HYDROGEN FROM BIOMASS (2)

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Contents

Summary

Biomass consists of organic compounds produced by the activities of living creatures, and can be a renewable feedstock for hydrogen production. Hydrogen is produced from biomass by gasification of biomass followed by its conversion into hydrogen. Three major technologies are available for gasification of biomass: thermochemical conversion, biomethanation, and hydrothermal treatment. Thermochemical conversion is suitable for treatment of rather dry biomass, while the others are suitable for treatment of biomass with high moisture content. A suitable technology should be chosen depending on the biomass species to be gasified. For product gas conversion into hydrogen, conventional technologies for the water-gas shift reaction and reformation reaction are applicable.

Hydrogen production from biomass has the advantages of renewability, carbon neutrality, and storability. It is a key technology to attain sustainable development with other hydrogen production technologies based on solar energy.

1. Overall Scope

1.1 Characteristics of Biomass Energy

Biomass consists of organic substances produced by the activities of living creatures that are utilized as energy resources. It can be classified by its origin as plant-oriented biomass or animal-oriented biomass. Plant-oriented biomass includes wood, grasses, charcoal, and agricultural residues. Animal-oriented biomass includes excrements, waste meat, and waste fish. Another classification of biomass is based on its generation.

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Biomass can be produced as a crop, namely bioenergy crop, or can be obtained as by-products or waste of agricultural, industrial, and other human activities. Examples of biomass crop are corn and sugarcane cultivated in Brazil and in the United States for ethanol production. Sugar is obtained from the biomass crop, in order to produce ethanol by fermentation, and use the ethanol as a gasoline additive. By-product or waste biomass includes agroresidue (rice husk, straw, stalks), residues from city activity (sewage sludge, municipal waste), and wastes from wood industry (wood chips, sawdust). Table 1 shows biomass resources arranged according to this classification.

Generation	**Origin**	
	Plant-oriented	**Animal-oriented**
Agroresidue	Agroresidue (rice husk, straw, stalk, etc.) Forestry residue (sawdust, wood chips, bark, etc.) Fishery (waste fish) Meat shop (waste meat)	Animal excrements (cows, pigs, chickens, etc.)
Bioenergy crop	Agricultural (corn, sugar cane, sweet sorghum) Wood (eucalyptus, oak, etc.) Marine biomass (water hyacinth, giant kelp, sea tangle, etc.)	
Waste	Municipal waste, pulp sludge, food processing wastes, urban wastewood, etc.	Sewage sludge (bacteria), etc.

Table 1. Classification of biomass resources.

One of the important characteristics of biomass energy is its renewability. Unlike fossil fuel and uranium ore, biomass species can be grown with the aid of solar energy. Thus, biomass energy can be an energy source on which sustainable development is attained. Of the many kinds of primary energy forms, only biomass and solar energy itself can be considered as renewable energy sources to supply a large part of world energy consumption.

Another important characteristic of biomass energy is carbon neutrality. Because all living creatures' activities are sustained by solar energy in the form of photosynthesized carbohydrates, biomass is a renewable energy resource. It is noteworthy that hydrogen production from biomass is basically carbon neutral unlike hydrogen production from fossil fuel conversion. Carbon dioxide released in the process of hydrogen production is fixed again by photosynthesis of plants, and thus carbon dioxide is not accumulated in the atmosphere as long as biomass is reproduced. However, it is to be noted that if biomass is only harvested and not reproduced, utilization of biomass is also another source of carbon dioxide production. Slash-and-burn agriculture in Southeast Asia is a significant source of carbon dioxide emissions.

Biomass energy is also characterized by its storability. With direct use of solar energy there is always the difficulty of energy storage. Daily fluctuation of solar radiation

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causes fluctuation in energy production by solar devices. However, heat and electricity, which are the main products of solar devices, are difficult to store. Hydrogen production by solar energy improves the situation. However, hydrogen is not a good energy storage medium compared to other fuels because of its low volumetric energy density. Biomass energy is also developed by solar energy, but it is easily stored for long periods without energy loss because it takes the form of carbohydrates and other organic compounds. Storage in the form of biomass and conversion to hydrogen for utilization is a favorable strategy to meet requirements of storability and usability.

As biomass is basically solid, and sometimes contains large amount of moisture, conversion of biomass into a secondary energy form is necessary for efficient use and easy handling. Direct combustion of biomass usually results in efficiency as low as 15%. Fermentation and thermochemical conversion are widely accepted as useful biomass conversion methods. Ethanol production by fermentation is already being put into practice. Methane production by fermentation is called biomethanation, and is widely used in developing countries. To obtain solid fuel, biomass is pyrolyzed to produce char. By removing moisture and increasing carbon content, heating value and energy efficiency are improved. Thermochemical conversion is also used for gaseous fuel production, which will be explained in Section 2.

Rough estimation shows 50 Pg of carbon is fixed by biomass every year on the ground, while 23 Pg is fixed in the ocean. The total amount of 73 Pg corresponds to 2500 EJ and is seven times as large as the annual energy consumption of the whole world (323 EJ in 1985), but the amount of biomass that is usable in practice is under discussion.

Today, biomass energy supplies 13–14% of world energy. It is widely used in developing countries. For example, agricultural residues are burned for cooking in south China. Biomethanation, production of methane by anaerobic fermentation of biomass, is widely used in India. Ethanol is produced from corn by fermentation in Brazil, which is used as motor fuel together with gasoline. However, biomass utilization is not common in developed countries because of its high cost and the large area required for its production. The reason for the high cost for biomass production is partly attributed to labor cost. Seeding, watering, fertilizing, extermination of harmful insects, cropping, and conveying can be automated only with considerable investment. Another reason for the high cost is that effective production of biomass requires fuels for machines and fertilizers produced by petroleum chemistry. Utilization of agricultural residue and city wastes such as sewage sludge is expected to reduce this cost to a large extent because of their negative costs. Using land for biomass cropping rather than food production could also cause problems. Increases in world population will result in increased food demand. Thus, fertile land in the world will be required for food production, and it is questionable if sufficient land area will be left for biomass production.

In spite of these disadvantages, biomass energy use is likely to increase in the twenty-first century because of its renewability and carbon neutrality. The World Energy Council proposed a scenario with biomass energy supply being increased to 70 EJ in 2020. The EPA (Environmental Protection Agency, US) proposed four scenarios in all of which biomass energy utilization is enhanced. The IPCC (Intergovernmental Panel for Climate Change) also considers biomass as one important countermeasure to

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greenhouse gas emissions caused by the use of fossil fuel. Effective use of biomass is thus required.

1.2 Importance of Hydrogen Production from Biomass

Hydrogen production from biomass enlarges the possibility of biomass utilization. Biomass itself is not an energy form that is easily used. Solid biomass is not easily handled. Liquid biomass usually contains large amounts of water, which cannot be used directly as fuel. Raw solid biomass also has high moisture content and cannot be a good fuel. The efficiency of direct use of biomass is low. However, when converted to hydrogen, transportation and utilization is facilitated, using well-developed hydrogen technologies. Since hydrogen can be moisture-free, biomass energy can be effectively utilized as fuel. When necessary, hydrogen from other clean and secure sources can be used in place of biomass-derived hydrogen. Thus, hydrogen production from biomass is expected to be one of the key technologies in the future hydrogen energy system.

Hydrogen production using solar energy can be conducted using electrolysis driven by solar cells or thermal decomposition of water driven by solar heating devices. However, because of the instability of solar radiation, stable operation of hydrogen production is not easy. Effective use of biomass as feedstock for hydrogen production can be a solution to this instability. Furthermore, because of the renewability of biomass, it has potential as an undepletable raw material for hydrogen production.

1.3 Technologies for Hydrogen Production from Biomass

Technology for biomass gasification		**Temperature**	**Pressure**	**Product gas**
Thermochemical gasification	Updraft gasifier	900–1200 K	Atmospheric	H_2, CO_2, CO, CH_4, other hydrocarbons N_2 (in case of air gasification)
	Downdraft gasifier			
	Fluidized bed gasifier			
	Circulating fluidized bed gasifier			
Biomethanation	—	Room temperature –330 K	Atmospheric	CH_4, CO_2
Hydrothermal gasification	Supercritical water gasification	850–950 K	25–35 MPa	H_2, CO_2, CO, CH_4,

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	Thermochemical environmental energy system	600–700 K	20 MPa	other hydrocarbons

Table 2. Biomass gasification technologies..

Technically, hydrogen production from biomass is conducted by biomass gasification and treatment of the product gas. Three major processes for biomass gasification are available today: thermochemical gasification, biomethanation, and hydrothermal treatment. These technologies are listed in Table 2.

Thermochemical gasification is treatment of biomass at temperatures as high as 900–1200 K, where biomass is chemically decomposed into producer gas. This technology is well developed for coal gasification, but proper modification is desirable, in view of the differences between the properties of coal and biomass.

For example, biomass is very reactive compared with coal. In order to raise the temperature of biomass feedstock, partial oxidation is often used. This technology is suitable for biomass feedstock whose moisture content is low. Otherwise, the biomass needs to be dried prior to gasification.

Biomethanation is anaerobic fermentation of organic compounds to produce methane. Product gas contains carbon dioxide as much as methane. Hydrothermal treatment is a recent technology in which biomass is treated in water at temperature and pressure close to or higher than the critical temperature and pressure of water (647 K, 22.1 MPa).

In this highly reactive water, with or without catalyst, biomass is easily decomposed at much lower temperatures than with conventional thermochemical gasifiers.

These gasification processes result in gas composed not only of hydrogen, but also of water, carbon dioxide, carbon monoxide, methane, ethane, and other hydrocarbons.

When hydrogen production is aimed at, conversion of the product gases into hydrogen is needed. For this purpose, conventional hydrogen production techniques are applicable. Carbon monoxide can be converted into hydrogen using the water-gas shift reaction:

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (1)$$

Methane and other hydrocarbons are converted through reformation, which is also used for some fuel cells:

$$CH_4 + H_2O \rightarrow CO + 3H_2 \quad (2)$$

Because treatment of product gas to produce hydrogen is discussed in an earlier section, only the gasification technology of biomass is discussed in this article.

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Biographical Sketch

Yukihiko Matsumura, born April 20, 1965, in Japan, received his education from the Department of Chemical Engineering, University of Tokyo with a Ph. D. degree in Chemical Energy Engineering. He has spent two years in Hawaii Natural Energy Institute; has been working on supercritical water technology; has published 15 papers; and is an associate professor of the Environmental Science Center, the University of Tokyo.