Progress in Biomass Energy Studies in MAFF, Japan[1]

Yutaka Mori
Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba Ibaraki 305-8686, Japan

Abstract

The Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan has been engaging in biomass energy development studies for more than two decades. The major focuses of the studies are biomass production and biomass conversion to energy. The representative results of the biomass energy production studies are (1) a novel steam gasification system for methanol production from biomass, (2) the conversion technologies of cellulosic and hemicellulosic materials into ethanol using a naturally occurring bacterial coculture and genetically modified enzymes, (3) the membrane technologies for ethanol separation and concentration, and (4) a semi-solid methane fermentation system for swine excreta. Rice husk, straw and bran are among the major biomass resources in Japan. These rice residues were tested as feedstocks for biomass energy production. Biomass energy studies by MAFF including the results with rice residues will be presented, and the future directions for biomass energy development together with the potential of rice as energy and material resources will be discussed.

Introduction

In order to achieve sustainable development, we have to improve the quality of life with minimum use of natural resources and minimum pressures on the environment. Our society depends too much on fossil fuels for energy as well as for industrial raw material. Fossil fuel reserves are limited and when burnt fossil fuels emit greenhouse gases to cause climate change. Thus development of renewable energy is indispensable for sustainable development. Renewable energy includes a wide range of naturally occurring replenishable energy sources, such as sun, wind, water and biomass resources, all of which generally emit no greenhouse gases. Biomass is regarded as neutral over its life cycle in terms of greenhouse gases.

Biomass, defined as material derived from plants or animal manure, is produced by green plants converting solar energy into plant material through photosynthesis. Annual production of biomass is estimated to be approximately 25 ~ 35 billion tons in Carbon, which is roughly equal to 10 times the total energy humankind consume annually (NEDO, 2000). There are basically two distinct sources of biomass energy: wastes from agriculture or industries, and energy plantations. Global biomass production potential is approximately 301 EJ/year with energy crops accounting for 61% and Asia as the most productive region (NEDO, 2000). Biomass used to be the predominant energy source for humankind for cooking and heating through combustion. As shown in Table 1, even now biomass is a major source of energy in the less developed countries, although in the developed countries the majority of energy is supplied with fossil fuels. It is evident that biomass energy will play an important role in the upcoming era when people live on diversified renewable energies. However to make this happen, biomass should be converted to liquids, gases or electricity, the forms

[1] Paper presented at the International Rice Congress, 16-20 September 2002, Beijing, China

adapted for the existing energy supply and utilization systems. The modern biomass energy production system should comprise technologies on production, harvesting, pretreatment, and conversion of biomass, which do no harm on the environment.

The Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan has been working for more than two decades on biomass utilization technologies aiming at development of efficient biomass energy conversion technologies as well as biomass production technologies. Some of the technologies are regarded as promising and have been under verification using pilot plants. We sincerely hope that our efforts will in cooperation with other countries contribute to solving energy and environmental issues which may endanger sustainable development of humankind.

MAFF activities on biomass energy development in Japan

(1) Biomass Resources in Japan:

Huge amount of organic wastes or residues are produced by the activities in agriculture, forest product industries, fisheries, and food industries (Table 2). These include rice straw, rice husk, livestock manure, thinned-out trees, and food processing residues, amounting to 170 million tons per year in total. Rice straw and rice husk account for the majority of agricultural residues in Japan with annual production of 10 million tons and 2 million tons, respectively. Presently most of the wastes or residues are disposed or incinerated and only fractions are composted or utilized for litter in the barn. It is urgently required to develop technologies to utilize those wastes and residues for energy and material production.

(2) Biomass Utilization Projects by MAFF:

MAFF has been engaging in the projects on biomass utilization since 1978 (Table 3). The focuses of the projects have been changing from biomass production in Green Energy Project, to bio-conversion technologies in Biomass Conversion Project, to introduction of new plants and crops in Bio-Renaissance Program, to biomass energy generation systems in Biomass Energy Project, and then to recycling system of biomass resources for reducing impacts on environment in Bio-Recycle Program. Recently more emphasis is laid on environmental aspects such as mitigation of greenhouse gases emission. MAFF is now conducting two projects, namely, Biomass Energy Project ? 2001- 2005? and Bio-Recycle Program ? 2002- 2006? involving researchers from autonomous institutes, universities, and private companies.

(3) Major outcomes in biomass production technologies and the present targets:

Major results from MAFF activities in biomass production technologies are as follows:

(a) Development and improvement of crops for biomass resources:

Photosynthesis genes were isolated and characterized. This is the basis for enhancing the photosynthesis activities of C3 crops such as rice by introduction of C4 plants genes. Potato containing 20-30% more starch than the ordinary ones was developed. A hybrid, which accumulates a large amount of sugar, was produced by crossing between sugar cane and sweet sorghum. These newly-bred crops can be excellent resources for energy and material.

(b) Development of cultivation technologies:

Cultivating methods for poplar, white birch, and acacia were established. A large-scale cultivation technology of giant kelp was developed. Machines for planting, cultivating, or harvesting of bamboo grass and water hyacinth were developed. These trees, seaweed, and plants are good resources for biomass energy for their high growth speed and mass productivity.

Present targets for biomass production are to improve crops for higher sugar contents and productivity and to develop their efficient cultivation technologies with less environmental impacts. The plants and crops under studies are sugar cane, sweet sorghum, guinea grass, sugar beet, maize, potato, and sweet potato. MAFF also has launched the research on production of gramineous crops for the purpose of non-food-use in the approximately 1 M ha of fallow fields that had resulted from cutting down of acreage for rice to cope with surplus of rice.

(4) Major outcomes in biomass conversion technologies and the present targets:

Major results obtained so far are as follows:

(a) Synthesis gas (H_2 / CO mixture) production from rice husk by thermal conversion.
(b) Methanol production by steam gasification of biomass.
(c) Development of semi-solid methane fermentation for methane production from swine excreta, kitchen refuse, and combustible municipal wastes.
(d) Development of a raw-starch hydrolyzing enzyme.
(e) Direct conversion of cellulosic and hemicellulosic materials into ethanol.
(f) Membrane technology for ethanol separation and concentration and development of a membrane bioreactor for ethanol production.

The present target of biomass conversion technology is to organize individual technologies into district systems for local energy supply.

(5) Case study 1: A novel steam gasification system for methanol production from agricultural residues including rice straw and rice husk:

Biomass materials contain much volatile compounds: for example, volatile compounds content of wood is 70 – 90%. These volatile compounds are devolatilized easily at relatively low temperatures (~300 ?), and the organic volatiles are rapidly transformed into gaseous products. When steam is incorporated into gasification, or by steam gasification, the volatile compounds are steam reformed to generate synthesis gases, mixtures of carbon monoxide and hydrogen, at temperatures above 600 ? . Presently Ni / Co catalyst is used to promote steam reforming. Methanol is synthesized on Cu / Zn catalyst following the reaction: $CO + 2H_2 = CH_3OH + 21.7$ kcal
The drawback of the steam gasification is tar formation, which results in a low energy recovery. The tar causes cogging of the pipes, which eventually stops the whole system. A team of MAFF project has overcome the problem by using a low-oxygen-containing gasification agent and pulverized biomass materials. The project team constructed a pilot plant (Fig. 1) and confirmed that a satisfactory amount of methanol was produced from various kinds of biomass feedstocks including rice bran, rice straw, and rice husk. Typical results are shown in Table 4.

(6) Case study 2: Direct conversion of cellulosic and hemicellulosic substances into ethanol (Mori et al. 1990, 1990, 1995): Cellulose and hemicellulose are the first and second most abundant biopolymers on Earth and make up major components of

biomass resources. When ethanol is produced from these polymers, they are first hydrolyzed to glucose, and then fermented to yield ethanol. The multiple steps of the process result in high costs in both facilities and labor. A MAFF project team succeeded in isolating a symbiotic coculture of cellulolytic and ethanologenic bacteria that efficiently converts cellulose and hemicellulose into ethanol. The exhaustive studies revealed that the cellulolytic bacteria produces the enzyme complexes termed the cellulosome (3.5 Mda) and polycellulosome (50-80 MDa) that exhibit extremely strong cellulose and hemicellulose hydrolyzing activities. These two bacteria form a very stable coculture through nutritional interdependence, which makes the stable and efficient ethanol conversion from cellulosic / hemicellulosic biomass possible. To improve ethanol production using the coculture, a membrane bioreactor was developed. The membrane bioreactor consisted of a fermentor and a pervaporation system (Fig. 2) and the ethanol produced in the fermentor was continuously extracted and recovered as concentrate by the membrane. It was demonstrated that the ethanol productivity increased remarkably using the bioreactor.

(7) The outline of Biomass Energy Project:

MAFF's ongoing studies on biomass energy are conducted in the Biomass Energy Project. The outline of the project is shown in Table 5. The project is composed of four teams, that is, the teams for Pretreatment, Ethanol production, Fuel production for fuel cells, and Demonstration. In the Pretreatment team, an energy-saving drying method of biomass resources, and physical and enzymatic pretreatments of woody substances to loosen their obstinate structures are being studied. Noteworthy is the effect of the ozone treatment in facilitating enzymatic hydrolysis of woody materials. In the Ethanol production team, one main study is improvement of cellulase and hemicellulases through protein engineering, while the others are attempts for direct ethanol conversion from cellulose and hemicellulose using a unique mushroom and a genetically modified yeast. In the Fuel production for fuel cells team, methane and dimethyl ether production from livestock excreta together with the basic study on hydrogen production by microorganisms from biomass resources are conducted. Finally in the Demonstration team, the systems for ethanol production and fuels for fuel cells production are scheduled to be tested using pilot plants. These systems are to be evaluated on an economic basis, energy balance, and impacts on the environment.

Problems and future directions

Since biomass is bulky and scattered in low density, its collection and transportation are difficult and costly. Eventually biomass energy facilities have to be situated in the vicinity of the region where biomass feedstocks (wastes or energy crops) are produced. Combustion and thermal conversion of biomass generate potentially hazardous emissions. Careful measures should be taken to reduce and remove these emissions. Growing energy crops may have an impact on environment from the use of agrochemicals and cause changes to water use as well as changes to biodiversity.

However, it is obvious that biomass energy can make a significant contribution together with other renewable energy to security of energy supply in a sustainable way. It can help mitigate climate change, reduce acid rain, and soil erosion. Japan has committed itself to national targets to reduce greenhouse gas emissions to meet the Kyoto Protocol obligation of reducing greenhouse gas emissions by 6 % from 1990 levels by 2008-12. In order to attain the objective and to contribute to maintaining the global environment, studies on biomass energy should be accelerated. The most influential technology in the relatively distant future probably is hydrogen generation from biomass resources.

References

(1) NEDO (New Energy Development Organization). 2000. New energy overseas information. Tokyo(Japan) 00-2: p 23-166.

(2) Mori Y. 1990. Characterization of a symbiotic coculture of Clostridium thermohydrosulfuricum and Clostridium thermocellum.Appl. Environ. Microbiol.56:37-42

(3) Mori Y, Inaba T. 1990. Ethanol production from starch in a pervaporation membrane bioreactor using Clostridium thermohydrosulfuricum. Biotechnol. Bioeng. 36:849-853.

(4) Mori Y. 1995. Nutritional interdependence between Thermoanaerobacter thermohydrosulfuricum and Clostridium thermocellum. Arch. Microbiol. 164:152-154.

(5) Sakai M, Nakagawa H. 2002. Biomass new liquid energy. Kagakukougyou nichihousha, Tokyo (Japan) p57-104.

Table 1. Biomass energy consumption in 1996 (PJ/year)

		Biomass	Share of Biomass in primary energy
OECD	Europe	2,340	3.3%
	North America	3,665	3.5%
	Pacific	571	1.7%
	OECD Total	6,575	3.1%
Non-OECD	Africa	9,236	49.5%
	Latin America	3,385	19.1%
	Asia (excl China)	14,622	36.3%
	China	8,628	18.8%
	Former USSR	803	2.1%
	Non-OECD-	130	2.5%
	Middle East	40	0.3%
	Non-OECD Total	36,844	20.5%
World		43,419	11.0%

From reference (1)

Table 2. Biomass Resources in Japan (tons / year)

◆ Agricultural residues		14 M
	rice husk 2 M	
	rice straw 10 M	
◆ Forestry		38 M
◆ Fisheries		4 M
◆ Animal industries		94 M
◆ Food industry		10 M
◆ Waste from household		10 M
	Total	170 M tons/year

Table 3. Biomass Utilization Projects by MAFF

Green energy project	? 1978- 1987?
Biomass conversion project	? 1981- 1990?
Bio-renaissance program	? 1991- 2000?
Biomass energy project	? 2001- 2005?
Bio-recycle program	? 2002- 2006?

Table 4. Energy recovery in methanol from various biomass resources

Biomass	Recovery (%)
Rice bran	57
Rice straw	54
Rice husk	55
Sorghum (ear)	57
Sorghum (leaves and stems)	56
Cedar chips	59

From reference (5)

Table 5. Outline of Biomass Energy Project

[1] Pretreatment methods: drying, destruction of the obstinate structure

[2] Ethanol production technologies: Enhancement of enzyme hydrolyzing activities, improvement of microorganisms by gene engineering, new membranes for ethanol concentration

[3] Production of fuels for fuel cells: hydrogen and methane production from agricultural residues, dimethylether production from livestock excreta.

[4] Demonstration of the key technologies: evaluation of the systems using pilot plants for ethanol production and production of fuels for fuel cells.

Figure 1. Pilot plant for methanol production from biomass.

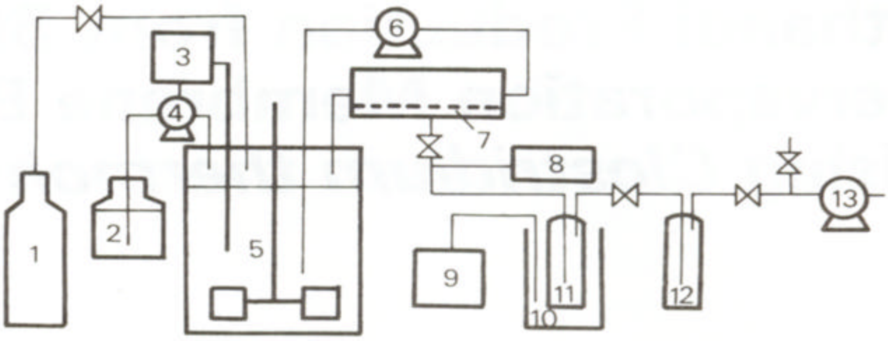

Figure 2. Schematic diagram of the pervaporation membrane bioreactor: (1) CO_2 cylinder; (2) 4*N* NaOH; (3) pH controller; (4) peristaltic pump; (5) jar fermentor; (6) circulation pump; (7) membrane; (8) Pirani gauge; (9) cooler; (10) bath; (11) trap 1 (20°C); (12) trap 2 (liquid N_2); and (13) vacuum pump.

Figure 2. Schematic diagram of the pervaporation membrane bioreactor (from reference 3)