism has been made rapid progress in the 20th century. Silage can be prepared from forage crops and grasses at the optimum stage of growth with suitable moisture content, about 50% to 70%. The forage material is collected, chopped into about 10- to 20-mm lengths and packed into silo. Current mechanical forage harvesters are used to collect and chop the forage material, and deposit it in trucks or wagons. These forage harvesters can either be tractor-drawn or self-propelled. Harvesters blow the silage into the wagon via a chute at the rear or a side of the machine. The inoculants of LAB were used for high quality silage making (Fig. 5.6.2).



Fig. 5.6.2. Cell form (left) and inoculant (right) of lactic acid bacteria “Chikuso 1”

5.6.3 Silage fermentation

The preservation of forage crops as silage depends upon the production of sufficient acids to inhibit the activity of undesirable microorganisms under anaerobic conditions. The epiphytic lactic acid bacteria (LAB) that naturally present on forage crops convey sugar into lactic acid in the ensiling process. It is well established that LAB play an important role in silage fermentation. LAB is a major component of the microbial flora which lives in various types of forage crops. The LAB commonly grow with other plant-associated microorganisms during silage fermentation, and they generally define the fermentation characteristics of silage. Moist dairy farm silage is based on natural lactic acid fermentation. The epiphytic LAB transform the water-soluble carbohydrates into organic acids during the ensiling process. As a result, the pH is reduced and the forage is preserved.

However, when the silo is opened and aerobic conditions prevail at feeding time, the silage is subject to aerobic microbial growth and is therefore potentially unstable. Furthermore, the deteriorated silage increases in dry matter loss and reduces in the nutritional value. Generally, the well-preserved silages are considered to be more liable to aerobic deterioration than poorly-

fermented silages and some aerobic microorganisms can be harmful to the health of livestock. Therefore, the prevention of aerobic deterioration is an important task in making silage.

5.6.4 Roll bale silage

Roll bale is another form of stored forage. Grass is cut and baled while it's still fairly wet. If it is too wet, it can't be baled and stored the same as hay. Thus, the proper moisture content for roll bale silage making is around 60 to 70%. The bales are wrapped tightly with 6 layers of 0.025-mm thick plastic film on a bale wrapper. The material then goes through a limited fermentation in which short chain fatty acids are produced to protect and preserve the forage. This method has become popular on some farms. In Japan, the roll bale silage preparation method of fresh rice straw was developed (Fig. 5.6.3), and the animal feed production from biomass resources is expected to make the best use of roll bale technology.



Fig. 5.6.3 Roll bale silage making (left) and wrapping (right) of rice straw.

5.6.5 Technological actuality

In recent years, the amount of silage conserved as roll bales has increased dramatically, and this system of making silage is now widely practiced in Japan and other countries. Today, the new silage inoculant of LAB and new types of chopped roll baler for silage making of corn and forage paddy rice were developed. The research of unused biomass resources for silage making of crops and food by-products are advanced in Japan.

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5.7 Composting

5.7.1 What is composting?

Compost is a mixture of biodegradable organic matter such as straw, husks, tree bark, animal waste products and organic animal/plant matter (excluding sludge and fish organs) that are accumulated or mixed, and decomposed by heat. However sludge and fish organs may be considered compost if properly processed.

5.7.2 Basic principles of composting

Composting is the process of accumulating, mixing and aerating organic matter to decompose them with aerobic bacteria inside the material, evaporate the moisture generated by the heat from decomposition, and sterilize or make the harmful microbes or weed seeds inactive, to render the compost mixture safe and hygienic. Figure 5.7.1 shows the composting process. Composting offers the advantages of: (1) being easy to handle by hygienically-minded users since it eliminates noxious odors and the sense of handling biological waste products, (2) producing nutrients including the correct amount of elements for safe and high quality fertilizer for soil and crops, and (3) contributing to create a society that recycles its resources.

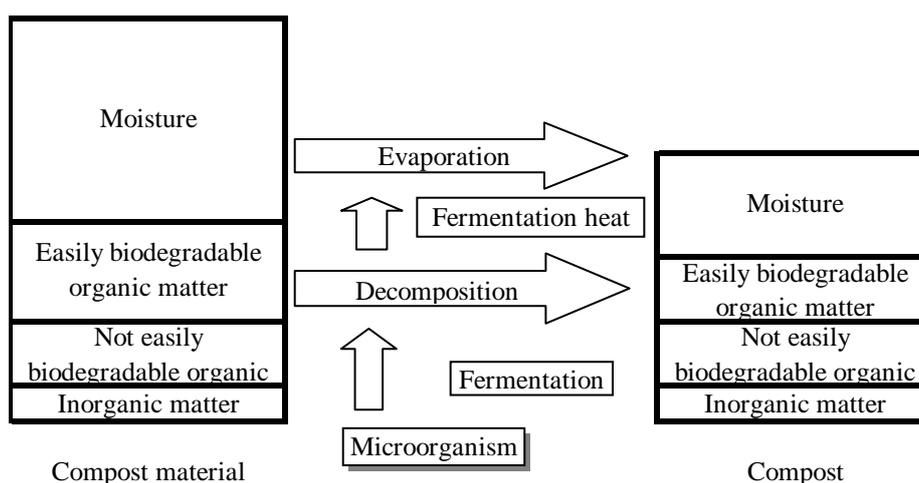


Fig. 5.7.1. Concept image of composting process.

5.7.3 Basic elements of composting

Composting is basically made up of (a) preprocessing, (a) fermentation processing, and (c)

product forming processing.

(a) Preprocessing

Preprocessing requires equipment for adjusting factors such as the moisture and organic matter, particle sizes, and aeration to make compost with the desired properties. When starting the composting, the moisture must usually be adjusted between 55 to 70 % and good aeration must be provided. This preprocessing includes additive methods (addition of adjustment materials such as shell, husks, sawdust, and chips), return methods (returning the product compost and mix with composting feedstock), and drying methods (drying using external energy).

(b) Fermentation

Fermentation requires a fermenting tank, aeration equipment and hydrolysis equipment. The fermentation tank decomposes organic matter and emits heat to raise the temperature of material accumulated in the fermentation tank so that conditions to produce safe and hygienic compost is attained by raising the temperature of the entire compost material to 65°C or higher and maintaining that temperature for 48 h or more. Fermentation methods are broadly grouped into accumulation methods and mechanical return methods. In the accumulation methods, materials such as compost, adjustment materials, and returned compost are accumulated on the floor and then repeatedly turned as needed with a shovel loader, etc. In the mechanical return method, an agitating device having a material loading slot and drainage slot for mixing the material is installed on the upper side wall of the fermentation tank. The aeration equipment maintains the material at a uniform aerobic state and provides ventilation to make the moisture evaporate from the material simultaneous with causing fermentation. The hydrolysis equipment supplies water to the material to ensure continued aerobic fermentation since microbial activity in the material ceases when the moisture in the material falls below 40%.

(c) Product forming process

The product forming process includes mechanical sorting and bagging/packing equipment for enhancing the product value and making the product compost easier to handle. Other facilities may include deodorizing equipment as part of environmental measures.

5.7.4 Current composting technology

Table 5.7.1 shows main materials usable in composting. Husk and woody materials have a low biodegradable material index so their decomposition takes time but are effective for

improving soil and can be used in combination with other materials to produce high quality compost. Raw garbage contains many materials impossible to ferment such as plastic, metal, and glass and also requires thorough sorting and the right preprocessing. Sludge may require special measures for dealing with heavy metals, etc.

Among the recycling technologies of composting, biogas, drying, carbonization, livestock feed, and incineration, composting can use various kinds of materials and offers significant advantages in terms of technology and distribution. However, amount and period of the product demand are limited, and some regions have excess compost stocks. Future production efforts will require elaborate quality control, composting of all material produced in a region, and regional consumption of the entire amount produced in those areas.

Further information

Japan Livestock Industry Association Ed., *Composting Facility Design Manual*(2003) (in Japanese)

Japan Organics Recycling Association Ed., *Composting Manual*(2004) (in Japanese)

Livestock Industry's Environmental Improvement Organization Ed., *Livestock Dung Process Facility – Machine Setup Guidebook (compost processing facility version)* (2005) (in Japanese)

Table 5.7.1. Comparison of materials available for composting and other recycling technologies (Japan Organics Recycling Association 2004).

Material Name	Type	Composting	Biogas	Drying	Carbonization	Livestock feed	Incineration
Livestock	Cattle dung	◎	○				
	Cattle dung/urine	○	◎				
	Dairy cow dung	◎	○				
	Dairy cow dung/urine	△	◎				
	Pig dung	◎	○				
	Pig dung/urine	△	◎				
	Chicken dung	◎		◎	◎		◎
Garbage	Raw garbage	◎	◎		△	△	○
Sludge	Dehydrated sludge	◎	◎	◎	○		○
Crop residue	Rice husks	◎			◎	△	◎
	Paddy straw	◎				○	
Wood	Sawdust	○			△		◎
	Bark	◎					◎
	Pruning waste	○			◎		◎
	Chips	◎			◎		◎

Note: ◎: Matches category ○: Usable △: Usable after preprocessing

Part 6. System development for sustainability

6.1 Fundamentals of LCA

6.1.1 Outline of life cycle assessment

Life Cycle Assessment (LCA) address the environmental impact of the target product or service throughout their life cycles; so called “from the cradle to the grave”, and measures the amounts of resources consumption and the emissions of all the stages from raw material acquisition through production, use, end-of-life treatment and final disposal (inventory analysis), then evaluating the impact based on the results of the inventory analysis (impact assessment).

International standard (ISO-14040) provides “Principles and framework” of LCA. ISO-14040 defines LCA as “LCA is one of the techniques being developed to better understand and address the impacts from products, both manufactured and consumed, including possible impacts associated

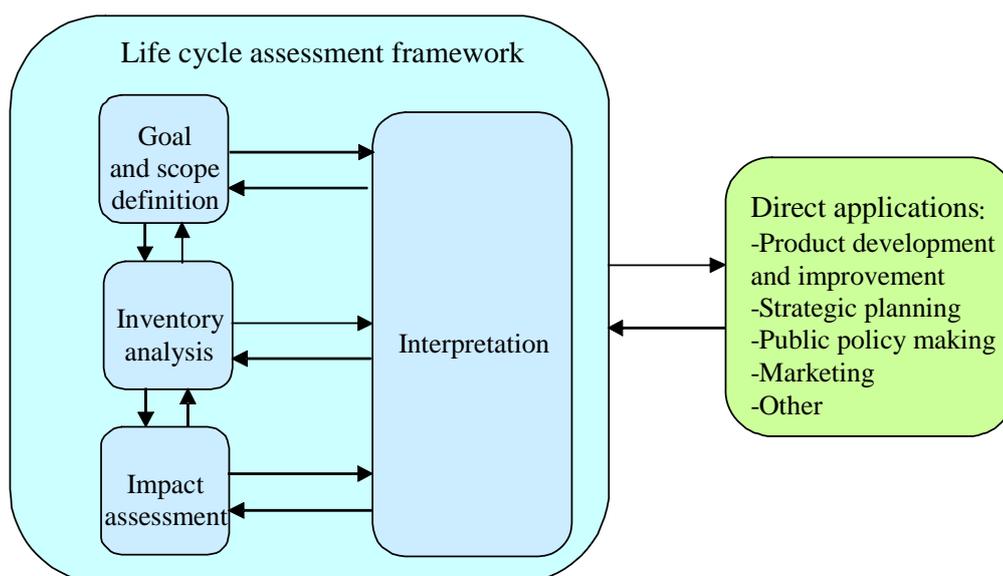


Fig. 6.1.1. Phases of a LCA.

with". ISO-14040 also clearly shows the four phases for conducting LCA: "Goal and scope definition", "Inventory analysis", "Impact assessment", and "Interpretation" (Fig. 6.1.1).

6.1.2 Goal and scope definition

In this phase, the practitioner of LCA defines the product system to be studied and clarifies the goal. For instance, assume that an "influence for global warming of a refrigerator" is defined as the evaluation target. According to the goal, LCA practitioner decides the emissions to be measured and the boundary to be evaluated. The target to be studied in LCA is originally "a function" of the product. For example, it is a function to "cool a thing in the storage" if it is "a refrigerator". Therefore, the same "function" such as same volume, same durability year is to be set when different models of refrigerator are compared. Moreover, when conducting LCA, it is difficult to cover everything in the process related to the target product or service. The process, whose contribution level is low in comparison with the goal of LCA, is excluded from a study (cut-off). A so-called cut-off criteria is used to decide to be excluded from the process. There is no general rule to cut-off because an important process can be different if the goal of study is different. It is fundamental that scope is consistent with the goal of the LCA.

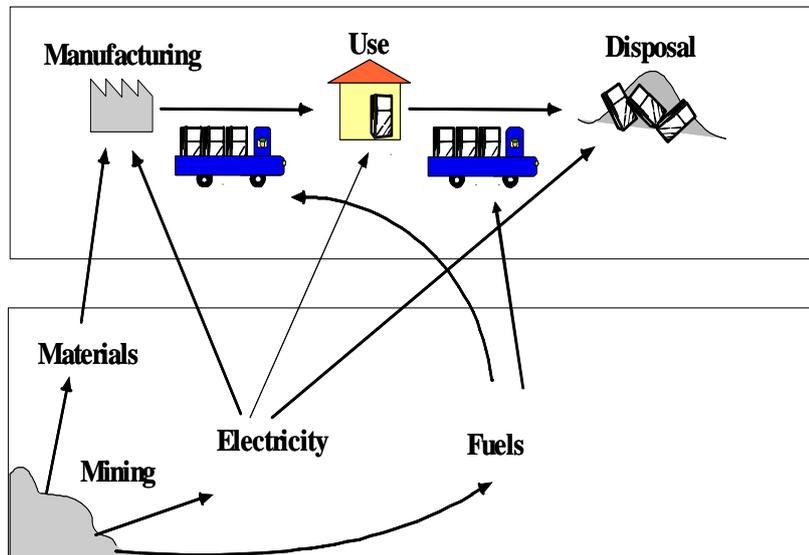
6.1.3 Lifecycle inventory analysis (LCI)

The inventory analysis is a phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle within the boundary (product system) determined from the goal of the study.

Firstly, the practitioner of inventory analysis needs to collect the data related to manufacturing, use, and final disposal of a targeted product. These data are generally called "Foreground data" and they should be collected by the practitioner of LCA.

The next data to collect are the input-output data for production of raw materials used to produce the product (including primary or secondary material), and for generation of electricity needed to utilize the product, etc. These data are generally called "Background data". It is difficult for the practitioner of LCA to collect the background data, and usually the background data is quoted from research papers or past LCA case studies. When LCA practitioner refers to some data, it is necessary to check the consistency because the emissions for the combustion of heavy oil or the electricity generation may be different from literature to literature. Relation of foreground data and background data is shown for Fig. 6.1.2.

Foreground Data (LCA Practitioner)



Background Data (Existing Database)

Fig.6.1.2 Foreground data and background data

In an inventory analysis, the following two items may be controversial: “System boundary” and “Allocation”. System boundary determines which unit processes shall be included within the LCA. The selection of the system boundary must be consistent with the goal of the study and important process must not be excluded in the system boundary. When any of two or more products come from the same unit process, “Allocation” is required. Allocation means partitioning the input or output flows of a process or a product system between the products under study and other by-products. In general, the inputs and outputs are allocated based on the weight ratio of the products. However, when the market values of the products are quite different, the inputs and outputs might be allocated in a proportion that reflects economic value.

6.1.4 Lifecycle impact assessment (LCIA)

The impact assessment on LCA consists of three parts: classification, characterization and total evaluation. At the phase of classification, the resource consumption or emissions are classified to the impact categories based on the potential environmental impacts.

Table 6.1.1 shows the default environmental impact categories list of the Society of

Table 6.1.1. Impact categories list of SETAC-Europe.

A. Input related categories (“resource depletion or competition”)

- | | |
|--|------|
| 1. abiotic resources (deposits, fund, flows) | glob |
| 2. biotic resources (funds) | glob |
| 3. land | loc |

B. Output related categories (pollution)

- | | |
|---|-------------------|
| 4. global warming | glob |
| 5. depletion of stratospheric ozone | glob |
| 6. human toxicological impacts | glob/cont/reg/loc |
| 7. ecotoxicological impacts | glob/cont/reg/loc |
| 8. photo-oxidant formation | cont/reg/loc |
| 9. acidification | cont/reg/loc |
| 10. eutrophication (incl. BOD and heat) | cont/reg/loc |
| 11. odour | loc |
| 12. noise | loc |
| 13. radiation | reg/roc |
| 14. casualties | loc |

Pro Memoria: Flows not followed up system boundary

input related (energy, material, plantation, wood, etc.)

output related (solid waste, etc.)

Environmental Toxicology and Chemistry (SETAC)-Europe that is the academic society leading LCA studies. It is necessary to be clear which environmental categories are studied, depending on the “Goal and Scope definition”. At the phase of characterization, each assigned LCI data for an impact category is multiplied by a “Characterization Factor” (quantifiable representation of an impact category) and the output is shown as a numerical indicator, “Category Indicator”.

Fig. 6.1.3 shows a general procedure of impact assessment, taking global warming and ozone layer depletion as an example. The numerical value expressing potential environmental impacts of emissions, like "Global Warming Potential (GWP)", is often used for the Characterization Factor. It is to be noted that ISO-14040 defines that “classification and characterization” are mandatory elements but “normalization, grouping and weighting” are optional elements. Although it is possible for a practitioner to make indexes based on carbon dioxide or chlorofluoro-carbon in such impact categories as "global warming" and "ozone layer depletion", but they decided that to integrate these different environmental impacts and to make a single index for decision making is not possible.

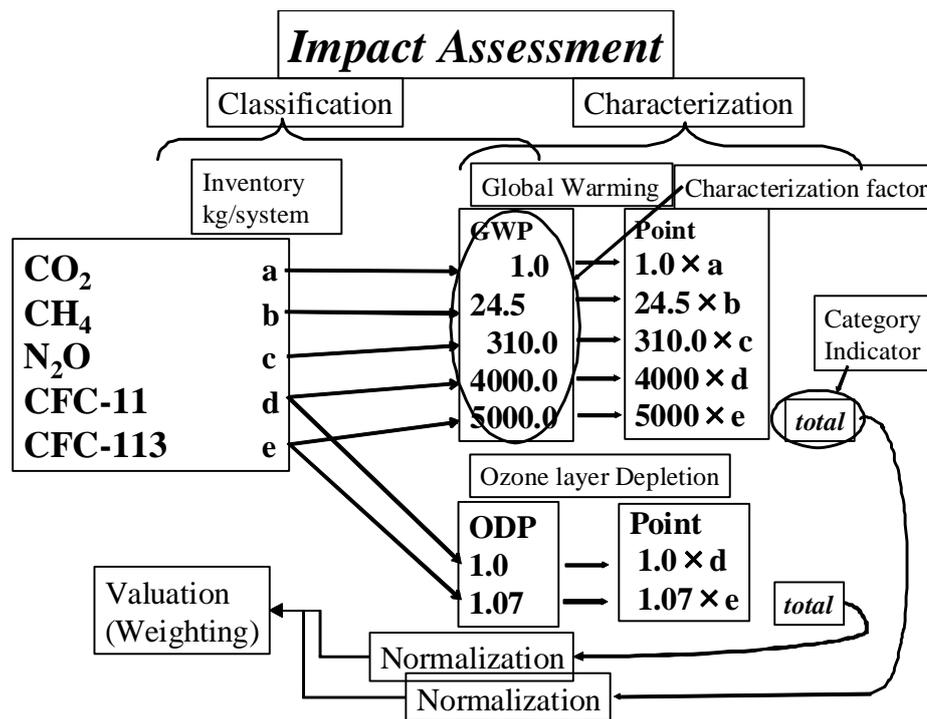


Fig. 6.1.3. General Procedure of Impact Assessment.

6.1.5 Interpretation

In LCA, practitioner may reach different results depending on the scope of the study, system boundaries and allocation procedures being taken in LCI and choice of characterization factors in LCIA. The influence of these procedures on the result has to be discussed in the phase of "interpretation". In many cases of current LCI, results of emissions and resource consumption are expressed by a single numerical value. However, each process data is suffering from measurement error and estimation error. In the ISO standard, it is necessary to evaluate data quality using the techniques to determine the effect of data error such as "sensitivity check" and "uncertainty analysis", when the practitioner undertakes interpretation.

Further information

SETAC "Guidelines for Life-Cycle Assessment A code of Practice", 1993

SETAC "Towards a Methodology for Life Cycle Impact Assessment", 1996

6.2 Energy Efficiency

When biomass is used as an energy source, not only energy efficiency of conversion technology, but also life cycle energy efficiency and environment load must be considered as is described in the preceding chapter. In other words, it is necessary to evaluate lifecycle stages of biomass: production, preprocessing, and energy conversion (Fig. 6.2.1).

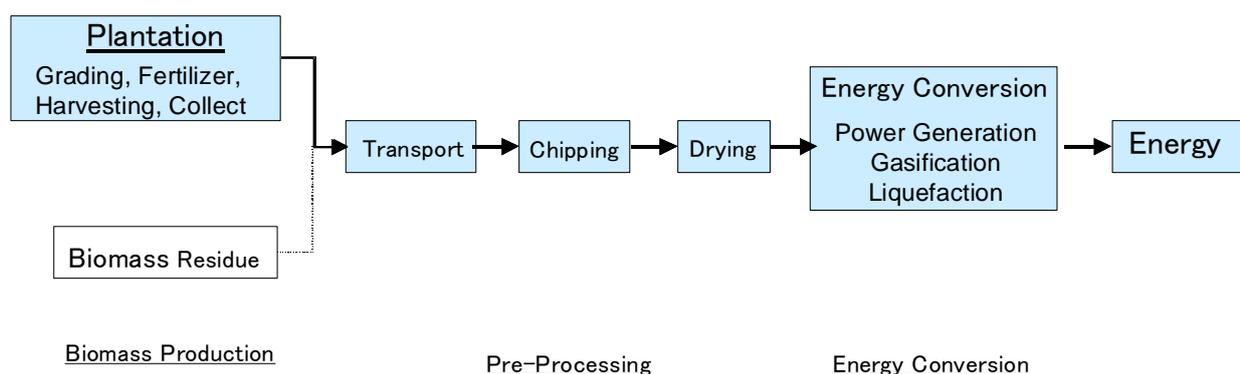


Fig. 6.2.1. Life Stages of Biomass Energy Conversion.

6.2.1 Energy consumption for biomass cultivation and harvest

The assumption as shown in Table 6.2.1 is set, although growth quantity and caloric value of biomass depend on tree types and/or local meteorological conditions.

Table 6.2.2-Table 6.2.4 obtained from references shows energy required for tree planting, describing electricity as primary energy based on power generation efficiency (38.1%) in Japan.

Table 6.2.4 shows the inventory of afforestation for pulp production in Brazil, which can be considered as an example of biomass energy production technology.

The growth rate is a value per each unit area and depends on intervals between trees. For Brazilian case, plenty of human work (task) reduces energy consumption. Energy efficiency of biomass production can be found by comparing calorific value of Table 6.2.1 and energy consumption of Tables 6.2.2- 6.2.4.

For example, North American case shows that 1.4 MJ of energy (about 7.4%) is consumed to produce biomass which has 18.8 MJ of caloric value per unit mass.

Table 6.2.1. Features of tree.

	North America	Indonesia	Brazil
Tree	Poplar	Acassia	Eucalyptus
Growth rate [t-dry/ha/year]	10	7.5	5.8
Calorific value [MJ/kg-dry]	18.8	16.7	18.8
Carbon content	0.5	0.5	0.5

Table 6.2.2. Planting energy in North America.

	Diesel Oil [MJ/kg-dry]	Natural Gas [MJ/kg-dry]	Electricity [MJ,kWh/kg-dry]	Total [MJ/kg-dry]
Grading	0.014	-	-	0.014
Fertilizer	0.024	0.281	0.073	0.378
Pesticide	0.029	0.010	0.005	0.044
Machinery	0.017	-	-	0.017
Harvest	0.731	-	-	0.731
Transport	0.240	-	-	0.240
Total	1.055	0.291	0.079	1.425

Table 6.2.3. Planting Energy in Indonesia.

	Diesel Oil [MJ/kg-dry]	Natural Gas [MJ/kg-dry]	Electricity [MJ,kWh/kg-dry]	Total [MJ/kg-dry]
Grading	0.367	-	-	0.367
Fertilizer	0.032	0.375	0.073	0.480
Pesticide	0.039	0.013	0.005	0.057
Machinery	0.225	-	-	0.225
Harvest	0.225	-	-	0.225
Transport	0.408	-	-	0.408
Total	1.296	0.388	0.079	1.763

Table 6.2.4. Planting Energy in Brazil.

	Diesel Oil [MJ/kg-dry]	Natural Gas [MJ/kg-dry]	Electricity [MJ,kWh/kg-dry]	Total [MJ/kg-dry]
Grading	0.024	-	-	0.024
Fertilizer	0.047	0.225	0.092	0.364
Pesticide	0.050	-	-	0.050
Machinery	-	-	-	0.000
Harvest	0.035	-	-	0.035
Transport	-	-	-	0.000
Total	0.156	0.225	0.092	0.473

6.2.2 Energy consumption of pretreatment for energy conversion of biomass

For biomass utilization, pretreatment such as transportation from plantation site, crushing (tipping), and drying are required.

Although each conversion technology requires particular chip size and moisture content of biomass, Table 6.2.5 shows an example (transportation energy, crushing energy, and drying energy). To calculate the transportation energy, it was assumed that 5 t-dry biomass was transported by the truck whose maximum load is 20 t and fuel mileage is 3 km/L. The crushing energy was obtained from the reference. Drying energy was calculated, assuming that biomass is dried till water content becomes 20% from 50%, considering approximately 20% heat loss in addition to the evaporation heat.

When transportation distance is 30 km, preprocessing energy is 75 MJ/t-dry (3.6%) for transportation, 0.786 MJ/t-dry (0.037%) for milling and 2,032 MJ/t-dry (96.4%) for drying respectively. This shows that energy consumption in transportation stage is relatively small on this assumption. Energy consumption in drying stage would be reduced by natural drying or drying with waste heat.

Table 6.2.5. Energy Consumption on Pretreatment.

		Energy Consumption
Transportation (Truck)	Diesel Oil	2.5 MJ/t-dry/km
Crushing Energy	Electricity	0.0832 kWh/t-dry ²)
Drying Energy	Heavy Oil	2,030 MJ/t-dry

6.2.3 Energy efficiency comparison between biomass energy and fossil fuel

Energy consumptions to produce 1 MJ energy were compared between biomass and fossil fuel (coal) (Table 6.2.6). For both cases, the transportation stages from production site to utilization site are omitted for simplification.

Fig. 6.2.2 shows energy consumption and CO₂ emission of biomass and fossil fuel respectively, then the part of ①+② and ①'+②' indicate the boundary here. In the case of biomass, ①+② means energy consumption for the stage of afforestation, crushing, and drying. Coal mining data were obtained from the data of Australia.

Fig. 6.2.3 shows the results of comparison. Energy consumptions of biomass production in North America, Indonesia and Brazil are 0.182 MJ/MJ-biomass, 0.200 MJ/MJ-biomass and 0.132 MJ/MJ-biomass, respectively, and energy consumption of coal production is 0.008 MJ/MJ- coal. The result shows that biomass production process requires much larger energy than coal production process in order to obtain equivalent energy.

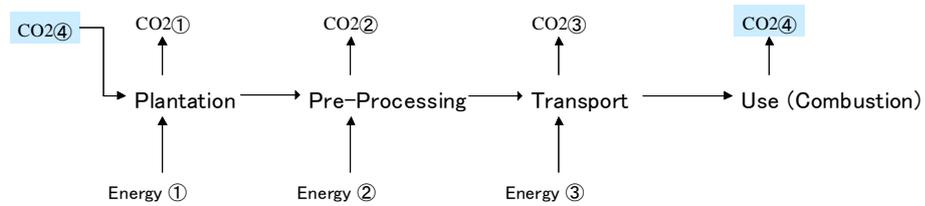
On the LCA, energy consumption evaluation target is determined based on the use of exhaustible energy resources. So biomass energy consumption is not counted as energy

consumption, if the biomass is obtained from sustainable afforestation. In addition to this energy consumption for production, 1 MJ of exhaustible energy resource is consumed at energy usage stage for coal. As a result, life cycle energy consumption becomes lower for biomass than for fossil fuel.

Table 6.2.6. Energy Consumption of Coal Mining.

Energy Source		Open-Cut Mining	Underground Mining
Electricity	kWh/t-coal	9.61	19.4
Diesel Oil	Kg/t-coal	4.158	0.6639
Gasoline	Kg/t-coal	0.01327	0.0113

Biomass Energy



Fossil Fuel Energy

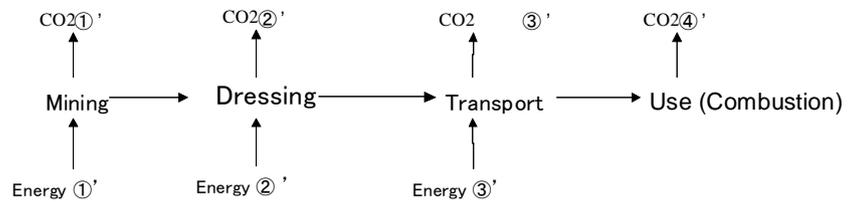


Fig. 6.2.2. Energy Consumption and CO2 Emission image on Biomass and Fossil Fuel.

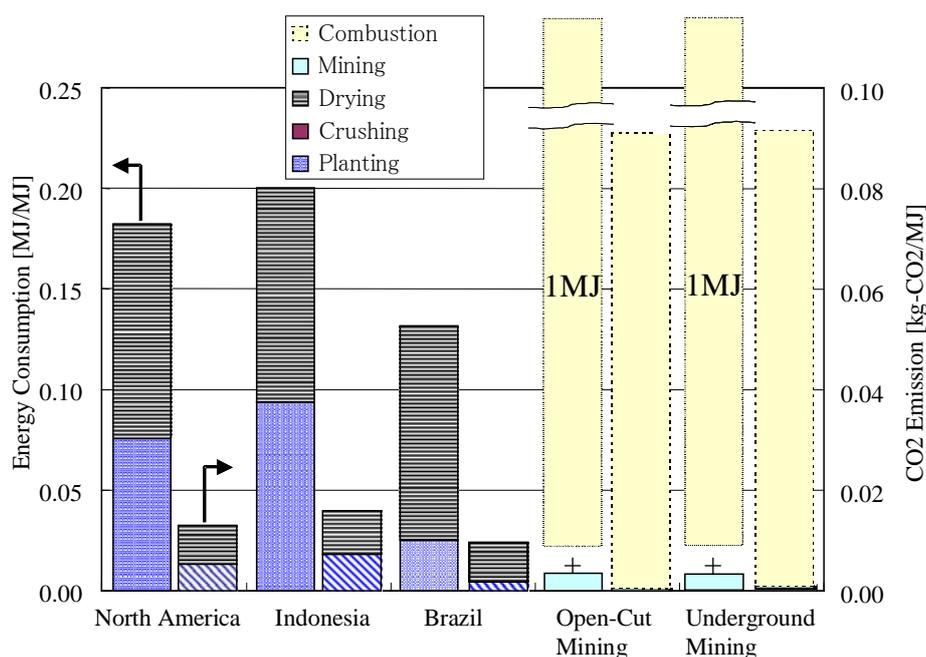


Fig. 6.2.3. Comparison Between Biomass and Coal on Energy Consumption and CO2

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6.3 Carbon Dioxide Emission and Environmental Impact

6.3.1 CO₂ Emission of biomass

On energy evaluation of biomass in the preceding paragraph, light oil, natural gas and electricity are consumed for planting stage; electricity for crushing stage; heavy oil for drying stage. And light oil, gasoline (light oil equivalency), electricity are consumed for coal mining. Evaluating CO₂ emission to consume energy such as light oil, heavy oil, gasoline and natural gas, it is necessary to consider CO₂ emission from combustion and production processes of

them. The power resources composition should be considered to evaluate CO₂ emission of electricity consumption. It was assumed that CO₂ emission according to production process of these energy was equal to those of Japan, and the emission factors were obtained from LCA results (Table 6.3.1) (Tahara 1997, Tahara 1998).

CO₂ emissions of biomass and coal are obtained by multiplying CO₂ emission factor, to energy consumption about biomass production (Fig. 6.2.1). The CO₂ emission of biomass production is 0.0130 kg-CO₂/MJ-biomass. The CO₂ emissions of open-pit and underground coal mining are 0.00053 kg-CO₂/MJ- coal, 0.00039 kg-CO₂/MJ- coal respectively and both of them become 0.091 kg-CO₂/MJ-coal with consideration burning(combustion) stage. It was assumed that the forest would absorb the CO₂ emission (CO₂ ④) from biomass combustion as shown in Fig. 6.2.2.

Table 6.3.1. Unit CO₂ Emission of Various Energy in Japan.

	CO ₂ Emission
Diesel Oil	0.0715 kg-CO ₂ /MJ
Heavy Oil	0.0746 kg-CO ₂ /MJ
Gasoline	0.0715 kg-CO ₂ /MJ
LNG	0.0516 kg-CO ₂ /MJ
Electricity	0.4378 kg-CO ₂ /kWh

6.3.2 Comparison between biomass power generation and the other

Biomass generation technology is compared with the other generation technology (coal fired, oil fired, LNG fired, hydropower, ocean thermal energy conversion, photovoltaic). The biomass power generation is defined as the scale that can manage as much as biomass grown by 30km² afforestation in North America, Indonesia, and Brazil. Annual quantity of sending end generation and power station scale of each power station are shown in table 6.3.2.

The CO₂ emission per 1kWh of each generation plant can be found dividing the sum of CO₂ emission on power station construction and operation (fuel burning and maintenance repair) by the amount of total generated energy, assuming durability year of each generation plant. The durability of all power stations was defined as 30 years here.

Table 6.3.3 and Fig. 6.3.1 show each plant CO₂ emission based on LCA. While facilities of biomass power generation have a similarity to thermal power generation by fossil fuel, CO₂ emission per unit electricity of the biomass generation has a drastic reduction because CO₂ emission on the biomass combustion is not counted. About CO₂ emission, biomass power

generation is a highly competitive technology to the other renewable energy generation.

Table 6.3.2. Plant Scale of Various Power Generation Station.

Type of Generation	Annual Generation [kWh/y]	Plant Scale [MW]	References
Coal Fired	6.08×10^9	1000	Uchiyama et al. , 1991
Oil Fired	6.17×10^9	1000	Uchiyama et al. , 1991
LNG Fired	6.34×10^9	1000	Uchiyama et al. , 1991
Hydropower	3.93×10^7	10	Resources Council, 1983
OTEC (2.5MW)	8.76×10^6	2.5	Resources Council, 1983
OTEC (100MW)	5.70×10^8	100	Tahara et al. , 1993
Photovoltaic (Indonesia)	1.18×10^7	10	Inaba et al. , 1995
Photovoltaic (Japan)	8.64×10^6	10	Inaba et al. , 1995
Biomass Fired (North America)	1.04×10^9	197	Tahara et al. , 1998
Biomass Fired (Indonesia)	1.65×10^8	94	Tahara et al. , 1998
Biomass Fired (Brazil)	5.98×10^8	114	Tahara et al. , 1998

Table 6.3.3. Unit CO2 Emission of Various Power Generation.

Type of Generation	Unit CO2 Emission [kg-CO ₂ /kWh]
Coal Fired	0.916
Oil Fired	0.756
LNG Fired	0.563
Hydropower	0.017
OTEC (2.5MW)	0.119
OTEC (100MW)	0.014
Photovoltaic (Indonesia)	0.148
Photovoltaic (Japan)	0.187
Biomass Fired (North America)	0.081
Biomass Fired (Indonesia)	0.119
Biomass Fired (Brazil)	0.024

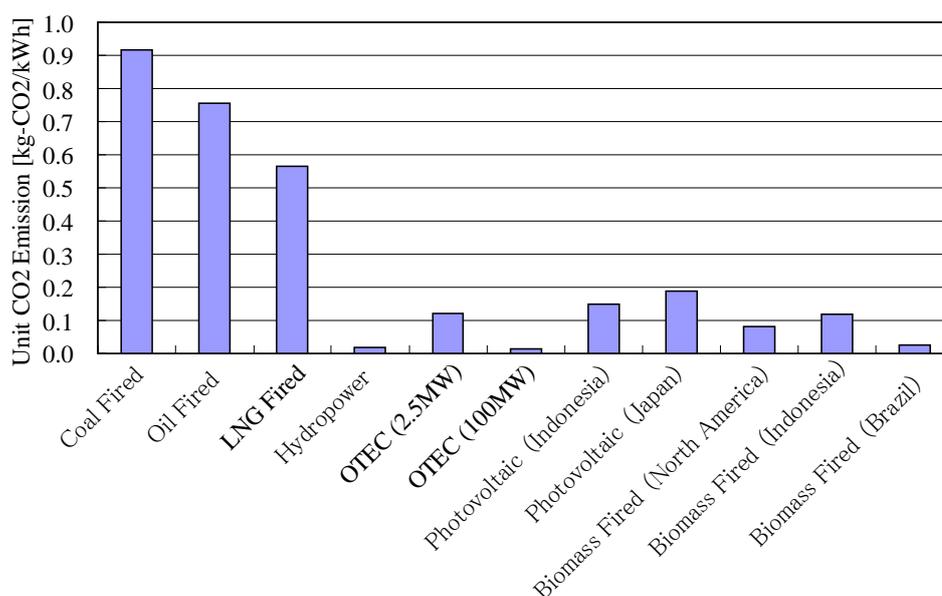


Fig. 6.3.1. Unit CO2 Emission of Various Power Generation.

6.3.3 Environmental impact of biomass

CO2 emission has been focused on as only one environmental impact of biomass. But it is necessary to consider the emission of other greenhouse gases such as CH4 and N2O in biomass production. Land use of biomass production is also key effect to environment.

In addition, the competition with food might be considered as derivative environmental impact in the case of cultivation type of biomass.

Further information

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6.4 Economical Evaluation of Bioenergy

6.4.1 Cost of bioenergy

Cost of Bioenergy can be disaggregated into 3 stages: resource cost, conversion technology cost, and secondary energy cost at consumer end.

Resource cost consists of not only cost of resource but also 1) opportunity cost (the value if biomass was used as material or food), 2) waste management cost for appropriate disposal, and 3) environment cost (environmental impact of biomass production).

Conversion technology cost is dependent on type of biomass input, type of technology, time frame of evaluation, and other factors.

Secondary energy (electricity, heat, fuel, and other forms that are converted from biomass resources) cost is calculated as summation of resource cost and conversion technology cost.

It is necessary to evaluate the cost of bioenergy with the latest information relating to energy cost, land use competition, available bioenergy technologies, externality of environment, and other aspects.

6.4.2 Bioenergy resource cost

Bioenergy resource consists of raw material, plantation bioenergy, and residue biomass (discharge during biomass conversion and consumption process). When raw material such as wood and food are converted into bioenergy, opportunity cost is incurred. Environment cost is estimated based on impacts on local land use change, biodiversity and aspects. Biomass residue can be negative when appropriate waste management of biomass is implemented.

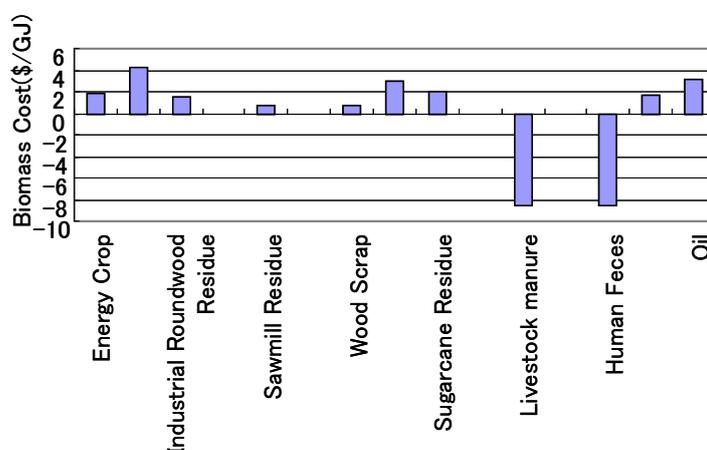


Fig. 6.4.1 Biomass Cost.

Bioenergy resource cost can be expressed by the following equation:

$$[\text{bioenergy resource cost}] = [\text{supply cost}] + [\text{opportunity cost}] + [\text{environment cost}] - [\text{disposal cost}]$$

Modern wood fuel and wooden chip have higher cost due to their good quality as material and opportunity cost. Cereal residues also have higher cost due to transportation and stock. Plantation cost is essentially high. Residue bioenergy can be available at negative cost due to waste management.

6.4.3 Biomass technology conversion cost

Traditional biomass is directly used as wood or charcoal. Modern biomass is consumed as useful energy carrier such as electricity, liquid fuels, and gaseous fuels. There are several types of conversion technologies such as electricity generation (steam generation, integrated gasification generation), pyrolysis, and fermentation (anaerobic digestion generation, ethanol production).

Generation cost of biomass integrated gasification was evaluated as follows. Installation cost was projected to be 2102 \$/kWe (capacity 75 MWe, efficiency 36%) in 1997 , 1892 \$/kWe (capacity 100MWe, efficiency 37%) in 2000, 1111 \$/kWe (capacity 110 MWe, efficiency 45%) in 2030 (price in the year of 1996). But still it is in experimental stage in 2001. Another evaluation estimates installation cost to be 1221 \$/kWe with 100 MWe capacity (1990 price). Annual expenditure (as a portion of annualized installation cost and operation cost) is assumed to be 12%.

Fig shows bioenergy conversion cost of typical technologies. Though cost of fermentation technology is higher than others, it can be moderated to include waste management cost of livestock manure. Technology cost for steam generation, integrated gasification generation, and pyrolysis is expected to be cheaper due to technology development and deployment, but it is uncertain. Cost of co-firing generation is the additional cost to reform existing coal fired plant.

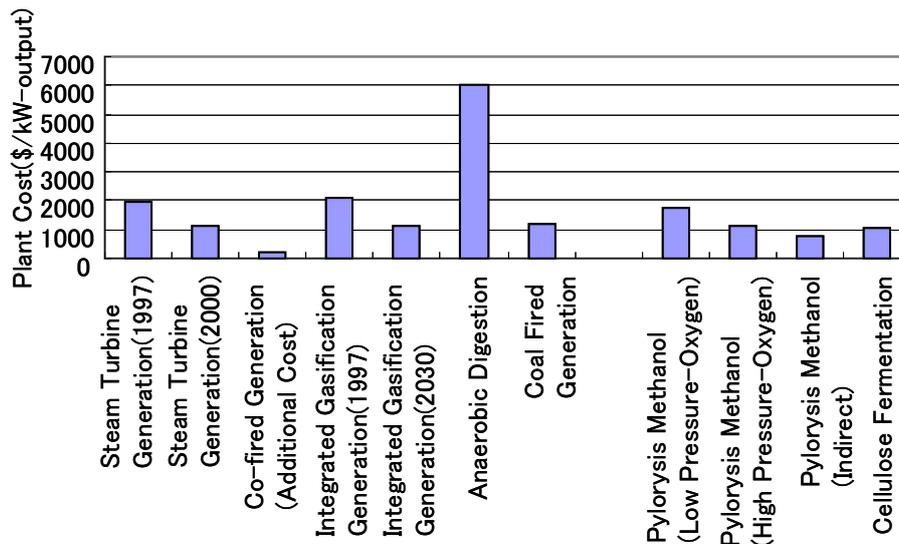


Fig. 6.4.2 Plant Cost.

6.4.4 Secondary energy cost

Secondary energy (converted into electricity, heat, and liquid fuels using biomass resources through appropriate conversion technologies) cost is calculated. Annual installation cost is calculated based on the following assumptions: 1) interest rate is 5%, 2) lifetime is 30 years (20 years for pyrolysis and fermentation generation), 3) annual expenditure is 12% (10% for fermentation generation, 17% for pyrolysis, 27% for ethanol fermentation). This analysis shows that integrated gasification generation is promising if it is well developed as predicted. Pyrolysis is also promising if its technology cost can reduce in the future. Furthermore, the cost evaluation includes uncertainty. Resource cost depends on local situation and technology cost is subjective to technology RDD. Therefore, for practical use, it is necessary to analyze the bioenergy cost based on the latest information.

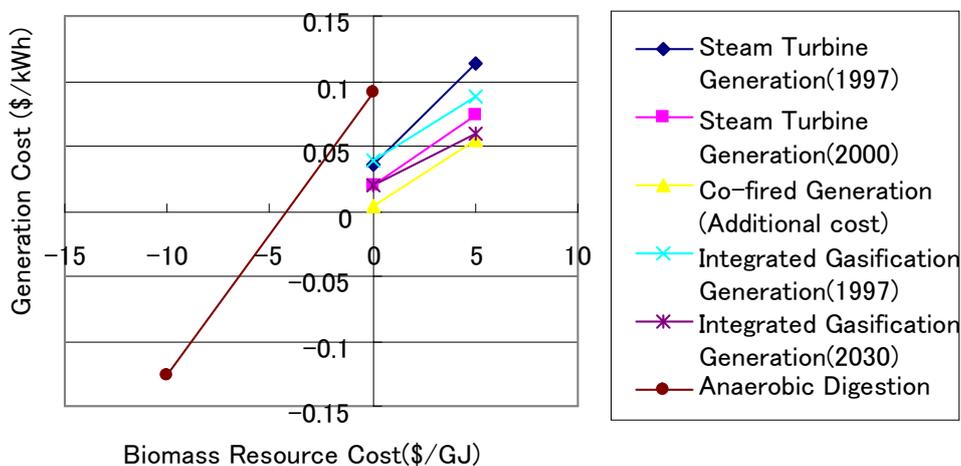


Fig 6.4.3 Biomass Cost (Generation).

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6.5 Other Evaluation

6.5.1 Standard of living

Since agriculture is of much importance for the economies under development, it is desirable that sustainable agriculture leads to improvement of farmers’ standard of living as well as their income. In this section, a small-scale biomethanation plant in a rural area of Thailand is taken up as an example. A small farm gave animal manure as feedstock for anaerobic digestion. Manure from 5 cows was feedstock. Product biogas was used for cooking. It was expected to be sufficient for 3-times cooking for 1 hour for a daily basis. In this sense, the small-scale biomethanation is desirable since the farmers can use the cattle manure in their own farm, and the product gas can be used for their own purpose. Utilization of the fermentation residue as fertilizer resulted in the recycling, reducing the amount of chemical fertilizer. It is usual for the Thai farmers to use chemical fertilizer that is not sustainable, and the product compost from this biomethanation plant is helpful to switch to sustainable agriculture. As a result, the plant achieved the local recycling of cattle manure as energy (biogas) and material (compost). Another good aspect of this biomethanation plant was the increase in farmers’ hygiene. The number of flies reduced after introduction of the plant.



Fig. 6.5.1. Fermentation reactor under construction.

The plant investigated in 2006 was the only one under operation, and other two were under

construction (Fig. 6.5.1). The reason for this should be the farmers' ignorance on this technology. During the discussion with Thai people, it was pointed out that education of people is important. In the rural area of Thailand, the literacy rate is not high. Actually, the investigated plant was a demonstration one fully supported by the local government to show neighbors the effectiveness of the biomethanation plant. In this sense, it is important to supply proper information on this technology to the farmers.

What is important for the biomass utilization for farmers to be effective is the accessibility of the biomass plant or biomass collecting site from farmers. Even if farmers possess or produce biomass feedstock, it is nothing if they do not have access to the sites where it can be made use of.

6.5.2 Farmers' income

By the use of the plant described above, the farmer did not need to pay 350 bahts a month (100 bahts = 2.85 US\$, as of December 2006), which was the cost of propane gas. This was a fair amount for a farmer's family, and they said that they were happy with the reduction of this cost. The fermentation residue was placed in a bag by 30 kg and sold at 12 bahts per bag. The system was quite simple, and the plant



Fig. 6.5.2. Ethanol production plant in Thailand.

could be fabricated by villagers in 9 days. The material cost 5,000 bahts and total cost was 7,400 bahts, so the economic payback period was 21.1 months. A person from the local government who knew the know-how could help the farmer for building. The means to make the process economically feasible is simple structure and free labor to help each other in the village. The materials are cheap. No special skill was needed for operation, the main body of operation is farmers themselves, and this reduces the labor cost. The simplicity results in no necessity of operation person or labor cost, and farmers themselves can construct the plant.

Incidentally, income of farmers living around an ethanol production plant in Thailand is discussed here (Fig. 6.5.2). The plant is planning to construct a 100,000-L/day ethanol plant and its feedstock is assumed to be cassava. It is because the market price of cassava is rather stable than that of molasses. The farmers could not get income when the plant used molasses

since the plant paid to sugar production factories. Therefore, the plant thinks that increase in the ethanol production from cassava will make cassava cultivation more attractive and people in rural area remain. The unit price of cassava chips is now 3.7 bahts/kg. In order to sell cassava to the plant, farmers have to chip and dry (below 18% of water content) for pretreatment. Considering this, they can earn 1 baht/kg and this profit is quite attractive for them.

There are mainly two ways to support farmers. One is to supply energy so that they have the access to useful fuels. In Thailand, small-scale biomethanation provides cooking gas to farmers, so they need not to buy propane gas for cooking. This support to farmers is also effective for sustainable agriculture due to the reduction of fossil fuel utilization. The other support is by cash. When they grow feedstock for ethanol production and sell it at a higher price, they can get money for buying electricity. Since those who use ethanol as fuel are richer compared to farmers, this mechanism can be considered as ‘redistribution of wealth.’

6.5.3 Energy security and foreign currency

Production of bioenergy is expected to improve domestic energy security. On the other hand, there are opportunities for developing countries to get foreign currency by exporting bioenergy. Here describes the commitment to bioenergy production by the Thai government briefly.

At the time of December 2006, the unit price of ethanol was 23.50 baht per liter, which is determined by the Ministry of Energy, Thailand. In Thailand, 6 plants are licensed to produce ethanol fuel from cassava. The production capacity of the 6 plants will be 702 million L/year, demanding 4.13 million ton/year of cassava. Thailand is the largest exporter of cassava in Asia. The average annual production is 20 million ton/year: About 8 million ton for domestic starch consumption; Another 8 million ton (cassava chips) for export; The remaining 4 million ton can be used for ethanol. Therefore, the cassava production for food and that for ethanol are balanced now. Cultivated area of cassava is about 1 million ha. The expansion of agricultural land is prohibited, but farmers can grow a different crop if allowed by the government. In the future, the amount of cassava production for ethanol may increase, while it is often said that bioenergy utilization may be in conflict with food production, *e.g.*, the international growing demand for ethanol may threaten the stability of domestic supply of food. Even the cassava production for food and that for ethanol are balanced in Thailand now, the future use of cassava root should be carefully determined. Moreover, the market price of cassava heavily declined before, so financial support by the government to farmers will be

necessary in some instances.

Further information

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6.6 Problems to be Considered

6.6.1 Biodiversity (An example of a palm-oil production)

(a) The summary of a palm-oil production

About biomass utilization, the palm oil production gives an urgent serious to biodiversity in Malaysia and Indonesia, now.

Malaysia and Indonesia account for about 85% of the palm oil production in the world. In Malaysia, a large scale plantation began to be suddenly developed in 1960's. An Indonesian government put out the policy said becoming the world's largest production country of palm oil, and production including the construction of a large scale plantation was begun in 1980's. From 1990 to 2002, the oil palm plantation areas increase about twice in Malaysia and more than 3 times in Indonesia.

As the development of the oil palm plantation, very large land need for the operation of oil mill (the scale of Southeastern Asian typical plantations is 10,000-25,000 ha), and there are a lot of things that the forest is destroyed in creation. About 87% of the deforestation in Malaysia from 1985 to 2000 is considered to be the oil palm plantation development, and it is said by Indonesia that at least 70% of the plantation cleared a forest. Furthermore, the oil palm plantations are developed more and more around the buffer zone such as the national parks, and the biological important area.

(b) Palm oil production and biodiversity

The palm oil plantations are overlapped the low land in tropical rain forests where hold the highest biodiversity on the earth, as it were, located the "Hot Spot" where is "the area that is on the verge of the destruction though to hold the high biodiversity on the earth scale". This area is a little habitation area of the orangutan, Sumatra tiger, Borneo elephant, rhinoceros,

Malaysian tapir and so on. Development of the oil palm plantations is the biggest menace for the rare tropical rain forests in Southeast Asia.

It's said 80-100% of mammal, reptiles and birds disappear as developing the plantations in the tropical forest. According to the investigation of Miura et al., more than 400 kinds of wild animals were found out in a natural forest or second growth, but the plantations after cut down all forest and cultivating only palm oil, less than 10 kinds were found.(see below)

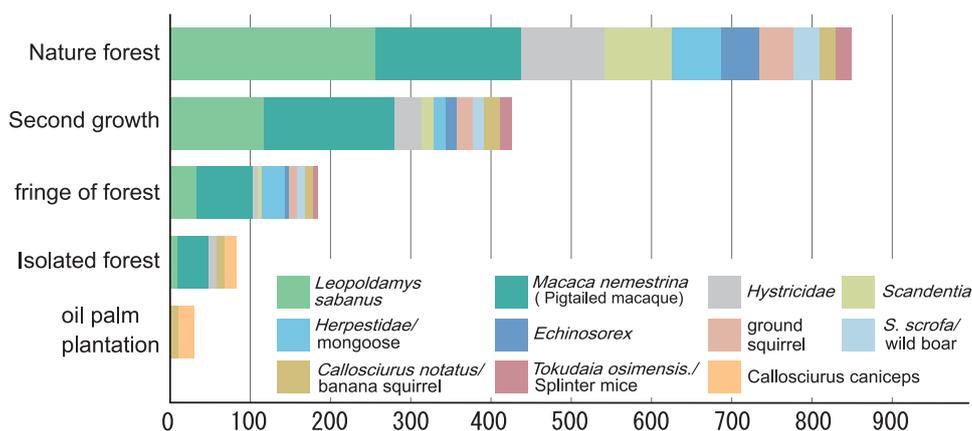


Fig. 6.6.1. Comparison of the appearance frequency of the wild animal used an automatic imager (in Malaysia)

(c) Other impacts due to the palm oil production

In Indonesia, though the control to the illegal felling is strengthened, the authorities permit easier to fell to develop the oil palm plantation. Some are considered to fake the authorities to get permissions of illegal felling. Furthermore, at the time of development, field firing is frequently illegal and as the result peat layer is fired. Then the very large area is disappeared and there is bad influence for the ecosystem. And CO₂ is produced at two billions tons per year that exceeds Japan's emission. This is a big cause of the climate change.

In addition described above, development of the oil palm plantations bring the injustice of local people impacts on economy, culture and social instability such as indigenous people depending on the forest as well as biological diversity disappearance. After the operation of the plantations started, there are problems of the pollutions of soil and river by pesticide and chemical fertilizer, soil erosion, such as the labor problems low wages, pesticide damage, child labor, illegal workers, water pollution by waste fluid and residual substance or methane outbreak and so on.

6.6.2 Land use competitions

The limit of biomass resources human beings use becomes obvious. Therefore, it is expected that competitions between of biomass uses such as food, material, and energy will become severe; consequently land use competitions between forest, arable land, pasture, and other lands will become severe, too.

(a) Competitions between forest, arable land, pasture, and other lands.

Forests have decreased by activity of human beings for long years. The forest area in the world has decreased by 1.2 billion hectares since 1700. Especially, the forest area of North Africa and the Middle East, and China decreased below half. In the same period the arable land in the world increased by 1.2 billion hectares. In the same period, the pasture in the world decreased a little by 70 million hectares. Thus, in the historical view point, the deforestation was caused by the increase of arable land. Conversely, the deforestation area was converted to arable land.

Concerning land use change after 1950, deforestation in developed regions has been stopped and forest areas in Western Europe and North America increase reversely. On the other hand, in developing regions such as tropical regions, China, and Middle East, deforestation continues. The reasons are conversion to arable land and pasture and un-sustainable slash-and-burn farming, etc.

The deforestation in the developing regions causes not only a regional environmental destruction but also global environmental problem of CO₂ emission. In addition, in regions in high population density and industries in high speed such as Japan, South Korea, and Taiwan, the arable lands are decreasing. This is because in those regions land demands for housing and factory increase and the agriculture is not competitive in the global agriculture markets. In Japan the arable land decreased by 10% from 5.0 million hectares to 4.6 million hectares between 1976 and 1991. In South Korea, the arable land decreased by 6.6% in the same period.

(b) Competition between food production and energy crop production

On arable land, energy crops are also producible besides food. In countries where surplus arable land is available such as the United States and Brazil, they could use the surplus arable land for energy crop production rather than for fallow field. Especially, in those countries in 2006 to 2007 when the oil price hits the historical record, they produce energy crops and produce biofuel such as bioethanol and bio-diesel (BDF). In the United States they produce bioethanol from corn on a large scale. In Brazil they produce bioethanol from sugarcane on a large scale. In addition, BDF is produced from vegetable oil such as rapeseed oil and palm oil.

However, since arable lands are limited, the production of energy crops reduces the arable land where food crops are producible. It is pointed out that excessive production of energy crop may lead to food shortage. In addition, it is explained in 6.7.5 that the competition between food production and energy crop production is handled in an energy model.

Further information

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6.7 Energy Models

6.7.1 Outline of energy models

An energy model is a mathematical model that expresses energy systems. Since energy systems including primary energy production, energy transportation, and energy conversion are complicated, it is difficult to get intuit insight about the desired energy system. Using the energy model they can analyze an economic energy systems and energy structure in the future.

An energy model is divided into two kinds that are a simulation type and an optimized type. The simulation type is a type that assembles energy system composition in the future deductively from the initial condition of the energy system and various kinds of exogenous assumptions such as future population and economic growth rates.

The optimization type is a type that uses mathematical optimization technique and finds the optimal energy system under exogenous constraints. The typical optimal standards are minimization of energy system cost and maximization of total consumption in the society. The typical exogenous constraints are energy resource constraints and data of energy conversion technologies.

6.7.2 Typical energy model

Energy models that are used for policy study about energy and environment were developed as following orders. First, energy models that focus on specific energy technologies that are gigantic technologies to need long-term development plan and huge cost such as nuclear

technologies.

Since latter half of 1980's when global warming is important topic, energy models that include overall energy systems and CO₂ emission have been developed. The first energy model that focused on policy study about global warming is Edmonds-Reilly model developed in the United States that is a simulation type model. ETA-MACRO and DICE model developed in the United States are typical optimization model that evaluate global energy, economy, and environment. In addition, GLUE model developed in Japan is a typical model that evaluates global bioenergy supply potential considering land use competitions and overall biomass flows.

6.7.3 DNE21 model

DNE21 model is an optimization model that was developed for assessment of technologies that mitigate global warming. DNE21 model is based on the NE21 (New Earth 21) model that was developed for numerical analysis of "New Earth Plan" announced in 1990 by Japanese government. DNE21 is dynamic model that minimizes inter-temporal energy systems cost in the world. In the model the world is divided into 10 regions and global energy systems till 2100 are analyzed. In the model bioenergy conversion technologies are analyzed in detail.

6.7.4 GLUE model

GLUE model is the abbreviation of global land use and energy model and was developed in Japan. The model that is a simulation model is a typical model that evaluates bioenergy supply potential in present and in the future. In the model, biomass demand is calculated by data of biomass demand per capita and population. Biomass supply potential is calculated by data of arable land area and arable land productivity. In the model the biomass demand and the biomass supply potential are compared and the surplus arable land and the energy crop supply potential produced on the surplus arable land are calculated. In addition, the model evaluates supply potential of biomass residues discharged from processes of biomass flows such as production, processing, consumption, disposal, and recycling.

The recent version of GLUE model is an optimization type and evaluates not only bioenergy supply potential but also biomass utilization technologies.

6.7.5 Land use competitions in GLUE model

In a GLUE model, the surplus arable land considering land use competitions is calculated as follows. Biomass demand is calculated from population and food demand per capita. Biomass supply potential is calculated from land areas for biomass production and the biomass productivity of the land areas. Then, surplus arable land considering land use competitions is calculated from the biomass demand and the biomass supply potential.

The details of the calculation about land use competitions are as follows. First, animal food demand produced from cereal feed is calculated from animal food demand minus fish supply minus animal food supply from pasture. Cereal demand is calculated from the cereal feed demand plus cereal demand for vegetable food. The land demand for cereals is calculated from the cereal demand divided by cereal productivity. The land for energy crop production is calculated from the total land for cereal production minus the land demand for cereal production. If the total land for cereal production is smaller than the land demand for cereal production, food shortage occurs and the land for energy crop production is zero.

Consequently, in a GLUE model it is assumed that the highest priority in the land use competitions of arable land is the land use for vegetable food production. The next is the land use for feed production that is converted to animal food. The last is the land use for energy crops production. In order to enlarge the total calorie supply, it is assumed that priority is given to supply of vegetable food over supply of animal food.

Further information

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Part 7. Biomass situation in Asian countries

7.1 China

7.1.1 Background

With rapid economic development, energy demand increases rapidly also in China. China's total energy consumption already occupies the second place in the world. Fig.1 shows the trends of China's oil consumption and net imports from 1990 to 2006. Since 1993 when China became a net import country of petroleum, the dependency of petroleum upon import increased from 7.6% in 1995 to 47.0% in 2006. It is forecasted that in 2020 the petroleum consumption and import in China will amount to 450 million tons and 250 million tons, respectively, with 55% dependency of petroleum upon petroleum import. It's expected that transportation will contribute the most oil consumption growth in future. Compared to the transportation oil consumption in 2000 which accounts for about 1/3 of the total petroleum consumption, it is forecasted that the ration will rise to 43% and 57% by 2010 and 2020.

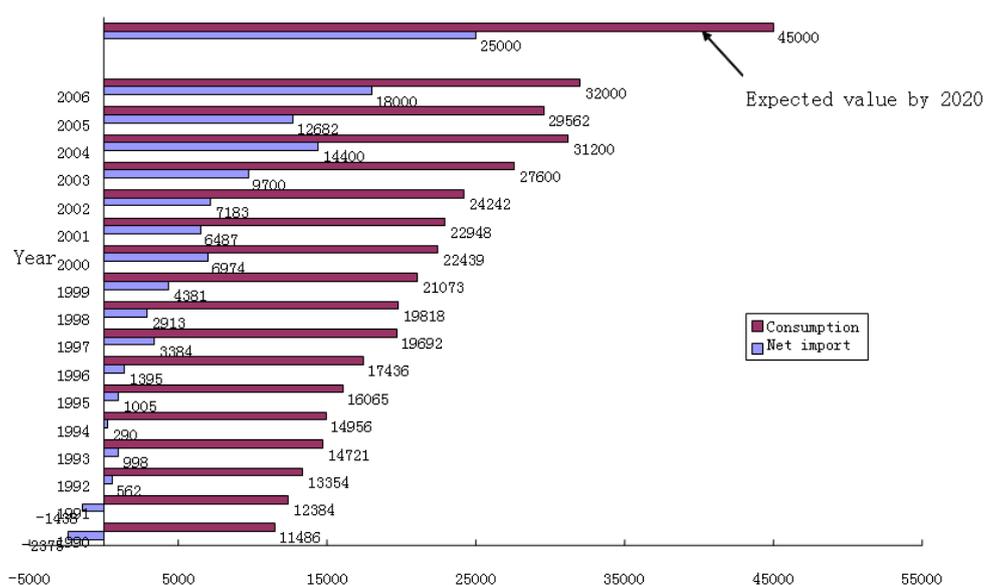


Fig. 7.1.1. Trends of China's oil consumption and net imports from 1990 to 2006

7.1.2 Situation of biofuels development in China

Because of the insufficient fuel supply and the requirements for energy saving and pollutants emissions reduction, China national government pays more and more attentions to research and development of bio-fuels. The People's Republic of China Renewable Energy Law was issued in 2005.

Ethanol gasoline project started in 2001 in China. There are only four plants permitted by the government to produce food based fuel ethanol. The governments' supports play an important role on simulating the ethanol gasoline development in China, especially at the initiation stage of the ethanol gasoline demonstration by preferential policies like incentives. The incentives include: 1) The excise tax of denatured fuel ethanol (5%) is free. 2) The value-added tax of denatured fuel ethanol is imposed first, and then given back to the ethanol provider. 3) The price of denatured fuel ethanol sold to the petroleum companies which are also the blending operators is (0.9111*manufacturer's price of 90# gasoline). While the market prices of all kinds of E10 (90#, 93# or 97#) are the same as 90#, 93# or 97# gasoline. 4) An allowance is paid to the ethanol provider. These incentives will be executed until 2008. Now ethanol gasoline has been used in 9 provinces and the total consumption was 1.54 million tons in 2006. However, to ensure the food safety, no more food based fuel ethanol plants are permitted by the China national government any more. In the future, non-food feedstock including cassava, sweet potato, sweet sorghum and lignocellulose are potential for fuel ethanol production. A 200 000 tons/year fuel ethanol plant with cassava as feedstock in Guangxi province has been permitted by the government and is expected to start up soon. The four exiting fuel ethanol plants are encouraged to use non-food feedstock too.

There are more than 10 biodiesel plants in China. The amount of production is about 100 000 tons/year. <Biodiesel Blend Stock (BD100) for Diesel Engine Fuels> was issued in May 2007. But there is not yet regular policy for biodiesel sales like fuel ethanol. Some biodiesel are for non-engine utilization. One problem of biodiesel development in China now is the feedstock supply. China needs to import more than 6 million tons edible oil per year. It is impossible to use edible oil such as soybean oil and rape seed oil for bio-diesel production. Now most biodiesel plants in China are using waste oils as feedstock. However, with the development of biodiesel, the price of waste oils is higher and higher. Woody oils are getting more and more attentions. The “national bioenergy-directed forest construction program” and “Woody feedstock plantation plan for biodiesel during 11th Five-Year plan” were issued by State Forestry Administration of China, which indicate that 400 000 hectares of *Jatropha curcas* will be

planted in Yunnan, Sichuan, Guizhou and Chongqing provinces; 250 000 hectares of *Pistacia Chinensis* will be planted in Hebei, Shanxi, Anhui and Henan Provinces; 50 000 hectares of *Cornus Wilsoniana* will be planted in Hunan, Hubei and Jiangxi Provinces; 133 333 hectares of *Xanthoceras Sorbifolia* will be planted in Inner Mongolia, Liaoning and Xinjiang provinces.

7.1.3 Conclusion

With the rapid economic development, the great insufficiency of energy supply has become the “Bottleneck” of sustainable development in China. Currently the important issue to be solved is to accelerate the development of biomass energy so as to relieve the pressure of resources and the environment. Moreover, as a responsible country, China should take the international responsibility to save energy and reduce pollution discharge. Hence, the biomass energy industry is promising with a fairly bright future in China. At present, the biomass energy consumption is 8% of the total fuel consumption. According to “Mid and Long Term Development Plan of Renewable Energies” issued on September 4th 2007, the percentages of biomass energy consumption will increase to 10% by 2010 and 15% by 2020. By 2010, annual consumption of non-grain based fuel ethanol shall reach 2 million tons, and that of biodiesel shall reach 200 000 tons in China; by 2020, annual consumption of fuel ethanol shall reach 10 million tons, and that of biodiesel shall reach 2 million tons in China.

7.2 Korea

7.2.1 Amount of biomass resources in Korea

Major biomass resources available in Korea are organic wastes and the agricultural and forest residues. The potential and recoverable amounts of biomass for energy utilization are summarized in Table 7.2.1. According to the data in Table 7.2.1, the total amount of biomass resources available in Korea is about 80 million ton, only 30% of the potential biomass resources are currently utilized for energy production.

Table 7.2.1. Biomass resources in Korea.

Resources	Potential, x 10 ³ Mt/ year	Recoverable, x 10 ³ Mt/ year
Forest residues	7,830	1,300
Agricultural residues	16,000	4,900
Food waste	5,100	5,100
Municipal waste	1,600	260
Animal wastes	47,000	
Sludge	2,500	280
Total		

S.C. Park et al. (2007).

7.2.2 Policies and Mansatories

New and Renewable Energy Promotion law enacted in 2002 approves bioenergy as a renewable energy and supports its implementation. The total exemption of excise duty is now available for biodiesel used as motor fuel. The current excise duty of diesel is about \$0.5/L. All Korean oil refineries should mix a certain amount of biodiesel in their diesel oil products (Table 7.2.2).

Table 7.2.2. Mandatory target for the biodiesel implementation (KMOCIE, 2007).

Year	2007	2008	2009	2010	2011	2012
Biodiesel content in diesel, %	0.5	1.0	1.5	2.0	2.5	3.0

7.2.3 Targets

For bioenergy, the following targets have been set up by Korean Ministry of Commerce, Industry and Energy (KMOCIE) in 2002 (Table 7.2.3).

Table 7.2.3. Targets for bioenergy implementation in Korea.

Year	2004	2005	2006	2007	2008	2009	2010	2011
Heat, x 10 ³ toe	236	277	283	472	477	483	489	679
Power, x GWh	1232	1848	2465	3081	3383	3697	4000	4313

7.2.4 Other activities

- Biodiesel

Severe air pollution over the big cities in Korea also helps the introduction of biodiesel in the transport sector because biodiesel blended fuels may reduce the emissions of the air pollutants from vehicles. Demonstration supply of BD20 had been started in Seoul Metropolitan and Chonbuk Province from May 2002 and lasted by June 2006. During the period of the demonstration supply, several important works have been done to resolve the controversial issues like the feasibility of BD20 as a motor fuel, the preparation of the biodiesel fuel specification and the establishment of distribution infra for the biodiesel blended fuels. After a year work, the draft for the standards having 16 specification parameters was made. The figures taken in the standards are virtually same to those of the European standards, EN14214. Actual fleet tests also have been done with BD5 and BD20 prepared with the biodiesel which meets the Korean biodiesel standards for two years. Through the fleet tests, BD20 was found to be not suitable for the passenger cars. In the meanwhile, no troubles have been observed with the use of BD5. So KMOCIE prepared a new biodiesel distribution system and enforced it from July of 2006 (Figure 1). According to new plan, all Korean oil refineries should buy 100,000 kl biodiesel /year and mix them into their diesel products and supply the blended diesel to all gas stations. As a result, all diesel oils sold in Korea contain about 0.5% of biodiesel. BD20 is allowed to supply only to captive fleets which have their own gas pumps.

With the strong support of Korean Government on biodiesel implementation, the biodiesel business is getting active. The stable supply of raw material is going to be an important issue. Various activities are under way to secure the stable supply of feedstocks for biodiesel production. The activities include the demonstration cultivation of winter rapeseed to determine the feasibility of mass production of canola domestically and *Jatropha* plantation in some Southeast Asian countries..

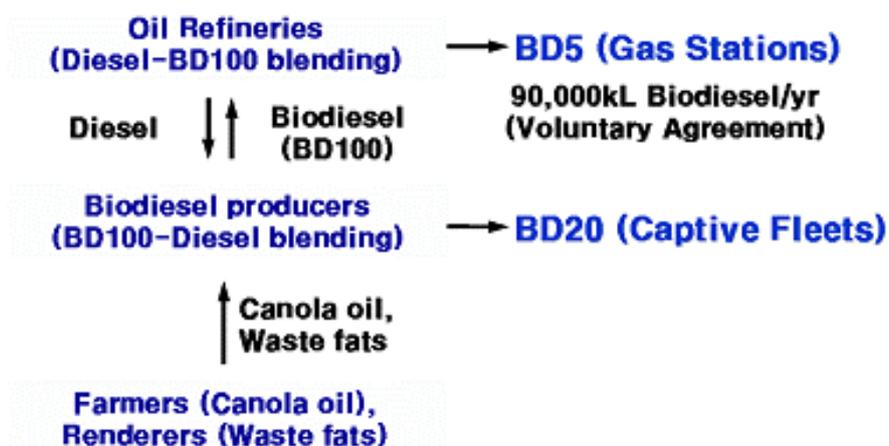


Fig. 7.2.1. New biodiesel distribution infra in Korea.

7.3 Myanmar

The land area of Myanmar is 690,00 km² (1.8 times as large as Japan), and it is the largest country in the continental South-East Asia. Its population is 52 million, and its climate belongs to tropical monsoon except northern region. Thus, its nature, biosystem, and biodiversity is unique and precious. Myanmar also enjoys plentiful resources such as rice, forestry resources, and mineral resources. About 70% of the working population belong to agricultural sector and occupies 60% of GDP, and industrial sector contributes to GDP by only 10%. Politically, after the World War II, the democratic system was achieved for a while, but the National Congress was ceased by the Coup d'etat in 1996, and the nation is under military administration since then. It is politically unclear, and economic problems remains, thus being one of the poorest country in the world. There are no laws enforced related with biomass, but all residue is used because of the lack in material and fuel. Mill residue is used as fuel, and livestock and food waste is used as fertilizer, leaving no residue. In a sense, biomass utilization is well made due to the poverty society.

Two interesting examples in terms of rice husk utilization were found during the onsite inspection. Electricity shortage, incomplete infrastructure, and shortage in fossil fuel resulted in employment of rice-husk steam boiler and steam piston engines (made in Germany, 1925) were driving the rice-cleaners (about 600 places). However, the thermal efficiency of the steam boiler is very low, and consumption of the rice husk is large, the number is decreasing.

Another example is the driving of small-scale rice cleaners by rice-husk gasifier and gas engine, which is spreading recently. All the gasifiers are domestic, and of the down-draft type. The rice husk is supplied from the top, and the ash is removed from the bottom. The other elements are combination of water scrubber, filter, and gas engine, and the product of Myanmar. Second-hand Japanese diesel engines (bus and truck) are modified to gas engines by exchanging injection nozzle with ignition plug. The output of the most gasifiers is 20-50 kW. Typically, 20 kW is produced by rice husk supply of 30 kg/h. About 100 of this type of gasification and power generation system were used in 2000, and it is estimated that 300 were used in 2005. The gasifier-power generation plant produced by the company under the Ministry of Commerce, Myanmar has electric output capacity of 140-160 kW. The system is equipped with a down-draft gasifier, water-cooling jacket at the bottom section of the furnace, and ash removal system. The product gas is washed with a water scrubber and stored in a gas tank before being supplied to the gas engine. The pamphlet says that this system is sold at about 350 kJPY (The prices of commodities is 1/100 of that in Japan). The composition of the product gas is shown in Table 7.3.1.

Table 7.3.1 The composition of the gas produced from rice husk.

Carbon dioxide	12.6	%
Carbon monoxide	17.9	%
Nitrogen	57.0	%
Oxygen	0.9	%
Hydrogen	8.8	%
Methane	1.9	%
Others	0.9	%

Production of the gasifier is conducted in a ironworks with several employees, but standardization of the parts is made, and they have some stocks of the parts. Myanmar still has many regulations, and biomass and other residues are needed to be used due to the lack in commodities and fuels. Bagasse produced from the sugar mills are used for self power generation. Rice husk and charcoals are used for various purposes, and no residues are available. One of the private rice mills strongly desired to improve the rice husk boiler and steam engine to achieve higher efficiencies.

Recently, private rice mills are gradually getting busy due to the policy of liberating the economy, although it is for the limited area. The shortage in electricity and fossil fuels will continue, and it is expected that the small-scale gasifier and gas engine system will be used

more and more for driving rice mill and other devices. Presently, production and introduction of biofuels are not yet made, but Myanmar has a large area and good climate and possesses high potential of producing forest resources and plantation crops. In long term, potential to produce bioethanol and biodiesel is as promising as Thailand, Malaysia, and Indonesia.

The proper form of biomass utilization differs from case to case depending on the natural, social, and economic conditions, and thus elaborate planning is needed. To collect the latest information for this purpose, collaboration office between universities and other sectors is desirable. This kind of collaborative network among university, academic organization, NPO, and international organization will encourage the utilization of small-scale biomass.

Myanmar is a Buddhist country has a high level of education (the rate of school attendance: 96.56%, the literacy rate: 93.3%). The economic development may be late among ASEAN countries, but for its development foreign universities and academic organizations can be a large help.

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7.4 Laos

Lao PDR is a mountainous country with a population of about 5.6 million, over 80% of which lives in rural areas and is engaged in rice-based agriculture and harvesting of forest products. The narrowly based economy is one of the least developed in Asia with an approximate per capita Gross National Product of around US\$ 500 per annum (2006)

The Main Economic in Laos is from the Agriculture , Forestry, Power Generation, Mining, Small industries and agriculture is 42.2 % of the Gross Domestic Product , while the Industry is 31.5 % , Services 25.4 % and Import duties 0.9 % (in 2006) .

Lao PDR is endowed with significant indigenous energy resources for electricity generation. Hydropower is the most abundant and cost-effective form. The energy resources range from traditional energy source such as fuel-wood to coal and hydropower. The forest areas which cover about 40 % of total land are a potential source for substantial traditional energy supplies.

The Lao power sector is in the good progress stage as 54.1 % of the population having access to electricity in 2006 . but the main energy consumption in Laos comes from fuelwood for cooking .

In order to meet the government target for the increasing the households electrification ration to be 70 % of total households in 2010 and 90% in 2020 , the Government set up the Power Sector Policy :

1. Maintain and expand an affordable, reliable and sustainable electricity supply in Lao PDR to promote economic and social development;
2. Promote power generation for export to provide revenues to meet GOL development objectives;
3. Develop and enhance legal and regulatory framework to effectively direct and facilitate power development; and
4. Strengthen institutions and institutional structures to clarify responsibilities, strengthen commercial functions and streamline administration

In order to meet those targets and Policies , now a day there are more than 50 MOU for the hydropower development with the capacity from 5 – 1080 MW and 6 projects are under construction , if we look on those hydropower development plan , we could see that there are

many waste wood in the reservoirs need to be clear and if we have the good technologies and investment capital then we could construct biomass cogeneration projects in Laos .

Lao PDR import 100 % fossil fuels , at the present there are 3 companies to conduct the survey for the natural gas and oil and it takes about 10 years for getting all information and for the production of natural gas and oil (if feasible) , for reduction of import fuel and high efficiency fossil fuel consumption , the government of Laos also support the biofuel as biodiesel from the Jatropha and palm oil and bioethanol from the sugarcane .

After the government announced for promotion of biofuel , there are some companies started the business by plantation of Jatropha to produce the bio diesel , the biggest investor is Kolao Farm company , their target is plant the Jatropha 40.000 hac , the factory is under construction , it is far from the Vientiane Municipality about 70 km .

The second company is LaoBiodiesel company just started the construction of the factory in Champasak province on 10 March 2008 and their plantation is 100 hac for the Jatropha .

There are two companies to invest on the palm oil , the first one in Champasak province with the plantation of 25 hac , this company started in 2006 and the second one in Bolikhamsay province with the plantation of 20 hac this company started in 2006 .

The other companies to invest on Jatropha for biodiesel are small plantation .

Under Lao – Thai cooperation of Energy sector , the Ministry of Energy of Thailand give one set of Biodiesel production equipment from Jatropha to Ministry of Energy and Mines for the demonstration .

The Promotion of biodiesel is much more popular than bioethanol because the investment cost and the technology of bioethanol is high and now there is only one small existing of sugar factory in Laos , there other two factories are under construction in Savannaketh province .

Because of there is no any document for the promotion of biofuel in Laos , the department of Electricity , Ministry of Energy and Mines requested New Energy and Industrial Technology Development Organization (NEDO) , Representative Office in Bangkok to support the finance to hire the Lao Institute of Renewable Energy in Laos (LIRE) to conduct the survey and drafted the recommendation for the Strategy and Policy for the Promotion of Biodiesel in Laos .

The target of the government to reduce the fossil fuel consumption 5 % by promotion of biodiesel production .

The details of Strategy and Policy will be developed more ..

7.5 Brunei Darussaalam

7.5.1 *General scope*

Brunei has large amount of fossil fuel resources such as oil and natural gas, and obtains half of its GDP by exporting these resources to enjoy good economy. Thus, they do not have interest in biofuel development so much.

Meanwhile, the land area is small (5,770 km²), and agricultural land is very small, thus most of the food is imported. National development plan always aims at improvement of self-supply rate of food. However, since its independence in 1984, governmental sector was developed and stable high-income jobs are available, which lead to the people's removal from agriculture. In general, agriculture is stagnant, and its productivity within total GDP is only 2.7%.

7.5.2 *Natural conditions of Brunei*

The whole country area belongs to the tropical climate. The tropical rain forest occupies 80% of the national land (4,690 km²). Seventy per cent of the forest is virgin, and half of which is environmentally preserved. The land is roughly divided into eastern and western regions, and the eastern region, Templon River basin, is undeveloped forest except seaside, and forms a vast national park. Most of the population lives in the three district in the western region.

Agricultural productivity of Eastern Asia countries including Brunei is low compared to the monsoon region. Tropic soil easy loses nutrition salts, and is not suitable for agriculture. Leaves and cut trees are soon decomposed by microbes and termites, leaving no humus behind. Additionally, as the effect of heat and water, soil components other than aluminum oxide and iron oxide are easily washed away, and the soil is barren. In the rain forest, the nutrition to support the forest is collected not by the soil, but by the trees and plants at the canopy.

Small scale agriculture includes dry rice cropping in the forest in the mountain region and rice cropping at the terraced paddy field. For short term, taros are produced by slash and burn agriculture to use the nutrition collected by the forest biomass, but this destroys the forest, which is the main nutrition collector, and the soil nutrition is used up in 2 years, and after that the land becomes barren.

At the low wet land where the washed nutrition is stored, Sago palm plantation is

possible. Swamp forest arises at this kind of land. This swamp forest is composed of trees with low height, and the plants grows only by single layer. This leads to good supply of light, but since the oxygen in soil lacks, humus decomposition is prevented, and peat is formed. Thus, even if agricultural field is made, the surface begins to sink soon to form pad. Agriculture is difficult in this region.

At the seaside exists mangrove forest at the brackish water region where seawater is comes and goes with low and high tide. The soil of this forest is strongly acidic due to the root acid that mangrove root secretes. This land cannot be used for slush and burn agriculture, and was barren in terms of agriculture. It was not until 20th century that it got used for fish breeding.

7.5.3 Policy of Brunei

In the 7th 5-year plan (1996–2000年) included activation of agriculture to improve self-supply rate of various agricultural product, but the rate stays only 20%, making biofuel development very difficult.

The plan proceeds study to improve the culturing technology and production system that fits the natural condition of the country so that food demand increasing year by year should be met. It proceeded introduction of new technologies such as water cultivation, and extending of agricultural area. For proceeding water cultivation, half of the expense needed for the tools and fertilizer were supported. The Ministry of Agriculture approved new land-developing zone in 2000. They are for production of vegetables (50 ha), fruits (500 ha), and livestock (100 ha).

The effort to improve self-supply rate of food is taking its effect. In 2004, production of eggs exceeded 100 million eggs/year, and chickens exceeded 13 million, achieving almost 100% of self-supply rate. (Note most of the feed is imported.) However, self-supply rate of other food is still low: tropical vegetables 53%, milk 13%, beef 3.85, goat 3%, other crops 2%, rice 1%. The agriculture has to be much more developed.

7.5.4 Characteristic biomass products

Sago palm (*Metroxylon sagu*) is characteristic to this region. It produces large amount of starch.

Sago palm production is distributed from Southeast Asia to Oceania. Brunei is

classified as sago district with Celebes Island and the Moluccas. This is the district where sago starch supplies several tens of per cent in the main starch supply.

Sago palm belongs to palm family, but is a unique angiosperm because starch can be obtained from its trunk. After 16 years from plantation, or 10 years under good conditions, it forms trunk with a diameter of 40-60 cm, and height of 12-15 m and stores high purity of starch inside in preparation for flowering and fruition. All of this starch is used for breeding, and the tree dies, leaving seeds behind. The tree is cut down just before flowering when the starch amount is the most, and the trunk is cut in the length less than 1 m. The trunk has a skin which is several centimeters thick. It is cut vertically, and the pith of starch which is held by the fibers inside is taken out. Starch is obtained by loosening the pith, washing it with water, and removing the fiber with a net, as precipitation in the water. In this way, 300-500 kg-wet (100-150 kg-dry) of starch is available from one mature tree.

The advantage of sago plantation is the easiness of the job and large amount of starch obtained with small labor. Sago palm can be cultivated with the peat soil, which most of the plant cannot grow with, and sago plantation does not deteriorates the soil. Sago is the most suitable plant for the seaside of the rainforest region.

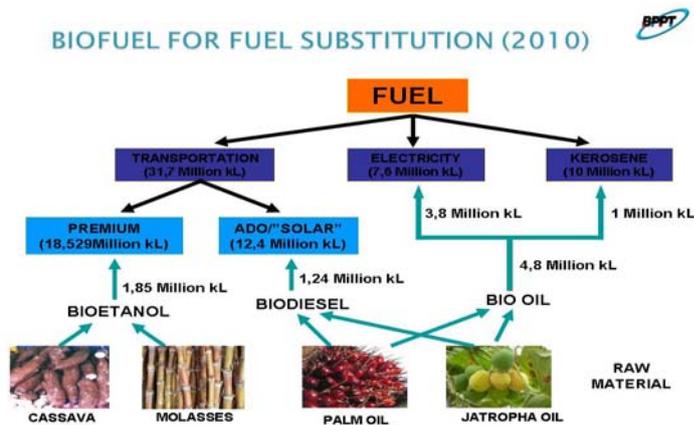
Production of ethanol from sago starch is technically easy, but the self-supply rate of the region is very low, and production of starch for biofuel is not practical.

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7.6 Indonesia



Source : Sony, 2007

Fig 7.6.1. Biofuel for fossil fuel substitution (2010)

The utilization of Biofuel itself is still very low. In order to balance the final energy mix and to alternate oil as the largest contributor of energy, the Government of Indonesia has set out that in 2025, Biofuel is expected to contribute at least 5% of National Energy Mix. As a mid-term goal, in 2010 Biofuel is targeted to take part as a source of energy in household and commercial sector, transportation and power plant sector. Biofuel will substitute the role of oil. It can be seen in the diagram (Fig. 7.6.1). For transportation sector, Biofuel in form of Bioethanol will contribute to 1.85 million kL of transportation energy mix, Biodiesel 1.24 million kL and Bio-oil 4.8 million kL respectively by 2010. Together, the summary of Biofuel will reach 10% of energy mix, only in transportation sector. For the household and commercial sector and power plant, Biofuel will be utilized in form of Biokerosene and Bio-oil or Pure

Plantation Oil.

The high potential for biofuel feedstock in Indonesia is provided by various biofuel feedstock that can be developed. Palm oil and Jatropha are developed as feedstock for biodiesel, meanwhile cassava and sugar cane are utilized as feedstock for bioethanol (Fig.7.6.2). However, as mentioned before, Indonesia is also opened for

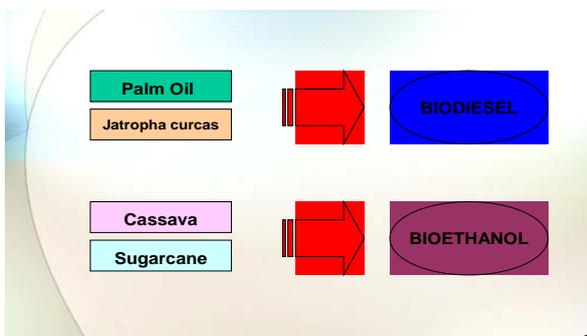


Fig. 7.6.2. Biofuel Feedstock.

the development of other biofuel feedstock such as corn, sago palm, sugar palm and sweet sorghum for bioethanol and coconut for biodiesel, depends on region's bioenergy potential. The potential land for special biofuel zone has been determined by the Government and is shown in Fig. 7.6.3.



No	Location	Commodity
1	Pacitan – Wonogiri – Wonosari (Pawonsari)	Cassava
2	Garut – Cianjur – Sukabumi Selatan	Cassava
3	Lebak – Pandeglang	Jatropha
4	Lampung – Sumsel – Jambi	Cassava, Sugarcane, jatropha, Palm
5	Riau	Palm
6	Aceh	Cassava, Sugarcane, Jatropha
7	Kaltim	Jatropha, Palm
8	Sulsel – Sultra – Sulteng – Gorontalo	Cassava, Sugarcane, Jatropha, Palm
9	NTB - NTT	Cassava, Jatropha
10	Maluku Utara	Sugarcane, Jatropha
11	Papua Utara and Irijabar	Palm
12	Merauke – Mappi – Boven Digul – Tanah Merah	Cassava, Sugarcane, Jatropha, Palm

Fig 7.6.3. Potential land for special biofuel zone.

Indonesia biomass resources are mainly from forestry (as an important natural resource because its tropical rain forest), estate crops, agriculture crops and municipal (city) waste. From estate crops, one the most important biomass resources (as well as for an energy alternative) is Oil Palm plantation (*Elaeis gueneensis*). Indonesia is the second largest producing palm oil country in the world, after Malaysia, (with the total land area of plantation

of about 6 million hectares and *Crude Palm Oil* (CPO) production of 15 million tons in 2006, see Fig. 7.6.4. Area and production Indonesia oil palm plantation) representing 18% of the world-wide production. The Indonesian palm oil industry continues to expand rapidly using large mills which produce hundreds of tons of waste on a year round basis. Considerable opportunity exists in Indonesia and other countries to produce significant quantities of biofuel, (for 100,000 tons of CPO will produce 100,000 tons of biodiesel and 12,000 tons of glycerol), and steam & electricity from the residual



Fig. 7.6.4. Area and production Indonesia oil palm plantation.
Source : Wahono, 2007

biomass while mitigating environmental impacts both locally and globally.

The palm oil residues generated from the palm oil production process are : fresh fruit bunches (FFB) or the oil palm fruit produce Crude palm oil (CPO) and Kernel palm oil (KPO) which can be utilized to produce biodiesel or to generate steam and power.

The climate of Indonesia is also well-known for very suitable of sugarcane (*Saccharum officinarum*). Indonesia is the richest country for sugarcane genetics and is believed as the origin of the world sugarcane (Papua). At least 2 million hectares of land is suitable for cane field which scattered over Papua (majority), Kalimantan, Sumatera, Maluku and Java. By the appropriate planning, policy and development, it is very likely Indonesia in the future will become one of sugar exporter countries and also as a bioethanol producer (similar to Brazil).

Cassava (*Manihot esculenta*), known as one of bioethanol feedstock is cultivated intensively nowadays by the farmers especially in Lampung, Java and NTT regions. The cultivated area is around 1.24 million hectares all over Indonesia and the production was 19.5 million tons in 2005. The conversion of cassava to bioethanol is 6.5:1 or 1 ton of cassava will produce 166.6 liter of bioethanol.

Jatropha curcas (English *Physic nut*) - another biomass source for biofuel, unlike palm oil and cassava, the seed and hence the oil is non-edible, so there is no competition between food vs fuel.

During Japanese occupancy (1942-1945), planting of Jatropha is a compulsory for native people. That's why Jatropha can still be found today in the eastern part of the islands, such as NTT and NTB provinces.

Various local names had been given to Jatropha Curcas, such as : *nawaih nawas* (Aceh), *jarak kosta* (Sunda), *jarak gundul*, *jarak cina*, *jarak pagar* (Java), *paku kare* (Timor), *peleng kaliki* (Bugis), etc.

Also, when the jatropha plantation is to be developed in the critical lands or barren lands has two important steps that have been achieved, i.e. afforestation or replanting and the conservation efforts which will result of the improvement of local/regional environment. And also the jatropha oil can be extracted and be used as fuel. Normally Jatropha seeds content average of 1,500 liter of oil/ha/year, with the productivity of 5 tons per ha of dry seeds and the oil yield of 30%.

The R&D of *Agriculture Institute, Department of Agriculture* has identified about 19.8 million ha of land (see map above, orange color) from various provinces in Indonesia are

Land suitability map for *Jatropha curcas* in Indonesia (1 : 1.000.000)



suitable for *Jatropha curcas* plantation, in which 14,277 million ha of land is categorized as a very suitable and 5,534 million ha is suitable (green color). The suitable land is scattered within 31 provinces with the largest being in East Kalimantan, South East Sulawesi, East Java, South Kalimantan, Lampung, Papua and West Irian Jaya provinces. It is projected that *Jatropha* cultivation areas in

Indonesia will achieve to 3 million ha by 2015. It is expected that *Jatropha* oil as fuel will play an important role in rural villages of Indonesia, so called "Energy Self Sufficient Villages", and ultimately to achieve poverty & jobless alleviation goals.

Of course Indonesia as a tropical country has many other biomass resources which can be developed and utilized as energy resources such as coconut (*Cocos nucifera*), corn (*Zea mays*), sorghum (*Sorghum bicolor L.*), arenga pinnata, rubber (*Hevea brasillensis*), sunflower (*Helianthus annuus*), nipa (*Nypa fruticans*), sweet potato (*Ipomoea batatas L.*), sago (*Metroxylon sp.*) and many others.

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7.7 Cambodia

7.7.1 Biomass resources in Cambodia

Biomass resources such as wood and agricultural residues are abundant in Cambodia. It is estimated that biomass fuel accounted for some 80% of the national energy consumption (MIME 2001) but biomass fuel used for power generation is limited for a few small-scale projects and negligible amount among the total national power production. Woody biomass accounts for more than 95% of the biomass energy used in the country.

According to our initial survey, rice husk and some other agricultural residues, old rubber wood occurred as the result of new planting and forest wood from plantations and managed natural forests are high potential energy source for electricity generation. The status of those high potential biomass resources is described below:

(i) Rice Husk: In 2003, rice was cultivated in 2.3 million ha of the field and 4.7 million ton was produced (MAFF 2003). The COGEN3 program which is funded by European Commission to promote the use of cogeneration in ASEAN countries has conducted a pre-investment study for a potential biomass-fired cogeneration project of 1.5MW electrical capacity at the Angkor Kasekam Roongroeung rice mill just outside Phnom Penh .

(ii) Cashew Nuts Shell: The cashew *Anacardium occidentale* is a tree in the flowering plant family, Anacardiaceae. Cashew nut is the single seed of the cashew fruit. Cashew nuts trees have been planted 37,140 ha in Cambodia (MAFF 2004) and the number of grower is increasing. The production in Cambodia would be 14,000 t/yr.

(ii) Other Agricultural Residues: Bagasse is the residue of sugar processing from sugarcane.

It represents 30% of total sugarcane weight. Direct combustion power generating system has been widely introduced to the sugar processing factory in the major sugar production countries. Cambodia produced 330,649 t of sugarcane in 2003. The production of cassava in 2003 was 330,649 t and the area of coconut farm was 27,054 ha. The productions of coconut and cassava residues are not known. The peanut production in 2003 was 18,483 t. Peanuts shells represent approximately 30% of the total weight of the peanuts.

(iv) Woody Biomass from Forests : The 95% of population is dependent on woodfuel for cooking (NIS 1999) and the biomass energy covered 86% of the total national energy supply (ADB 1996). The total fuel wood consumption was estimated about 6 million m³, while log production estimated 1.5 million m³ in 1995 (World Bank and others 1995).

(v) Plantations: There are total 11,125 ha of forest plantations mainly with *Acacia spp.* and *Eucalyptus spp.* in Cambodia (2003). The purpose of plantation of most case is production of wood chip materials for export.

(vi) Tree Farming: Tree farming of fast growing species is an appropriate method of supplying biomass for village level electrification. Anlong Ta Mei Community Energy Cooperative in Battambang province, the only biomass electricity generation operating in practical manner in Cambodia uses tree farming system for fuel supply.

(vii) Community Forestry: Community forestry (CF) is recognized as an important strategy to manage the forest at sustainable manner in Cambodia. The majority case of CF activity is managing existing primary or degraded forest rather than reforestation by planting.

7.7.2 Current Biomass Electrification Used in Cambodia

There are biomass fuelled electricity generation facilities in Cambodia.

(i) Centre for Livestock and Agriculture Development (CelAgrid)

CelAgrid is the institute conducting various research on rural development mainly based on agricultural technologies. There are 17 academic staff and 40 students working in the institute. They purchased a 9 kWe (gross) biomass gasification electricity generation system from Ankur Scientific (India) in September 2004. Center's currently conducting a research on comparing different biomass such as coconut husk, cassava stem, mulberry stem and Cassia tree for suitability and efficiency for gasification.

(ii) Anlong Ta Mei Community Energy Project

Anlong Ta Mei village (Bannan District, Battambang Province) community energy cooperative project is the only biomass electricity supply system operated profitable base rather than research. The project introduced a 9 kWe biomass gasification electricity generation system (same model as CelAgrid) and set up a mini grid. They use planted *Leucaena* branches for the fuel. They started the operation in February 2005.

(iii) NEDO and Biogas Hybrid Power Generation Project

In December 2003, Japan's NEDO completed the construction of a hybrid electricity generation system consist of a solar photovoltaic (50 kW) and 2 x 35kWe duel fuel biogas engine near Sihanoukville. The biogas is extracted from cattle excrements from a farm. The system is currently operating but the project is considered to be mainly a demonstration and research venture and would not economically viable yet.

7.7.3 Wood and Other Biomass Use in Cambodia

- 94 % of fuel wood is used directly as fuel,
- 6 % of fuel wood is converted to charcoal,
- 90 % of total fuel wood supply is consumed directly by households in rural areas,
- 8 % of total fuel wood supply is used in other urban households,
- Less than 1 % of total fuel wood supply is used in industrial sector,
- Less than 1 % of total fuel wood supply is used in service sector
- The other biomasses such as wood, wood waste and rice husk are used by brick kilns, bakeries, and food processing,
- Cane husk, palm branches and tree leaf are used by cane sugar and palm sugar producers,
- Coconut branches, coconut husk and rice husk are used by rural households for cooking animal food,
- Some rural households use coconut branches, palm branches, rice straw with cow dung, rice husk and wood waste for cooking their food.
- They use these biomasses for directly firing.

7.8 Malaysia

In Malaysia, biomass resources are mainly from the palm oil, wood and agro-industries. All of these residues come in many forms such as palm oil mill residues, bagasse, rice husks and wood/forest residues. Major sources of biomass come from the oil palm residues in the form of empty fruit bunches (EFB), fibers, shells, palm trunks, fronds and palm oil mill effluent (POME). The energy content in each residue is different to each other. This is mainly because the caloric value, moisture content and some other parameters that are different.

As shown in table below, the palm oil residues accounts for the largest biomass waste production in the country. This is because the palm oil mill residues are easily available and are presently requiring cost effective means of disposal. Currently, most of these residues are disposed of through incineration and dumping. A small portion is used as fuel for the mills' heat and power requirement in a very inefficient manner.

Table 7.8.1. Biomass and energy resource potential.

Sector	Quantity kton / yr	Potential Annual Generation (GWh)	Potential Capacity (MW)
Rice Mills	424	263	30
Wood Industries	2177	598	68
PalmOil Mills	17980	3197	365
Bagasse	300	218	25
POME	31500	1587	177
Total	72962	5863	665

7.8.1 Biomass energy utilization in Malaysia

The abundant biomass resources coming mainly from its palm oil, wood and agro-industries are used mainly to produce steam for processing activities and also for generating electricity. Biomass fuels contribute to about 16 percent of the energy consumption in the country, out of which 51 percent comes from palm oil biomass waste and 27 percent wood waste. Other biomass energy contributors are from plant cultivations, animal and urban wastes. There are currently about 400 palm oil mills in operation, which self generates electricity from oil palm

wastes not only for their internal consumption but also for surrounding remote areas. Studies also found that 75.5 percent of the potential biomass that can be harnessed in Malaysia is unutilized and wasted.

7.8.2 Oil palm residues

The oil palm industry generates residues during the harvesting, replanting and milling processes. The residue that comes from the milling processes are fruit fibers, shell and empty fruit bunches (EFB). Other residues including trunks and fronds are available at the plantation area. Currently shells and fibres are used as boiler fuel to generate steam and electricity for the mill's consumption. The EFB is return back to the plantation for mulching. This is only practiced in bigger plantations. For old palm oil mills, the EFB is burned in the incinerator to produce fertilizer. However, there are still palm oil mills disposing the EFB through landfill method particularly the mills without enough plantations or estates.

Palm oil mill effluent (POME) is the wastewater discharged from the sterilization process, crude oil clarification process and cracked mixture separation process. The amount of POME generated depends on the milling operation. For a palm oil mill with good housekeeping, it is estimated that 2.5 tonnes of POME are generated from every tonne of crude palm oil produced. The average value for Malaysian palm oil mill is 3.5 tonnes for every tonne of crude palm oil produced. The POME contains high chemical and biological oxygen demand, total solids and require a treatment system before it can be discharged to the environment. Biogas is generated from the biological treatment of POME. The composition is mainly methane (60-70%) and carbon dioxide (30-40%). The calorific value is between 4740-6560 kcal per Nm³ and the electricity generation is 1.8 kWh/cm³ of biogas. Some plantations practice zero waste management system.

Table 7.8.2. Residue product ratio and potential power generation from palm oil mill residues.

Type of Industry	Production Year 2002 (Thousand Tonnes)	Residue	Residue Product Ratio (%)	Residue Generated (Thousand Tonnes)	Potential Energy (PJ)	Potential Electricity Generation (MW)
Oil Palm	59,800	EFB at 65%MC	21.14	12,640	57	521
		Fiber	12.72	7,606	108	1032
		Shell	5.67	3,390	55	545
	Total Solid			16,670	220	2098
	POME @ 3.5m ³ per ton CPO or 65% of FFB)			38,870		320

7.8.3 Paddy residues

There are two seasons of paddy planted in Malaysia. The main season refers to the period of paddy planting from 1st of August to 28th February and off season covers the period of paddy planting from 31st March to 31st July of the year. The total paddy planted areas for Malaysia in the year 2000 was about 600,287 hectares and producing 2,050,306 tones of paddy. Malaysia is about 65% self sufficient in rice supply and another 35% is imported from Thailand and Vietnam. Paddy straw and rice husk are generated as biomass residue during the harvested and milling processes. The paddy straw is left in the paddy field and the rice husk is generated in the rice mill. Both of the biomass are discharged by landfill and open burning. Only a small quantity of rice husk is used for energy generation and other application such as silica production and composting.

It is assumed that only 2% of the rice husk is used for energy production. The balance is treated as landfill method. The paddy straw is usually burned in the open burning areas. The amount of rice husk and paddy straw generated in future are dependent on the planted area, the paddy yield and government policies on agriculture. The government plans to increase the yield from the existing rate to 10 metric tonne per hectare in the future. With this target value more rice husk and paddy straw is available for biomass CHP plant. The issue of solid biomass is difficulties in transportation and handling due to very low density and abrasive nature of the material.

Table 7.8.3. Residue product ratio and potential power generation from rice mill residues.

Type of Industry	Production Year 2000 (Thousand Tonne)	Residue	Residue product Ratio (%)	Residue Generated (Thousand Tonne)	Potential Energy (PJ)	Potential Power (MW)
Rice	2,140	Rice Husk	22	471	7.536	72.07
		Paddy Straw	40	856	8.769	83.86
TOTAL	2,140			1327	16.305	155.93

7.8.4 Sugar cane residues

Basically in Malaysia, there are only 2 out of 5 sugar factories, which use sugar cane as raw materials for refined sugar production. The other plants would use solely brown sugar as raw materials for sugar production. The main objectives of the industry are for food security supply, creation of jobs, development of industrial projects in rural areas and reducing foreign exchange.

Bagasse is the residue after sugarcane has been processed to remove the sugar juice. On average, about 32 % of bagasse is produced from every tonne of sugar cane processed. The amount of sugar cane processed in 2002 is about 1,111,500 tonnes. Thus, the amount of bagasse produced is 355,680 tonnes. This bagasse is not wasted as it acts as a biomass residue fuel to the boiler for its cogeneration plant. This saves the factory expenditure in boiler fuel oil and electricity expenses.

At the current rate of usage, all of the bagasse is used as fuel for its cogeneration plant. In fact there is insufficient bagasse for the sugar mills. Thus, they are buying other biomass residues such as rice husk, wood off cuts and palm oil residues to be used as fuel.

7.8.5 Wood residues

Total forest areas in Malaysia are about 5.9 million hectares. Only 1.29% of the total area is allowed for logging industry. The balance is mainly for permanent forest estate, forest plantation, state land, and wildlife reserve and annual coupe for permanent forest estate. Wood industries are mainly referred to the logging industry, saw milling industry, the panel product industry (plywood, veneer, particle board, and medium density fibre board), the moulding

industry and the furniture industry. The forest industries are rapidly moving away from manufacturing low value products to value added products. These industries generated different type of biomass residues namely sawdust, off cut and wood barks. A waste minimization program is implemented in the wood based industries due to shortage of tropical wood supply. A value added such as particle board and finger joints are manufactured from the wood waste for the furniture industry.

The wood industries maximized the biomass residues into the value added products. The residue such as off-cut from the saw mills is used as fuel for the kiln drying or sold as boiler fuels. The middle portions of the log from the plywood and veneer mills are used as boiler fuels. The remaining wastes are mainly the bark and the saw dust. In the isolated areas they are burned in the incinerator or boiler to produce heat.

The generation of biomass residues from the wood based industry is declined due to limited supply of logs and maximization of residues into value added product. The biomass from the processing plants is used as fuel for their combined heat and power plant or sell to the potential users such as brick manufactures. The chart below shows the estimated potential energy and electricity from the waste generated from the saw mills, plywood and moulding plants.

7.8.6 Municipal solid waste (MSW)

The Malaysian population has been increasing at a rate of 2.4 % per annum or about 600,000 per annum since 1994. With this population growth, the MSW generation also increases, which makes MSW management crucial. Currently, the MSW is managed mainly through landfill. However, due to rapid development and lack of new space for it, the big cities and islands are considering incineration to tackle this problem.

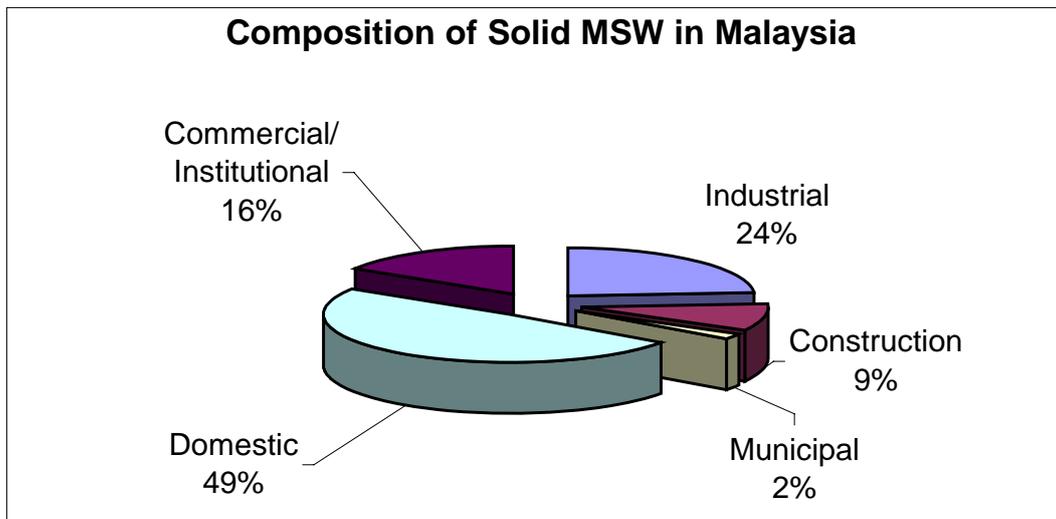


Fig. 7.8.1. Pie Chart of Typical Malaysian MSW Composition.

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7.9 Philippines

7.9.1 Fundamental energy policy

The Philippine Energy Plan is focused on its primary goal of energy independence and power market reforms.

As a major reform agenda of the Arroyo Administration, the objective of the energy independence package is to reach an energy self sufficiency level of 60% by 2010 and beyond. To realize this goal, five major strategies have been identified and this includes two major strategies directly related to renewable energy (RE) to include biomass energy. The two major strategies are the following: 1) intensifying renewable energy resource development and

increasing the use of alternative fuels.

7.9.2 Intensifying renewable energy resource development

In line with the government's intensified efforts to promote RE development and use, the Philippine Department of Energy (DOE) formulated the Renewable Energy Policy Framework which embodies its objectives, goals, policies and strategies as well as programs and projects to further develop the RE sector within the perspective of the sector's supply and demand prospects and its current stage of development. Specifically, the identified long-term goals are the following: (i) increase RE-based generating capacity by 100 percent within the next ten years; and (ii) increase non-power contribution of RE to the energy mix by 10 MMBFOE in the next 10 years. Included in these goals is the increase in the contribution of biomass, solar and wind in power generation.

Resource Potential

Based on current projections of the Philippine Department of Energy (DOE), RE will provide at least 40 percent of the country's primary energy requirements for the next 10 years beginning 2005. Other RE such as biomass, used mostly for non-power applications, will remain to be the largest contributors to the total share of RE in the energy supply mix with at least 30 percent share. According to the Power Development Plan, biomass will provide 30 MW capacity in 2007 and will increase to 55 MW in 2008.

Based on the study, "Power Switch and Strategies for Clean Power Development in the Philippines", the country has a potential resource capacity of 235.7 MW from bagasse resources. Other studies as well, shows the potential of the country for several small 1-2 MW rice hull fired power plants just like 1 MW rice hull fired power plant currently installed in the Northern part of Luzon.

7.9.3 Increasing the use of alternative fuels

The government will continue to promote the use of alternative energy in the transport sector particularly biofuels (i.e cocobiodiesel or cocomethyl ester, fuel ethanol and jatropa carcus.)

The President has signed into law RA 9367 or the Biofuels Law that mandates the use of biodiesel and bioethanol nationwide.

At present, biodiesel is already being used nationwide at 1% of the total volume of diesel sold.

This is in accordance with the provision of the Law that , three months after the approval of the Act, a minimum of 1% biodiesel by volume shall be blended into all diesel engine fuels sold in the country. The country has 211.3 million liters per year capacity from 5 accredited biodiesel producers.

Biodiesel requirement in 2007 is 41 million liters at 1% blend. 100% compliance nationwide.

Targets:

Within two years from the effectivity of the Act, the Philippine Department of Energy, may mandate a total of 2% blend depending on the results of the study by the national Board created under the Act. Provided that the ethanol and biodiesel blends conform to Philippine National Standard. Two years from the effectivity of the Act, at least 5% bioethanol by volume of the total volume of gasoline fuel sold and distributed by each and every oil company in the country. Within four years from the effectivity of the Act, the Philippine Department of Energy, may mandate a minimum of 10% blend depending on the results of the study by the national Board created under the Act.

Raw Material Requirement:

For bioethanol, supply of feedstock is initially from sugar based ethanol. With 880,000 liters per day committed capacity from various plants. Other feedstocks considered are sweet sorghum and cassava. For biodiesel, is currently from coconut oil or CME but *Jatropha* is also being considered.

Current feedstock yield: sugarcane has 23.98 million metric tons, corn has 5.25 million metric tons, and cassava 1.64 million metric tons. Coconut oil production is 1.4 billion liters per year (80% for export and 20% for local use).

Biodiesel requirement : 85 million liters in 2008, 229 million liters in 2010 and 277 million liters per year in 2015.

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7.10 Singapore

Singapore has always enjoyed a reputation as a “Garden City” for being “clean and green” due to its effective management of the urban environment and maintenance of the green space. With a land mass of approximately 700 square km and population of 4.5 million, it has also invested heavily on the environmental infrastructures such as waste water treatment and waste disposal facilities. Most recently, it has embarked on the recycling and reuse of the water resources under a program called “Newater” which has become a model for many countries to follow.

It is now 2008, energy security dominates international stage, crude oil price is nearing a record high of over \$100 US a barrel, global warming and climate change are now household concerns. Europe-led market demand for biofuels is all the rage. Singapore claims to be the world’s second largest petroleum refinery center with installed capacity of well over 1 million barrels/d. However, Singapore relies on the import of nearly 100% of its raw energy supply. This reliance on imported fossil energy necessarily subjects Singapore's economic and environmental sustainability to external factors that all energy importing countries must also face. These included global oil/gas market fluctuations; political instability of the oil exporting countries; international protocol (Kyoto Agreement) to limit CO₂ emission from fossil energy use, as well as changes in public energy consumption patterns.

Government has encouraged development of clean, alternative energy programs such as the Sinergy Program which provided a testbed for hydrogen based fuel cell vehicles since the 1990’s. More recently, it has announced major R&D funding program on clean and renewable energy. It has successfully attracted major investments for the manufacturing of solar-PV panels with the announced capacity of 1,500 MWe per year, as well as a wafer manufacturing plant to provide the mono-silicon materials needed for the solar cells.

On the other hand, private sector investors have taken advantage of Singapore’s strategic location in the tropical SE Asia together with its well established infrastructures for crude oil handling, storage, and refineries. Singapore is benefiting directly from its proximity to this rich repository of biomass resources. In recent years, Singapore has attracted major foreign direct

investments in biodiesel production facilities. All together, 6 biodiesel production projects have been confirmed, with a total combined capacity of close to 2 million tonnes/per year and the total investment dollars is close to S\$2 billion. All of these investments aim to bring in crude plant/seed based oil from the region and refine them in Singapore. A regional biofuels analysis center is also being set-up to cope with the anticipated demand from all these activities.

Domestically, Singapore generates about 650,000 Tonnes/year of biomass wastes which includes food waste, wood/timber wastes and sludge/biosolids. Many of the woody biomass comes from the thriving shipping/trans-shipping industry in Singapore where wooden pallets are routinely disposed when they become unrepairable. Increasingly, the government of Singapore, through the National Environment Agency (NEA) and private sector investors are exploring opportunities for their energy recovery and utilisation. Once plant has been built by local investor to convert food waste to biogas, another diverts about 600 tonnes/d of municipal solid waste (MSW) for recycling and reuse, of which about 300 tonnes/d of woody biomass are used as fuel for cogen. The third recovers energy and generates hot water from horticultural wastes. Government is now encouraging more opportunities for diverting biomass waste from the incinerators and landfill sites. It is expected that more private sector investment will see the economic benefit for recovering energy from the biomass resources.

In summary, Singapore is in the forefront of bioenergy R&D, it is also racing ahead to explore more sustainable 2nd and 3rd generation of biofuels technology and will likely to lead the commercial developments of these renewable energy due to its pro-active government policies for attracting investments.

7.11 Thailand

The Royal Thai Government launched a strategy to increase renewable energy share in the energy mix since 2005. This was a cabinet resolution, binding all governmental agencies to harmonize policy direction to achieve the declared policy targets. In response to this policy needs, the Ministry of Energy has set forth the seven strategies for energy sufficiency

development as follows.

1. Establish the independent organization to regulate electricity and natural gas
2. Foster energy security by recourse to His Majesty Sufficiency Initiatives
3. Promote efficient energy usage
4. Promote the development of renewable energy
5. Seek for appropriate pricing structure for energy
6. Establish clean energy development mechanism
7. Encourage private sectors and the public to contribute to policy making process.

Targets of Biomass-derived energy :

The target set forth by the government is that Thailand must increase the share of renewable energy in the final energy consumption from 0.5% in 2005 to 8% by 2011 (6,540 ktoe). The target for renewable share in the transportation fuel is 3% for biofuels i.e. bioethanol use must be at least 3 Million L/day and biodiesel must be 4.0 Million L/day by 2011. A target for biomass-derived heat and steam is 4% equivalent to 3940 KTOE by 2011. A share of 1% was set for electricity from renewable resources which is equivalent to 3251 MW by 2011. Due to recent price increase of crude oil, an adjustment of the target has been announced by the government to start implementing E20 gasohol (20% blend of ethanol into gasoline) on January 1st 2008 and B2 (2% blend of biodiesel into biodiesel) has been mandated since February 1st, 2008. This implementation has made Thailand the first country in Asia to fully commercialize both bioethanol and biodiesel blends all over the country.

Duties

The policy targets and implementation milestones are reviewed and adjusted periodically and reported to the government by the National Energy Policy Committee.

Biomass utilization

At the end of 2007 more than 4000 service stations distribute E10 gasohol all over the country and all stations distribute B2 as mandated by the government. B5 biodiesel blend is now available in more than 3000 stations. Bioethanol used in December was 600 KL/day in average. Biodiesel used was 150 KL/day in for low-blend of 2-5% before the mandatory period. After the mandate of blending 2% biodiesel in all highspeed diesel, the use of biodiesel jumped to above 1 million l./day level in February 2008. Renewable electricity production

reached 2057 MWe and biomass-based heat and steam was 1840 KTOE in 2007.

Amount of biofuel production

Biodiesel Production is about 1,150 KL/day; production capacity is 2,185 KL/day. Bioethanol Production is 700 KL/day (Feb.2008) and the production capacity is 1,150 KL/day.

Situation of biofuel introduction

Biofuel introduction is now accelerating in Thailand. Bioethanol-blended gasoline (E10) is now reaching 6 ML/day out of 20 ML/day of total gasoline consumption and the bioethanol blends(E10) gained a market share of 23% of all gasoline use at the end of 2007. Biodiesel-blended diesel is now 3 ML/day out of 50 ML/day total diesel consumption in December 2007. The consumption figure for Feb. 2008, the market for B5 was 5ML/day of the total diesel market of 50 ML/day, the rest of the fuels were B2 blended as mandated by the government.

Energy crops

For ethanol, 1-2 million tons of molasses are used as raw material (this is by-product from sugar production which is about 5 million tons from 64 million cane production), another raw material for ethanol is cassava, only 180,000 tons out of 26 million tons of cassava roots is used for ethanol production. For biodiesel, about 100,000 tons of palm oil is used for biodiesel out of 1.5 million tons production in 2007. The use of palm oil for biodiesel in 2008 is expected to reach 300,000 tons levels.

Future prospects

Many new ethanol plants using both molasses and cassava will begin production in 2008; it is expected that by December 2008 the total production capacity will reach 8 Million litres /day and Thailand can produce much more due to the surplus of raw materials for ethanol. As for biodiesel, the government started to promote the new oil palm plantation with a target to increase area by 200,000 acres/year for the next 5 years so that raw material will be sufficient to meet the target for biodiesel production. By 2011, it is expected that Thailand will have 1.1 million hectares of oil palm plantation, at least half of the production will be used for bioenergy production by 2011. In this respect, the bioenergy crop development in Thailand, given the appropriate policy implementation, will be the new engine of growth to increase the income

for rural agricultural sectors. It is also foreseen that co-operation among the Greater-Mekong subregion in biomass energy areas will also enhance the significance of energy sufficiency development in the region.

Successful examples

Thailand is today the only country in Asia to adopt bioenergy into the main consumer market where both bioethanol and biodiesel blends are available in all region of the country. Renewable electricity and heat/steam are also promoted in the industry and substantial progress are being made to meet the target set by the government.

MTEC and NSTDA will focus on the R&D efforts to help the industry and the small and medium enterprize to adopt and integrate bionergy into their respective energy production and utilization. The success of Thailand will be a good example for other countries in the region, especially LPDR, Cambodia, Myanmar and Vietnam, to explore the ways forward with this new developmental vehicle. It is expected that CDM mechanism and climate-change adaptation schemes will become a significant developmental issue in the coming years.

7.12 Vietnam

7.12.1 Governmental policy

Project No 177/2007/QD-TTg (Nov. 20, 2007) of Gov. for development of biofuels to 2015 and line of vision to 2025 and Gov. Strategy No 1855/QD-TTg (Dec. 27, 2007) for development of National Energy to 2020 and line of vision to 2050. The government approves a new and renewable energy as 3, 5 and 11% to 2010, 2020 and 2050 respectively. There are no duties for biomass introduction. Ministry of Industry and Trade; Ministry of Science and Technology; Ministry of Agriculture and Rural Development; Ministry of Natural Resources and Environment.

7.12.2 Utilization of biomass

Availability, amount used, and how to use, for each biomass is listed below.

- Livestock waste: availability: Pig dung - 25.7 million tons/year; Cattle dung - 20.2 million tons/year; Buffalo dung - 16.0 million tons/year; Municipal garbage - 6.4 million tons/year , amount used 70-80% (compost; fertilizer; Biogas...)
- Food waste: availability not determined (animal feed)
- Paper: consumption 997,400t/year, amount used 70% (recycle)
- Black liquor: availability not determined, amount used 40% (combustion)
- Sawn wood: 3,414 thous. m³ Lumber-mill residue: amount used 100% (energy use)
- Forestry residue: availability 1,648.5 thousand tons/year, amount used 0%
- Non-edible portions of farming crops: availability: rice straws:76 Mt/year; rice husks 7.6 Mt/years; Bagasse2.5 Mt/year, amount used 20% (compost, animal feed, animal bedding material, electricity, Mushroom production...); 73,800 tons of used cooking oil; 60,000 tons of "Basa" fish oil (2005) now producing 10,000-tons/year

Amount of biofuel production is shown below.

Bioethanol

Feedstock: Casava, molasses, rice

Production:76.63 ML in 2006.

Biodiesel

Feedstock: waste cooking oil; Basa fish oil; rubber oil; Jatrofa

Production: R&D project"

Biofuel introduction has not been made, but by plan of Gov. to 2021 will be 100,000 t of E5 and 50,000 t of B5 available on the market

7.12.3 Energy crops

Amount of production and utilization of energy crops are none, but in the future, introduction of 2 ethanol factories using cassava, each productivity of 100 ML/year (1 factory produces 50ML/year using molasses and sugarcane) is planned.

7.12.4 Successful examples

40,000 family-size biogas digesters (1-50 m³) had been installed. Development of new technology for biofuel production from agricultural residue is under way.

7.13 Japan

7.13.1 Policy

New Energy Promotion Law (Jan. 2002) approves bioenergy as a "new energy", and supports its introduction. The council for energy in METI (Ministry of Economy, Trade and Industry) publishes the target values for "new energy" at 2010; thermal use of biomass, 3.08 million kL oil equivalent, and electricity production from biomass and wastes, 5.86 million kL oil equivalent. These values, however, have no duty.

The strategy for biomass utilization "Biomass Nippon Strategy" was published in cabinet (Dec. 2002). The target values at 2010 were revised (Mar. 2006); biofuel for transportation, 0.5 million kL oil equivalent, utilization rate of unutilized biomass, 25%, number of "Biomass Town", 300 areas. Ministry of Agriculture, Forestry, and Fishery approves municipalities that utilize biomass based on the characteristics of the region as "Biomass Towns".

7.13.2 Status of biomass utilization

The status of biomass utilization in Japan is shown in Fig. 7.13.1. Livestock waste is used as compost etc., food waste as compost and animal feed, lumber-mill residue as energy and fertilizer, construction-derived wood residue as paper production, particleboard production, animal bedding material, combustion etc., sewage sludge as construction material and compost, non-edible portions of farming crops as compost, animal feed, animal bedding material etc. paper waste as recycle and heat production, black liquor as combustion use. Forestry residue is not any used.

Bio diesel fuel from waste cooking oil is produced around 3,000 t/year. Bio-ethanol production is almost in R&D stage, and bio-ethanol is produced commercially 1,400 kL from waste wood in 2007. Test sales of ETBE-mixed gasoline (3%-EtOH equivalent) and E3 just started in 2007.

Energy crops is not tried yet. Introduction is limited due to the limited land and high labor cost, although test production of sugarcane and ethanol production is going on in Okinawa.

7.13.3 Successful example

The First Energy Service Co., Ltd., commercially collects waste wood and produces electricity. They established 3 power generation companies using waste wood; 10,000 kW at Iwakuni Wood Power Co., Ltd., 11,500 kW at Shirakawa Wood Power Co., Ltd., and 12,000 kW at Hita Wood Power Co., Ltd.

7.13.4 Other comments

Non

Further information

MAFF webpage: <http://www.maff.go.jp/j/biomass/index.html>

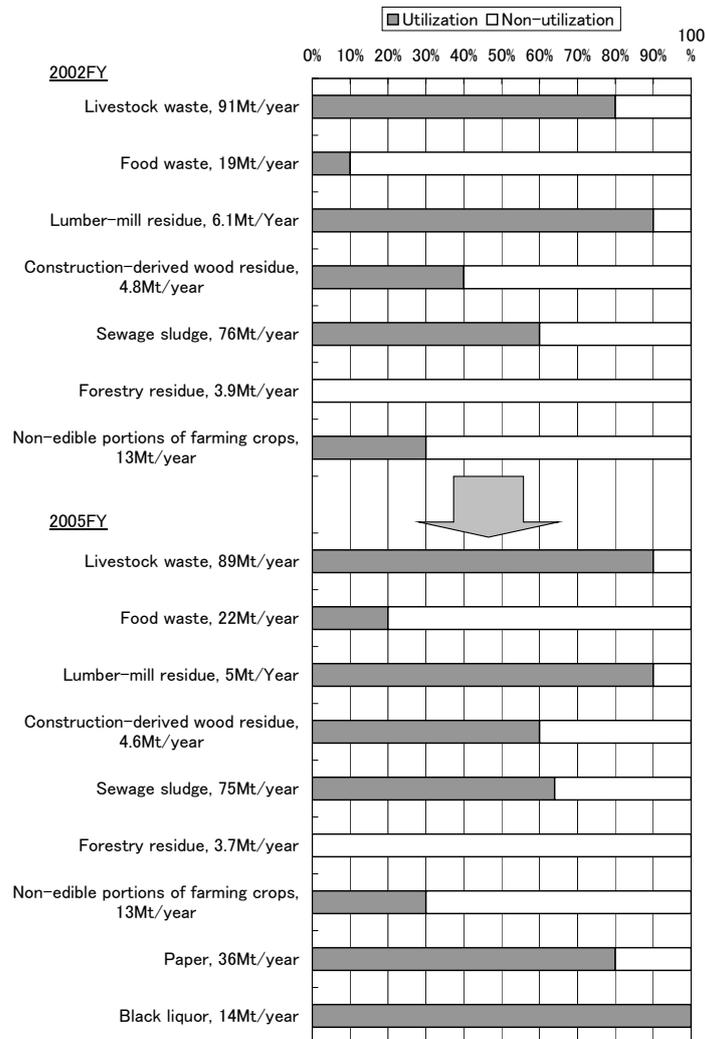


Fig. 7.13.1. Status of biomass utilization in Japan.

7.14 Taipei, Chinese

7.14.1 Policies, mandatories, and targets

One of the key tasks of energy policy in Taiwan is to stabilize energy supply to increase energy independence. The installed capacity of power generation from renewable energy is identified to be 12% in total to enhance energy self sufficiency, and the target of 10% in total is set to be reached in 2010. Power generation from biomass and wastes is set to be the third largest sources of renewable energy, which is 1.44% in total (741MW) in 2010. In order to promote the utilization of renewable energy, the “Renewable Energy Development Bill” has been drafted and submitted to the Legislative Yuan for approval.

The application of biofuels to transportation sector is in growing trend in recent years. The pilot project started by Environmental Protection Administration is to blend 20% of biodiesel (B20) to garbage truck from 2004. Since then, the Bureau of Energy proceeded the demonstration project with four stages. Firstly, the Green Bus Project was started in 2006, which 2% of biodiesel (B2) is blended to bus fleet operated by public sector. Secondly, test sales of B1 at gas station of Taoyuan county,

Chiayi city, and Chiayi county was started in 2007, which is called Green County Project. Thirdly, the target of B1 sales at all gas station will be reached in July, 2008. Finally, the target of B2 applied in nationwide area, which is estimated to be 100 dam³/year (100,000 kL/year) in total will be reached in 2010.

The application of bioethanol was started in 2007, test sales of E3 at 8 gas station in Taipei city is focused on official’s car, and private car is also encouraged to use. The target of E3 at all gas station of Taipei and Kaohsiung city will be started in January, 2009. It is expected to use E3 in nationwide area in 2011, which is estimated to be 100 dam³/year (100,000 kL/year) in total.

Up to now, subsidizing for biomass utilization is still inevitable. The related mandatories are listed below:

- Measures for purchasing electricity from renewable energy sources
- Measures for rewarding methane power generation in landfill
- Measures for subsidizing energy crop green bus projects
- Measures for subsidizing green county promoting projects
- Measures for subsidizing green official’s car pilot projects

Considering the area of farm to cultivate energy crops is limited, it is possible to import biofuels from abroad. The “Petroleum Administration Act” should be revised to enhance the management of imported renewable energy, such as bioethanol, biodiesel etc.

7.14.2 Amount of resources

Up to now, most of biomass utilization in Taiwan is wastes and residues. The noticeable items are listed below:

- There are 24 municipal solid waste incinerators equipped with power generation facilities, and total capacity is 528.8 MW.
- There are installed capacity of power generators utilizing biogas generated from 4 large landfills and some middle to small scale pig farms.
- There are also some power plants using industrial and agricultural wastes, including bagasse, paper mill waste, plastic waste, rice hull and RDF-5 (Refuse Derived Fuel) etc. The total capacity of these plants is around 67.5 MW.

In addition, the enforcement of recycling used frying oil was started in September, 2007 for enterprise. Household is also encouraged. The potential biodiesel product from used frying oil is estimated to be around 80,000 kL/year.

In the near future, 80 km² (8,000 ha) of rested cultivating farm is planned to cultivate energy crops. The potential of farmland for cultivating energy crops could be 5,000 km² (500,000 ha).

If seaweed could be cultivated around 100 km² (10,000 ha) of seashore, the potential product of 150-300 dam³ (150,000-300,000 kL) biodiesel is expected.

Part 8. Examples for biomass utilization

8.1 Small-Scale Biomethanation

8.1.1. *What are biomethane and biomethanation?*

Biomethane (sometimes referred to as "Biogas") is generated from organic materials as they decay. The main component of biomethane is CH₄ (55%-70%) and CO₂ (25%-40%). Biomethane can be used for cooking, lighting, heating, generating electricity and so on.

Biomethanation is the process of conversion of organic matter in the waste (liquid or solid) to biomethane and manure by microbial action in the absence of air, known as "anaerobic digestion."

8.1.2. *Situation of biomethane in China*

The annual quantity of waste in China is more than 150 million tons. The production and disposal of large quantities of life and industrial waste without adequate or proper treatment result in widespread environmental pollution. While some of these wastes can be collected and biomethane is generated from anaerobic digesters where the manure decomposes. Especially in some far rural area where the transportation of electricity is expensive, biomethane is a good way to provide energy for cooking, lighting and heating, etc.

Since 1950s, Chinese governments encouraged small-scale biomethanation using animal and agricultural waste as feedstock. Table 1 shows the rural biomethane development in China. Till 2006, about 20 million families in rural area are using biomethane for cooking and lighting. Annual consumption reaches 5 million standard coal equivalent. Subsidy of 2.5 billion RMB from government is for small-scale biomethanation development, which means one small-scale biomethanation can get subsidy of 800-1200 RMB. China nation government plans to build 30 million biomethane digesters in 2010 and 45 million biomethane digesters in 2020.

Table 8.1.1. Survey of rural biomethane in China, 1991-2005.

Year	Biomethane digesters (million)	Annual output (billion m ³)
1991	4.75	1.11
1995	5.70	1.47
1999	7.63	2.25
2001	9.57	2.98
2002	11.10	3.70
2003	12.89	4.58
2004	15.41	5.57
2005	18.07	7.06

8.1.3. Characteristics of small-scale biomethanation

In China, the area of small-scale biomethane digester is about 6-8 m². Annual output is 300 m³. Cost of each biomethane digester is 1500-2000 RMB.

In spite of providing energy, biomethane in China also has the following characteristics: 1) environment friendly. For an 8-10 m³ biomethane digester, dejecta of 5-8 pigs or 2000-3000 chickens can be used. 2) The residues in the digester can also be used for fertilizer. 3) economically. It saves money of buying electricity or save labor of seeking firewood. And the woods can be saved.

8.1.4. Process of small-scale biomethanation

The process of small-scale biomethanation includes feedstock collecting, pretreatment, fermentation, treatment and purifying, storage and transportation, where the fermentation digester is the main equipment. The digesters are required to be airtight and impervious to make sure they are anaerobic. The temperature in the digester should be maintained at 20-40°C. There should be enough manure in the digester. Appropriate water (about 80%) content and pH (7-8.5) are required.

Batch fermentation and semi-continuous fermentation are usual technologies for small-scale biomethanation. In batch fermentation technology, all the feedstock is added at the first. The biomethane generates fast at the beginning and then decreases. This technology is easy for

management, but the biomethane generation rates are different. In semi-continuous fermentation technology, 1/4 - 1/2 feedstock was added at the first. When the biomethane generation slows down, more feedstock is added to make the biomethane generation work in order.

8.1.5. Energy supply of small-scale biomethanation

Usually, the biomethane generation rate of digester is 0.2-0.25 m³/(m³.d). So annual output of a 10 m³ digester is about 600 m³ biomethane. Usually, heat value of 1 m³ biomethanol is equivalent to that of 3.3 kg raw coal. As mentioned in previous, annual consumption of biomethane reached 5 million standard coal equivalent in China. It is obvious that biomethane plays an important role in rural energy supply.

Further information

<http://www.cogeneration.net/BioMethanation.htm>

Wang Haibo, Yang Zhanjiang, Geng Yejiang. Analysis on the influence factors of rural household biogas production in China. *Renewable Energy Resources*, Vol. 25 No.5 Oct. 2007: 106-109

<http://www.biogas.cn/>

Gao Yunchao, Kuang Zheshi, etc. Development progress and current situation analysis of the rural household biogas in China, *Guangdong Agricultural Sciences*, 2006. 1: 22-27

Huang Fenglian, Zheng Xiaohong, etc. Actions and modes of household biogas for new rural area construction in China. *Guangdong Agricultural Sciences*, 2007. 8: 114-116

8.2 Large Scale Biomethanation

8.2.1 Outline of large scale biomethanation

Anaerobic digestion has been in practical use for a long time. Its industrial installations had started as early as in around 1900. Since then, the anaerobic digestion systems have been continuously improved and enlarged to treat a wide range of biomass wastes such as food industry wastewater/waste, garbage, livestock waste, night soil and sewage sludge among others.

8.2.2 Large-scale anaerobic digestion systems

A typical anaerobic digestion system in large-scale is depicted in Fig. 8.2.1. The function of each unit process is described below.

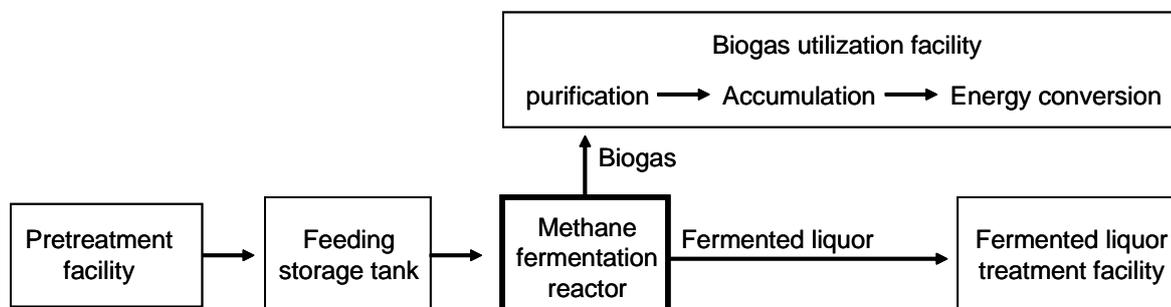


Fig. 8.2.1. A typical anaerobic digestion system in large-scale.

(a) Pre-treatment process

It is often required for an effective anaerobic digestion that the received biomass waste is conditioned in a pre-treatment process such as removal of foreign matters not suitable for anaerobic digestion, pulverization, dilution by water, thickening, and/or acid or alkali treatment. Some biomass wastes such as garbage, which is a mixture of various organic and inorganic matters, and, thus is not always consistent in its composition and properties, are subjected to mechanical and/or magnetic separation in order to get rid of indigestible materials such as metals and plastics. The separated biomass waste is pulverized and added with dilution water to prepare waste slurry for the next unit process.

(b) Slurry storage tank

Prepared slurry is temporarily stored in a slurry storage tank for leveling dairy fluctuations in both quality and quantity. If the ambient temperature is suitable, microbial activities of acidogens in the storage tank may increase. If this occurs, accumulation of organic acids in the slurry can cause a decrease in pH to as low as around 4. The slurry storage tank must be designed to resist corrosion due to such low pH conditions.

(c) Methane fermenter (anaerobic digester)

Three major functional microbial groups are active in the methane fermenter. These three functions that take place sequentially are; hydrolysis, acidogenesis and methanogenesis. The final products of the reactions are methane and carbon dioxide. The hydrolysis reaction is often the rate-limiting pathway of an anaerobic digestion process on not-readily biodegradable or recalcitrant biomass such as sewage sludge and ligneous biomass, whereas the methanogenesis is likely to be the rate-limiting pathway on readily biodegradable biomass

such as garbage and starchy wastewater. In order to establish an efficient anaerobic digestion system, it is important to consider the rate-limiting pathway and to select the most suitable reactor design for the properties of anticipated biomass waste. For example, the overall rate of anaerobic digestion on readily biodegradable biomass waste heavily depends on the density of active methanogens in the reactor, thus the reactor should be designed to maximize the density or mass of the methanogens within the system.

(d) Fermentation wastewater treatment

Fermentation wastewater discharged from the anaerobic digester usually contains high concentrations of organic matters, nitrogen compounds and phosphorus compounds. The fermentation wastewater should be treated to reduce the concentrations of these pollutants to meet the standards for final discharge to a receiving body of water or sewer system. The most typical fermentation wastewater treatment system is the activated sludge process with tertiary treatment.

(e) Biogas utilization

Since most of the biomass wastes contain proteins (a source of nitrogen and sulfur) and sulfate salts, the biogas contains certain concentrations of hydrogen sulfide and ammonia. The biogas produced from sewage sludge, which sometimes contains a considerable amount of silicones, may contain siloxanes as well. Since these impurities can possibly cause damage to biogas utilization facilities such as a gas engine, gas boiler, gas turbine and fuel cell, and/or cause secondary air pollution, a biogas utilization unit process is often equipped with a desulfurization device and/or siloxane remover prior to the gas holding tank.

8.2.3 Examples of large-scale anaerobic digestion systems

Some of the typical implementations of large-scale anaerobic digestion systems are described below.

(a) Sewage Sludge

Sewage sludge is a waste biomass which is discharged in large quantities from sewage treatment facilities. For a long time, anaerobic digestion has been one of the treatments on sewage sludge to stabilize the sludge and reduce its volume. The reactor design usually applied to sewage sludge digestion is a completely mixed reactor design (Fig. 8.2.2). A contemporary anaerobic digester for sewage sludge is as large as 10,000 m³ in the effective volume. Typical design parameters include the operational temperatures of ambient (ca. 20 degC) to mesophilic (ca. 35 degC) range, and the relatively long retention time of 20 to 30 days.

(b) Industrial organic wastewater

Industrial wastewater containing readily biodegradable organic matters, but little solids, such as the wastewater discharge from a beer brewery, the UASB (up-flow, anaerobic sludge blanket) reactor design, which was originally developed in the Netherlands, is usually selected. The UASB reactor design maintains a high density of anaerobic microorganisms in the form of self-aggregated microbial "granules" that enables a high rate of anaerobic digestion.

(c) Organic wastes from food industries

Anaerobic digester designs which allow a high rate anaerobic digestion on readily biodegradable biomass containing high concentrations of organic solids are being developed, and some have already been in actual operation in recent years. An example of such a new design is the DAPR (down-flow anaerobic packed-bed reactor) design. Many high-rate anaerobic digestion facilities for food wastes and distillery wastes, incorporating the DAPR design, have been implemented in Japan. The largest facility as of writing has the design capacity of 400 tons/day (Fig. 8.2.3).



Fig. 8.2.2. Example of a large scale sewage sludge anaerobic digester. (Northern second sewage treatment plant)



Fig. 8.2.3. Example of a large scale biomethanation plant of food waste. (Distilled spirit processing waste recycling plant of Kirishima Shuzo co. LTD.)

Further information

R.E.Speece: Anaerobic Biotechnology, Archae Press, pp.127, Tennessee (1996)

Japan Sewage Works Association: Sewage Facilities planning, policy and explanation (second part) 2001, pp.384, Japan (2001)

J.B.Lier: Current Trends in Anaerobic Digestion; Diversifying from waste(water) treatment to re-source oriented conversion techniques, 11th IWA World Congress on Anaerobic Digestion, 23-27 September

2007, Brisbane, Australia (2007)

Hisatomo Fukui and Motonobu Okabe: Distilled spirit processing waste recycling plant using thermophilic dawn-flow packed-bed reactor, Gas fuel manufacture from biomass and its energy utilization, NTS, pp.265-275, Japan (2007)

8.3 Jatropha Plantation

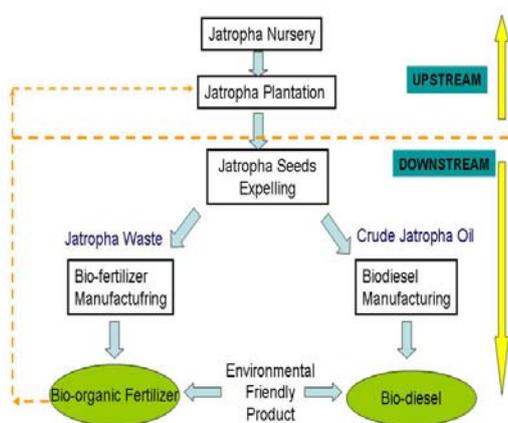


Fig. 8.3.1. Fully integrated jatropha business.



Fig. 8.3.2. Jatropha plantation. (Bambang P., 2007)

Jatropha integrated business consists of upstream and downstream activities. Upstream activity includes jatropha nursery and jatropha plantation. Down stream activity includes seeds expelling process where crude jatropha oil resulted can be used for biodiesel manufacturing, whereas jatropha by product/waste (i.e. seed cake, seed shell, glycerin) can be used to manufacture bio-fertilizer and other applications. Both activities are known as an environmental friendly products.

8.3.1 Jatropha cultivation

Cultivation of Jatropha is uncomplicated (Fig. 8.3.2). *Jatropha curcas* can grow in wastelands/marginal areas and grows almost anywhere, even on gravelly, sandy and saline soils. It can thrive on the poorest stony soil and grow in the crevices of rocks without competing with annual food crops, thus filling an ecological niche. Complete germination is achieved within 9 days. Adding manure during the germination has negative effects during that phase, but is favourable if applied after germination is achieved.

However, it is usually multiplied by cuttings, because this gives faster results than multiplication by seeds. The flowers only develop terminally, so a good ramification (plants presenting many branches) produces the greatest amount of fruits. Another productivity factor

is the ratio between female and male flowers within an inflorescence (usually about 1 female to 10 male flowers - more female flowers mean more fruits).

Jatropha curcas can grow at annual rainfall of 300 - 2,380 mm, with the optimum rain fall on 625 mm/year. The best time to start planting is in dry season or before the rainy season, with the annual average temperature is 20 - 28°C.

8.3.2 Propagation method

There are two propagation methods, i.e. Generative (seeding) and Vegetative propagation (cutting). For monocler business, satisfactory planting widths are 2 x 2, 2.5 x 2.5 and 3 m x 3 m. This is equivalent to crop densities of 2,500, 1,600 and 1,111 plants/ha. However, plants propagated by cutting show a lower longevity and posses a lower drought and disease resistance than plants propagated by seeds. Only during its first two years does it need to be watered in the closing days of the dry season. Ploughing and planting are not needed regularly,



Fig. 8.3.3. Jatropha fruits and seeds.

as this shrub has a life expectancy of approximately forty years. The use of pesticides and other polluting substances are not necessary, due to the pesticidal and fungicidal properties of the plant.

1 ha of jatropha plant normally will give yield to 2,250 kg of seeds (Fig 8.3.3 Jatropha fruits & seeds) and 750 kg of oil, hence the ratio of seed to oil is 3: 1. Seed oil can be extracted either hydraulically using a press or chemically using solvents, however, chemical extraction cannot be achieved on a small scale basis.

8.3.3 Jatropha biodiesel

Esterification – Transesterfication known as ‘estrans’ process (Fig. 8.3.4) has been developed and patented by Prof. R. Sudradjat (2003). There are two stages in this process :

1. In this esterfication process, free fatty acid (the main cause for biodiesel acidity) is transformed to

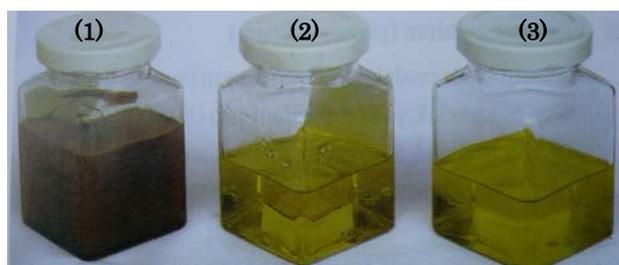


Fig 8.3.4. 3 grades estrans quality.

biodiesel (methyl ester).

2. Triglyceride and fatty acid which are still bonded in triglyceride in the oil is converted to methyl ester via transesterification. By this process, oil conversion to biodiesel (without glycerol) of 99.75% can be achieved.

Other feature of this process is the usage of methanol/ethanol reactant can be reduced to < 20% and HCl catalyst can be substituted with solid catalyst from natural substance (FKS) which is much cheaper and can be recycled.

From a production cycle, three grades estrans quality (Fig. 8.3.4) can be obtained : 1) Crude Jatropha Oil (CJO) - as a substitution of kerosene or residue which can be used for direct combustion; 2) Jatropha Oil (JO) - as diesel oil (ADO) substitution for engines with have low rpm (such as portable generator set, tractor/bulldozer, etc.; 3) Biodiesel as fuel (automotive).

Fig. 8.3.5 shows the typical process diagram for jatropha biodiesel production from the seeds. It can be seen, it involves washing, blanching and drying of seeds before proceeding into peeling process. The resulted seed meat is grinded with a grinding machine, the grinded powder is pressed by a hydraulic pressing machine (manual or electric). The crude jatropha oil (CJO) then can be extracted and the residue seed cake can be utilized for animal feedstock, biopesticides, etc.

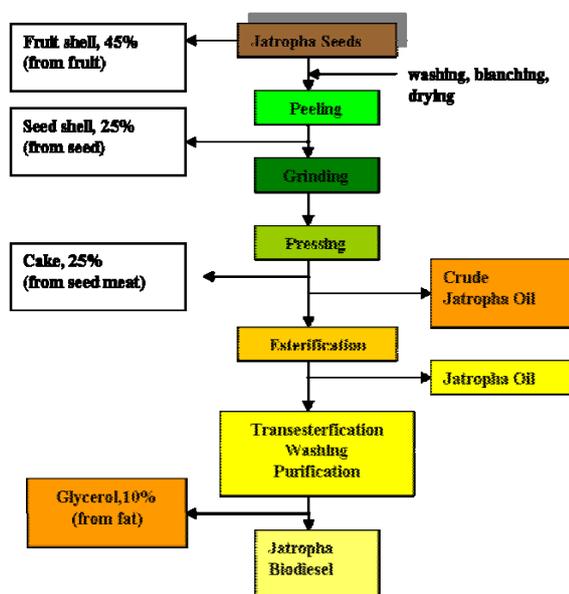


Figure 5. Jatropha Biodiesel Process Diagram
(Source : R. Sudradjat, 2006)

Fig. 8.3.5. Jatropha Biodiesel Process Diagram.
(Source: R Sudradjat, 2006)

The production of Jatropha Oil (JO) is carried out by using a estrans reactor where JO is heated at temperature between 50 – 60°C. Methanol as a solvent (5%) is used and HCl catalyst (10% v/v) is applied and then mixed them together. The esterification process will take 2 hours at 50°C. The mixture will direct to a glycerol separator where the aging process will take 4 hours. The glycerol (white paste) will stay at the bottom part whereas the top part JO can be extracted and feed to water separator and neutralization. In this water separator, JO is rinsed twice by using demineralization water, then neutralization is done by using 0.01% of NaHCO₃ and finally the demineralization

using water is carried out again. The final product will be pumped out to the storage tank.

Biodiesel production : JO is fed into an estran reactor with the temperature of 50 – 60°C. The mixture of methanol (10% v/v) and KOH catalyst (0.5% v/v) is then put into the reactor. Stir properly during transesterification process for 0.5 – 1 hour and keep the temperature at about 50°C. Separate the biodiesel from glycerol with the same procedure as JO making. Same procedure also for washing and neutralization process, but in here use 0.01% of CH₃COOH instead of NaHCO₃. Finally, the final product of Jatropha biodiesel is ready to be used as diesel fuel (ADO) substitution. The characteristic of Jatropha biodiesel is shown Table below.

Table 8.3.1. Characteristic comparison of Jatropha Oil, Biodiesel CPO & Diesel Oil.

(Source : Soerawidjaja, Tatang H, 2005)

Parameter	Jatropha Oil	Biodiesel CPO	Diesel Oil (ADO)
Density (g/cm ³)	0.92	0.87	0.841
Viscosity (cSt)	52	-	6 – 11.75
Cetane number	51	64	51
Flash point (°C)	240	182	50
Sulfur (ppm)	0.13	0.0068	1.2
Iodin number (mg iodine/g)	105.2 ± 0.7	-	-
Acid number (mg KOH/g)	3.5 ± 0.1	0.5	-
Calorific value (kcal/kg)	9,720	8,783	10,200

8.4 Power Generation from Rice Husk

8.4.1 Power producer promotion in Thailand

In 2007, Ministry of Energy (Thailand) has strongly promoted SPP (Small Power Producer: 10-90 MW) and VSPP (Very Small Power Producer: < 10 MW), in particular those using biomass, with high grid buyback price of electricity and simple procedure for obtaining license permit in order to cope with the energy situation. As of October 2007, there are more than 77 SPP and VSPP with installed capacity over 1,100 MW, half of which are sold back to the grid.

8.4.2 Biomass power plant in Thailand

As shown in Fig. 8.4.1, biomass power plants are all distributed throughout the country, especially in the central and northeastern parts. In term of the electricity sold back to the grid, more than half of the power plants use bagasse as the feedstock fuel, followed by rice husk/Eucalytus bark of 31%, as shown in Fig. 8.4.2.

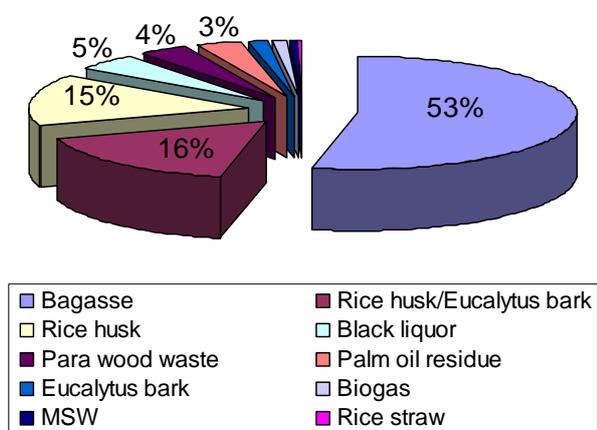


Fig. 8.4.2. Biomass Power Plants by Fuel (Grid).

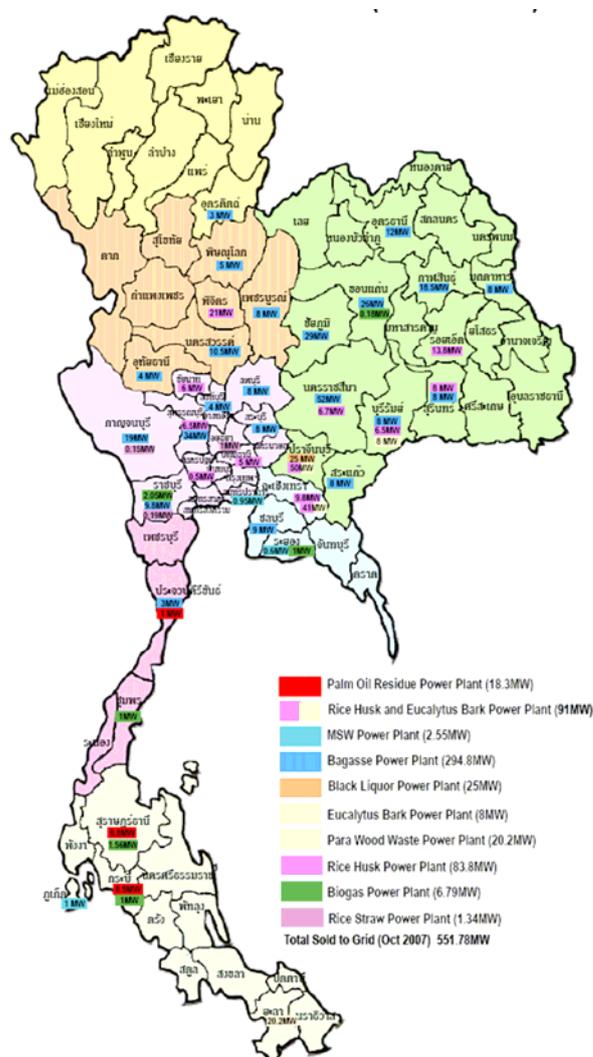


Fig. 8.4.1. Distribution of Biomass Power Plant in Thailand

Source: adapted from Energy for Environment Foundation (<http://www.efe.or.th>)

8.4.3 Gasification technology for rice husk

Despite many biomass power plants, some of them are still running at the low efficiency using conventional burning to produce a steam for power generation. Hence, thermo-mechanical conversion process like gasification technology can help solve the problem. Rice husk is another attractive feedstock for biomass power plant due to its plentiful availability from the rice mills, its small size and low moisture. Recently, Ministry of Energy has funded a project to demonstrate the feasibility of constructing the community biomass gasification system (using rice husk) to Kasetsart University and Great Agro Co., Ltd. This project was initiated to foster Sufficiency Economy philosophy by His Majesty the King of Thailand. The system produces not only 80kW electricity but also heat and biomass ash for fertilizer, as shown in Fig. 8.4.3. The system design uses three-stage fluidized bed pyrolysis and gasification, comprising of 5 main units: drying, pyrolysis, gasification, cooling system and engine/generator set, as shown in Fig. 8.4.4.



Fig. 8.4.3. Concept of Biomass Gasification System.

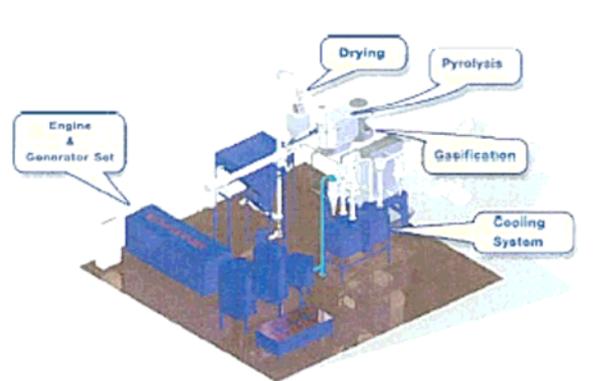


Fig. 8.4.4. Units of Gasification System.

As shown in Fig. 8.4.5 and 8.4.6, the system was installed at Lamlukka Cooperative Rice Mill & Paddy Center Market Co., Ltd for demonstration and test run for more than 360 hours. With gas flow rate of 240 m³/hr (heating value at 4.5 MJ/m³) and rice husk consumption of 85 kg/hr, the overall gasification system efficiency is 92%. In other words, 1.25 kg/hr consumption of rice husk generates 1 kW of electricity. Furthermore, the residue tar volume from the system is approximately 22 mg/m³. On the economic analysis, this 80kW system requires a capital investment of ~3.9M Baht with the operating cost of ~1.79 Baht/unit. Assume that the system produces the electricity at 460,800 unit/year, which substitutes the electricity cost of 3 Baht/unit, the net profit is estimated to be 0.56M Baht/year with the

payback period of 7 year. The next step would be the collaboration between MTEC and Great Agro Co., Ltd to scale up the system to 1MW capacity.

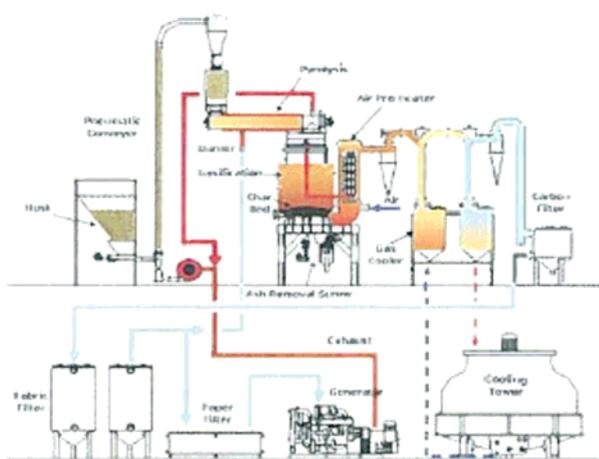


Fig. 8.4.5. Flow Diagram of Gasification System



Fig. 8.4.6. Test Run of the Complete Set

Further information

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8.5 Ethanol Production

8.5.1 What is a good source for ethanol production?

In Thailand, most existing commercial ethanol production plants use molasses as a feedstock but with increasing new facilities to use cassava in the near future. However, these two energy crops are still considered as food, which may interfere with the ‘food vs. fuel’ issue. As a result, more people are looking for alternative non-edible energy crops. Among many others, lignocellulose from various agricultural residues has received a great deal of attention, commencing the era of 2nd generation lignocellulosic bioethanol.

8.5.2 Lignocellulosic biomass feedstock for ethanol in Thailand

Each year in Thailand, agricultural industries generate millions of tons of various lignocellulosic biomass feedstock known as agricultural residues, including rice straw, sugar

cane bagasse, corn stover/fiber and wood chip. Sugarcane and rice, mostly concentrated in the North and Northeastern provinces, are the first two largest national agricultural productions (in weight) as shown in the table below.

Table 8.5.1. The first four largest agricultural production in Thailand (2004).

	Sugarcane	Rice	Cassava	Maize
Production (thousand tons)	64,974	27,038	21,440	4,216
Harvested Area (thousand rai*)	7,009	63,709	6,608	6,810
Yield per rai (kilograms)	9,270	424	3,244	619

Source: Office of Agricultural Economics (2004) * 6.25 rai = 1 hectare

In general, these residues are inefficiently utilized, which most often, also causes environmental problems. Rice straw is considered wastes and disposed off through various methods such as open-air burning (as shown in Fig. 8.5.1 and 8.5.2), dumping or animal feeding. A rather more attractive method to manage these abundantly available rice straws is through cellulosic ethanol



Fig. 8.5.1. Open-air burning causes air pollution.



Fig. 8.5.2. Burning also causes soil pollution.

8.5.3 R&D pioneer work on processing

Since lignocellulose is mainly composed of cellulose, hemicellulose and lignin, it needs additional pretreatment in order to get sugar monomer ready for the fermentation process.

Typical process requires SHF (Separate Hydrolysis and Fermentation) of great complexity involving pretreatment, fractionation, delignification, hydrolysis and fermentation. Alternatively, pretreatment with proper steam explosion yields the hydrolysate, which can be enzymatically digested and fermented in a single reactor via SSF (Simultaneous Saccharification and Fermentation) method, as shown in Fig. 8.5.3, 8.5.4 and 8.5.5, involving only the pretreatment and hydrolysis/fermentation steps. The goal is to seek for the appropriate SSF that uses a commercially available cellulase enzyme and microorganism available in Thai market.

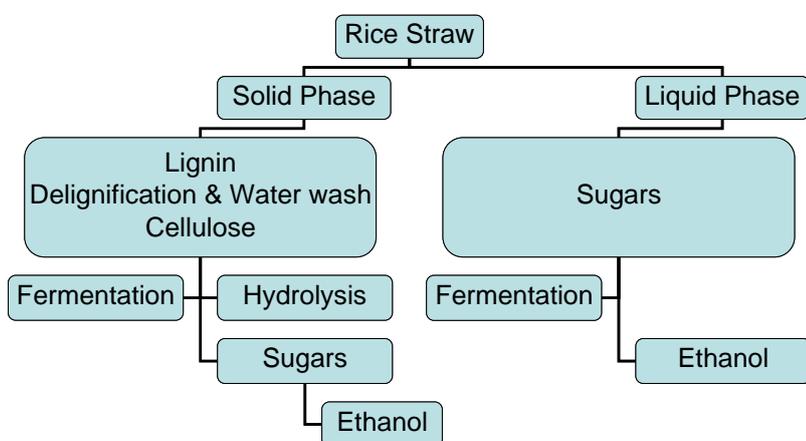


Fig. 8.5.3. Typical process of lignocellulosic ethanol production.



Fig. 8.5.4. Prototype of steam explosion unit.

Source: C. Pomchaitaward *et al*, MTEC report (2007)

The steam explosion was applied to rice straw Supunburi1™ showing good carbohydrate recovery and high ethanol concentrations obtained in a single reactor with minimal enzyme and yeast supplementation. A 150 g of dried rice straw was steamed with pressure between 10 to 25 bar (with corresponding temperature 185 and 210 °C, respectively) for 5 minutes. Higher steam pressure (or higher temperature) favored hemicelluloses solubilization. However, the strong influence of steam pressure on the cellulose solubilization was not found. The optimum



Fig.8.5.5. Exploded rice straw.

pretreatment condition resulted in the production of a very small amount of sugar decomposition products, which enabled an effective fermentation of sugars to ethanol. In conclusion, mild steam pretreatment condition at 15 bars for 5 minutes results the highest hydrolysis yield.

This process substantially reduces the complexity of the overall rice straw to ethanol bioconversion, while simultaneously lowering the capital investment cost and time associated with the need for separate processes. Furthermore, it significantly lowers environmental impact due to less hazardous process chemicals and conditions involved. Last but not least, it provides an alternative for better energy efficiency in agricultural residue management.

Further information

- C. Pomchaitaward et al, Feasibility Study of Ethanol Production from Lignocellulosic Materials via the Steam Explosion Pretreatment, MTEC in-house project report 2007 (chaiyapp@mtec.or.th)
- S. Nivitchanyong, Alternative Energy Cluster, MTEC (siriluck@mtec.or.th)

APPENDIX

A1 Tokyo Declaration on Asian Biomass

A2. Kyoto Protocol

A3. Statistics on Asian Countries

A4. Unit Conversion

A5. Atomic Weight

A6. Thermodynamic Properties

A7. Heating Values of Fossil Fuels and Lifetime

A8. APEC Framework

A9. Each Country's Targets

A10. Related histories

A11 Each country's language

A12 Related books

A1 Tokyo Declaration on Asian Biomass

A1.1 Tokyo Declaration on Asian Biomass

At the Biomass Asia Forum, which was organized mainly by the Ministry of Agriculture, Fishery, and Forestry, Japan, Tokyo Declaration on Asian Biomass was adopted. This declaration arranged the things to be considered and the direction of activities for the utilization of biomass in Asian countries based on the discussion in the forum. The declaration is as following.

Tokyo Declaration on Asian Biomass

Considering the increasing expectations held for biomass, the Biomass Asia Forum adopts the following declaration for the effective utilization of Asian biomass resources.

1. The renewability and carbon neutrality of biomass resources should be recognized and the utilization of biomass resources promoted.
2. When using biomass resources, the importance of sustainability should be emphasized and reductions in carbon dioxide emissions properly evaluated.
3. The contribution of biomass resources to the activation of Asian industry and regional economies should be recognized and appropriate measures taken to make the most of these economic effects.
4. When using biomass resources, the possibility of creating a recycling society should be discussed and appropriate measures for realizing such a society promoted.
5. The effectiveness of the development and introduction of appropriate technologies in the

utilization of biomass resources should be recognized and the development of related technologies through appropriate support and subsidization promoted.

6. An association to promote biomass resource utilization, composed of members from Asian countries, should be organized and should conduct self-supporting activities.

7. Utilization of biomass resources should contribute to the improvement of conditions in all countries; thus biomass utilization that contributes to the solution of poverty, prevention of environmental damage, suppression of disease, and realization of a better quality of life should be promoted and policies for realizing such utilization pursued.

A1.2 Biomass Asia Workshop and Biomass Asia Forum

Structuring of a network for the purpose of sharing information among members related to Asian biomass and developing mutual understanding is important. There are two streams in this term. The one is Biomass Asia Forum, which was organized mainly by the Ministry of Agriculture, Forestry, and Fishery, Japan, and the other is Biomass ASEAN Project, which is proceeded mainly by the National Institute of Advanced and Industrial Science and Technology, Japan (AIST), and Japan International Research Center for Agricultural Science (JIRCAS) with the subsidies from the Ministry of Education, Culture, Sports, Science and Technology, Japan. In the year of 2004, these two projects started independently, but soon it was notice that both projects have similar goals, and it was decided to have a joint-workshop, which was the 1st Biomass Asia Workshop, held in January, 2005, in Tokyo and Tsukuba, Japan. In December, 2005, the 2nd Biomass Asia Workshop was held in Bangkok, Thailand, and Biomass Asia Forum was held in January, 2006 in Tokyo. Through these workshops and forum, the situation of biomass in Asian countries was studied, and the purpose of its effective use was discussed. Based on these concept, the network development was discussed at the 3rd Biomass Asia Workshop in Novemer, 2006. This flow is shown in Fig. 1.

The 4th Biomass Asia Workshop was held in November, 2007 in Shah Alam, Malaysia. The 5th workshop is to be held in China.

To overview the trend of recent biomass activities, the program of the 4th Biomass Asia Workshop is also shown here.

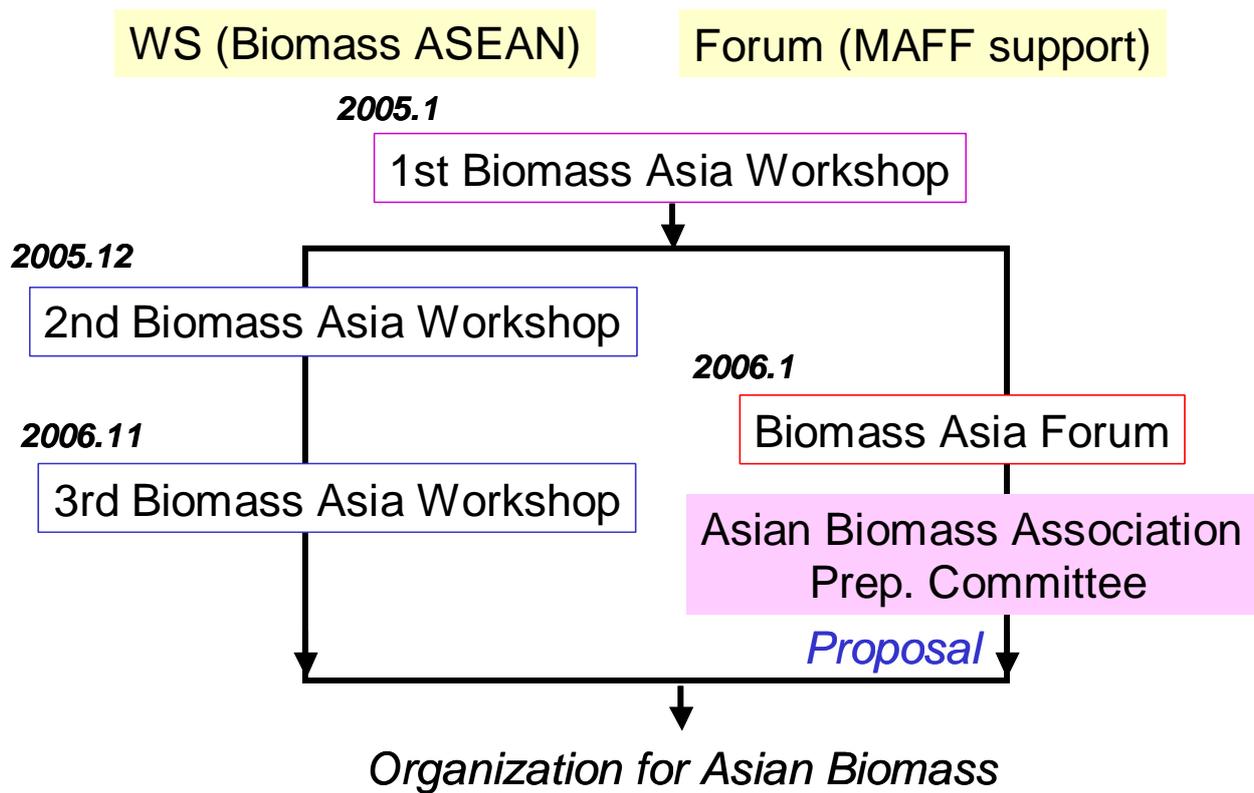


Fig. A1.2.1 Events regarding the networking on Asian Biomass utilization.

Fourth Biomass-Asia Workshop

Date: 20-22 November, 2007

Venue: Grand BlueWave Hotel Shah Alam

Perbandaran, Seksyen 14, 40000 Shah Alam, Selangor Darul Ehsan, Malaysia

Day 1 (Nov. 20, 2007)

0830-0900 Registration

Opening Remarks

0900-0915 Tatsuo Katsura

Senior Vice President, AIST, on behalf of Representative of Biomass-Asia Research Consortium, Japan

0915-0930 Kunio Oguri

Deputy Director General, Agriculture, Forestry and Fisheries Research Council Secretariat, MAFF, Japan

0930-1000 Break

Special Lecture

Chair: Zainal Abidin Mohd Yusuf (Vice President, SIRIM, Malaysia)

1000-1030 Lignocellulose refinery system must be realized for global environment and economy

Kenji Iiyama

President, JIRCAS, Japan

1030-1100 Coffee Break

Plenary Lecture

Chair: Yasuyuki Yagi (Councillor, International Affairs Dept., AIST, Japan)

1100-1125 Food Security with Biofuels: FAO Perspective

Abdolreza Abbassian

Secretary of the Intergovernmental Group on Grains, FAO, UN

1125-1150 Biomass for Energy Generation in Malaysia

Anuar Abdul Rahman

CEO of Pusat Tenaga Malaysia (PTM)

1150-1215 Biomass for Material Application

Peesamai Jenvanitpanjakul

Deputy Governor, Thailand Institute of Scientific and Technological Research (TISTR), Thailand

1215-1240 Policy and Legislation on Biofuel Utilisation

Datu Dr. Michael Dosim Lunjew

Secretary General, Ministry of Plantation Industries and Commodities Malaysia

1240-1420 Lunch / Poster Session

Keynote Speech

1430-1500 H.E. Dato' Sri Dr. Lim Keng Yaik
Minister of Energy, Water and Communications, Malaysia

Future Prospect of Biomass Utilisation in Asian Countries
Chair: Masayuki Kamimoto (Research Coordinator, AIST, Japan)
1500-1525 Biomass-Asia Project-Second Stage: Research and Technological Development for Sustainable Biomass Utilization in Asian Countries

Kinya Sakanishi

Representative of Research Core for Asian Biomass Energy, AIST, Japan

1525-1550 The Road Map of Chinese Biomass Energy Development

Haibin Li

Guangzhou Institute of Energy Conversion (GIEC),

Chinese Academy of Sciences (CAS), China

1550-1610 Coffee Break

1610-1635 Rice-Sugarcane Complex Model

Klanarong Sriroth

Associate Professor, Department of Biotechnology, Faculty of Agro-Industry, Kasetsart University, Thailand

1635-1700 Palm Complex Model

Wahono Sumaryono

Deputy Chairman for Agroindustry and Biotechnology,

Agency for Assessment and Application of Technology (BPPT), Indonesia

- Panel Discussion -

Asian Partnership on Sustainable Environmentally Benign Biomass Production and Utilisation

Moderator: Yukihiro Matsumura (Professor, Hiroshima University, Japan)

1700-1830

< Panelists >

China: The Development of Biofuels in China

Dehua Liu

Professor, Director of Institute of Applied Chemistry, Department of Chemical Engineering, Tsinghua University

Indonesia : Biofuel Development in Indonesia

Petrus Panaka

Professor, Project Development Advisor, PT Gikoko Kogyo Indonesia

Malaysia : Sustainable Biomass Production and Utilisation

- Profit, People and Planet -

Mohamad Ali Hassan

Dean, Faculty of Biotechnology and Biomolecular Sciences, University Putra Malaysia (UPM)

Philippines: Non-fossil Energy

Luis F. Razon

Director, University Research Coordination Office, Associate Professor, Department of Chemical Engineering, De La Salle University

Thailand : Asian Partnership on Sustainable Environmentally Benign Biomass Production and Utilization

Nuwong Chollacoop

National Metal and Materials Technology Center (MTEC),
National Science and Technology Development Agency (NSTDA)
Vietnam : Seaweed: Potential Biomass for Ethanol Production
Truong Nam Hai
Deputy Director, Institute of Biotechnology,
Vietnamese Academy of Science and Technology (VAST)

2000-2130 Reception
hosted by Dato' Dr. Halim Man
Secretary General for Ministry of Energy, Water and Communications, Malaysia

Day 2 (Nov. 21, 2007)

<Room 1>

Palm Oil Energy Complex Model

Chair:

Chen Sau Soon (SIRIM, Malaysia)

Tomoaki Minowa (AIST, Japan)

0900-0920 Palm Oil Industry in Malaysia

Dato' Dr. Choo Yuen May,

Deputy Director-General, Malaysian Palm Oil Board

0920-0940 Electricity Generation from Palm Oil Mills in Indonesia
(extended abstract)

Soni Solistia Wirawan

Head of Institute for Engineering

and Technology System Design

(Engineering Center), BPPT,

Indonesia

0940-1000 Palm Oil Energy Complex and CDM

Yoshihito Shirai

Professor, Graduate School of Life

Science and Systems Engineering,

Kyushu Institute of Technology,

Japan

1000-1020 Potential of Oil Palm Trunk as a Source for Ethanol Production

Ryohei Tanaka

FFPRI, Japan

co-authored by Yutaka Mori (JIRCAS)

Mohd Nor Mohd Yusoff (FRIM)

Othman Sulaiman (USM)

Shu Yoshida (Sojitz Machinery Corporation)

1020-1040 Coffee Break

1040-1100 Biomass Plastics from Palm Oil Mill Effluent in Malaysia

Mohamad Ali Hassan
Dean, Faculty of Biotechnology
and Biomolecular Sciences,
University Putra Malaysia(UPM),
Malaysia

1100-1120 Co-firing of Biomass with Coal for Power Generation

Suthum Patumsawad
Assistant Professor, Department of Mechanical Engineering, King Mongkut's
Institute of Technology North
Bangkok (KMITNB), Thailand

1120-1140 Benchmarking of Biodiesel Fuel Standards for Vehicles in East Asia

Shinichi Goto
Director, Research Center for New
Biomass Technology Research
Center, AIST, Japan

1140-1200 Production of Second-Generation Biofuels from Palm Wastes

Shinichi Yano
Senior Research Scientist,
Biomass Technology Research
Center, AIST, Japan

1200-1220 Discussion

<Room 2>

Utilisation of Agriculture and Wood Wastes

Chair :

Guangwen Xu (CAS, China)
Takahiro Yoshida (FFPRI, Japan)

Brazil: Brazilian Present and Future Ethanol Production - Biomass Ethanol Potential

Elba P.S.Bon
Associate Professor in Biochemistry,
Chemistry Institute,
Federal University of Rio de Janeiro

Cambodia: Biomass in Cambodia

Lieng Vuthy
Deputy Director, Department of
Energy Techique, Ministry of
Industry, Mines and Energy

China: High Efficient Conversion of Cellulosic Process Residue into Middle-Caloric Gas

Guangwen Xu
Professor, Institute of Process Engineering, CAS

Indonesia: Agricultural and Wood Waste Potentials and Utilization in Indonesia
Unggul Priyanto
Director, Energy Resources Development Technology Center, BPPT

Japan: Biomass Refinery Systems -Case Study at Miyako Island, Japan-
Yoshiyuki Shinogi
Head, Laboratory of Farmland
Engineering, Department of Land and Water Resources, National Institute for Rural
Engineering, NARO

1020-1040 Coffee Break

Laos: Brief Report of Biomass in LAO PDR
Bouathep Malaykham
Chief of Electric Power Management
Division, Department of Electricity,
Ministry of Energy and Mines

Myanmar: Anhydrous Ethanol Production
Su Su Hlaing
Lecturer of Department of Chemical
Engineering, Mandalay
Technological University

Philippines : Outlook of Biomass Industry in the Philippines
Ruby B. De Guzman
Supervising Science Research
Specialist Alternative Fuels and
Energy Technology Division,
Department of Energy

Thailand : Zero Waste Agriculture for Jatropha Plantation
Siriluck Nivitchanyong
Assistant Director, MTEC,
Alternative Energy Program Host,
NSTDA

Vietnam : Utilization of Agricultural and Wood Wastes in Vietnam
Tran Dinh Man
Deputy Director, Institute of
Biotechnology, VAST

Discussion
Moderator's Summary
Moderator: Yukihiro Matsumura
(Hiroshima University, Japan)

1220-1330 Lunch / Poster Session

For Sustainable Biomass Utilization

Chair: Yoshihito Shirai (Professor, Kyushu Institute of Technology, Japan)

1330-1355 Asia Biomass Community

Issei Sawa

Senior Manager, Liquid Biofuel, New Energy Business Unit, Mitsubishi Corporation, Japan

1355-1420 Financing for Biomass and Renewable Energy Projects

Mohd Nordin Che Omar

Manager of High Technology, representing Chairman of Bank Pembangunan Malaysia

1420-1445 Evaluation of Environmental Impacts of Biomass Utilisation by LCA

Masayuki Sagisaka

Deputy Director, Life Cycle Assessment Research Center, AIST, Japan

1445-1510 Improving Drought and Salt Stress Tolerance in Plants by Gene Transfer

Yasunari Fujita

Senior researcher, Biological Resources Division, JIRCAS, Japan

1530-1600 Coffee Break

Way Forward Session

-Panel Discussion-

Moderator: Shinya Yokoyama (Professor, The University of Tokyo, Japan)

1600-1730 Moderator's Summary : Energy Situation in Asian Region

< Panelists >

Haibin Li, China

Wahono Sumaryono, Indonesia

Kinya Sakanishi, Japan

Mohamad Ali Hassan, Malaysia

Peesamai Jenvanitpanjakul, Thailand

Tran Dinh Man, Vietnam

for the 5th Biomass-Asia Workshop

Closing Remarks

1730-1740 Masakazu Yamazaki

Vice President, AIST, Japan

1740-1750 Chen Sau Soon

Senior General Manager, Environment & Bioprocess Technology Centre

SIRIM, Malaysia

2000-2130 Workshop Dinner hosted by AIST

Day 3 (Nov. 22, 2007)

Technical tour

1. Waste to Energy Plant, Banting
2. Biodiesel Palm Oil Mill, Labu

A1.3 Asia Biomass Association

Based on the discussion on structuring of network, which is also clearly stated in the Tokyo Declaration on Asian Biomass, setting of Asia Biomass Association was proposed at the Biomass Asia forum.

This proposal is further based on the concept that conventional collaborative activities on Asian biomass are based on programs supported by a specific budget, and when the program is over, the activity is also over, but that the network should be continued, and thus the network should be free from specific budget. For example, the Ministry of Agriculture, Forestry, and Fishery, Japan does not have the eternal budget for the Biomass Asia Forum. The Ministry of Education, Culture, Sport, Science, and Technology, Japan is supporting the Biomass ASEAN Project only for three year. The network so far built up should not be cancelled, but the activities of the network are wanted to continue even when these budgets are over. Thus, structuring of the framework of the association was decided.

As the first step, a preparation committee was decided to be placed where the detail of the network that allows voluntary based activities without any budget is discussed. The name of the network was decided to be Asia Biomass Association (tentative), and the following fundamental policies were agreed.

- The Asia Biomass Association should be a voluntary-based neutral and non-political group.
- The association is composed of individual and group members, and has a steering committee, management committee, and, when necessary, working groups.
- Its activity is based on the membership fee, and the membership fee is decided by the steering committee based on the GDP per capita of each country.
- The least activities should be management of a mailing list and homepages. When budget is available, publication of brochure, organization of Biomass Asia Conference, and other activities by the proposal of other members should be made.

Members of the preparation committee is selected from the attendants of the Forum, one from each of 9 countries including Japan, and as the chair, Dr. Shin-ya Yokoyama was nominated. The management of the preparation committee was undertaken by the research group SETA, where Dr. Yokoyama is working as the International Steering Committee Chair.

This preparation committee decided to officially start the Asia Biomass Association in March, 2008. For this purpose, the following agreement was made.

Agreement of the Asian Biomass Association

1. This association should be known as the “Asian Biomass Association”, and abbreviated as “ABA”. It is a framework network based on voluntary activities and shall be a neutral and apolitical association.

2. The purpose of this association is to achieve effective utilization of Asian biomass based on the Tokyo Declaration on Asian Biomass. For this purpose, the association manages its homepage and the mailing list of the members.

3. The members of the association are a person or a group from Asian countries who are interested in the purpose of this association.

4. This association has the following bodies.

Steering Committee

Management Committee

Working Groups

5. The Steering Committee is composed of representatives from Asian countries. The number of the representatives is one for a country. The representative of a country is decided by the discussion among the members of the country’s nationality.

6. The Organization Committee has a Chair who is selected by election among the members of the committee. The duration of the Chairmanship is 2 years, and re-election is limited to 2 times.

7. The Organization Committee nominates members of the Management Committee.

8. The Organization Committee decides the activities of the association other than those shown above, and entrusts it to the Management Committee, and other parties. The Organization Committee decides the place of the office of the Association.
9. The Organization Committee starts and terminates the Working Groups for the activities of the association.
10. The Association Members includes personal members and group members. The joining and removal of a member needs approval by the Organizing Committee.
11. The membership fee is decided by the Organization Committee.
12. Amendment of this agreement requires the consent of 2/3 of its members.

The management of the mailing list and homepages were entrusted to Japan Institute of Energy. The Steering Committee members from each country are shown in Table A1.3.1.

Table A1.3.1 Steering Committee members

Country	Steering Committee member
Japan	Prof. Shin-ya Yokoyama*
Malaysia	Prof. Mohamad Ali Hassan
Philippines	Dr. Jessie Cansanay Elauria
Indonesia	Dr. Petrus Panaka
Vietnam	Dr. Hai Nam Truong
China	Prof. Dehua Liu
Thailand	Dr. Paritud Bhandhubanyong
Korea	Dr. Jin-Suk Lee
Taiwan	Prof. Tzay-An Shiau
Laos	Mr. Bouathep Malaykham

A2. Kyoto Protocol

A2.1 The United Nations Framework Convention on Climate Change (UNFCCC)

The Parties to this Convention,

Acknowledging that change in the Earth's climate and its adverse effects are a common concern of humankind,

Concerned that human activities have been substantially increasing the atmospheric concentrations of greenhouse gases, that these increases enhance the natural greenhouse effect, and that this will result on average in an additional warming of the Earth's surface and atmosphere and may adversely affect natural ecosystems and humankind,

Noting that the largest share of historical and current global emissions of greenhouse gases has originated in developed countries, that per capita emissions in developing countries are still relatively low and that the share of global emissions originating in developing countries will grow to meet their social and development needs,

Aware of the role and importance in terrestrial and marine ecosystems of sinks and reservoirs of greenhouse gases,

Noting that there are many uncertainties in predictions of climate change, particularly with regard to the timing, magnitude and regional patterns thereof,

Acknowledging that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions,

Recalling the pertinent provisions of the Declaration of the United Nations Conference on the Human Environment, adopted at Stockholm on 16 June 1972,

Recalling also that States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction,

Reaffirming the principle of sovereignty of States in international cooperation to address climate change,

Recognizing that States should enact effective environmental legislation, that environmental standards, management objectives and priorities should reflect the environmental and developmental context to which they apply, and that standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries,

Recalling the provisions of General Assembly resolution 44/228 of 22 December 1989 on the United Nations Conference on Environment and Development, and resolutions 43/53 of 6 December 1988, 44/207 of 22 December 1989, 45/212 of 21 December 1990 and 46/169 of 19 December 1991 on protection of global climate for present and future generations of mankind,

Recalling also the provisions of General Assembly resolution 44/206 of 22 December 1989 on the possible adverse effects of sea-level rise on islands and coastal areas, particularly low-lying coastal areas and the pertinent provisions of General Assembly resolution 44/172 of 19 December 1989 on the implementation of the Plan of Action to Combat Desertification,

Recalling further the Vienna Convention for the Protection of the Ozone Layer, 1985, and the Montreal Protocol on Substances that Deplete the Ozone Layer, 1987, as adjusted and amended on 29 June 1990,

Noting the Ministerial Declaration of the Second World Climate Conference adopted on 7 November 1990,

Conscious of the valuable analytical work being conducted by many States on climate change and of the important contributions of the World Meteorological Organization, the United Nations Environment Programme and other organs, organizations and bodies of the United Nations system, as well as other international and intergovernmental bodies, to the exchange of results of scientific research and the coordination of research,

Recognizing that steps required to understand and address climate change will be environmentally, socially and economically most effective if they are based on relevant scientific, technical and economic considerations and continually re-evaluated in the light of new findings in these areas,

Recognizing that various actions to address climate change can be justified economically in their own right and can also help in solving other environmental problems,

Recognizing also the need for developed countries to take immediate action in a flexible manner on the basis of clear priorities, as a first step towards comprehensive response strategies at the global, national and, where agreed, regional levels that take into account all greenhouse gases, with due consideration of their relative contributions to the enhancement of the greenhouse effect,

Recognizing further that low-lying and other small island countries, countries with low-lying coastal, arid and semi-arid areas or areas liable to floods, drought and desertification,

and developing countries with fragile mountainous ecosystems are particularly vulnerable to the adverse effects of climate change,

Recognizing the special difficulties of those countries, especially developing countries, whose economies are particularly dependent on fossil fuel production, use and exportation, as a consequence of action taken on limiting greenhouse gas emissions,

Affirming that responses to climate change should be coordinated with social and economic development in an integrated manner with a view to avoiding adverse impacts on the latter, taking into full account the legitimate priority needs of developing countries for the achievement of sustained economic growth and the eradication of poverty,

Recognizing that all countries, especially developing countries, need access to resources required to achieve sustainable social and economic development and that, in order for developing countries to progress towards that goal, their energy consumption will need to grow taking into account the possibilities for achieving greater energy efficiency and for controlling greenhouse gas emissions in general, including through the application of new technologies on terms which make such an application economically and socially beneficial,

Determined to protect the climate system for present and future generations,

Have agreed as follows:

ARTICLE 1
DEFINITIONS*

For the purposes of this Convention:

1. "Adverse effects of climate change" means changes in the physical environment or biota resulting from climate change which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare.
2. "Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.
3. "Climate system" means the totality of the atmosphere, hydrosphere, biosphere and geosphere and their interactions.
4. "Emissions" means the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.

5. "Greenhouse gases" means those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation.
6. "Regional economic integration organization" means an organization constituted by sovereign States of a given region which has competence in respect of matters governed by this Convention or its protocols and has been duly authorized, in accordance with its internal procedures, to sign, ratify, accept, approve or accede to the instruments concerned.
7. "Reservoir" means a component or components of the climate system where a greenhouse gas or a precursor of a greenhouse gas is stored.
8. "Sink" means any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.
9. "Source" means any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere.

* Titles of articles are included solely to assist the reader.

ARTICLE 2
OBJECTIVE

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

ARTICLE 3
PRINCIPLES

In their actions to achieve the objective of the Convention and to implement its provisions, the Parties shall be guided, *INTER ALIA*, by the following:

1. The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly,

the developed country Parties should take the lead in combating climate change and the adverse effects thereof.

2. The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration.
3. The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.
4. The Parties have a right to, and should, promote sustainable development. Policies and measures to protect the climate system against human-induced change should be appropriate for the specific conditions of each Party and should be integrated with national development programmes, taking into account that economic development is essential for adopting measures to address climate change.
5. The Parties should cooperate to promote a supportive and open international economic system that would lead to sustainable economic growth and development in all Parties, particularly developing country Parties, thus enabling them better to address the problems of climate change. Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade.

ARTICLE 4 COMMITMENTS

1. All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall:
 - (a) Develop, periodically update, publish and make available to the Conference of the Parties, in accordance with Article 12, national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties;

- (b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change;
- (c) Promote and cooperate in the development, application and diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol in all relevant sectors, including the energy, transport, industry, agriculture, forestry and waste management sectors;
- (d) Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems;
- (e) Cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods;
- (f) Take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change;
- (g) Promote and cooperate in scientific, technological, technical, socio-economic and other research, systematic observation and development of data archives related to the climate system and intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding the causes, effects, magnitude and timing of climate change and the economic and social consequences of various response strategies;
- (h) Promote and cooperate in the full, open and prompt exchange of relevant scientific, technological, technical, socio-economic and legal information related to the climate system and climate change, and to the economic and social consequences of various response strategies;
- (i) Promote and cooperate in education, training and public awareness related to climate change and encourage the widest participation in this process, including that of non-governmental organizations; and
- (j) Communicate to the Conference of the Parties information related to implementation, in accordance with Article 12.

2. The developed country Parties and other Parties included in Annex I commit themselves specifically as provided for in the following:

- (a) Each of these Parties shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention, recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol would contribute to such modification, and taking into account the differences in these Parties' starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort regarding that objective. These Parties may implement such policies and measures jointly with other Parties and may assist other Parties in contributing to the achievement of the objective of the Convention and, in particular, that of this subparagraph;
- (b) In order to promote progress to this end, each of these Parties shall communicate, within six months of the entry into force of the Convention for it and periodically thereafter, and in accordance with Article 12, detailed information on its policies and measures referred to in subparagraph (a) above, as well as on its resulting projected anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol for the period referred to in subparagraph (a), with the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol. This information will be reviewed by the Conference of the Parties, at its first session and periodically thereafter, in accordance with Article 7;
- (c) Calculations of emissions by sources and removals by sinks of greenhouse gases for the purposes of subparagraph (b) above should take into account the best available scientific knowledge, including of the effective capacity of sinks and the respective contributions of such gases to climate change. The Conference of the Parties shall consider and agree on methodologies for these calculations at its first session and review them regularly thereafter;
- (d) The Conference of the Parties shall, at its first session, review the adequacy of subparagraphs (a) and (b) above. Such review shall be carried out in the light of the best available scientific information and assessment on climate change and its impacts, as well as relevant technical, social and economic information. Based on this review, the Conference of the Parties shall take appropriate action, which may include the adoption of amendments to the commitments in subparagraphs (a) and (b) above. The Conference of the Parties, at its first session, shall also take decisions regarding criteria for joint implementation as indicated in subparagraph (a) above. A second review of subparagraphs (a) and (b) shall take place not later than 31 December 1998, and thereafter at regular intervals determined by the Conference of the Parties, until the objective of the Convention is met;

- (e) Each of these Parties shall :
- i) Coordinate as appropriate with other such Parties, relevant economic and administrative instruments developed to achieve the objective of the Convention; and
 - (ii) Identify and periodically review its own policies and practices which encourage activities that lead to greater levels of anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol than would otherwise occur;
- (f) The Conference of the Parties shall review, not later than 31 December 1998, available information with a view to taking decisions regarding such amendments to the lists in Annexes I and II as may be appropriate, with the approval of the Party concerned;
- (g) Any Party not included in Annex I may, in its instrument of ratification, acceptance, approval or accession, or at any time thereafter, notify the Depositary that it intends to be bound by subparagraphs (a) and (b) above. The Depositary shall inform the other signatories and Parties of any such notification.
3. The developed country Parties and other developed Parties included in Annex II shall provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in complying with their obligations under Article 12, paragraph 1. They shall also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of implementing measures that are covered by paragraph 1 of this Article and that are agreed between a developing country Party and the international entity or entities referred to in Article 11, in accordance with that Article. The implementation of these commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among the developed country Parties.
4. The developed country Parties and other developed Parties included in Annex II shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects.
5. The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention. In this process, the developed country Parties shall support the development and enhancement of endogenous capacities and technologies of developing country Parties. Other Parties and organizations in a position to do so may also assist in facilitating the transfer of such technologies.
6. In the implementation of their commitments under paragraph 2 above, a certain degree of flexibility shall be allowed by the Conference of the Parties to the Parties included in Annex I undergoing the process of transition to a market economy, in order to enhance the ability of these Parties to address climate change, including with regard to the historical level of anthropogenic emissions of greenhouse gases not controlled by the

Montreal Protocol chosen as a reference.

7. The extent to which developing country Parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed country Parties of their commitments under the Convention related to financial resources and transfer of technology and will take fully into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties.
8. In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures, especially on:
 - (a) Small island countries;
 - (b) Countries with low-lying coastal areas;
 - (c) Countries with arid and semi-arid areas, forested areas and areas liable to forest decay;
 - (d) Countries with areas prone to natural disasters;
 - (e) Countries with areas liable to drought and desertification;
 - (f) Countries with areas of high urban atmospheric pollution;
 - (g) Countries with areas with fragile ecosystems, including mountainous ecosystems;
 - (h) Countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and
 - (i) Land-locked and transit countries.

Further, the Conference of the Parties may take actions, as appropriate, with respect to this paragraph.

9. The Parties shall take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology.
10. The Parties shall, in accordance with Article 10, take into consideration in the implementation of the commitments of the Convention the situation of Parties, particularly developing country Parties, with economies that are vulnerable to the adverse effects of the implementation of measures to respond to climate change. This applies notably to Parties with economies that are highly dependent on income generated from the production, processing and export, and/or consumption of fossil fuels and associated energy-intensive products and/or the use of fossil fuels for which such Parties have serious difficulties in switching to alternatives.

ARTICLE 5
RESEARCH AND SYSTEMATIC OBSERVATION

In carrying out their commitments under Article 4, paragraph 1(g), the Parties shall:

- (a) Support and further develop, as appropriate, international and intergovernmental programmes and networks or organizations aimed at defining, conducting, assessing and financing research, data collection and systematic observation, taking into account the need to minimize duplication of effort;
- (b) Support international and intergovernmental efforts to strengthen systematic observation and national scientific and technical research capacities and capabilities, particularly in developing countries, and to promote access to, and the exchange of, data and analyses thereof obtained from areas beyond national jurisdiction; and
- (c) Take into account the particular concerns and needs of developing countries and cooperate in improving their endogenous capacities and capabilities to participate in the efforts referred to in subparagraphs (a) and (b) above.

ARTICLE 6
EDUCATION, TRAINING AND PUBLIC AWARENESS

In carrying out their commitments under Article 4, paragraph 1(i), the Parties shall:

- (a) Promote and facilitate at the national and, as appropriate, subregional and regional levels, and in accordance with national laws and regulations, and within their respective capacities:
 - (i) The development and implementation of educational and public awareness programmes on climate change and its effects;
 - (ii) Public access to information on climate change and its effects;
 - (iii) Public participation in addressing climate change and its effects and developing adequate responses; and
 - (iv) Training of scientific, technical and managerial personnel.
- (b) Cooperate in and promote, at the international level, and, where appropriate, using existing bodies:

- (i) The development and exchange of educational and public awareness material on climate change and its effects; and
 - (ii) The development and implementation of education and training programmes, including the strengthening of national institutions and the exchange or secondment of personnel to train experts in this field, in particular for developing countries.
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ARTICLE 7
CONFERENCE OF THE PARTIES

1. A Conference of the Parties is hereby established.
2. The Conference of the Parties, as the supreme body of this Convention, shall keep under regular review the implementation of the Convention and any related legal instruments that the Conference of the Parties may adopt, and shall make, within its mandate, the decisions necessary to promote the effective implementation of the Convention. To this end, it shall:
 - (a) Periodically examine the obligations of the Parties and the institutional arrangements under the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge;
 - (b) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under the Convention;
 - (c) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under the Convention;
 - (d) Promote and guide, in accordance with the objective and provisions of the Convention, the development and periodic refinement of comparable methodologies, to be agreed on by the Conference of the Parties, inter alia, for preparing inventories of greenhouse gas emissions by sources and removals by sinks, and for evaluating the effectiveness of measures to limit the emissions and enhance the removals of these gases;
 - (e) Assess, on the basis of all information made available to it in accordance with the provisions of the Convention, the implementation of the Convention by the Parties, the overall effects of the measures taken pursuant to the Convention, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being

achieved;

- (f) Consider and adopt regular reports on the implementation of the Convention and ensure their publication;
 - (g) Make recommendations on any matters necessary for the implementation of the Convention;
 - (h) Seek to mobilize financial resources in accordance with Article 4, paragraphs 3, 4 and 5, and Article 11;
 - (i) Establish such subsidiary bodies as are deemed necessary for the implementation of the Convention;
 - (j) Review reports submitted by its subsidiary bodies and provide guidance to them;
 - (k) Agree upon and adopt, by consensus, rules of procedure and financial rules for itself and for any subsidiary bodies;
 - (l) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and
 - (m) Exercise such other functions as are required for the achievement of the objective of the Convention as well as all other functions assigned to it under the Convention.
3. The Conference of the Parties shall, at its first session, adopt its own rules of procedure as well as those of the subsidiary bodies established by the Convention, which shall include decision-making procedures for matters not already covered by decision-making procedures stipulated in the Convention. Such procedures may include specified majorities required for the adoption of particular decisions.
4. The first session of the Conference of the Parties shall be convened by the interim secretariat referred to in Article 21 and shall take place not later than one year after the date of entry into force of the Convention. Thereafter, ordinary sessions of the Conference of the Parties shall be held every year unless otherwise decided by the Conference of the Parties.
5. Extraordinary sessions of the Conference of the Parties shall be held at such other times as may be deemed necessary by the Conference, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.
6. The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not Party to the Convention, may be represented at sessions of the Conference of the Parties as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by the Convention, and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties as

an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure adopted by the Conference of the Parties.

ARTICLE 8 SECRETARIAT

1. A secretariat is hereby established.
 2. The functions of the secretariat shall be:
 - (a) To make arrangements for sessions of the Conference of the Parties and its subsidiary bodies established under the Convention and to provide them with services as required;
 - (b) To compile and transmit reports submitted to it;
 - (c) To facilitate assistance to the Parties, particularly developing country Parties, on request, in the compilation and communication of information required in accordance with the provisions of the Convention;
 - (d) To prepare reports on its activities and present them to the Conference of the Parties;
 - (e) To ensure the necessary coordination with the secretariats of other relevant international bodies;
 - (f) To enter, under the overall guidance of the Conference of the Parties, into such administrative and contractual arrangements as may be required for the effective discharge of its functions; and
 - (g) To perform the other secretariat functions specified in the Convention and in any of its protocols and such other functions as may be determined by the Conference of the Parties.
 3. The Conference of the Parties, at its first session, shall designate a permanent secretariat and make arrangements for its functioning.
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ARTICLE 9 SUBSIDIARY BODY FOR SCIENTIFIC AND TECHNOLOGICAL ADVICE

1. A subsidiary body for scientific and technological advice is hereby established to provide the

Conference of the Parties and, as appropriate, its other subsidiary bodies with timely information and advice on scientific and technological matters relating to the Convention. This body shall be open to participation by all Parties and shall be multidisciplinary. It shall comprise government representatives competent in the relevant field of expertise. It shall report regularly to the Conference of the Parties on all aspects of its work.

2. Under the guidance of the Conference of the Parties, and drawing upon existing competent international bodies, this body shall:
 - (a) Provide assessments of the state of scientific knowledge relating to climate change and its effects;
 - (b) Prepare scientific assessments on the effects of measures taken in the implementation of the Convention;
 - (c) Identify innovative, efficient and state-of-the-art technologies and know-how and advise on the ways and means of promoting development and/or transferring such technologies;
 - (d) Provide advice on scientific programmes, international cooperation in research and development related to climate change, as well as on ways and means of supporting endogenous capacity-building in developing countries; and
 - (e) Respond to scientific, technological and methodological questions that the Conference of the Parties and its subsidiary bodies may put to the body.
3. The functions and terms of reference of this body may be further elaborated by the Conference of the Parties.

ARTICLE 10
SUBSIDIARY BODY FOR IMPLEMENTATION

1. A subsidiary body for implementation is hereby established to assist the Conference of the Parties in the assessment and review of the effective implementation of the Convention. This body shall be open to participation by all Parties and comprise government representatives who are experts on matters related to climate change. It shall report regularly to the Conference of the Parties on all aspects of its work.
2. Under the guidance of the Conference of the Parties, this body shall:
 - (a) Consider the information communicated in accordance with Article 12, paragraph 1, to assess the overall aggregated effect of the steps taken by the Parties in the light of the latest scientific assessments concerning climate change;
 - (b) Consider the information communicated in accordance with Article 12, paragraph 2, in

order to assist the Conference of the Parties in carrying out the reviews required by Article 4, paragraph 2(d); and

- (c) Assist the Conference of the Parties, as appropriate, in the preparation and implementation of its decisions.

ARTICLE 11 FINANCIAL MECHANISM

1. A mechanism for the provision of financial resources on a grant or concessional basis, including for the transfer of technology, is hereby defined. It shall function under the guidance of and be accountable to the Conference of the Parties, which shall decide on its policies, programme priorities and eligibility criteria related to this Convention. Its operation shall be entrusted to one or more existing international entities.
2. The financial mechanism shall have an equitable and balanced representation of all Parties within a transparent system of governance.
3. The Conference of the Parties and the entity or entities entrusted with the operation of the financial mechanism shall agree upon arrangements to give effect to the above paragraphs, which shall include the following:
 - (a) Modalities to ensure that the funded projects to address climate change are in conformity with the policies, programme priorities and eligibility criteria established by the Conference of the Parties;
 - (b) Modalities by which a particular funding decision may be reconsidered in light of these policies, programme priorities and eligibility criteria;
 - (c) Provision by the entity or entities of regular reports to the Conference of the Parties on its funding operations, which is consistent with the requirement for accountability set out in paragraph 1 above; and
 - (d) Determination in a predictable and identifiable manner of the amount of funding necessary and available for the implementation of this Convention and the conditions under which that amount shall be periodically reviewed.
4. The Conference of the Parties shall make arrangements to implement the above-mentioned provisions at its first session, reviewing and taking into account the interim arrangements referred to in Article 21, paragraph 3, and shall decide whether these interim arrangements shall be maintained. Within four years thereafter, the Conference of the Parties shall review the financial mechanism and take appropriate measures.
5. The developed country Parties may also provide and developing country Parties avail

themselves of, financial resources related to the implementation of the Convention through bilateral, regional and other multilateral channels.

ARTICLE 12

COMMUNICATION OF INFORMATION RELATED TO IMPLEMENTATION

1. In accordance with Article 4, paragraph 1, each Party shall communicate to the Conference of the Parties, through the secretariat, the following elements of information:
 - (a) A national inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, to the extent its capacities permit, using comparable methodologies to be promoted and agreed upon by the Conference of the Parties;
 - (b) A general description of steps taken or envisaged by the Party to implement the Convention; and
 - (c) Any other information that the Party considers relevant to the achievement of the objective of the Convention and suitable for inclusion in its communication, including, if feasible, material relevant for calculations of global emission trends.
2. Each developed country Party and each other Party included in Annex I shall incorporate in its communication the following elements of information:
 - (a) A detailed description of the policies and measures that it has adopted to implement its commitment under Article 4, paragraphs 2(a) and 2(b); and
 - (b) A specific estimate of the effects that the policies and measures referred to in subparagraph (a) immediately above will have on anthropogenic emissions by its sources and removals by its sinks of greenhouse gases during the period referred to in Article 4, paragraph 2(a).
3. In addition, each developed country Party and each other developed Party included in Annex II shall incorporate details of measures taken in accordance with Article 4, paragraphs 3, 4 and 5.
4. Developing country Parties may, on a voluntary basis, propose projects for financing, including specific technologies, materials, equipment, techniques or practices that would be needed to implement such projects, along with, if possible, an estimate of all incremental costs, of the reductions of emissions and increments of removals of greenhouse gases, as well as an estimate of the consequent benefits.
5. Each developed country Party and each other Party included in Annex I shall make its initial communication within six months of the entry into force of the Convention for that Party. Each Party not so listed shall make its initial communication within three

years of the entry into force of the Convention for that Party, or of the availability of financial resources in accordance with Article 4, paragraph 3. Parties that are least developed countries may make their initial communication at their discretion. The frequency of subsequent communications by all Parties shall be determined by the Conference of the Parties, taking into account the differentiated timetable set by this paragraph.

6. Information communicated by Parties under this Article shall be transmitted by the secretariat as soon as possible to the Conference of the Parties and to any subsidiary bodies concerned. If necessary, the procedures for the communication of information may be further considered by the Conference of the Parties.
7. From its first session, the Conference of the Parties shall arrange for the provision to developing country Parties of technical and financial support, on request, in compiling and communicating information under this Article, as well as in identifying the technical and financial needs associated with proposed projects and response measures under Article 4. Such support may be provided by other Parties, by competent international organizations and by the secretariat, as appropriate.
8. Any group of Parties may, subject to guidelines adopted by the Conference of the Parties, and to prior notification to the Conference of the Parties, make a joint communication in fulfilment of their obligations under this Article, provided that such a communication includes information on the fulfilment by each of these Parties of its individual obligations under the Convention.
9. Information received by the secretariat that is designated by a Party as confidential, in accordance with criteria to be established by the Conference of the Parties, shall be aggregated by the secretariat to protect its confidentiality before being made available to any of the bodies involved in the communication and review of information.
10. Subject to paragraph 9 above, and without prejudice to the ability of any Party to make public its communication at any time, the secretariat shall make communications by Parties under this Article publicly available at the time they are submitted to the Conference of the Parties.

ARTICLE 13
RESOLUTION OF QUESTIONS REGARDING IMPLEMENTATION

The Conference of the Parties shall, at its first session, consider the establishment of a multilateral consultative process, available to Parties on their request, for the resolution of questions regarding the implementation of the Convention.

ARTICLE 14

SETTLEMENT OF DISPUTES

1. In the event of a dispute between any two or more Parties concerning the interpretation or application of the Convention, the Parties concerned shall seek a settlement of the dispute through negotiation or any other peaceful means of their own choice.
 2. When ratifying, accepting, approving or acceding to the Convention, or at any time thereafter, a Party which is not a regional economic integration organization may declare in a written instrument submitted to the Depositary that, in respect of any dispute concerning the interpretation or application of the Convention, it recognizes as compulsory ipso facto and without special agreement, in relation to any Party accepting the same obligation:
 - (a) Submission of the dispute to the International Court of Justice, and/or
 - (b) Arbitration in accordance with procedures to be adopted by the Conference of the Parties as soon as practicable, in an annex on arbitration.
- A Party which is a regional economic integration organization may make a declaration with like effect in relation to arbitration in accordance with the procedures referred to in subparagraph (b) above.
3. A declaration made under paragraph 2 above shall remain in force until it expires in accordance with its terms or until three months after written notice of its revocation has been deposited with the Depositary.
 4. A new declaration, a notice of revocation or the expiry of a declaration shall not in any way affect proceedings pending before the International Court of Justice or the arbitral tribunal, unless the parties to the dispute otherwise agree.
 5. Subject to the operation of paragraph 2 above, if after twelve months following notification by one Party to another that a dispute exists between them, the Parties concerned have not been able to settle their dispute through the means mentioned in paragraph 1 above, the dispute shall be submitted, at the request of any of the parties to the dispute, to conciliation.
 6. A conciliation commission shall be created upon the request of one of the parties to the dispute. The commission shall be composed of an equal number of members appointed by each party concerned and a chairman chosen jointly by the members appointed by each party. The commission shall render a recommendatory award, which the parties shall consider in good faith.
 7. Additional procedures relating to conciliation shall be adopted by the Conference of the Parties, as soon as practicable, in an annex on conciliation.
 8. The provisions of this Article shall apply to any related legal instrument which the

Conference of the Parties may adopt, unless the instrument provides otherwise.

ARTICLE 15
AMENDMENTS TO THE CONVENTION

1. Any Party may propose amendments to the Convention.
2. Amendments to the Convention shall be adopted at an ordinary session of the Conference of the Parties. The text of any proposed amendment to the Convention shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate proposed amendments to the signatories to the Convention and, for information, to the Depositary.
3. The Parties shall make every effort to reach agreement on any proposed amendment to the Convention by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted amendment shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.
4. Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to the Convention.
5. The amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.
6. For the purposes of this Article, "Parties present and voting" means Parties present and casting an affirmative or negative vote.

ARTICLE 16
ADOPTION AND AMENDMENT OF ANNEXES TO THE CONVENTION

1. Annexes to the Convention shall form an integral part thereof and, unless otherwise expressly provided, a reference to the Convention constitutes at the same time a reference to any annexes thereto. Without prejudice to the provisions of Article 14, paragraphs 2(b) and 7, such annexes shall be restricted to lists, forms and any other

material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

2. Annexes to the Convention shall be proposed and adopted in accordance with the procedure set forth in Article 15, paragraphs 2, 3 and 4.
3. An annex that has been adopted in accordance with paragraph 2 above shall enter into force for all Parties to the Convention six months after the date of the communication by the Depositary to such Parties of the adoption of the annex, except for those Parties that have notified the Depositary, in writing, within that period of their non-acceptance of the annex. The annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.
4. The proposal, adoption and entry into force of amendments to annexes to the Convention shall be subject to the same procedure as that for the proposal, adoption and entry into force of annexes to the Convention in accordance with paragraphs 2 and 3 above.
5. If the adoption of an annex or an amendment to an annex involves an amendment to the Convention, that annex or amendment to an annex shall not enter into force until such time as the amendment to the Convention enters into force.

ARTICLE 17 PROTOCOLS

1. The Conference of the Parties may, at any ordinary session, adopt protocols to the Convention.
2. The text of any proposed protocol shall be communicated to the Parties by the secretariat at least six months before such a session.
3. The requirements for the entry into force of any protocol shall be established by that instrument.
4. Only Parties to the Convention may be Parties to a protocol.
5. Decisions under any protocol shall be taken only by the Parties to the protocol concerned.

ARTICLE 18 RIGHT TO VOTE

1. Each Party to the Convention shall have one vote, except as provided for in paragraph 2 below.
2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to the Convention. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

ARTICLE 19 DEPOSITARY

The Secretary-General of the United Nations shall be the Depositary of the Convention and of protocols adopted in accordance with Article 17.

ARTICLE 20 SIGNATURE

This Convention shall be open for signature by States Members of the United Nations or of any of its specialized agencies or that are Parties to the Statute of the International Court of Justice and by regional economic integration organizations at Rio de Janeiro, during the United Nations Conference on Environment and Development, and thereafter at United Nations Headquarters in New York from 20 June 1992 to 19 June 1993.

ARTICLE 21 INTERIM ARRANGEMENTS

1. The secretariat functions referred to in Article 8 will be carried out on an interim basis by the secretariat established by the General Assembly of the United Nations in its resolution 45/212 of 21 December 1990, until the completion of the first session of the Conference of the Parties.
2. The head of the interim secretariat referred to in paragraph 1 above will cooperate closely with the Intergovernmental Panel on Climate Change to ensure that the Panel can respond to the need for objective scientific and technical advice. Other relevant scientific bodies could also be consulted.

3. The Global Environment Facility of the United Nations Development Programme, the United Nations Environment Programme and the International Bank for Reconstruction and Development shall be the international entity entrusted with the operation of the financial mechanism referred to in Article 11 on an interim basis. In this connection, the Global Environment Facility should be appropriately restructured and its membership made universal to enable it to fulfil the requirements of Article 11.

ARTICLE 22
RATIFICATION, ACCEPTANCE, APPROVAL OR ACCESSION

1. The Convention shall be subject to ratification, acceptance, approval or accession by States and by regional economic integration organizations. It shall be open for accession from the day after the date on which the Convention is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.
2. Any regional economic integration organization which becomes a Party to the Convention without any of its member States being a Party shall be bound by all the obligations under the Convention. In the case of such organizations, one or more of whose member States is a Party to the Convention, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under the Convention. In such cases, the organization and the member States shall not be entitled to exercise rights under the Convention concurrently.
3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by the Convention. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

ARTICLE 23
ENTRY INTO FORCE

1. The Convention shall enter into force on the ninetieth day after the date of deposit of the fiftieth instrument of ratification, acceptance, approval or accession.
2. For each State or regional economic integration organization that ratifies, accepts or approves the Convention or accedes thereto after the deposit of the fiftieth instrument of ratification, acceptance, approval or accession, the Convention shall enter into force on the ninetieth day after the date of deposit by such State or regional economic integration organization of its instrument of ratification, acceptance, approval or

accession.

3. For the purposes of paragraphs 1 and 2 above, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

ARTICLE 24 RESERVATIONS

No reservations may be made to the Convention.

ARTICLE 25 WITHDRAWAL

1. At any time after three years from the date on which the Convention has entered into force for a Party, that Party may withdraw from the Convention by giving written notification to the Depositary.
 2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.
 3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from any protocol to which it is a Party.
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ARTICLE 26 AUTHENTIC TEXTS

The original of this Convention, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary- General of the United Nations.

IN WITNESS WHEREOF the undersigned, being duly authorized to that effect, have signed this Convention.

DONE at New York this ninth day of May one thousand nine hundred and ninety- two.

ANNEX I AND ANNEX II COUNTRIES

Annex I

Australia
Austria
Belarus*
Belgium
Bulgaria*
Canada
Czechoslovakia*
Denmark
European Economic Community
Estonia*
Finland
France
Germany
Greece
Hungary*
Iceland
Ireland
Italy
Japan
Latvia*
Lithuania*
Luxembourg
Netherlands
New Zealand
Norway
Poland*
Portugal
Romania*
Russian Federation*
Spain
Sweden
Switzerland
Turkey
Ukraine*
United Kingdom of Great Britain and Northern Ireland
United States of America

*Countries that are undergoing the process of transition to a market economy.

Annex II

Australia
Austria
Belgium

Canada
Denmark
European Economic Community
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Japan
Luxembourg
Netherlands
New Zealand
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom of Great Britain and Northern Ireland
United States of America

A2.2 Kyoto Protocol to the United Nations Framework Convention on Climate Change

The Parties to this Protocol,

Being Parties to the United Nations Framework Convention on Climate Change, hereinafter referred to as "the Convention",

In pursuit of the ultimate objective of the Convention as stated in its Article 2,

Recalling the provisions of the Convention,

Being guided by Article 3 of the Convention,

Pursuant to the Berlin Mandate adopted by decision 1/CP.1 of the

Conference of the Parties to the Convention at its first session,

Have agreed as follows:

Article 1

For the purposes of this Protocol, the definitions contained in Article 1 of the Convention shall apply. In addition:

1. "Conference of the Parties" means the Conference of the Parties to the Convention.
2. "Convention" means the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992.
3. "Intergovernmental Panel on Climate Change" means the Intergovernmental Panel on Climate Change established in 1988 jointly by the World Meteorological Organization and the

United Nations Environment Programme.

4. "Montreal Protocol" means the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in Montreal on 16 September 1987 and as subsequently adjusted and amended.

5. "Parties present and voting" means Parties present and casting an affirmative or negative vote.

6. "Party" means, unless the context otherwise indicates, a Party to this Protocol.

7. "Party included in Annex I" means a Party included in Annex I to the Convention, as may be amended, or a Party which has made a notification under Article 4, paragraph 2(g), of the Convention.

Article 2

1. Each Party included in Annex I, in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development, shall:

(a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as:

(i) Enhancement of energy efficiency in relevant sectors of the national economy;

(ii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation;

(iii) Promotion of sustainable forms of agriculture in light of climate change considerations;

(iv) Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative

environmentally sound technologies;

(v) Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas emitting sectors that run counter to the objective of the Convention and application of market instruments;

(vi) Encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures which limit or reduce emissions of greenhouse gases not controlled by the Montreal Protocol;

(vii) Measures to limit and/or reduce emissions of greenhouse gases not controlled by the Montreal Protocol in the transport sector;

(viii) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy;

(b) Cooperate with other such Parties to enhance the individual and combined effectiveness of their policies and measures adopted under this Article, pursuant to Article 4, paragraph 2(e)(i), of the Convention. To this end, these Parties shall take steps to share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency and effectiveness. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, consider ways to facilitate such cooperation, taking into account all relevant information.

2. The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

3. The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as to minimize adverse effects, including the adverse effects of climate change, effects on international trade, and social, environmental and economic impacts on

other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9, of the Convention, taking into account Article 3 of the Convention. The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol, if it decides that it would be beneficial to coordinate any of the policies and measures in paragraph 1(a) above, taking into account different national circumstances and potential effects, shall consider ways and means to elaborate the coordination of such policies and measures.

Article 3

1. The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.

2. Each Party included in Annex I shall, by 2005, have made demonstrable progress in achieving its commitments under this Protocol.

3. The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I. The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8.

4. Prior to the first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol, each Party included in Annex I shall provide, for consideration by the

Subsidiary Body for Scientific and Technological Advice, data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change, the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties. Such a decision shall apply in the second and subsequent commitment periods. A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided that these activities have taken place since 1990.

5. The Parties included in Annex I undergoing the process of transition to a market economy whose base year or period was established pursuant to decision 9/CP.2 of the Conference of the Parties at its second session shall use that base year or period for the implementation of their commitments under this Article. Any other Party included in Annex I undergoing the process of transition to a market economy which has not yet submitted its first national communication under Article 12 of the Convention may also notify the Conference of the Parties serving as the meeting of the Parties to this Protocol that it intends to use an historical base year or period other than 1990 for the implementation of its commitments under this Article. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall decide on the acceptance of such notification.

6. Taking into account Article 4, paragraph 6, of the Convention, in the implementation of their commitments under this Protocol other than those under this Article, a certain degree of flexibility shall be allowed by the Conference of the Parties serving as the meeting of the Parties to this Protocol to the Parties included in Annex I undergoing the process of transition to a market economy.

7. In the first quantified emission limitation and reduction commitment period, from 2008 to

2012, the assigned amount for each Party included in Annex I shall be equal to the percentage inscribed for it in Annex B of its aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A in 1990, or the base year or period determined in accordance with paragraph 5 above, multiplied by five. Those Parties included in Annex I for whom land-use change and forestry constituted a net source of greenhouse gas emissions in 1990 shall include in their 1990 emissions base year or period the aggregate anthropogenic carbon dioxide equivalent emissions by sources minus removals by sinks in 1990 from land-use change for the purposes of calculating their assigned amount.

8. Any Party included in Annex I may use 1995 as its base year for hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for the purposes of the calculation referred to in paragraph 7 above.

9. Commitments for subsequent periods for Parties included in Annex I shall be established in amendments to Annex B to this Protocol, which shall be adopted in accordance with the provisions of Article 21, paragraph 7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall initiate the consideration of such commitments at least seven years before the end of the first commitment period referred to in paragraph 1 above.

10. Any emission reduction units, or any part of an assigned amount, which a Party acquires from another Party in accordance with the provisions of Article 6 or of Article 17 shall be added to the assigned amount for the acquiring Party.

11. Any emission reduction units, or any part of an assigned amount, which a Party transfers to another Party in accordance with the provisions of Article 6 or of Article 17 shall be subtracted from the assigned amount for the transferring Party.

12. Any certified emission reductions which a Party acquires from another Party in accordance with the provisions of Article 12 shall be added to the assigned amount for the acquiring Party.

13. If the emissions of a Party included in Annex I in a commitment period are less than its assigned amount under this Article, this difference shall, on request of that Party, be added to the assigned amount for that Party for subsequent commitment periods.

14. Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention. In line with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on Parties referred to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.

Article 4

1. Any Parties included in Annex I that have reached an agreement to fulfil their commitments under Article 3 jointly, shall be deemed to have met those commitments provided that their total combined aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of Article 3. The respective emission level allocated to each of the Parties to the agreement shall be set out in that agreement.

2. The Parties to any such agreement shall notify the secretariat of the terms of the agreement on the date of deposit of their instruments of ratification, acceptance or approval of this Protocol, or accession thereto. The secretariat shall in turn inform the Parties and signatories to the Convention of the terms of the agreement.

3. Any such agreement shall remain in operation for the duration of the commitment period specified in Article 3, paragraph 7.

4. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization, any alteration in the composition of the organization after adoption of this Protocol shall not affect existing commitments under this Protocol. Any alteration in the composition of the organization shall only apply for the purposes of those commitments under Article 3 that are adopted subsequent to that alteration.

5. In the event of failure by the Parties to such an agreement to achieve their total combined level of emission reductions, each Party to that agreement shall be responsible for its own level of emissions set out in the agreement.

6. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization which is itself a Party to this Protocol, each member State of that regional economic integration organization individually, and together with the regional economic integration organization acting in accordance with Article 24, shall, in the event of failure to achieve the total combined level of emission reductions, be responsible for its level of emissions as notified in accordance with this Article.

Article 5

1. Each Party included in Annex I shall have in place, no later than one year prior to the start of the first commitment period, a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. Guidelines for such national systems, which shall incorporate the methodologies specified in paragraph 2 below, shall be decided upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session.

2. Methodologies for estimating anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Where such methodologies are not used, appropriate adjustments shall be applied according to methodologies agreed upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise such methodologies and adjustments, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to methodologies or adjustments shall be used only for the purposes of ascertaining compliance with commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

3. The global warming potentials used to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases listed in Annex A shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise the global warming potential of each such greenhouse gas, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to a global warming potential shall apply only to commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

Article 6

1. For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that:

- (a) Any such project has the approval of the Parties involved;
- (b) Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur;
- (c) It does not acquire any emission reduction units if it is not in compliance with its obligations under Articles 5 and 7; and
- (d) The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.

2. The Conference of the Parties serving as the meeting of the Parties to this Protocol may, at its first session or as soon as practicable thereafter, further elaborate guidelines for the implementation of this Article, including for verification and reporting.

3. A Party included in Annex I may authorize legal entities to participate, under its responsibility, in actions leading to the generation, transfer or acquisition under this Article of emission reduction units.

4. If a question of implementation by a Party included in Annex I of the requirements referred to in this Article is identified in accordance with the relevant provisions of Article 8, transfers and acquisitions of emission reduction units may continue to be made after the question has been identified, provided that any such units may not be used by a Party to meet its commitments under Article 3 until any issue of compliance is resolved.

Article 7

1. Each Party included in Annex I shall incorporate in its annual inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, submitted in accordance with the relevant decisions of the Conference of the Parties, the necessary supplementary information for the purposes of ensuring compliance with Article 3, to be determined in accordance with paragraph 4 below.

2. Each Party included in Annex I shall incorporate in its national communication, submitted under Article 12 of the Convention, the supplementary information necessary to demonstrate compliance with its commitments under this Protocol, to be determined in accordance with paragraph 4 below.

3. Each Party included in Annex I shall submit the information required under paragraph 1 above annually, beginning with the first inventory due under the Convention for the first year of the commitment period after this Protocol has entered into force for that Party. Each such Party shall submit the information required under paragraph 2 above as part of the first national communication due under the Convention after this Protocol has entered into force for it and after the adoption of guidelines as provided for in paragraph 4 below. The frequency of subsequent submission of information required under this Article shall be determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol, taking into account any timetable for the submission of national communications decided upon by the Conference of the Parties.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the preparation of the information required under this Article, taking into account guidelines for the preparation of national communications by Parties included in Annex I adopted by the Conference of the Parties. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall also, prior to the first commitment period, decide upon modalities for the accounting of assigned amounts.

Article 8

1. The information submitted under Article 7 by each Party included in Annex I shall be reviewed by expert review teams pursuant to the relevant decisions of the Conference of the Parties and in accordance with guidelines adopted for this purpose by the Conference of the Parties serving as the meeting of the Parties to this Protocol under paragraph 4 below. The information submitted under Article 7, paragraph 1, by each Party included in Annex I shall be reviewed as part of the annual compilation and accounting of emissions inventories and assigned amounts. Additionally, the information submitted under Article 7, paragraph 2, by each Party included in Annex I shall be reviewed as part of the review of communications.

2. Expert review teams shall be coordinated by the secretariat and shall be composed of experts selected from those nominated by Parties to the Convention and, as appropriate, by intergovernmental organizations, in accordance with guidance provided for this purpose by the Conference of the Parties.

3. The review process shall provide a thorough and comprehensive technical assessment of all aspects of the implementation by a Party of this Protocol. The expert review teams shall prepare a report to the Conference of the Parties serving as the meeting of the Parties to this Protocol, assessing the implementation of the commitments of the Party and identifying any potential problems in, and factors influencing, the fulfilment of commitments. Such reports shall be circulated by the secretariat to all Parties to the Convention. The secretariat shall list those questions of implementation indicated in such reports for further consideration by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the review of implementation of this Protocol by expert review teams taking into account the relevant decisions of the Conference of the Parties.

5. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, with the assistance of the Subsidiary Body for Implementation and, as appropriate, the Subsidiary Body for Scientific and Technological Advice, consider:

(a) The information submitted by Parties under Article 7 and the reports of the expert reviews thereon conducted under this Article; and

(b) Those questions of implementation listed by the secretariat under paragraph 3 above, as well as any questions raised by Parties.

6. Pursuant to its consideration of the information referred to in paragraph 5 above, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take decisions on any matter required for the implementation of this Protocol.

Article 9

1. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall periodically review this Protocol in the light of the best available scientific information and assessments on climate change and its impacts, as well as relevant technical, social and economic information. Such reviews shall be coordinated with pertinent reviews under the Convention, in particular those required by Article 4, paragraph 2(d), and Article 7, paragraph 2(a), of the Convention. Based on these reviews, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take appropriate action.

2. The first review shall take place at the second session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. Further reviews shall take place at regular intervals and in a timely manner.

Article 10

All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, without introducing any new commitments for Parties not included in Annex I, but reaffirming existing commitments under Article 4, paragraph 1, of the Convention, and continuing to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4, paragraphs 3, 5 and 7, of the Convention, shall:

(a) Formulate, where relevant and to the extent possible, cost-effective national and, where appropriate, regional programmes to improve the quality of local emission factors, activity data and/or models which reflect the socio-economic conditions of each Party for the preparation and periodic updating of national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties, and consistent with the guidelines for the preparation of national communications adopted by the Conference of the Parties;

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change:

(i) Such programmes would, inter alia, concern the energy, transport and industry sectors as well as agriculture, forestry and waste management. Furthermore, adaptation technologies and methods for improving spatial planning would improve adaptation to climate change; and

(ii) Parties included in Annex I shall submit information on action under this Protocol, including national programmes, in accordance with Article 7; and other Parties shall seek to include in their national communications, as appropriate, information on programmes which contain measures that the Party believes contribute to addressing climate change and its adverse impacts, including the abatement of increases in greenhouse gas emissions, and enhancement of and removals by sinks, capacity building and adaptation measures;

(c) Cooperate in the promotion of effective modalities for the development, application and

diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies;

(d) Cooperate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives to reduce uncertainties related to the climate system, the adverse impacts of climate change and the economic and social consequences of various response strategies, and promote the development and strengthening of endogenous capacities and capabilities to participate in international and intergovernmental efforts, programmes and networks on research and systematic observation, taking into account Article 5 of the Convention;

(e) Cooperate in and promote at the international level, and, where appropriate, using existing bodies, the development and implementation of education and training programmes, including the strengthening of national capacity building, in particular human and institutional capacities and the exchange or secondment of personnel to train experts in this field, in particular for developing countries, and facilitate at the national level public awareness of, and public access to information on, climate change. Suitable modalities should be developed to implement these activities through the relevant bodies of the Convention, taking into account Article 6 of the Convention;

(f) Include in their national communications information on programmes and activities undertaken pursuant to this Article in accordance with relevant decisions of the Conference of the Parties; and

(g) Give full consideration, in implementing the commitments under this Article, to Article 4, paragraph 8, of the Convention.

Article 11

1. In the implementation of Article 10, Parties shall take into account the provisions of Article 4, paragraphs 4, 5, 7, 8 and 9, of the Convention.

2. In the context of the implementation of Article 4, paragraph 1, of the Convention, in accordance with the provisions of Article 4, paragraph 3, and Article 11 of the Convention, and through the entity or entities entrusted with the operation of the financial mechanism of the Convention, the developed country Parties and other developed Parties included in Annex II to the Convention shall:

(a) Provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in advancing the implementation of existing commitments under Article 4, paragraph 1(a), of the Convention that are covered in Article 10, subparagraph (a); and

(b) Also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of advancing the implementation of existing commitments under Article 4, paragraph 1, of the Convention that are covered by Article 10 and that are agreed between a developing country Party and the international entity or entities referred to in Article 11 of the Convention, in accordance with that Article.

The implementation of these existing commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among developed country Parties. The guidance to the entity or entities entrusted with the operation of the financial mechanism of the Convention in relevant decisions of the Conference of the Parties, including those agreed before the adoption of this Protocol, shall apply *mutatis mutandis* to the provisions of this paragraph.

3. The developed country Parties and other developed Parties in Annex II to the Convention may also provide, and developing country Parties avail themselves of, financial resources for the implementation of Article 10, through bilateral, regional and other multilateral channels.

Article 12

1. A clean development mechanism is hereby defined.
2. The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.
3. Under the clean development mechanism:
 - (a) Parties not included in Annex I will benefit from project activities resulting in certified emission reductions; and
 - (b) Parties included in Annex I may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3, as determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol.
4. The clean development mechanism shall be subject to the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to this Protocol and be supervised by an executive board of the clean development mechanism.
5. Emission reductions resulting from each project activity shall be certified by operational entities to be designated by the Conference of the Parties serving as the meeting of the Parties to this Protocol, on the basis of:
 - (a) Voluntary participation approved by each Party involved;
 - (b) Real, measurable, and long-term benefits related to the mitigation of climate change; and
 - (c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.

6. The clean development mechanism shall assist in arranging funding of certified project activities as necessary.

7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, elaborate modalities and procedures with the objective of ensuring transparency, efficiency and accountability through independent auditing and verification of project activities.

8. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall ensure that a share of the proceeds from certified project activities is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

9. Participation under the clean development mechanism, including in activities mentioned in paragraph 3(a) above and in the acquisition of certified emission reductions, may involve private and/or public entities, and is to be subject to whatever guidance may be provided by the executive board of the clean development mechanism.

10. Certified emission reductions obtained during the period from the year 2000 up to the beginning of the first commitment period can be used to assist in achieving compliance in the first commitment period.

Article 13

1. The Conference of the Parties, the supreme body of the Convention, shall serve as the meeting of the Parties to this Protocol.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, any member of the Bureau of the Conference of the Parties representing a Party to the Convention but, at that time, not a Party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall keep under regular review the implementation of this Protocol and shall make, within its mandate, the decisions necessary to promote its effective implementation. It shall perform the functions assigned to it by this Protocol and shall:

(a) Assess, on the basis of all information made available to it in accordance with the provisions of this Protocol, the implementation of this Protocol by the Parties, the overall effects of the measures taken pursuant to this Protocol, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;

(b) Periodically examine the obligations of the Parties under this Protocol, giving due consideration to any reviews required by Article 4, paragraph 2(d), and Article 7, paragraph 2, of the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge, and in this respect consider and adopt regular reports on the implementation of this Protocol;

(c) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(d) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(e) Promote and guide, in accordance with the objective of the Convention and the provisions of

this Protocol, and taking fully into account the relevant decisions by the Conference of the Parties, the development and periodic refinement of comparable methodologies for the effective implementation of this Protocol, to be agreed on by the Conference of the Parties serving as the meeting of the Parties to this Protocol;

(f) Make recommendations on any matters necessary for the implementation of this Protocol;

(g) Seek to mobilize additional financial resources in accordance with

Article 11, paragraph 2;

(h) Establish such subsidiary bodies as are deemed necessary for the implementation of this Protocol;

(i) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and

(j) Exercise such other functions as may be required for the implementation of this Protocol, and consider any assignment resulting from a decision by the Conference of the Parties.

5. The rules of procedure of the Conference of the Parties and financial procedures applied under the Convention shall be applied *mutatis mutandis* under this Protocol, except as may be otherwise decided by consensus by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

6. The first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be convened by the secretariat in conjunction with the first session of the Conference of the Parties that is scheduled after the date of the entry into force of this Protocol. Subsequent ordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held every year and in conjunction with ordinary sessions of the Conference of the Parties, unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

7. Extraordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held at such other times as may be deemed necessary by the Conference of the Parties serving as the meeting of the Parties to this Protocol, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

8. The United Nations, its specialized agencies and the International Atomic Energy

Agency, as well as any State member thereof or observers thereto not party to the Convention, may be represented at sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by this Protocol and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties serving as the meeting of the Parties to this Protocol as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure, as referred to in paragraph 5 above.

Article 14

1. The secretariat established by Article 8 of the Convention shall serve as the secretariat of this Protocol.

2. Article 8, paragraph 2, of the Convention on the functions of the secretariat, and Article 8, paragraph 3, of the Convention on arrangements made for the functioning of the secretariat, shall apply *mutatis mutandis* to this Protocol. The secretariat shall, in addition, exercise the functions assigned to it under this Protocol.

Article 15

1. The Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation established by Articles 9 and 10 of the Convention shall serve as, respectively,

the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol. The provisions relating to the functioning of these two bodies under the Convention shall apply *mutatis mutandis* to this Protocol. Sessions of the meetings of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol shall be held in conjunction with the meetings of, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of the Convention.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the subsidiary bodies. When the subsidiary bodies serve as the subsidiary bodies of this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3. When the subsidiary bodies established by Articles 9 and 10 of the Convention exercise their functions with regard to matters concerning this Protocol, any member of the Bureaux of those subsidiary bodies representing a Party to the Convention but, at that time, not a party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

Article 16

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, as soon as practicable, consider the application to this Protocol of, and modify as appropriate, the multilateral consultative process referred to in Article 13 of the Convention, in the light of any relevant decisions that may be taken by the Conference of the Parties. Any multilateral consultative process that may be applied to this Protocol shall operate without prejudice to the procedures and mechanisms established in accordance with Article 18.

Article 17

The Conference of the Parties shall define the relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability for emissions trading. The Parties included in Annex B may participate in emissions trading for the purposes of

fulfilling their commitments under Article 3. Any such trading shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction commitments under that Article.

Article 18

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, approve appropriate and effective procedures and mechanisms to determine and to address cases of non-compliance with the provisions of this Protocol, including through the development of an indicative list of consequences, taking into account the cause, type, degree and frequency of non-compliance. Any procedures and mechanisms under this Article entailing binding consequences shall be adopted by means of an amendment to this Protocol.

Article 19

The provisions of Article 14 of the Convention on settlement of disputes shall apply *mutatis mutandis* to this Protocol.

Article 20

1. Any Party may propose amendments to this Protocol.
2. Amendments to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed amendment to this Protocol shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed amendments to the Parties and signatories to the Convention and, for information, to the Depositary.
3. The Parties shall make every effort to reach agreement on any proposed amendment to this Protocol by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted amendment shall be communicated

by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

4. Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to this Protocol.

5. The amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.

Article 21

1. Annexes to this Protocol shall form an integral part thereof and, unless otherwise expressly provided, a reference to this Protocol constitutes at the same time a reference to any annexes thereto. Any annexes adopted after the entry into force of this Protocol shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

2. Any Party may make proposals for an annex to this Protocol and may propose amendments to annexes to this Protocol.

3. Annexes to this Protocol and amendments to annexes to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed annex or amendment to an annex shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed annex or amendment to an annex to the Parties and signatories to the Convention and, for information, to the Depositary.

4. The Parties shall make every effort to reach agreement on any proposed annex or amendment to an annex by consensus. If all efforts at consensus have been exhausted, and no

agreement reached, the annex or amendment to an annex shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted annex or amendment to an annex shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

5. An annex, or amendment to an annex other than Annex A or B, that has been adopted in accordance with paragraphs 3 and 4 above shall enter into force for all Parties to this Protocol six months after the date of the communication by the Depositary to such Parties of the adoption of the annex or adoption of the amendment to the annex, except for those Parties that have notified the Depositary, in writing, within that period of their non-acceptance of the annex or amendment to the annex. The annex or amendment to an annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.

6. If the adoption of an annex or an amendment to an annex involves an amendment to this Protocol, that annex or amendment to an annex shall not enter into force until such time as the amendment to this Protocol enters into force.

7. Amendments to Annexes A and B to this Protocol shall be adopted and enter into force in accordance with the procedure set out in Article 20, provided that any amendment to Annex B shall be adopted only with the written consent of the Party concerned.

Article 22

1. Each Party shall have one vote, except as provided for in paragraph 2 below.

2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to this Protocol. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

Article 23

The Secretary-General of the United Nations shall be the Depositary of this Protocol.

Article 24

1. This Protocol shall be open for signature and subject to ratification, acceptance or approval by States and regional economic integration organizations which are Parties to the Convention. It shall be open for signature at United Nations Headquarters in New York from

16 March 1998 to 15 March 1999. This Protocol shall be open for accession from the day after the date on which it is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2. Any regional economic integration organization which becomes a Party to this Protocol without any of its member States being a Party shall be bound by all the obligations under this Protocol. In the case of such organizations, one or more of whose member States is a Party to this Protocol, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under this Protocol. In such cases, the organization and the member States shall not be entitled to exercise rights under this Protocol concurrently.

3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by this Protocol. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

Article 25

1. This Protocol shall enter into force on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55 per cent of the total carbon dioxide emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification, acceptance, approval or accession.

2. For the purposes of this Article, "the total carbon dioxide emissions for 1990 of the Parties included in Annex I" means the amount communicated on or before the date of adoption of this

Protocol by the Parties included in Annex I in their first national communications submitted in accordance with Article 12 of the Convention.

3. For each State or regional economic integration organization that ratifies, accepts or approves this Protocol or accedes thereto after the conditions set out in paragraph 1 above for entry into force have been fulfilled, this Protocol shall enter into force on the ninetieth day following the date of deposit of its instrument of ratification, acceptance, approval or accession.

4. For the purposes of this Article, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

Article 26

No reservations may be made to this Protocol.

Article 27

1. At any time after three years from the date on which this Protocol has entered into force for a Party, that Party may withdraw from this Protocol by giving written notification to the Depositary.

2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.

3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from this Protocol.

Article 28

The original of this Protocol, of which the Arabic, Chinese, English, French, Russian and

Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

DONE at Kyoto this eleventh day of December one thousand nine hundred and ninety-seven.

IN WITNESS WHEREOF the undersigned, being duly authorized to that effect, have affixed their signatures to this Protocol on the dates indicated.

Annex A

Annex B

Annex A	Party	Quantified emission limitation or reduction commitment (percentage of base year or period)
Greenhouse gases		
Carbon dioxide (CO ₂)		
Methane (CH ₄)		
Nitrous oxide (N ₂ O)	Australia	108
Hydrofluorocarbons (HFCs)	Austria	92
Perfluorocarbons (PFCs)	Belgium	92
Sulphur hexafluoride (SF ₆)	Bulgaria*	92
Sectors/source categories	Canada	94
Energy	Croatia*	95
Fuel combustion	Czech Republic*	92
Energy industries	Denmark	92
Manufacturing industries and construction	Estonia*	92
Transport	European Community	92
Other sectors	Finland	92
Other	France	92
Fugitive emissions from fuels	Germany	92
Solid fuels	Greece	92
Oil and natural gas	Hungary*	94
Other	Iceland	110
Industrial processes	Ireland	92
Mineral products	Italy	92
Chemical industry	Japan	94
Metal production	Latvia*	92
Other production	Liechtenstein	92
Production of halocarbons and sulphur hexafluoride	Lithuania*	92
Consumption of halocarbons and sulphur hexafluoride	Luxembourg	92
Other	Monaco	92
Solvent and other product use	Netherlands	92
Agriculture	New Zealand	100
Enteric fermentation	Norway	101
Manure management	Poland*	94
Rice cultivation	Portugal	92
Agricultural soils	Romania*	92
Prescribed burning of	Russian Federation*	100
	Slovakia*	92

savannas	Slovenia*	92
Field burning of agricultural residues	Spain	92
Other	Sweden	92
Waste	Switzerland	92
Solid waste disposal on land	Ukraine*	100
Wastewater handling	United Kingdom of Great Britain and Northern Ireland	92
Waste incineration	Ireland	
Other	United States of America	93

* Countries that are undergoing the process of transition to a market economy.

A3. Statistics on Asian Countries

Representative statistic data of the Asian countries for which data was available is shown in TableA3.1.1.

Table A3.1.1 Statistics on Asian countries. (As of 2003)

	GDP [GUSD]*1	Population [M]*2	Primary energy consumption [Mtoe]*3	CO2 emission [Mt-C]*4
Brunei Darussalam	5	0.3	3	2
Indonesia	168	215	118	91
Japan	4,876	128	517	336
Korea	586	48	205	124
Malaysia	99	25	54	41
Philippines	85	82	32	19
P. R. China	1,375	1,288	1,190	1,127
Singapore	93	4	22	14
Taipei, Chinese	314	23	98	69.6
Thailand	141	62	74	58
Vietnam	38	81	21	17
Whole Asia	9,246	3,467	2,783	2,280

*1 billion US dollar

*2 million people

*3 million ton oil equivalent

*4 million ton as C

A4. Unit Conversion

Literatures of biomass is found in many fields, and sometimes, unfamiliar units are used. Since utilization of SI unit is recommended, SI unit is explained first, and then conversion with other units is explained in this part. If you can read Japanese, books by Koizumi and Ebihara are useful.

A4.1 SI Unit System

Utilization of SI Unit Systems was recommended at the International at the General Conference on Weights and Measures in 1960, and many countries including Japan officially employs this unit system. SI unit system is composed of seven base units, and derived units, which are derived by combining these base units. It also employs prefixes to express integer power of 10 to be multiplied to the base unit. The following are the list of these units.

Table A4.1.1 SI base units

Base quantity	Symbol (name)	Base quantity	Symbol (name)
Length	m (meter)	Thermodynamic temperature	K (kelvin)
Mass	kg (kilogram)	Amount of substance	mol (mole)
Time	s (second)	Luminous intensity	cd (candela)
Electric current	A (ampere)		

Table A4.1.2 Units for angles

Base quantity	Symbol (name)
Plane angle	rad (radian)
Solid angle	sr (steradian)

*1 To understand the concept of solid angle, consider the light emitted from a flash light. How wide the light is emitted is the solid angle. Considering a sphere with radius R whose center is the light source, 1 sr of solid angle is the wideness of the light when the light forms area or R^2 on the sphere.

*2 These units were originally supplementary units, but became derived units in 1995.

Table A4.1.3 Representative SI derived units

Base quantity	Symbol (name)	Expression in terms of SI base units
Force	N (newton)	m kg s^{-2}
Pressure	Pa (pascal)	$\text{N m}^{-2} = \text{m}^{-1} \text{kg s}^{-2}$
Energy, work	J (joule)	$\text{N m} = \text{m}^2 \text{kg s}^{-2}$
Power	W (watt)	$\text{J s}^{-1} = \text{m}^2 \text{kg s}^{-3}$

TableA4. 1.4 SI prefixes

Symbol (name)	Factor	Symbol (name)	Factor
da (deca)	10 ¹	d (deci)	10 ⁻¹
h (hecto)	10 ²	c (centi)	10 ⁻²
k (kilo)	10 ³	m (milli)	10 ⁻³
M (mega)	10 ⁶	μ (micro)	10 ⁻⁶
G (giga)	10 ⁹	n (nano)	10 ⁻⁹
T (tera)	10 ¹²	p (pico)	10 ⁻¹²
P (peta)	10 ¹⁵	f (femto)	10 ⁻¹⁵
E (exa)	10 ¹⁸	a (atto)	10 ⁻¹⁸
Z (zetta)	10 ²¹	z (zepto)	10 ⁻²¹
Y (yotta)	10 ²⁴	y (yocto)	10 ⁻²⁴

*1 When possible, choose a prefix so that preceding number falls in 0.1-1000. For example, 50 pm is recommended, not 0.05 nm.

*2 The base unit of mass is "kg", but the prefix is added to "g". For example, 29 mg is used, not 20 mkg.

*3 To produce derived units formed from multiple units, only one prefix is used. For example, 20 kg/m² is used, not 20 kg/m². The exception is "kg." For example, 21 MJ/kg is used, not 21 kJ/g.

A4.2 Unit conversion

Although using SI unit system is recommended, in the field of energy, traditional unit such as “barrel” or “ton oil equivalent” are often used even today. Conversion of unit is also needed when reading old literature.

When a quantity in one unit is to be expressed in another unit, a conversion formula is needed. For example, temperature in °C T_C is converted to temperature in K T_K by the following formula.

$$T_K = T_C + 273.15$$

When the conversion formula takes the form of the proportional equation, the proportionality constant is called conversion factor. For example, in the conversion formula to convert length in in (inch) to length in m (meter)

$$L_m = 2.54 \times 10^{-2} L_{in},$$

the conversion factor is 2.54×10^{-2} m/in .

To convert derived units formed from multiple units, substitute the original unit with the corresponding conversion formulae. For example, to convert 1 500 ft/h to a value in m/s, $1 \text{ ft} = 3.048 \times 10^{-1} \text{ m}$ and $1 \text{ h} = 3\,600 \text{ s}$ are used as follows.

$$\begin{aligned} 1\,500 \text{ ft/h} &= 1\,500 \left(3.048 \times 10^{-1} \text{ m} \right) / \left(3\,600 \text{ s} \right) \\ &= \left(1\,500 \right) \left(3.048 \times 10^{-1} \right) / \left(3\,600 \right) \text{ m/s} \\ &= 0.127 \text{ m/s} \end{aligned}$$

To convert an equation expressed in one unit system to the equation expressed in another unit system, substitute the conversion formulae to the variables in the equation. For example, when the following formula for water vapor pressure

$$\ln(p_{Torr}) = 18.30363 - \frac{3816.44}{227.02 + T_C}$$

is to be converted to SI unit systems, the conversion formulæ

$$p_{Torr} = 7.50062 \times 10^{-3} p_{Pa}$$

$$T_C = T_K - 273.15$$

are substituted. Then,

$$\ln(7.50062 \times 10^{-3} p_{Pa}) = 18.30363 - \frac{3816.44}{227.02 + (T_K - 273.15)}$$

$$\ln(7.50062 \times 10^{-3}) + \ln p_{Pa} = 18.30363 - \frac{3816.44}{227.02 - 273.15 + T_K}$$

$$\ln p_{Pa} = 18.30363 - \ln(7.50062 \times 10^{-3}) - \frac{3816.44}{227.02 - 273.15 + T_K}$$

and finally,

$$\ln p_{Pa} = 23.1964 - \frac{3816.44}{-46.13 + T_K}$$

is obtained.

In the following pages are shown the tables of conversion factors. The horizontal line shows the same quantity. Fortran expression is employed where 3.937×10^1 is expressed as 3.9370E+01 and so on. For example, the first line of the Table A4.2.1 means

$$1 \text{ m} = 3.2808 \text{ ft} = 39.37 \text{ in}$$

Table A4.2.1 Conversion factors for length

m	ft	in
1	3.2808E+00	3.9370E+01
3.0480E-01	1	1.2000E+01
2.5400E-02	8.3333E-02	1

Table A4.2.2 Conversion factors for area

m ²	km ²	a	ha	acre	mu (畝)* ¹	tan (反)* ²	tsubo (坪)* ³
1	1.0000E-06	1.0000E-02	1.0000E-04	2.4711E-04	1.5000E-03	1.0083E-03	3.0248E-01
1.0000E+06	1	1.0000E+04	1.0000E+02	2.4711E+02	1.5000E+03	1.0083E+03	3.0248E+05
1.0000E+02	1.0000E-04	1	1.0000E-02	2.4711E-02	1.5000E-01	1.0083E-01	3.0248E+01
1.0000E+04	1.0000E-02	1.0000E+02	1	2.4711E+00	1.5000E+01	1.0083E+01	3.0248E+03
4.0468E+03	4.0468E-03	4.0468E+01	4.0468E-01	1	6.0702E+00	4.0805E+00	1.2241E+03
6.6667E+02	6.6667E-04	6.6667E+00	6.6667E-02	1.6474E-01	1	6.7222E-01	2.0165E+02
9.9174E+02	9.9174E-04	9.9174E+00	9.9174E-02	2.4507E-01	1.4876E+00	1	2.9998E+02
3.3060E+00	3.3060E-06	3.3060E-02	3.3060E-04	8.1694E-04	4.9590E-03	3.3335E-03	1

*1 Traditional Chinese unit.

*2 Traditional Japanese units: 1 cho (町) = 10 tan (反), 1 tan (反) = 10 se (畝).

*3 For the case of rice field and forest, 1 tsubo is called 1 bu (步).

Table A4.2.3 Conversion factors for mass

Kg	t	short ton (tn)	long ton (l.tn)	lb (pound)	oz (ounce)	kan (貫, Japanese)
1	1.0000E-03	1.1023E-03	9.8421E-04	2.2046E+00	3.5274E+01	2.6667E-01
1.0000E+03	1	1.1023E+00	9.8421E-01	2.2046E+03	3.5274E+04	2.6667E+02
9.0719E+02	9.0719E-01	1	8.9286E-01	2.0000E+03	3.2000E+04	2.4192E+02
1.0160E+03	1.0160E+00	1.1200E+00	1	2.2400E+03	3.5840E+04	2.7095E+02
4.5359E-01	4.5359E-04	5.0000E-04	4.4643E-04	1	1.6000E+01	1.2096E-01
2.8349E-02	2.8349E-05	3.1250E-05	2.7902E-05	6.2500E-02	1	7.5600E-03
3.7500E+00	3.7500E-03	4.1336E-03	3.6907E-03	8.2672E+00	1.3228E+02	1

Short ton is used in US. Long ton is used in UK.

Table A4.2.4 Conversion factors for volume

m ³	L	ft ³	US gallon	UK gallon	bb1	koku (石)* ¹
1	1.0000E+03	3.5315E+01	2.6417E+02	2.1997E+02	6.2898E+00	5.5440E+03
1.0000E-03	1	3.5315E-02	2.6417E-01	2.1997E-01	6.2898E-03	5.5440E+00
2.8317E-02	2.8317E+01	1	7.4805E+00	6.2288E+00	1.7811E-01	1.5699E+02
3.7854E-03	3.7854E+00	1.3368E-01	1	8.3267E-01	2.3810E-02	2.0986E+01
4.5461E-03	4.5461E+00	1.6054E-01	1.2010E+00	1	2.8594E-02	2.5204E+01
1.5899E-01	1.5899E+02	5.6146E+00	4.2000E+01	3.4972E+01	1	8.8143E+02
1.8038E-04	1.8038E-01	6.3699E-03	4.7650E-02	3.9677E-02	1.1345E-03	1

*1 Traditional Japanese units: 1 koku (石) = 100 sho (升).

*2 Sometimes, the amount of gaseous substance is expressed using the unit of volume with “N”. This amount corresponds to the amount of substance in the gas of the stated volume at normal state (0°C, 1.013x10⁵ Pa). For example, gas of 22.4 Nm³ corresponds to 1 kmol.

*3 For liter, “L” is recommended to distinguish from “l (capital i)” and “1 (one)”.

Table A4.2.5 Conversion factors for energy (1)

J	kWh	kcalIT	KcalJP	kL oil equivalent	t oil equivalent
1	2.7778E-07	2.3885E-04	2.3889E-04	2.5826E-11	2.3885E-11
3.6000E+06	1	8.5984E+02	8.6000E+02	9.2973E-05	8.5984E-05
4.1868E+03	1.1630E-03	1	1.0002E+00	1.0813E-07	1.0000E-07
4.1860E+03	1.1628E-03	9.9982E-01	1	1.0811E-07	9.9982E-08
3.8721E+10	1.0756E+04	9.2483E+06	9.2500E+06	1	9.2483E-01
4.1868E+10	1.1630E+04	1.0000E+07	1.0002E+07	1.0813E+00	1

*1 Ton oil equivalent is abbreviated as TOE.

*2 To calculate the efficiency of process, especially when heat demand and electricity demand are compared, the amount of electric energy is converted to the equivalent thermal energy by dividing it by power generation efficiency. The efficiency used for this purpose should differ from country to country, or depending on the case. In Japan, governmental statistics employs 1 kWh = 9.42 MJ, assuming power generation efficiency of 38.1% for the case after 1971.

Table A4.2.6 Conversion factors for energy (2)

J	Btu	kgf m	ft lbf	HP h
1	9.4782E-04	1.0197E-01	7.3750E-01	3.7417E-07
1.0551E+03	1	1.0759E+02	7.7810E+02	3.9477E-04
9.8066E+00	9.2948E-03	1	7.2324E+00	3.6693E-06
1.3559E+00	1.2852E-03	1.3827E-01	1	5.0734E-07
2.6726E+06	2.5331E+03	2.7253E+05	1.9710E+06	1

Btu stands for British thermal unit.

Table A4.2.7 Conversion factors for pressure

Pa	psi	kgf/cm ²	atm	bar	Torr
1	1.4499E-04	1.0194E-05	9.8697E-06	1.0000E-05	7.5010E-03
6.8971E+03	1	7.0307E-02	6.8073E-02	6.8971E-02	5.1735E+01
9.8100E+04	1.4223E+01	1	9.6822E-01	9.8100E-01	7.3585E+02
1.0132E+05	1.4690E+01	1.0328E+00	1	1.0132E+00	7.6000E+02
1.0000E+05	1.4499E+01	1.0194E+00	9.8697E-01	1	7.5010E+02
1.3332E+02	1.9329E-02	1.3590E-03	1.3158E-03	1.3332E-03	1

*1 1 Torr = 1mmHg. Also expressed as torr, but since this unit is named after a person's name (Torricelli), capitalization is recommended.

*2 There are two expression of pressure: absolute and gauge. The absolute and gauge pressures are expressed by adding A and G after the unit, respectively. The absolute pressure is measured from the absolute vacuum. The gauge pressure is measured from the atmospheric pressure. Thus, the former is larger than the latter by 1 atm. For example, 5 atmG = 6 atmA.

Gauge pressure

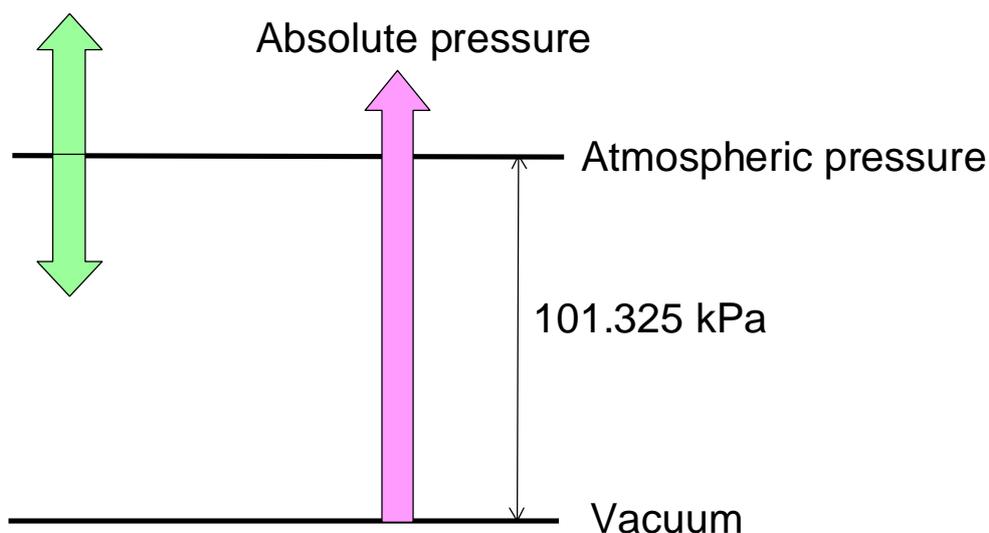


Fig. 4.2.1 Absolute pressure and gauge pressure

Table A4.2.8 Conversion factors for power

W	metric horse power	HP	kgf m/s	ft lb/sec	kcal/sec
1	1.3596E-03	1.3410E-03	1.0197E-01	7.3756E-01	2.3885E-04
7.3550E+02	1	9.8630E-01	7.5000E+01	5.4248E+02	1.7567E-01
7.4571E+02	1.0139E+00	1	7.6042E+01	5.5001E+02	1.7811E-01
9.8066E+00	1.3333E-02	1.3151E-02	1	7.2330E+00	2.3423E-03
1.3558E+00	1.8434E-03	1.8182E-03	1.3826E-01	1	3.2383E-04
4.1868E+03	5.6925E+00	5.6145E+00	4.2694E+02	3.0880E+03	1

A4.3 Concentrations of alcohol and sugar

There exists various expressions for the concentration of sugar and alcohol due to tradition. Ethanol production from sugar is an important technology for biomass use, but various units are used from literature to literature. Special caution should be taken when reading literatures.

A4.3.1 Concentration of alcohol

The following units are used.

Molar concentration: SI unit. Molar number of alcohol (ethanol) in 1 L of the solution. The unit is mol(-EtOH)/L(-solution). Sometimes it is expressed as “M”.

Molal concentration: SI unit. Molar number of alcohol in 1 kg of solvent. The unit is mol(-EtOH)/kg(-solvent). Sometimes it is expressed as “m”.

Volumetric percentage: The ratio of volume of alcohol before mixing to the sum of the volumes of water and alcohol before mixing. Because the volume decreases by mixing of water and alcohol, the volumes before mixing is employed as the base. The unit is expressed as vol%.

Proof (US): Used in US. The volumetric percentage is doubled.

Proof (British): Special measure with water being 100 proof under and pure alcohol being 75.1 proof over. When the volumetric percentage is w , the value in this unit is $(w/57.1) \times 100 - 100$. Namely, for the alcohol concentration of 57.1 vol %, the British proof is zero.

A4.3.2 Concentration of sugar

Molar and molal concentration is defined in the same way as alcohol. However, make clear which sugar is stated; mol-glucose, total mole of sugars available for ethanol fermentation, monomer only, or monomer equivalent for monomer, dimer, trimer, etc.

Weight percentage: percentage of weight of sugar in 1 kg of solution. The unit is wt % or mass %.

Brix: The same as weight percentage. However, this is not equivalent to the brix used as a unit of density.

A4.4 Temperature

Absolute temperatures and others are to be distinguished. Absolute temperature corresponding to the Celsius temperature °C is K (kelvin), and that corresponding to the Fahrenheit temperature °F is R (rankine). Since they are not in proportional relation, the following conversion formulae have to be used. Table A4.4.1 shows the conversion formulae.

Table A4.4.1 Conversion formulae for temperature

Unit conversion	Conversion formulae
°C → K	$TK = TC + 273.15$
°C → °F	$TF = 1.8 TC + 32$
°C → R	$TR = 1.8 TC + 491.67$
K → °C	$TC = TK - 273.15$
K → °F	$TF = 1.8 TK - 459.67$
K → R	$TR = 1.8 TK$
°F → °C	$TC = (5/9) (TF - 32)$
°F → K	$TK = (5/9) (TF + 459.67)$
°F → R	$TR = TF + 459.67$
R → °C	$TC = (5/9) TR - 273.15$
R → K	$TK = (5/9) TR$
R → °F	$TF = TR - 459.67$

A4.5 Heating values (See also Chap. 2.4)

Heating values are the amount of heat that is released when an organic compound is completely burned. Depending on the state of product water, i.e. steam or liquid water, the value differs by the latent heat. When the product water is in the form of steam, the heating value is smaller, and called lower heating value (LHV). When the product water is in the form of liquid, the heating value is called higher heating value (HHV). It is always to be noted which heating value is used, and proper heating value should be used depending on the situation. These heating values are equivalent to the value of the change in enthalpy for the corresponding combustion reaction, but with the changed sign. The conversion formula between these values are:

$$HHV[\text{MJ/kg}] = LHV[\text{MJ/kg}] + 20.3w_H$$

where w_H is the weight fraction of the hydrogen atoms in the organic compound.

When heating values of biomass whose water content is not zero is discussed, the following are to be noted.

1. Is the heating value for dry weight or wet weight?
2. Is the latent heat of the contained water subtracted from the heating value or the latent heat is neglected?

As for the item 1, the following section of “mass basis” should be consulted. As for the item 2, when processes such as combustion is discussed, this latent heat cannot be practically recovered, and usually subtracted from the beginning, but when process such as biomethanation is discussed, this latent heat is neglected.

When the water content based on weight is w_w [kg-water/kg-wet], the heating value from which latent heat of the contained water is subtracted, HV_{net} [J/kg-wet], and the value where this subtraction is not made, HV_{int} [J/kg-wet] are related as:

$$HV_{net} = HV_{int} - w_w \Delta H_{ww}$$

where ΔH_{ww} is the latent heat based on mass. The value of ΔH_{ww} is 2.443×10^6 J/kg - H₂O at 25°C.

A4.6 Weight basis

When characteristic value of biomass per unit weight is discussed, the caution should be made for the following:

1. Is the unit weight with water, or without?
2. Is the unit weight with ash, or without?

When the biomass with low water and ash contents such as dry wood is discussed, the effect of this difference is small. However, when biomass with high water and ash contents such as sewage sludge is discussed, this effect is important. The relation between values based on dry weight x_{db} and that based on wet weight x_{wb} are expressed as following, using weight fraction of water w_w .

$$x_{db} = \frac{p}{m_{db}} = \frac{p}{m_{wb}(1-w_w)} = \frac{p/m_{wb}}{(1-w_w)} = \frac{x_{wb}}{(1-w_w)}$$

where, p is the physical value to be discussed, m_{db} and m_{wb} are dry weight and wet weight, respectively. Similarly, the relation between values based on weight free of ash x_{af} , and that based on weight including ash, x_{wa} , are expressed as following, using weight fraction of ash, w_{ash} .

$$x_{af} = \frac{p}{m_{af}} = \frac{p}{m_{wa}(1-w_{ash})} = \frac{p/m_{wa}}{(1-w_{ash})} = \frac{x_{wa}}{(1-w_{ash})}$$

For example, when biomass with water content of 20 wt% is gasified, and gas production based on wet weight is $0.75 \text{ m}^3/\text{kg}$ - wet, gas production based on dry weight is:

$$\frac{0.75}{(1-0.2)} = 0.9375 \text{ m}^3/\text{kg} \text{ - dry}$$

A4.7 Other comments

In the engineering field in US, the symbol “MM” is sometimes used. This corresponds to 10^6 from the fact that M expresses 1000 in Roman numeric system, and that $1000 \times 1000 = 10^6$. For example, 500 MMG means 500×10^6 gallon = 500 million gallon.

When unfamiliar unit ending with M is found, it can mean some amount “per minute”. For example, 200 rpm means 200 revolutions per minute, 4 GPM means 4 gallon per minute, and 35 ccm means 35 cubic centimeters per minute.

A5. Atomic weight

A5.1 Atomic weight

Atomic weight is often needed in the calculation related biomass. Table A5.1.1 shows the list of atomic weight. The values for C, H, O, N, S are often used.

Table A5.1.1 Atomic weight

Atomic number	Symbol of element	Element	Atomic weight [g/mol]
1	H	Hydrogen	1.0079
2	He	Helium	4.0026
3	Li	Lithium	6.941
4	Be	Beryllium	9.0122
5	B	Boron	10.811
6	C	Carbon	12.0107
7	N	Nitrogen	14.0067
8	O	Oxygen	15.9994
9	F	Fluorine	18.9984
10	Ne	Neon	20.1797
11	Na	Sodium	22.9897
12	Mg	Magnesium	24.305
13	Al	Aluminum	26.9815
14	Si	Silicon	28.0855
15	P	Phosphorus	30.9738
16	S	Sulfur	32.065
17	Cl	Chlorine	35.453
18	Ar	Argon	39.948
19	K	Potassium	39.0983
20	Ca	Calcium	40.078

Table A5.1.1 Atomic weight (Continued)

Atomic number	Symbol of element	Element	Atomic weight [g/mol]
21	Sc	Scandium	44.9559
22	Ti	Titanium	47.867
23	V	Vanadium	50.9415
24	Cr	Chromium	51.9961
25	Mn	Manganese	54.938
26	Fe	Iron	55.845
27	Co	Cobalt	58.9332
28	Ni	Nickel	58.6934
29	Cu	Copper	63.546
30	Zn	Zinc	65.39
31	Ga	Gallium	69.723
32	Ge	Germanium	72.64
33	As	Arsenic	74.9216
34	Se	Selenium	78.96
35	Br	Bromine	79.904
36	Kr	Krypton	83.8
37	Rb	Rubidium	85.4678
38	Sr	Strontium	87.62
39	Y	Yttrium	88.9059
40	Zr	Zirconium	91.224
41	Nb	Niobium	92.9064
42	Mo	Molybdenum	95.94
43	Tc	Technetium	98
44	Ru	Ruthenium	101.07
45	Rh	Rhodium	102.9055
46	Pd	Palladium	106.42
47	Ag	Silver	107.8682
48	Cd	Cadmium	112.411
49	In	Indium	114.818
50	Sn	Tin	118.71

Table A5.1.1 Atomic weight (Continued)

Atomic number	Symbol of element	Element	Atomic weight [g/mol]
51	Sb	Antimony	121.76
52	Te	Tellurium	127.6
53	I	Iodine	126.9045
54	Xe	Xenon	131.293
55	Cs	Cesium	132.9055
56	Ba	Barium	137.327
57	La	Lanthanum	138.9055
58	Ce	Cerium	140.116
59	Pr	Praseodymium	140.9077
60	Nd	Neodymium	144.24
61	Pm	Promethium	145
62	Sm	Samarium	150.36
63	Eu	Europium	151.964
64	Gd	Gadolinium	157.25
65	Tb	Terbium	158.9253
66	Dy	Dysprosium	162.5
67	Ho	Holmium	164.9303
68	Er	Erbium	167.259
69	Tm	Thulium	168.9342
70	Yb	Ytterbium	173.04
71	Lu	Lutetium	174.967
72	Hf	Hafnium	178.49
73	Ta	Tantalum	180.9479
74	W	Tungsten	183.84
75	Re	Rhenium	186.207
76	Os	Osmium	190.23
77	Ir	Iridium	192.217
78	Pt	Platinum	195.078
79	Au	Gold	196.9665

Table A5.1.1 Atomic weight (Continued)

Atomic number	Symbol of element	Element	Atomic weight [g/mol]
80	Hg	Mercury	200.59
81	Tl	Thallium	204.3833
82	Pb	Lead	207.2
83	Bi	Bismuth	208.9804
84	Po	Polonium	209
85	At	Astatine	210
86	Rn	Radon	222
87	Fr	Francium	223
88	Ra	Radium	226
89	Ac	Actinium	227
90	Th	Thorium	232.0381
91	Pa	Protactinium	231.0359
92	U	Uranium	238.0289
93	Np	Neptunium	237
94	Pu	Plutonium	244
95	Am	Americium	243
96	Cm	Curium	247
97	Bk	Berkelium	247
98	Cf	Californium	251
99	Es	Einsteinium	252
100	Fm	Fermium	257
101	Md	Mendelevium	258
102	No	Nobelium	259
103	Lr	Lawrencium	262

A6. Thermodynamic Properties

A6.1 Thermodynamic properties of fundamental chemicals

Heat release and heat absorption with chemical reaction or phase transition, and the extent to which a chemical reaction proceeds can be obtained using thermodynamics. In this chapter is shown part of the data needed for this calculation. Detail can be found in Chemical Handbook, a book by Ried et al., Steam Table, Chemical Engineering Handbook etc. For thermodynamic calculation, books by Atkins, Komiiyama (in Japanese), Yamaguchi (in Japanese), and other textbook on physical chemistry or chemical thermodynamics can be consulted. There is a book that collects thermodynamic data of general substances including biomass.

A6.2 Standard enthalpy of formation, standard entropy, and standard Gibbs free energy of formation

Table A6.2.1 shows the standard enthalpy of formation, standard entropy, and standard Gibbs free energy of formation for chemical substances related to biomass. “g”, “l”, and “s” for state stand for gas, liquid, and solid, respectively.

Table A6.2.1 Standard enthalpy of formation, standard entropy, and standard Gibbs free energy of formation for chemical substances related to biomass.

Substance	Chemical formula	State	Standard enthalpy of formation [kJ mol ⁻¹]	Standard entropy [J mol ⁻¹]	Standard Gibbs free energy of formation [kJ mol ⁻¹]
Carbon monoxide	CO	g	-110.53	197.67	-137.17
Ethanol	C ₂ H ₅ OH	l	-277.1	159.86	-173.9
Ethane	C ₂ H ₆	g	-83.8	229.60	-31.9
Ethene (Ethylene)	C ₂ H ₄	g	52.5	219.56	68.4
Formic acid	HCOOH	l	-425.1	131.84	-362.6
Glucose	C ₆ H ₁₂ O ₆	s	-1273.3	N/A	N/A
Acetic acid	CH ₃ COOH	l	-484.3	158.0	-388.9
Oxygen	O ₂	g	0	205.14	0
Hydrogen	H ₂	g	0	130.68	0
Carbon (graphite)	C	s	0	5.74	0
Carbon dioxide	CO ₂	g	-393.51	213.74	-394.36
Propane	C ₃ H ₈	g	-104.7	270.02	-24.2
Water	H ₂ O	l	-285.83	69.91	-237.13
Water	H ₂ O	g	-241.82	188.83	-228.57
Methanol	CH ₃ OH	l	-239.1	127.19	-166.8
Methane	CH ₄	g	-74.4	186.38	-50.3

From Chemistry Handbook (Kagaku Benran).

A6.3 Enthalpy change of transition for water, methanol, and ethanol

Table A6.3.1 shows the enthalpy change of transition for water, methanol, and ethanol.

Table A6.3.1 Enthalpy change of transition for water, methanol, and ethanol.

	Transition	Temperature of transition at 1.013×10 ⁵ Pa [°C]	Enthalpy change of transition [kJ/mol]
Water	s → l	273.15	6.01
Water	l → g	373.15	40.66
Methanol	l → g	337.9	35.27
Ethanol	l → g	351.7	38.6

From Chemistry Handbook (Kagaku Benran).

A6.4 Enthalpy change of combustion

Table A6.4.1 shows the enthalpy change of complete combustion of chemical substances. These values are for the case when liquid water is formed, and by changing the sign, higher heating value for the substance is obtained. These values can be calculated using data in Table A6.2.1.

Table A6.4.1 Enthalpy change of combustion

Substance	State	Enthalpy of combustion [kJ mol ⁻¹]	Substance	State	Enthalpy of combustion [kJ mol ⁻¹]
Carbon monoxide	g	-282.98	Acetic acid	l	-874.3
Ethanol	l	-1367.6	Hydrogen	g	-285.83
Ethane	g	-1560.7	Carbon (graphite)	s	-393.51
Ethene (Ethylene))	g	-1411.2	Propane	g	-2219.2
Formic acid	l	-254.24	Methanol	l	-725.7
Glucose	s	-2803.3	Methane	g	-890.7

From Chemistry Handbook (Kagaku Benran). Some values are calculated by the author.

A7. Heating Values of Fossil Fuels and Lifetime

A7.1 Heating values of fossil fuels and lifetime

Table A7.1.1 shows the heating values of fossil fuels and lifetime.

Table A7.1.1 Heating values of fossil fuels and lifetime

	Petroleum	Coal	Natural gas
Heating value (representative)* [MJ/kg]	40	28	56
R/P ratio [year]**	46	219	64

* These are representative values, and actual values differs largely depending on the production site and treatment. These values are higher heating values.

** Reserve/Production ratio.

A8. APEC Framework

A8.1 What is APEC?

APEC (Asia-Pacific Economic Cooperation) is a forum that aims at sustainable development in the Asia and Pacific region, and all main countries and regions participate with. It started at the ministerial conference in November, 1989 (Canberra, Australia), and has been organizing top-level conferences since 1993. Its main activities are liberalization and harmonization of trade and investment, and economical and technological collaboration in the region.

Table A8.1.1 APEC Countries

Australia	Russia
Brunei Darussalam*	Singapore*
Cambodia	Taipei, Chinese
Canada	Thailand*
Chili	United States of America
Hongkong, Chinese	Vietnam*
Indonesia*	
Japan	
Korea	
Laos	
Malaysia*	
Mexico	
New Zealand	
Papua New Guinea	
Peru	
Philippines*	
P. R. China	

* ASEAN Countries

A9. Each Country's Targets

A9.1 Each country's target for biomass introduction

Table A9.1.1 shows the target of biomass introduction for each country.

Table A9.1.1 Target of each country

Country	Target
Cambodia	There are no targets.
Indonesia	Development of biofuel plantation in 5.25 M ha unused land. According to Road Map Biofuel Development the Biofuel utilization (biodiesel, bioethanol, bio-oil) will be 2% of national energy mix of 5.29 M kL by 2010.
Japan	Thermal use of biomass: 3.08 M kL, Electricity production from biomass and wastes: 5.86 M kL oil equivalent at 2010
Korea	Thermal use of biomass: 0.679 million kL, Electricity production from biomass and wastes: 0.367 million kL oil equivalent at 2011
Laos	Now the government drafting the policy and target for the biofuel especially biodiesel from the Jatropha to mix with the fossil diesel to be B5 by the year 2012, B5 by the year 2015 and B15 by 2020. And For the Ethanol is E10 by the year 2015 and E20 by the year 2020. These target is under drafting of the document.
Malaysia	The target for electricity generation from renewable energy (including biomass) is set at 350MWe in Peninsular Malaysia and 50MWe in Sabah

Table A9.1.1 Target of each country (Continued)

Country	Target
Philippines	Two years from the effectivity of the Act, at least 5% bioethanol by volume of the total volume of gasoline fuel sold and distributed by each and every oil company in the country. Within four years from the effectivity of the Act, the Philippine Department of Energy, may mandate a minimum of 10% blend depending on the results of the study by the national Board created under the Act. Three months after the approval of the Act, a minimum of 1% biodiesel by volume shall be blended into all diesel engine fuels sold in the country. Within two years from the effectivity of the Act, the Philippine Department of Energy, may mandate a total of 2% blend depending on the results of the study by the national Board created under the Act. Provided that the ethanol and biodiesel blends conform to Philippine National Standard.
P. R. China	Percentages of renewable energy consumption will be 10% by 2010 and 15% by 2020. By 2010, annual consumption of non-grain based fuel ethanol shall reach 2 M tons, and that of biodiesel shall reach 200 000 tons in China. By 2020, annual consumption of fuel ethanol shall reach 10 M tons, and that of biodiesel shall reach 2 M tons in China.
Taipei, Chinese	<ol style="list-style-type: none"> 1. Electricity installed capacity of 741MW from biomass and wastes in 2010 2. Biodiesel production : 100 thousand KL in 2010 3. Bioethanol production: 100 thousand KL in 2011

A10. Related histories

A10.1 History related to Asian biomass

Table A10.1.1 shows the recent history related to Asian biomass.

Table A10.1 Time table on Asian biomass

2005.1	1 st Biomass Asia Workshop (Tokyo and Tsukuba)
2005.12	2 nd Biomass Asia Workshop (Bangkok)
2006.1	Biomass Asia Forum (Tokyo)
2006.11	3 rd Biomass Asia Workshop (Tokyo and Tsukuba)
2007.3	Startup of Asia Biomass Association
2007.4	Laos joins Asia Biomass Association
2007.11	4 th Biomass Asia Workshop (Shar Alam)

A11 Each country's language

A11.1 Each country's language and greeting words

Table A11.1.1 shows each country's language and greeting words.

Table A11.1.1 Language and "Hello" in each country

Country	Language	"Good morning/ afternoon"
Brunei Darussalam	Malay	Selamat pagi/ petang
Cambodia	Khmer	Arun suo sdei/ Tiveah suor sdei
Indonesia	Bahasa Indonesia	Selamat pagi/ sinag
Japan	Japanese	Ohayo/ Kon'nichiwa
Korea	Korean	Annyunghaseyo/ Annyunghashimnikka
Laos	Lao	Sabaidee
Malaysia	Bahasa Melayu	Selamat pagi/ petang
Philippines	Filipino, English	Magandang umaga
P. R. China	Chinese	Nihao
Singapore	Mandarin, English, Malay, Hokkien	Nihao
Taipei, Chinese	Chinese, Taiwanese	Nihao
Thailand	Thai	Sawatdee
Vietnam	Vietnamese	Xin chao

A12 Related books

A12.1 Books in English

Knoef, H. Ed., “Handbook Biomass Gsification”, BTG Biomass Technology Group (2005)

Van Loo, S. and Koppejan, J. Eds., “Handbook of Biomass Combustion and Co-Firing”, Twente University Press (2002)

Klass, D. L., “Biomass for Renewable Energy, Fuels, and Chemicals,” Academic Press (1998)

Boyle, G. Ed., “Renewable Energy Power for a Sustainable Future,” Oxford University Press (1996)

Wyman, C. E. Ed., “Handbook on Bioethanol: Production and Utilization”, Taylor & Francis (1996)

Kitani, O. and Hall, C. W. Eds., “Biomass Handbook”, Gordon and Breach Science (1989)

E. S. Domalski, T. L. Jobe, Jr., T. A. Milne, Eds., “Thermodynamic data for biomass materials and waste components”, American Society of Mechanical Engineers (1987)

A12.2 Books in Japanese (in Japanese)

日本エネルギー学会「バイオマス用語事典」 オーム社 (2006)

坂志朗「バイオディーゼルのすべて」 アイピーシー (2005)

木谷収「バイオマスー生物資源と環境」 コロナ社 (2004)

小宮山宏ら編著「バイオマス・ニッポンー日本再生に向けて」 日刊工業新聞社 (2003)

日本エネルギー学会「バイオマスハンドブック」 オーム社 (2002)

湯川英明編「バイオマスー究極の代替エネルギー」 化学工業日報社 (2002)

横山伸也「持続社会へむけて バイオエネルギー最前線」 森北出版 (2001)

坂志朗編著「バイオマス・エネルギー・環境」 アイピーシー (2001)

山地憲治、山本博巳、藤野純一「バイオエネルギー」 ミオシン出版 (2000)

坂井正康「バイオマスが拓く 21世紀エネルギー 地球温暖化の元凶 CO2 排出はゼロにできる」
森北出版 (1998)

本多淳裕「バイオマスエネルギー：生物系資源・廃棄物の有効利用」 省エネルギーセンター (1986)

鈴木周一編「バイオマスエネルギー変換」 講談社 (1983)

M.スレッサー, C.レウイス著；須之部淑男, 増川重彦訳「バイオマス：生物エネルギー資源」 共立
出版 (1982)

山沢新吾編「バイオマスエネルギー」 朝倉書店 (1982)

柴田和雄, 木谷収編「バイオマス：生産と変換」 上, 下, 学会出版センター (1981)

A12.3 Books in Chinese (in Chinese)

日本能源学会編、史仲平、華兆哲訳「生物質和生物能源手冊」化学工業出版社（2007）

小宮山宏他編著、李大寅、蔣偉忠訳「日本生物質総合戦略」中国環境化学出版社（2003）

中国農村能源年鑑編集委員会編「中国農村能源年鑑 1997」中国農業出版社（1997）