Biomass Power Generation by CFB Boiler

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Plant-derived biomass is now considered as one of the most prospective energy sources in the future for reducing carbon dioxide emissions and conserving fossil fuel resources. The effective utilization of biomass includes such biomass wastes as waste paper, waste building material wastes and agricultural wastes. CFB (Circulating Fluidized Bed) boilers provide the best solution for biomass power generation because they can accommodate a wide range of fuels and their environmental impact is small. It is expected that CFB Biomass power plants will be widely used in the future.

1. Significance of biomass power generation

1.1 Definition of biomass

The word "biomass" is originally an ecological term meaning the entire stock of biological resources. However, this paper focuses on biological resources as a category of energy resource and limits the term "biomass" to any fuel derived from plants or vegetables. In addition to fuels converted directly from plants, such as firewood and charcoal, biomass in this paper includes such plant-derived wastes as waste paper, wood-derived wastes and agricultural wastes.

Fossil fuel, which is a general term covering coal, petroleum and natural gas, is in contrast to this concept of biomass. Fossil fuel is believed to be originated from organisms that lived a long time ago and is a non-renewable energy source representing a stock of past biological activity. On the other hand, the biomass is a renewable energy source that can be consumed within the volume of production. This renewability makes biomass fuel markedly different from fossil fuel.

1.2 Renewable energy

Renewable natural energy includes biomass, solar energy (photovoltaic power generation and solar thermal electric power generation), geothermal energy, wind energy, wave energy, tidal energy, ocean thermal energy and hydraulic energy.

Biomass is the only one of these energy types that is composed of organic substances. From the viewpoint of power generation, this means that the existing power generation systems developed for fossil fuels can also be used for biomass fuel.

1.3 Carbon cycle on the earth

Both biomass and fossil fuels are organic substances, and thus both generate carbon dioxide upon combustion. However, their effects on increasing atmospheric carbon dioxide concentration are different.

Fig.1 shows the location and flow of carbon in zone of the earth. This figure was developed from the 1994 IPCC (Intergovernmental Panel on Climate Change) report[1]. The arrows in the figure represent the flow carbon in terms of Gt/y (giga tons per year), where one giga ton is equal to one billion tons. The numbers in the squares represent carbon stocks in terms of giga tons.

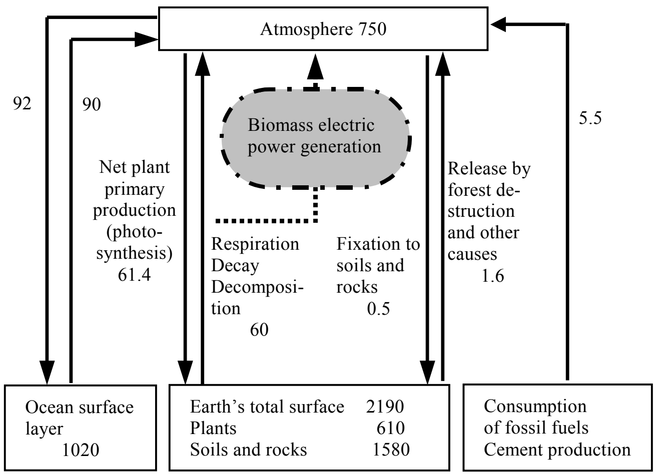

Fig.1 Carbon flow on the earth's surface layer

Carbon on the earth surface lays in three zones: the atmosphere, ground and ocean. Carbon flows in the system encompassing these three zones interact with each other, each having functions of both absorption and release. In effect, the overall function of the system is to keep the atmospheric carbon dioxide concentration within a certain level. Combustion of fossil fuel, by contrast, releases carbon that was stored underground and to the cycle. This represents an irreversible flow of carbon to the atmosphere and should be regarded as a disturbance to the balance of global circulation of carbon.

The consumption of biomass can never exceed the production. Moreover, the concept of renewability assumes that there will be reproduction corresponding to the amount consumed. The liberation of carbon dioxide by the combustion of biomass is an element of the carbon cycle between the atmosphere and plants and is not a disturbance that could disrupt the balance of the system. Hence, biomass is considered to be an effective fuel for the following two reasons:

(1) The carbon dioxide generated as a result of combustion constitutes one of the elements of the carbon cycle between the atmosphere and the plant kingdom and therefore does not affect the atmospheric carbon dioxide concentration.

(2) The use of biomass as fuel helps reduce consumption of fossil fuel, thereby reducing disturbances to the carbon cycle.

1.4 Concept of biomass power generation

Biomass is one of the most promising sources of renewable energy. **Fig.2** shows an estimate of the future primary energy supply by source, as excerpted from the second IPCC[2] report. The estimate forecasts that the total primary energy consumption by industrialized countries over the next 100 years will stay virtually unchanged, while that by developing countries will increase sharply. On the other hand, the consumption of the fossil energy will decrease in both industrial and developing countries, while that of renewable energy, notably biomass, will increase.

Cultivation of biomass for harvesting energy could compete with agricultural production of food and feeds, as well as industrial use of fibers and wood. To avoid such competition, biomass could be used in a cascaded fashion covering various uses that include fuel, instead of using biomass exclusively for fuel. Some good examples are given below.

(1) Waste paper made from plants should be recycled back to paper several times before finally being used as fuel.

(2) Wood-derived wastes should be cut into chips. The better quality will be used for making paper or plywood, and the poor processed into fuels.

There is a guidelines for thermal recycling of waste paper, as well as for material recycling (recycled paper)[3]. The papermaking industry has initiated thermal recycling of waste paper[4]. For industrialized countries, including Japan, the use of waste biomass for power generation is the most practical and desirable way of using biomass as an energy source.

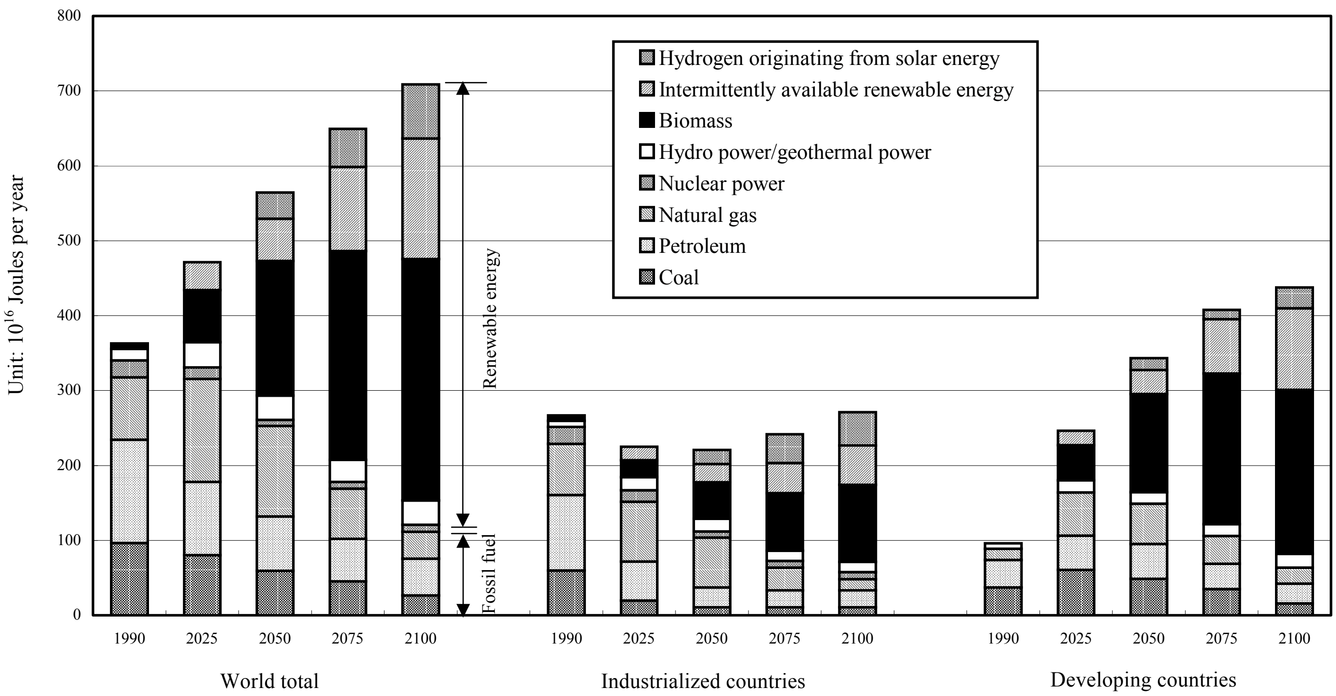

Fig.2 Primary energy supply forecast for biomass promotion case (source: IPCC 1995 report)

2. Biomass power generation, problems and countermeasures

2.1 Biomass power generation problems

The followings are prospective biomass fuel.

(1) Waste building materials

Wood-derived wastes with inadequate quality for recycling as raw materials for plywood or papermaking.

(2) Miscellaneous waste paper

Paper having problems with too poor quality to be recycled as paper.

(3) Paper sludge

Organic wastes produced in paper making processes.

(4) Agricultural wastes

Rice husks, straws, bagasse (residue of sugar cane), oil palm bunch (residue of palm oil manufacturing process).

These biomass fuels have the following problems compared to fossil fuels.

(1) Quality is unstable, and water contents are high.

(2) Production is thinly widespread, limiting large-scale consumption. This is particularly true with agricultural waste.

(3) Availability varies in seasons.

(4) Agricultural wastes are commonly burned in the open or in simple incinerators that deteriorate the surrounding environment.

2.2 Conditions for power generation facilities

All biomass power generation must clear the following conditions.

2.2.1 Stable supply

Stable power supply is vital for power plant. Multi fuel combustion contributes to stable power generation, especially because the availability of biomass is seasonally unstable.

2.2.2 Reduction of impact for the environment

A great deal of reduction of carbon dioxide, nitrogen oxides and sulfur oxides emission has to be expected.

2.2.3 High efficiency

The gross thermal efficiency (ratio of the electric power output to the input fuel energy) should be maximized. In the case of steam power generation using a boiler and a steam turbine generator, the efficiency of power generation depends on both the boiler efficiency and the steam cycle efficiency. The former is the ratio of the effective thermal output of the steam to the calorific values of the input fuel, while the latter is the ratio of the electric power output to the effective thermal output of the steam.

Boiler efficiency is generally improved by increasing the combustion efficiency (reduction of heat loss due to incomplete combustion) and implementing low excess air combustion (reduction of excess air ratio). The application of these measures depends largely on the fuel properties and combustion system.

The technology developed for traditional thermal power generation, such as rising temperature and pressure to higher level, shall be used to improve the steam cycle efficiency. However, the minimum size of a steam power generation is considered to be 10 MW in terms of economical viability.

Efficiency will also be evaluated on whole system including pretreatment process. If the fuel requires pretreatment, such as a gasification or liquefaction, the energy consumed through such process should be counted as an energy loss. Accordingly, if biomass can be utilized directly, the use of biomass would have higher advantage in overall efficiency than that of fuels that require gasification or liquefaction process.

2.2.4 Features of circulating fluidized bed combustion

Table 1 compares various combustion systems, and **Fig. 3** shows their interrelationships.

The circulating fluidized bed combustion system enables the fuel particles to be fluidized the combustion air. This combustion system is characterized by quick fluidization and installation of the duct at the outlet of the flue gas to collect particles. This combustion system has the following advantages compared to other combustion systems.

(1) Wide applicability of fuels

The combustion time is comparatively long for the incineration in the entire area and also for the recirculation. This feature improves the combustion efficiency and makes this system applicable to a wide range of fuels as well as mixture combustion. In addition, particles circulating in the furnace retain sufficient heat to dry even fuel with high moisture content. Thus such fuel can be utilized without preliminary drying.

(2) Limited impact for environment

Feeding limestone to the furnace provides desulfurization. Also multi-stage air injection, along with the lower combustion temperatures of 850℃ to 950℃, makes low level of NOx emission.

(3) Low-excess-air combustion

As high-speed fluidizing flow is applied, the relative velocity of particle speed and air molecule speed will be great, and is promoting gas-solid reactions. This enables the excess air ratio to be set at a low level.

Table 1 Comparison of various solid combustion schemes

Combustion system	Stoker combustion	BFB (Bubbling fluidized bed)	CFB (Circulating fluidized bed)	Burner combustion
Mechanism of combustion				
Flow of solid fuel	Transported on stoker	Fluidized by combustion air in a layer of the bed material	Fluidized by combustion air and circulated through the combustion chamber and cyclone	Moving in association with the combustion air
Combustion zone	On the stoker	Within and on the surface of the bed material	Entire area of the combustion furnace	Entire area of the combustion furnace
Mass transfer in the combustion chamber	Slow	Limited within the concentrated zone	Active vertical movement, and associated with heat transfer	Limited to the direction of gas flow
Controllability of combustion	Slow response	Medium response	Quick response	Quick response
Low excess air combustion	Difficult	Possible	Possible	Possible
Fuel				
Applicability to various fuels	Fair	High	High	Limited
Fuel pretreatment	Generally not necessary	Generally not necessary	Lumps must be crushed	Fine crushing necessary
Environmental load				
Low SOx combustion	In-furnace desulfurization not possible	Poor in-furnace desulfurization	High rate of in-furnace desulfurization	In-furnace desulfurization not possible
Low NOx combustion	Difficult	Not compatible with in-furnace desulfurization	Compatible with in-furnace desulfurization	Low NOx burners available (limited applicability)
Others				
Appropriate facility size	Small	Small to medium	Medium to large	Large

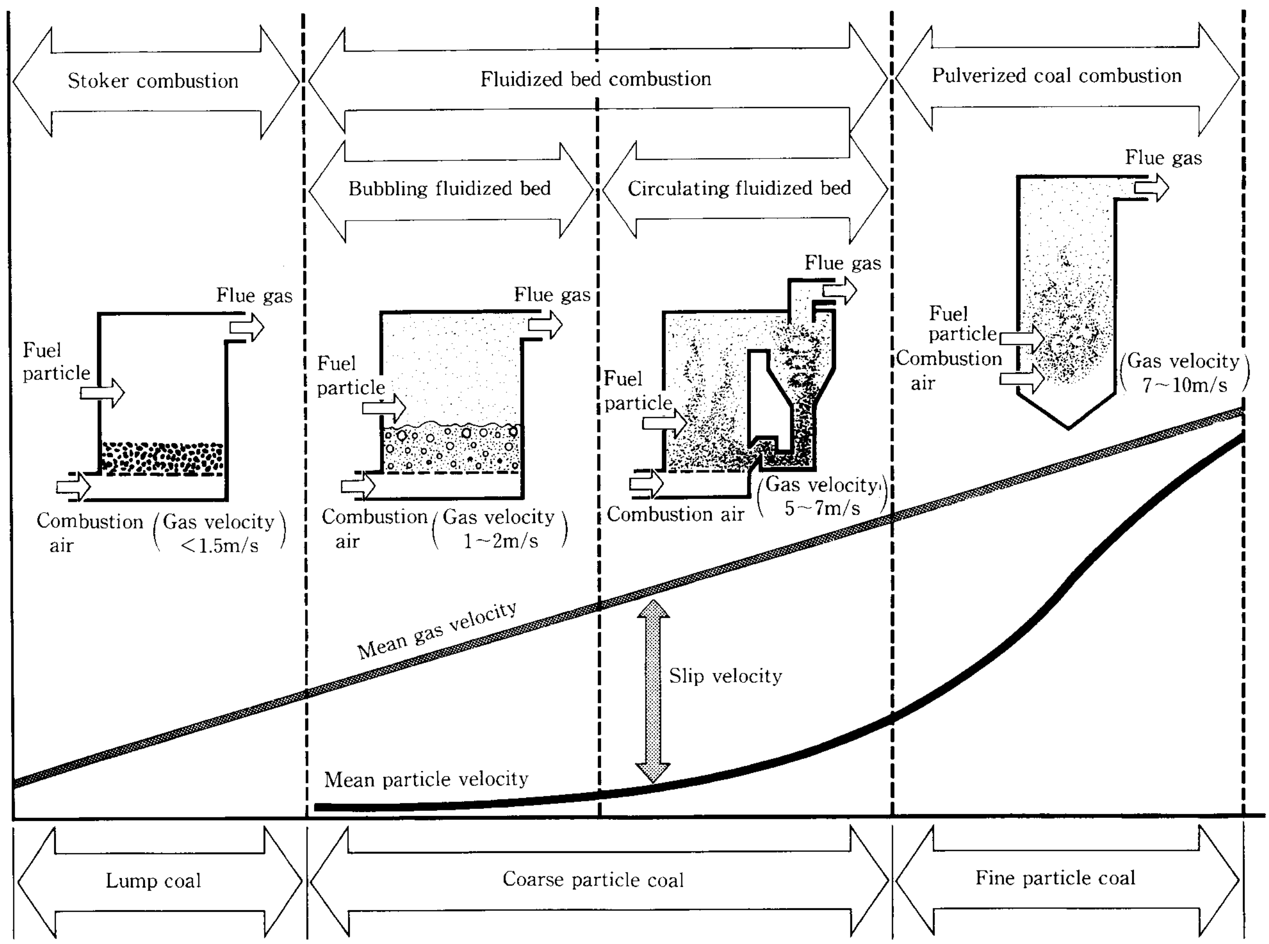

Fig.3 Combustion gas velocity for various solid combustion schemes

(4) High equipment economics

As the environmental impact of this system is low, no special exhaust gas treatment facility is required. This results in a simpler configuration of the facilities, which, in turn, reduces the initial investment. This effect is particularly eminent in medium-scale power plants.

These advantages of the system contribute to the solution of problems unique to biomass power generation.

2.2.5 Biomass combustion by CFB for power generation

Gasification and liquefaction fuel conversion technologies have been proposed for effective biomass utilization. These technologies are, however, all in the developmental stage.

The relations of the problems unique to biomass, the requirements for power generation, and the features of CFB combustion is summarized in **Fig.4**. This figure shows that CFB boilers system is the most effective method for biomass power generation.

3. Example of biomass power generation plan

An example of a biomass power generation plan is presented below.

In Japan, the volume of building material waste is assumed to increase as the numbers of private houses rebuilt increases. The Ministry of Construction reported that 6.32 million tons of building material waste was generated in fiscal 2000[5]. This number is expected to increase four-fold by fiscal 2010[6]. **Fig.5** shows the volume and distribution of building material waste.

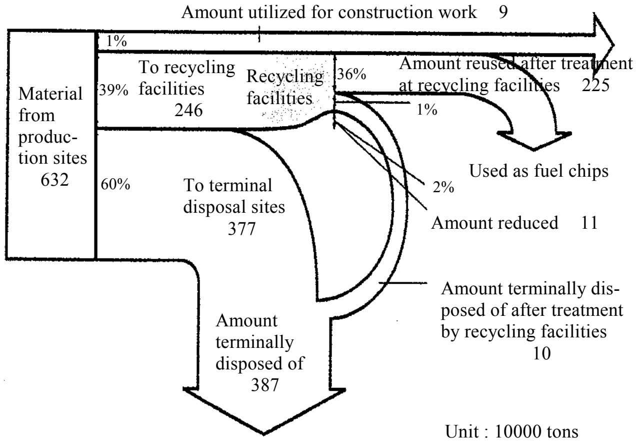

Fig.5 Volume and distribution of waste building materials

Building material waste fed to recycling facilities are first crushed and compacted. Higher quality chips are recycled as raw material for making plywood or paper. Low quality chips are also created. At present, the amount processed by recycling facilities is limited because the system of such recycled product is not sufficiently established. In other words, the limited demand for low-quality chips is a constraint on the recycling of building material waste as a whole.

If the use of these low-quality chips for fuel is disseminated, the recycling of waste building materials will be realized. Moreover, this application can accommodate the larger amount of building material waste in the near future. With this background, NKK developed a plan for a biomass power plant using CFB boiler to burn low-quality wood chips, and has also presented this plan to various parties concerned.

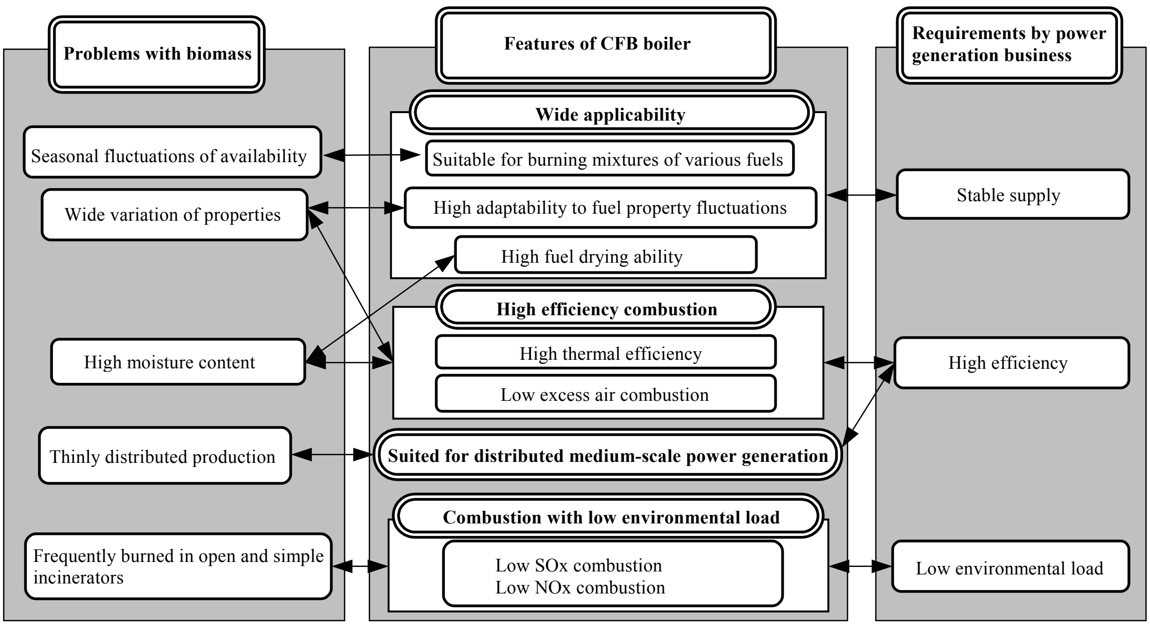

Fig.4 Biomass power generation problems and countermeasures

As a result of this effort, the Japan Wood Preserving Society awarded NKK, jointly with NKK's affiliate in Osaka, a project entitled "Development of Appropriate Recovery and Treatment System by Recycling and Combustion of Wood-based Wastes Including Wood Treated for Preservation." In this project, NKK participated in a feasibility study for a thermal power generation project using wood-based wastes. **Table 2** introduces an outline of this study[7].

Table 2 Outline of the thermal power station using wood-based wastes

Amount of waste building materials recycled	Total	180 thousand tons/year
	Power generation	130 thousand tons/year
Power generation facility	Combustion system	CFB
	Power generation efficiency (generating terminal)	31%
	Capacity	20 MW
	Electric power sold to the grid	141 GWh/year
Environmental impact	Reduction in carbon dioxide emission	56.6 thousand tons/year
	Resource saving (Diesel fuel equivalent)	37.2 thousand kiloliters/year

4. Conclusion

The use of plant-derived biomass as fuel will be expected as one of the most important primary energy sources for reducing carbon dioxide emissions and conserving fossil fuel resources. The effective utilization of waste paper, waste building materials, and such biomass wastes as agricultural wastes are particularly important.

CFB boilers have many advantages including wide adaptability of fuels, low environmental impact, and ideal methods for direct combustion of biomass. CFB biomass is an effective measure for the dissemination of utilization of biomass energy.

NKK is confident to see the bright future of CFB biomass power plant.

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