Seaweed Bioethanol Production in Japan – The Ocean Sunrise Project

Masahito Aizawa, Vice Chairman
Association of Quality Assurance for Marine Products
Ken Asaoka, Director
Across Consultants Inc.
Masaya Atsumi, Director
Tokyo Fisheries Promotion Foundation
Toshitsugu Sakou
Professor Emeritus, Tokai University

***Abstract*- Seaweed Bioethanol Production in Japan, titled the "Ocean Sunrise Project", aims to produce seaweed bioethanol by farming and harvesting *Sargassum horneri,* utilizing 4.47 million km² (sixth largest in the world) of unused areas of the exclusive economic zone (EEZ) and maritime belts of Japan. Through seaweed bioethanol production, the Project aims to combat global warming by contributing an alternative energy to fossil fuel. This paper outlines the results of the project's feasibility research conducted by Tokyo Fisheries Promotion Foundation.**

I. INTRODUCTION

Global warming is a serious environmental issue on a global scale, common to all humankind. Carbon dioxide emissions from burning fossil fuel are thought of as one major contributor to global warming. To combat such issues, there have been several international framework and efforts taken, such as the Kyoto Protocol (1997). Usage of alternative energy using biofuel is expanding to curb carbon dioxide emissions. One example is the Japanese government, which has announced plans to produce 6 million kl of biofuel by the year 2030.

Biofuel production expansion is seen especially in agriculture producing countries such as the U.S. and Brazil. However, it has drawn international attention due to global price increase of food. According to FAO figures, the current production of main crops worldwide is estimated at roughly 3.6 billion tons. Assuming that 10% of the crops is to be used for biofuel, it would be 40 million tons of oil equivalent. On the other hand, global oil consumption is estimated at 3.8 billion tons annually, and biofuel produced from crops can only satisfy 1% of oil consumption. Therefore, the role of crops as an energy source is merely a provisional one, and biofuel production using other resources must be developed.

Thus, possibilities of utilizing unused cellulose from straw, rice straw, etc. as other raw materials for biofuel is being researched. If the incidence rate of these cellulose resources is assumed at 1.5 times that of agricultural crops (for rice, rice straw is estimated at 140% that of brown rice[1], the total is 3.5 billion tons. If the ethanol production rate from the remaining amount is supposed at 0.2 (oil conversion using heat), it can be calculated that 700 million tons of bioethanol will be produced using oil conversion. The theoretical supply limit of unused cellulose energy, therefore, is 18% (Table 1).

Table1. Bioethanol Production Cap of Major Land Crops

	World Production (FAO, 2002)	Amount Directed to Ethanol Production (Assumption)	Amount of Converted Ethaonol
Wheat	570 million tons	60 million tons	10 million tons oil equivalent
Rice	570 million tons	60 million tons	10 million tons oil equivalent
Corn	600 million tons	60 million tons	11 million tons oil equivalent
Barley	140 million tons	10 million tons	3 million tons oil equivalent
Potato	300 million tons	30 million tons	1 million ton oil equivalent
Sweet potato	140 million tons	10 million tons	1 million ton oil equivalent
Total	2.32 billion tons	230 million tons	36 million tons oil equivalent

Fig. 1. Production of Seaweed and Land Plants[2]

Meanwhile, the majority of oceans that make up 70% of the Earth's surface area exist as unused space. Since seaweed possess bioenergy production potential comparable to that of land plants(Fig.1), farming large amount of seaweed as energy crop means the possibility of producing sufficient amount of fossil fuel alternative energy without burdening the food supply. Consequently, there is much to expect from energy production from seaweed as marine biomass as a major methodology to solve global environmental and energy issues. Given this background, the possibilities of the marine biomass energy development project "Ocean Sunrise Project" were considered with the objective to comprehensively solve global environmental issues, energy issues, as well as utilization issue of unused spaces.

II. PROJECT SUMMARY

A. Project Image

The mid- to long term goal of the Ocean Sunrise Project is to produce 5 million kl of bioethanol by farming 150 million tons of *Sargassum fulvellum*, utilizing the water surface of less than 1% of Japan's economic zone of 4.48 million km² (sixth in the world). If this scale of production were to be expanded to the three largest oceans (Pacific Ocean, Atlantic Ocean, Indian Ocean) totaling 300 million km^2, approximately 1billion kl of bioethanol can be produced. Nonetheless, seaweed farming at such a scale necessitates deep water farming technology; gradual development of farming and harvesting technology at various water depths through demonstrations is required.

B. Overall Material Flow

The material flow of the Ocean Sunrise Project is water, of which 90% of the 150 million tons of seaweed produced annually is contained in seaweed. The remaining 10% is consumed in the fermentation and distillation process. Any remaining water in seaweed after evaporation from natural drying, fermentation and distillation will be discharged back into the ocean. Out of the seaweed substances consumed during the fermentation and distillation processes, 58% is processed as bioethanol through fiber, alginate, and mannitol processes. The remaining 42% consists of organic components, nutritive salt and ash, and will be used efficiently as mineral supplements for cattle feed or fertilizer(Fig2,).

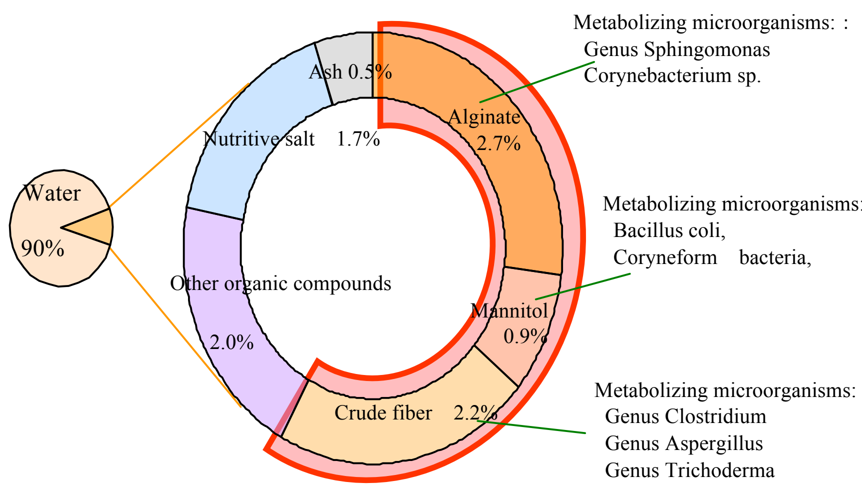
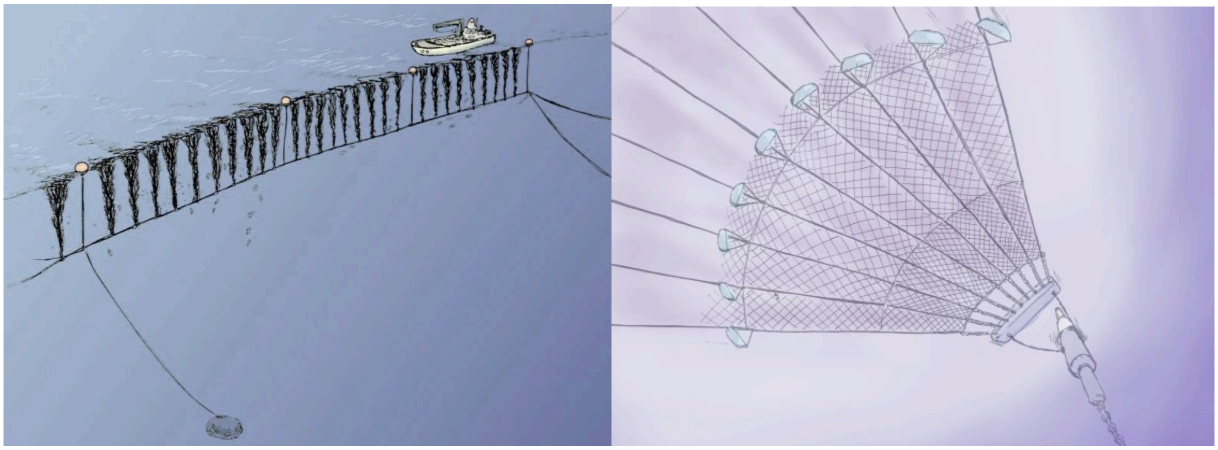


Fig.2 Main components of seaweed and metabolizing microorganisms[3]-[7]



Farming Facility for Coastal Zones　　　　Farming Facility for Off-shore Zones

Fig. 3 Images of Farming Facilities

As there are several issues that seaweed farming facilities face, such as facility and maintenance costs, a soft facility structure using ropes and nets are planned. The envisioned system will be located in coastal zones with water depth less than or equal to 500m, and off-shore zones (oceans partially included) with water depth of 500 to 3,000m.

In coastal zones, kelp (*Laminaria*) and wakame seaweed (*Undaria pinnatifida*) farming technologies generalized in Japan will be adapted. Ropes will be laid at the water surface, to which seeds will be planted and grown (Fig.3 left). Harvesting would require developing a reaping vessel, but applying laver farming technology as an alternative are already being considered. These seaweed production costs aim for 1,000 yen per 1 ton of wet weight.

In offshore zones (oceans partially included), sea kite farming using ocean currents are being envisioned. The sea kites will assume a configuration applied from trawl nets, with a triangular shape with dimensions of 1.5 km in length and 1.0 km in width. Equipment made of canvas configured similarly to that of otter boards of trawl nets will be placed onto sea kites and the spread out position will be maintained by the power of ocean currents. Single point mooring, applied from deep water mooring technology, will be used. Seaweed production per facility is projected at 60,000~190,000 tons annually(Fig.3 right).

C. Transport System

To mitigate transport and land storage costs, a water bag transport system is suggested for the Ocean Sunrise Project. Such system would apply water bag transport system used for transport of large quantities of water. The water bags will not only be used for storing seaweed in ports or on the ocean, but also are being considered as alternate facility for fermenters.

D. Seaweed Biofuel Production

Seaweed biofuel is produced by converting alginate, mannitol and fiber contained in seaweed into ethanol, butanol, etc. The key in these production processes lies in how efficient the constructed fermentation system can be constructed. The Ocean Sunrise Project emphasizes a highly efficient fermentation system, pursuing technological development such as applying RITE (Research Institute of Innovative Technology for the Earth) system consisting of alginate glycation and highly efficient fermentation technologies.

III. CONSIDERATION OF POINTS OF EMPHASIS

A. Comparison of Ethanol Production Rate

Ethanol production from seaweed is estimated at approximately 27 kg per 1 ton of raw material using contained components, or approximately 34 liters of ethanol. Similarly, results from estimating ethanol production using land crops are shown in Table 2. Seaweed contains a high percentage of water, possessing a lower production rate compared to land crops. Nonetheless, ethanol production potential is high, comparable to that of sugarcane, since productivity per area is high. In addition, as ethanol conversion of alginates is currently being researched, the corresponding conversion rate is a theoretical figure.

Table2. Ethanol Production from Major Land Crops and Seaweed

Raw material	Moisture in raw material [8]	Carbohydrates, etc. (Subject to Fermentation)[8]	Ethanol Production per 1 ton of raw material	
			(kg/t)	(l/t)
Corn	14.5%	70.6%	360.8	462.6
Barley	14.0%	76.2%	389.5	499.3
Wheat	10.0%	75.2%	384.4	492.8
Rice	15.5%	73.8%	377.2	483.6
Sweet potato	66.1%	31.5%	161.0	206.4
Potato	79.8%	17.6%	90.0	115.3
Sugarcane	60.0%	15.0%	76.7	98.3
Seaweed (*Sargassum horneri*)	90.0%	5.8%	29.6	38.0

Seaweed contains different components subject to fermentation (alginates, etc.) than that of land crops (starches, glucose) and thus there is a difference in production coefficient.

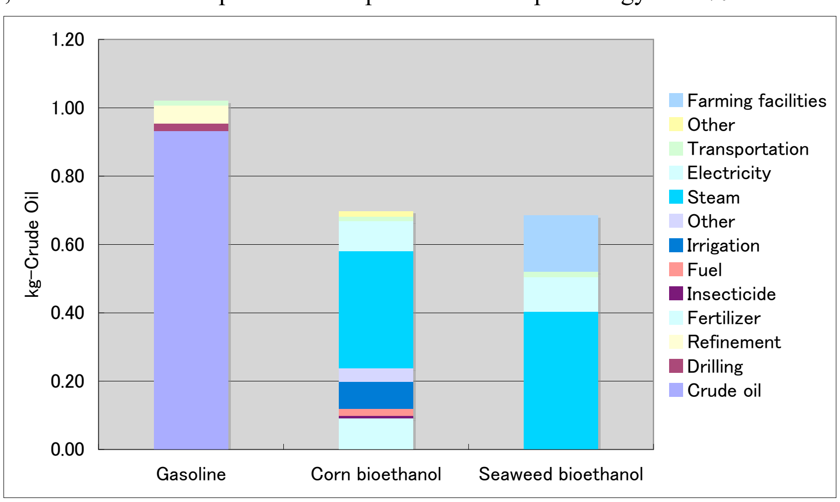
B. Raw Material Prices (Comparison with Crops and Edible Seaweed)

In order to use seaweed as raw material for energy, a major cut in production costs is necessary; even greater scale for edible seaweed. Considering the labor costs in Japan, in order to cut costs various processes need to be automated. There is fishery equipment already on the market that could provide hints, and applying such equipment will continue to be considered.

Currently Japan's other ethanol production plans state the necessity to procure raw materials for 60-70 yen per liter in order to produce ethanol at 100 yen per liter. To produce seaweed ethanol at an equivalent price, seaweed production costs need to be suppressed to under 2 yen/kg. For example, the price of wakame seaweed (*Undaria pinnatifida*) is 500 yen/kg (processed by salting) both domestically and abroad, but by pursuing rationalization and automation, attaining the target price is thought to be possible.

C. Energy Balance Estimate

The energy balance in the fermentation process use estimated values, but overall the energy balance is thought to be almost equivalent to that of bioethanol of land crops(Fig.4). When refining via distillation, it is estimated that production is possible with input energy at 70% of calorific power of ethanol. Similarly to other bioethanols, as energy consumption during the refining process is high, realization of new energy-saving technology such as membrane dehydration, etc. is desired. When refining using membrane dehydration, it is estimated that production is possible with input energy at 55% of calorific power of ethanol.



	Energy	Ratio
Gasoline	1.02kg- crude oil	100**%**
Corn Bioethanol[9]	0.70kg- crude oil	69.8%
Seaweed bioethanol	0.70kg- crude oil	68.6%

Fig.4 Resource consumption in ethanol production equivalent to 1 kg of gasoline (oil based)

IV. CONCLUSION

There is sufficient possibility for seaweed, especially large brown algae, as energy crop. By farming seaweed on a large scale using unused ocean space, a new oil alternative that does not compete with food supply can be expected. In realizing the Ocean Sunrise Project, many of the applied technology can be applied to existing technology in Japan. Technological development and demonstration experiments toward concrete commercialization of the project are expected to take place in the next five years approximately, and the project has an extremely high realization factor. Furthermore, the key is how to farm seaweed in large quantities at low cost; in developing countries where labor costs are lower, realization potential of seaweed farming is high.

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