BEST MIXING OF HYDROGEN AND ELECTRICITY IN YAKUSHIMA ISLAND - A BASIC STUDY FOR FUTURE SUSTAINABLE SOCIETY IN YAKUSHIMA -

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Abstract

Yakushima island, one of the World Heritage sites, is located in the southern part of Japan. Currently, the major energy source for electricity is hydroelectric. The amount of electric energy consumed is 58,600 MWh/y (or 211 TJ/y). The rest of the energy consumed on the island includes gasoline, LP gas, gas oil, heavy oil and kerosene. The amount is 529 TJ/y. On this island, hydroelectric, wind, photovoltaic, solar thermal, biomass and waste energy sources are available as renewable energy sources. From a previous feasibility study, it was found that the renewable energy sources can meet the current consumption of fossil fuels in Yakushima. In order to propose a practical vision for the replacement of fossil fuels, supply forms of the renewable energy sources (hydrogen and electricity) and available devices (hydrogen-driven and electric-driven) are discussed here. Then an appropriate combination of hydrogen and electricity was proposed. Finally, an estimation for required energy resulted in a 22 MW- hydroelectric power plant.

INTRODUCTION

Yakushima island, one of the World Heritage sites, is a small circular island located in the ocean 60 km from the south most tip of Kyushu Island. On this island, there have been several activities and research projects related to ecology and environmental preservation. There are two major reasons for such activities. Firstly, Yakushima is geologically closed. This fact enables people to better understand flows of materials, energy and money. Secondly, since Yakushima is one of the World Heritage sites, Yakushima people are very aware of any activities related to ecology and environmental preservation such as zero-emission, which was proposed by Gunter Pauli [1]. Currently, the major energy source for electricity on Yakushima is hydroelectric. The amount of electricity consumed is 58,400 MWh/y (or 211 TJ/y). The rest of the energy consumed on the island is mainly fossil fuel including LP gas, kerosene, gasoline diesel oil and heavy oil. The amount is 530 TJ/y. On this island, hydroelectric, wind, photovoltaic, solar thermal, biomass and waste energy sources are available as renewable energy sources. The details of estimating the potential of renewable energy sources on Yakushima were reported in previous papers [2,3]. In this paper, a study was carried out to propose how to utilize those renewable energy sources in order to eradicate fossil fuel consumption from the island. The replacement for fossil fuels is expected to be hydrogen or electricity. Firstly, available devices using hydrogen or electricity and their energy converting efficiencies were investigated. Secondly, an appropriate combination of hydrogen and electricity as delivery forms of energy was proposed. Thirdly, an estimation was carried out to

determine what amount of renewable energy sources are required to produce the hydrogen and electricity.

1. FACTS AND CURRENT ENERGY CONSUMPTION IN YAKUSHIMA

Figure 1 shows a map of Yakushima, whose area is 502 km^2. 95 % of this area consists of mountainous regions. HEPP in Figure 1 stands for 'hydroelectric power plant.' The flat region of Yakushima constitutes the coast line. One of the most characteristic features of Yakushima is the huge amount of rainfall as shown in Figure 2.

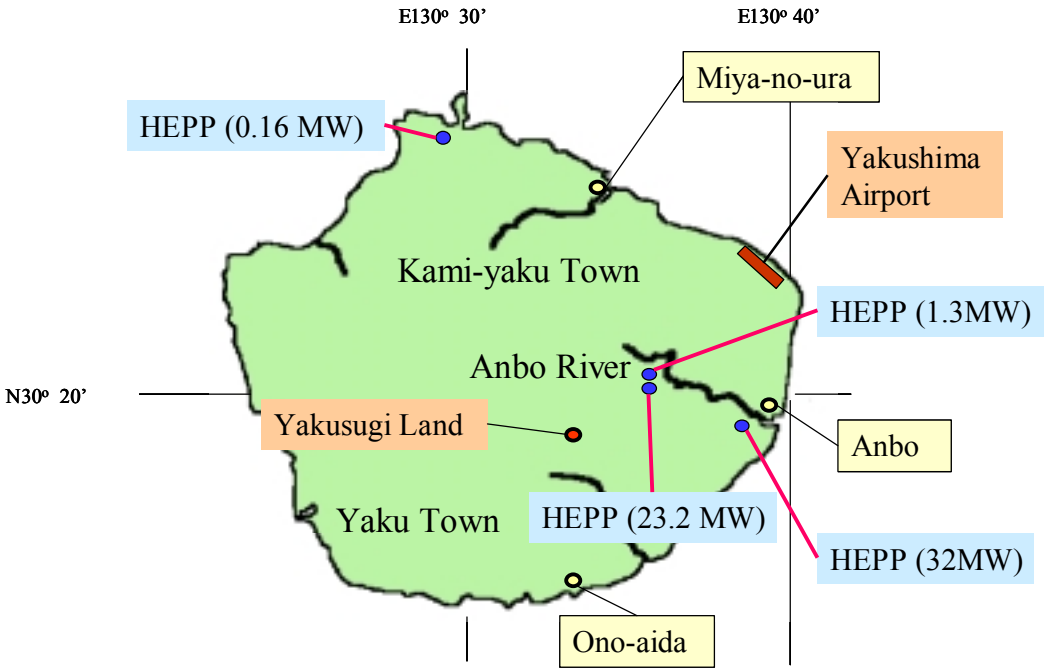

Figure 1 A map of Yakushima.

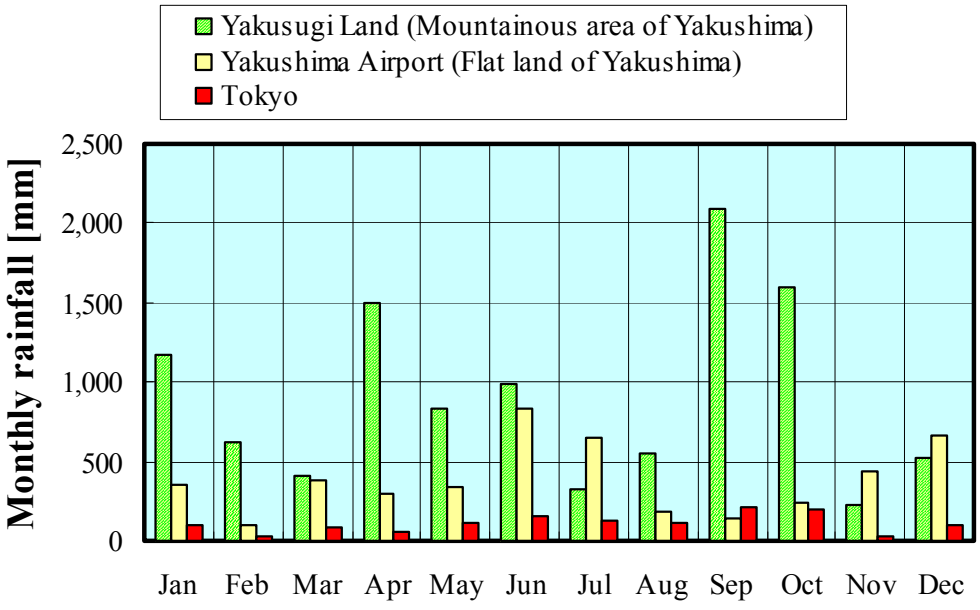

Figure 2 Rainfall data of Yakushima.

The upper half of Yakushima is called Kami-yaku Town and the lower half is called Yaku Town. Miyano-ura is the capital of Kami-yaku Town; Ono-aida is the capital of Yaku Town. Miyano-ura, Anbo and Ono-aida are the most populated places on the island. The population of Yakushima is 14,000, which has undergone little change in the last ten years. From 1960 to 1990, with the decline of Yakushima's lumber business due to cheaper imported lumber, the population decreased from 24,000 to 13,900. The industry structure of Yakushima is summarized in Table 1 as the number of workers in each industry category in 1995. As can be seen from the Table, the four major industries of the island are the primary industries, construction, wholesale and retail, and services.

Table 1 The structure of industry in Yakushima (number of workers, 1995).

Industry		Kami-yaku	Yaku	Total	Remarks
Primary	Agriculture	248	685	933	
	Forestry	40	98	138	
	Fishing	102	110	212	
Secondary	Mining	10	4	14	
	Construction	512	532	1,044	
	Manufacture	379	246	625	Decreasing
Tertiary	Wholesale and retail	708	507	1,215	Increasing
	Finance, insurance and real estate	51	55	106	
	Transportation and communications	254	170	424	
	Utility supply	12	12	24	
	Services	749	380	1,129	Increasing
	Public servant	183	160	343	
Total		3,248	2,959	6,207	

In Yakushima, primarily, the consumed energy sources are classified into two types; electricity and fossil fuels. In the Kyushu area to which Yakushima belongs, most of the electricity is supplied by Kyushu Electric Power Co. Inc. In Yakushima, most electricity is supplied by Yakushima Denko Co. Ltd., whose main product is silicon carbide. The company has three power plants along the Anbo River on the island (see Figure 1), and consumed 16 % of their generated electricity for its silicon carbide production. The rest is delivered to the residential sector in the island. The fossil fuels are LPG, kerosene, gasoline, diesel oil and heavy oil, which are all imported from outside the island. The annual amounts consumed of these energy sources in Yakushima's residential sector are listed in Table 2.

The data are mainly from a local government report [4]. The electricity consumption per capita in Yakushima is therefore 15 GJ/y, whose counterpart for the whole of Japan is estimated as 26 GJ/y [5]. The fossil fuel consumption per capita is 38 GJ/y, whose counterpart for the whole of Japan is estimated as 81 GJ/y [5] (electricity generation use excluded).

Table 2 Energy consumption in Yakushima.

Type of energy		Annual consumption [TJ]
Electricity	Hydroelectricity	210.6
Fossil fuels	LP gas	51.3
	Kerosene	58.6
	Gasoline	143.3
	Diesel oil	181.3
	Heavy oil	95.3
Total		740.4

2. POTENTIAL OF RENEWABLE ENERGY SOURCES IN YAKUSHIMA

The potential of renewable energy sources in Yakushima was estimated in order to propose how to replace fossil fuels with renewable energy sources. As renewable energy sources, hydroelectric, wind, photovoltaic, solar thermal, biomass and waste energy sources were taken into account in this paper. Each potential is shown in Figure 3, together with the current consumption, as shown above in Table 2. The details of the estimates were described in previous papers [2, 3]. The basic data quoted were from a local government report [6]. The first noticeable thing in Figure 3 is that the hydroelectric potential is huge. This is attributed to the great amount of rainfall in Yakushima as shown in Figure 2. The second is the considerable amount of wind power potential. In 80 % of the area of Yakushima, the average wind velocity is higher than 6 m/s [7], which is the threshold level of acceptable availability for wind turbines. Though the energy of a representative biomass, wood scraps, is only 103.5 TJ/y, a theoretical biomass potential derived from the forest area (481 km^2) and a standard biomass growing rate (288 t-C/ km^2/y) is 7,800 TJ/y.

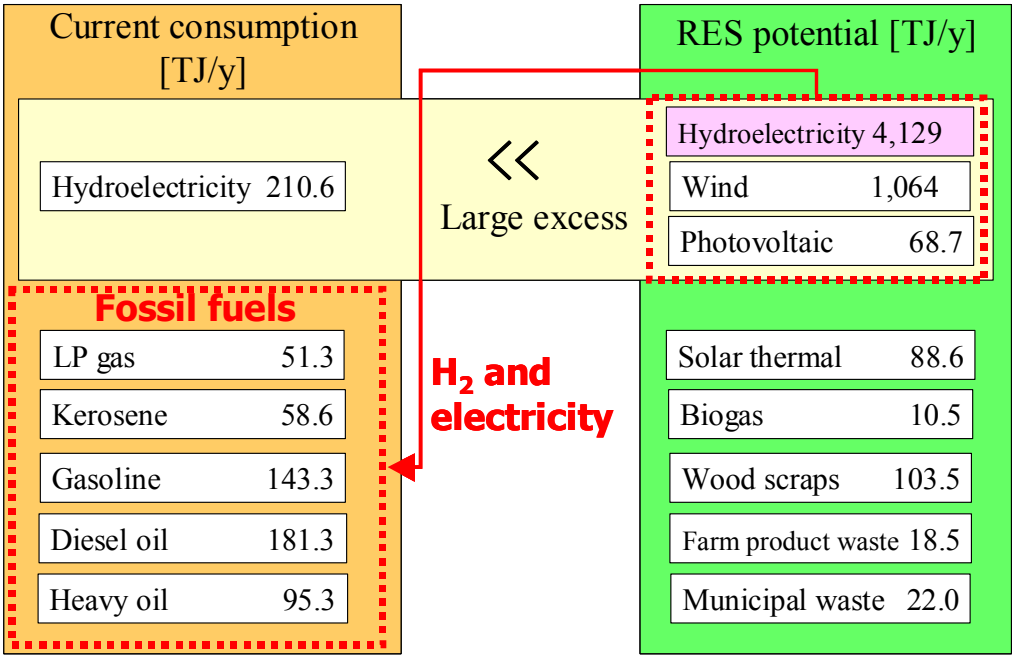

Figure 3 Comparison of current energy consumption with potential of renewable energy sources.

From the discussion above, a feasible option in order to achieve energy sustainability is to replace fossil fuels with renewable energy sources, mainly, hydroelectric power as shown in Figure 3. The delivery forms available are hydrogen and electricity.

3. HOW TO REPLACE FOSSIL FUELS WITH RENEWABLE ENERGY SOURCES

Now we are ready to discuss how to replace fossil fuels with renewable energy sources in Yakushima. Table 3 shows the current situation of fossil fuel consumption (left), and options for replacing fossil fuels (right). In this paper, the shadowed devices were selected. The process for the selection is discussed below.

As shown in Table 3 (right), for cooking, bath, hot water supply and air conditioning, electric

appliances are selected, because they have much better efficiency than fuel cells. Especially, in Yakushima, since hydrogen is produced by electrolysis of water, the overall efficacy for utilizing fuel cells becomes poorer.

From the viewpoint of energy efficiency, battery cars are better than fuel cell cars. The things which should be taken into account are that battery cars have some serious disadvantages, such as a long refuelling time, a short cruising distance and a heavy maintenance burden (not only economically, but also environmentally) due to a large battery. This is why fuel cell cars are selected for the replacement of gasoline and diesel cars, even though the technology for fuel cell cars has not yet matured.

Table 3 Options for replacing fossil fuels.

Fossil fuels			Options for replacing fossil fuels			
Type	Use	Annual consumption [TJ]	Electic-driven machine for replacing fossil fuels	Hydrogen-driven machine for replacing fossil fuels		Annual electricity consumption [TJ]
LP gas	Cooking	25.6	IH cooker	-		12.8
	Bath and hot water supply	25.6	Electric heater	Fuel cell		20.5
Kerosene	Bath	52.7	Electric heater	Fuel cell		42.2
	Air conditionig (heating)	5.9	Air conditioner	Fuel cell		2.0
Gasoline	Automobile	143.3	Battery car	Fuel cell car	Hydrogen internal combustion car	149.4
Diesel oil		181.3				218.2
Heavy oil	Ship	23.8	-	Fuel cell ship		28.6
	Boiler	71.5	Electric boiler	-		60.2
Total		529.7	Total			533.8

To replace all the fossil fuel consumption in Yakushima, 534 TJ (or 148 GWh) of electricity is required annually. Since the availability of hydroelectric turbines is expected to be 75 % in Yakushima, a hydroelectric power plant of 22 MW is sufficient to supply 148 GWh of electricity. Since the capacity 22 MW is almost the same as one of the power plants now operating in Yakushima (see Figure 1), this proposal is not unrealistic.

The combination we chose is hydrogen for transportation and electricity for domestic energy. It is noteworthy to mention that what the authors has chosen is similar to the basic concept of the ECTOS project [8], which is aiming for a hydrogen society in Iceland. The idea of the ECTOS project originated from Professor Bragi Arnason's proposal [9], in which hydrogen produced by water electrolysis is utilized as fuel in Iceland. The surplus is exported to other countries as a commodity. Iceland has a huge potential of hydroelectric and geothermal energy, which can be utilized as cheap electricity to produce hydrogen. In this way, Iceland may obtain sustainability both in energy and for the economy.

Since Yakushima's physical scale is quite smaller than that of Iceland, it is very difficult for Yakushima to have a perfect sustainability, or in other words, a perfect sustainability is not the purpose of Yakushima's hydrogen society. The purpose is to create a small scale hydrogen society, or a public demonstration site [10], which will encourage the transformation of fossil

fuel societies to hydrogen societies [8-12] not only in Japan but all over the world. Another effect of Yakushima's small scale hydrogen society is the promotion of a new eco-tourism utilizing the hydrogen-related sites in Yakushima. This would be a good replacement for the construction industry (Table 1), which is expected to decline in the near future because of the reductions in government subsidies.

CONCLUSIONS

In order to propose a practical vision for the replacement of fossil fuels with renewable energy sources, supply forms of the renewable energy sources (hydrogen and electricity) and available devices (hydrogen-driven and electric-driven) were discussed. An appropriate combination of hydrogen and electricity was proposed. What we propose is fuel cell cars and ships for transportation, and electric appliances for others, such as bath, hot water supply and air conditioning (heating). Finally, an estimation was carried out to determine what amount of renewable energy sources is required to produce the hydrogen and electricity. The result was a 22 MW-hydroelectric power plant.

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