HYDROGEN FROM BIOMASS (1)

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Summary

Hydrogen, which does not liberate carbon dioxide during combustion, is considered to be an important alternative energy resource of the 21st century.

However, conventional industrial hydrogen production technology requires the immediate or indirect consumption of fossil fuels resulting in CO_2 emission and fuel exhaustion.

Hydrogen can be produced from biomass using biological process. Biomass has a key role to play in a global energy supply in the future.

However, only a small portion of biomass is presently used, and it is the unused source that should be used effectively. Biological hydrogen production could be a potentially environmentally acceptable energy production method.

In particular, photo-hydrogen production by photosynthetic bacteria has the advantage that with sunlight as the energy source, hydrogen and biomass can be produced simultaneously.

This feature is effective for the promotion of environmentally acceptable energy production technology aimed at producing hydrogen from organic wastewater.

1. Introduction

Biomass is produced by the actions of air, water, and soils using sunlight as energy source; it is a renewable source of clean energy. However, only a small portion of biomass is presently used, and it is the unused source that should be used effectively (Table 1). Approximately two billion metric tons of biomass are present on the earth, and 0.2 billion metric tons are added every year. Biomass produced per year corresponds to approximately 10 times of yearly world energy. Biomass can also be used as a substrate for energy production, particularly for hydrogen production.

			Consumption Biomass	
	Population (million)	**Total demand of energy (EJ)**	**Traditional technology**	**New technology**
North America	276	95.6	1.6	0.8
Western Europe	454	57.9	0.8	0.4
East Europe	386	68.8	1.3	0.4
Japan, Australia	144	21.1	0.2	0.3
Total of a developed nation	1,263	243.4	5.9	1.9
South America	448	17.5	5.3	1.9
Middle and Near East, North Africa	271	12.3	0.9	0.0
Sahara Africa	501	12.2	5.9	0.2
Pacific, Southeast Asia	1,163	45.8	14.6	0.7
South Asia	1,146	20.9	8.6	0.3
Total of a developing nation	4,029	108.3	35.3	3.1
Total of the world	5,292	352.3	39.2	5.0
New Renewable Energy Resources, 1994 (World Energy Council)				

Table 1 The biomass energy utilization in the world

By using microorganisms, hydrogen can be obtained from wood or marine biomass. Diverse microorganisms are able to produce hydrogen, ranging from photosynthetic microorganisms that depend on light energy for acquiring the necessary energy for growth to non-photosynthetic microorganisms that depend on organic and inorganic compounds (Table 2). Microorganisms capable of producing hydrogen are classified into anaerobic bacteria, fermentation bacteria, aerobic bacteria, photosynthetic bacteria, and algae. These microorganisms can be used alone or as mixtures of multiple microorganisms depending on the biomass to be used.

Available Energy Form	Enzyme of Hydrogen Evolution	A class of Bacteria		A Genus of Bacteria	Electron Donor
		Green Algae		*Chlamydomonas*	Water
	Hydrogenase		Heterocyst	*Chlorella*	↑
		Blue-Green Algae		*Anabaena*	↑
Photosynthesis			Non-Heterocyst	*Oscillatoria*	↑
			Non-sulfur Bacteria	*Rhodopseudomonas*	Organic Matters (Organic Acids)
	Nitrogenase	Photosynthetic Bacteria		*Rhodobacter*	↑
				Rhodospirillum	↑
			Sulfur Bacteria	*Chromatium*	Sulfates
				Thiocapsa	↑
		Obligate Anaerobes		*Clostridium*	Organic Matters (Sugers)
	Hydrogenase			*Methanobacterium*	↑
Non-Photosynthesis		Facultative Anaerobes		*Escherichia*	↑
			Facultative Aerobes	*Azotobacter*	↑
	Nitrogenase	Nitrogen Fixing Bacteria		*Clostridium*	↑
			Facultative Anaerobes	*Klebsiella*	↑

Table 2 Classification of Hydrogen Evolution Bacteria

2. Photobiological Hydrogen Production by Photosynthetic Microorganisms (Bacteria)

The advantage of using photosynthetic microorganisms is the ability to use light energy such as sunlight as an energy source (Figure 1).

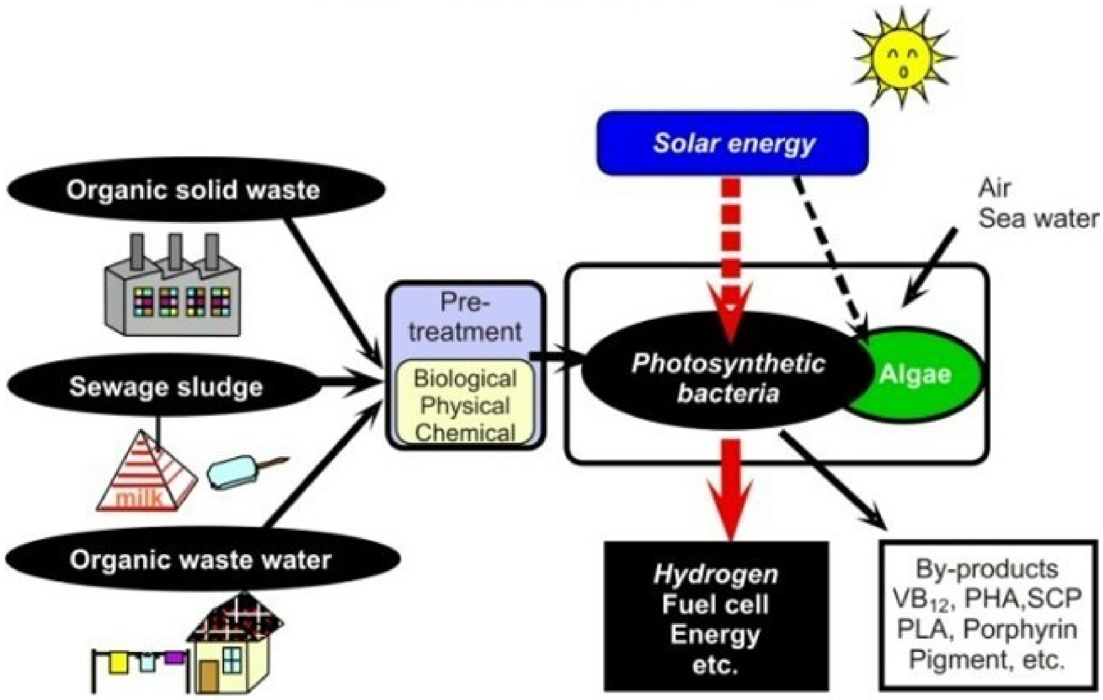

Figure 1. Conceptual illustration for photo-hydrogen production by photosynthetic organisms

Photosynthetic microorganisms are roughly divided into algae (including cyanobacteria), which are able to use water as electron donor, and photosynthetic bacteria, which depend on organic compounds. Both microorganisms are capable of photobiological hydrogen production; however, algae and cyanobacteria are not suitable for hydrogen production, because these microorganisms do not directly degrade organic compounds such as biomass. Accordingly, in this article, photobiological hydrogen production by photosynthetic bacteria is described.

An advantage of photobiological hydrogen production by photosynthetic bacteria is that wastewater disposal and energy production can be simultaneously performed using organic wastewater as a substrate (Table 3).

Photosynthetic bacteria are able to grow by utilizing organic acids, carbohydrates, and sulfuric compounds such as hydrogen sulfide. Photosynthetic bacteria are able to rapidly assimilate volatile fatty acids (VFA) represented by acetate and propionate even at a high concentration. Thus, photosynthetic bacteria have been used in wastewater disposal at a tofu factory and animal barn. Alcohol is also a promising substrate for hydrogen production because of its high hydrogen to carbon ratio.

Substrates	Strains	Production rate
Organic acids		
Malate	*Rba. capsulatus*	130〜168 $mm^3 \cdot h^{-1} \cdot$ mg dcw.$^{-1}$
Malate	*Rba. sphaeroides*	138〜262 $mm^3 \cdot h^{-1} \cdot$ mg dcw.$^{-1}$
Lactate	*Rba. Sphaeroides* RV	62 $ml \cdot h^{-1} \cdot g$ dcw^{-1}
Lactate	*Rsp.* Gunes	0.6 dm^3 $H_2 \cdot dm^3$ culture$^{-1} \cdot h^{-1}$
Mixed VFA	*Rba. sphaeroides* NR3	1.7 dm^3 $H_2 \cdot dm^3$ culture$^{-1} \cdot d^{-1}$
Mixed VFA	*Rba. sphaeroides* RV	2.0 dm^3 $H_2 \cdot dm^3$ culture$^{-1} \cdot d^{-1}$
Aromatic acids	*Rps. palustris* DSM 131	310 μmol $H_2 \cdot h^{-1} \cdot g$ dcw.$^{-1}$
Sugar		
Raw corn	*Rps. gelatinosa* T-20	74 $dm^3 \cdot$ kg corn starch^{-1}
Raw potato	*Rps. gelatinosa* T-20	1.3 $ml \cdot h^{-1}$
Raw cassava	*Rps. gelatinosa* T-20	0.5 $ml \cdot h^{-1}$
Glucose	*Rsp. rubrum* KS-301	91 $ml \cdot h^{-1}$
Sulfur compounds		
Hydrogen sulfate	*Chromatium* sp. PBS 1071	6 $mol \cdot h^{-1} \cdot$ mg dcw.$^{-1}$
Food waste		
Yogrut waste	*Rps. rubrum* S-I	12-20 ml $H_2 \cdot dm^3$ culture$^{-1} \cdot$ 10 d^{-1}
Whey waste	*Rps. rubrum* S-I	8-20 ml $H_2 \cdot dm^3$ culture$^{-1} \cdot$ 10 d^{-1}
Sugar refinery	*Rps. palustris*	35-50μl $H_2 \cdot h^{-1} \cdot$ mg dry cell^{-1}
Sugar cane	*Rps. capsulata* DSM 1710	14 μl $H_2 \cdot mg \cdot Chl^{-1} \cdot h^{-1}$
Tofu waste	*Rba. sphaeroides* RV	12.9 ml $H_2 \cdot$ ml culture-1
Agricultural waste		
Orange process waste	*Rps.* sp. Miami PBE2271	90 $mm^3 \cdot g$ dcw.$^{-1}$
Still waste	*Rba. sphaeroides* O.U.001	0.5 $m^3 \cdot 144\ h^{-1}$
Starch waste	*Rps.* sp. BHU 1-4	88 μl $H_2 \cdot h^{-1} \cdot$ mg dcw.$^{-1}$
Glucose waste	*Rps.* sp. D	0.5 dm^3 $H_2 \cdot dm^3$ culture$^{-1} \cdot d^{-1}$
Cow dung	*Rps. rubrum* S-I	6.3 mm^3 $H_2 \cdot h^{-1} \cdot$ mg dry cell^{-1}
Rice	*Rps. rubrum* S-I	35 mm^3 $H_2 \cdot h^{-1} \cdot$ mg dry cell^{-1}
Organic waste water		
Paper mill	*Rsp. molischianim*	70-139μl $H_2 \cdot h^{-1} \cdot$ mg dry cell^{-1}

Heated sludge	*Rba. sphaeroides* RV	0.7 $dm^3\ H_2 \cdot dm^3$ culture$^{-1} \cdot d^{-1}$
Lactic fermentated vegetable	*Rba. sphaeroides* RV	62 ml $H_2 \cdot g$ dcw.$^{-1}$

Table 3 Photo-hydrogen production from biomass

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Biographical Sketch

Jun Miyake, born June 4, 1951, in Japan, received his education from the Faculty of Science, University of Osaka (Chemistry, 1971–1975), Graduate School, University of Osaka (Biochemistry, 1975–1980) and University of Osaka with Ph.D. degree. He has served as the Vice Director, Tissue Engineering Research Center (TERC), National Institute of Advanced Industrial Science and Technology (AIST), an Independent Administrative Institution (IAI) under Ministry of Economy, Trade and Industry (METI), Tsukuba, Japan, and has taught at the University of Tokyo. Other appointments include Councilor of the Council for Hydrogen Energy Systems Society in Japan (HESS, 1995–), Coordinator of the MITI/AIST Protein Nano-Technology project (1998–1999), Coordinator of the RITE/MITI Biohydrogen project (1992–1999), Coordinator, MITI/AIST BioEcoMonitoring project (1998–2005), and Coordinator of the MITI/AIST 3 Dimensional Cell Tissue Culture project (1998–2006). He has published about 200 original papers and reviews.