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Estimation Method for the Construction of Hydrogen Society with Various Biomass Resources in Japan -Project of Cost Reductions in Biomass Transport and Feasibility for Hydrogen Station with Biomass-

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Abstract**—**It was determined that woody biomass and livestock excreta can be utilized as hydrogen resources and hydrogen produced from such sources can be used to fill fuel cell vehicles (FCVs) at hydrogen stations. It was shown that the biomass transport costs for hydrogen production may be reduced the costs for co-generation. In the Tokyo Metropolitan Area, there are only a few sites capable of producing hydrogen from woody biomass in amounts greater than 200 m3/h-the scale required for a hydrogen station to be operationally practical. However, in the case of livestock excreta, it was shown that 15% of the municipalities in this area are capable of securing sufficient biomass to be operationally practical for hydrogen production. The differences in feasibility of practical operation depend on the type of biomass.

Keywords**—**Biomass Resources, Hydrogen Production, Hydrogen Station, Transport Cost.

I. INTRODUCTION

BIOMASS is carbon neutral, because biomass fixes carbon dioxide by photosynthesis even though carbon dioxide is released into the atmosphere by combustion. The majority of biomass conversion processes involve co-generation or a combined heat and power system. The reality, however, is that little progress is being made towards real-world use. Regarding co-generation with biomass, therefore, large-scale operations and heat demand exists are necessary for improving total energy efficiency. Another factor that may hinder the utilization of biomass is the economic challenge of its collection and transport. It suffers disadvantages in that it is present in low densities over a broad geographic range.

Along with growing public awareness of the environmental impact of energy (such as in the cases of issues like global warming and the depletion of fossil fuels), hydrogen energy is attracting attention as a secondary energy form that has excellent future potential. Although hydrogen exists naturally only in small amounts, as secondary energy, it may be produced from a variety of primary energy sources. It is also the only energy source capable of inter-conversion with electric power, and it is an extremely clean form of energy in that its combustion produces only water. Among the many methods of producing hydrogen are steam reforming with petroleum, natural gas, or biomass, water electrolysis, and the utilization of by-product hydrogen obtained from petroleum refining or coke production processes. However, the entire process from production of raw materials through hydrogen production may entail the emission of large volumes of carbon dioxide. Its adoption must be carefully and considered, taking into account factors such as life-cycle assessment (LCA) techniques [1]. Hydrogen production from biomass is extremely advantageous in LCA terms over numerous other methods of hydrogen production [2], [3].

II. METHODS OF HYDROGEN PRODUCTION FROM BIOMASS IN JAPAN

Table I summarizes the methods of producing hydrogen from biomass that have been demonstrated or developed for practical use in Japan to date. The sources of biomass are divided into the two types of “dry” and “wet”. Produced methane with some conversion methods in the table should be converted to hydrogen by steam reforming. (see remarks) As for the scale of the conversion plants in the table, data for a small laboratory plants is also included. The hydrogen recovery rate of pressure swing adsorption (PSA), which is adopted for separate hydrogen from produced gas, is estimated at 80% on high-pressure specification.

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TABLE I
METHODS OF HYDROGEN PRODUCTION FROM BIOMASS IN JAPAN

Sources of biomass		Conversion technique	Gas composition, energy efficiency, etc.	Scale & remarks	Ref #
Dry	Woody biomass (Forest cuttings, thinned wood, sawmill scrap, etc.)	Low temperature fluidized-bed gasification	H_2: 66%, CH_4: 2%, cold gas efficiency: 70%	B: 10 t/d (dry)	[4]
		Partial-oxidation gasification	H_2: 62%, cold gas efficiency: 60%	B: 10 t/d (dry)	[4]
		Steam gasification	H_2: 60%, 17 m^3/h (H_2)	B: 1.4 t/d (wet)	[5]
			H_2: 83%, CH_4: 15%, 0.5 m^3/h (H_2)	B: at 1 g/h (laboratory)	[6]
	Grasses, seaweed	Supercritical-water gasification	H_2: 10% or less, CH_4: 45%	CH_4 reforming req.	[4]
	Agricultural waste	Dry methane fermentation + steam gasification	CH_4: 60%, CO_2: 40%, 150 m^3/t wet, 21.5 MJ/m^3	B: 50 t/d (wet); raw waste CH_4 reforming req.	[7]
	Waste paper, grass	Hydrogen fermentation, methane fermentation + steam gasification	H_2: 5.23 mol/dry-kg CH_4: 8.39 mol/dry-kg	Estimate from NEDO process (grass)	[8]
Wet	Livestock excreta, food waste, sewage sludge	Methane fermentation + steam gasification	CH_4 fermentation: 40% energy efficiency, reform: 67% heat efficiency	B: 10 t/d (dry); CH_4 reforming req.	[4]
		Hydrogen fermentation, methane fermentation + steam gasification	H_2: 2.95 mol/dry-kg CH_4: 8.57 mol/dry-kg	Estimate from NEDO process	[8]
	Sewage sludge, food waste	Supercritical-water gasification	H_2: 10% or less, CH_4: 50%	CH_4 reforming req.	[4]

Pressure swing adsorption (PSA) hydrogen recovery rate: 80% (high pressure spec)

III. BIOMASS COLLECTION AND TRANSPORT COSTS

One of the factors requiring the most consideration in promoting the utilization of biomass is how to reduce the costs involved in collection and transportation. Since biomass is present in low densities over a broad geographic range, reducing related collection and transportation costs requires consideration of how to collect the biomass and transport it to sites efficiently. In general, the distance from forest to hydrogen station is shorter than that to co-generation site, because heat demand in co-generation sites is only fulfilled at large-scale factories such as dairy farms or sawmills.

Taking as an example co-generation with woody biomass on a scale of 100 tons daily, Table II summarizes the collection and transportation costs for biomass according to a METI report [9].

TABLE II
BIOMASS COLLECTION AND TRANSPORT COSTS

Condition		Costs (yen/ton)
Standing timber price (thinned wood)		5,900
Logging & collection costs		4,000
Transport costs	Cost A (loading place to collection yard)	3,100
	Cost B (collection yard to end-use location), the distance is about 60 km	5,300
Total cost		18,300
Cost B ratio (%) = Cost B / total cost		30%

The transport cost B to the location of a co-generation site, where electric power and heat consumptions are adequate, is high and accounts for some 30% of the total cost.

TABLE III
RELATIONSHIP BETWEEN TRANSPORT DISTANCE AND TRANSPORT COST B

Transport distance	Transport cost B (yen)
$x \leq 10$ km	230.3 yen/km ┌ton
10 km$<x\leq$50 km	57.9 yen/km ┌ton + 1724
50 km$<x\leq$100 km	50.6 yen/km ┌ton + 2090
100 km$\leq x\leq$200 km	31.4 yen/km ┌ton + 4010
200 km$<x\leq$500 km	27.5 yen/km ┌ton + 4790
500 km$<x$	27.7 yen/km ┌ton + 4690

Table III shows the relationship between transport distance and transport cost B, according to the METI report. A transport cost B at a transport distance of around 60 km is indicated in Table II. Using Table III, one can calculate transport costs for various transport distances.

This table indicates that transport cost may be marginally reduced within a transport range of 10 km.

IV. POSSIBILITIES FOR HYDROGEN PRODUCTION FROM BIOMASS IN MOUNTAINOUS TOWNS AND VILLAGES IN THE KANTO DISTRICT

Working towards the establishment of a hydrogen society, the Japanese government currently has a propagation plan in which the primary component is fuel-cell vehicles (FCV). (See Fig. 1)

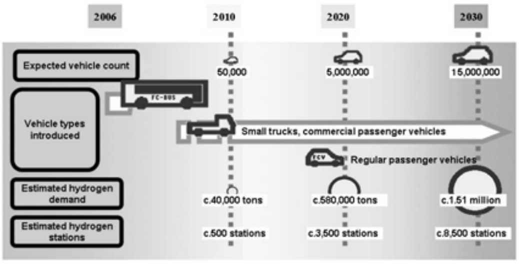

Fig. 1 FCV Propagation Targets

Given the issues of biomass collection and transportation, one may conceive of methods utilization in which hydrogen is produced at sites at which biomass is availably converted to hydrogen and FCVs are refilled at hydrogen stations, thus allowing reduction of the ratio of cost B in the table.

Where Q: Volume of utilizable biomass (tons/year)

Q_w: Volume of utilizable woody biomass

i: Type of woody biomass (forest cuttings, sawmill scrap, orchard pruning, park pruning)

$Q_w = \sum Q_i$

Qs: Volume of utilizable livestock waste

j: Type of livestock waste (dairy cow excreta, meat cattle excreta, hog excreta, poultry manure)

$Q_s = \sum Q_j$

S: Municipal area (km^2)

N: Current petrol station count (locations) and

ρ: Proportion converted to hydrogen stations (%)

the volume of utilizable biomass q (tons/day) per hydrogen station will be

$$q = Q/ [(N\rho/100)360]$$

Further, where annual hydrogen plant downtime is five days (1 day of periodic maintenance and four days annual holidays), the biomass collection area s (km^2) per hydrogen station location will be

$$s = S/ (N\rho/100)$$

The average biomass transport distance (km) L will be

$$L = 10[S/ (N\rho\pi)]^{1/2}$$

Where hydrogen stations are constructed at multiple locations in a municipality, as in Fig. 2, the biomass service area may be segmented simply and distance L calculated as its radius and understood as the average distance from biomass loading place to collection yard to end-use location in Table II for woody biomass. The distance from collection yard to end-use location corresponding to transport cost B is thus shorter than distance L.

The required production volume for a commercialized hydrogen station is defined as the volume required for hydrogen fillings of the same volume as for gasoline-operated vehicles filling at existing petrol stations, and preliminary calculations indicate a level of 200-300 m^3/h is sufficient to obtain profitability [13]. Therefore, it is discussed below whether the calculated volume of hydrogen produced from biomass is more than 200 m^3/h or not.

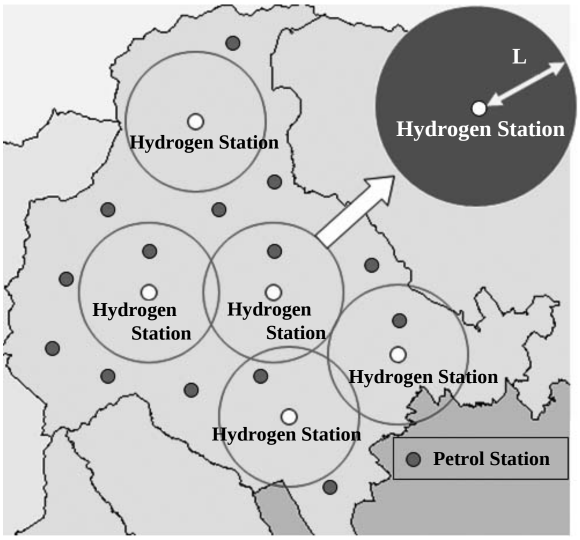

Fig. 2 Biomass Transport Distance L

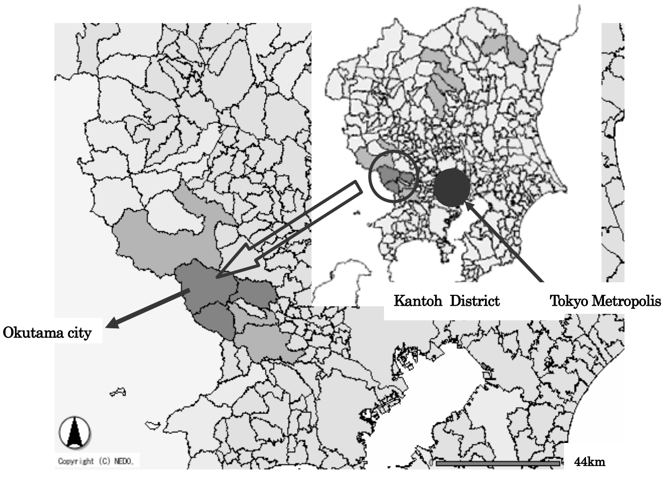

Fig. 3 Location of Okutama City, Tokyo-to

Example for Okutama city in Tokyo-to

The trial calculation below addresses a relatively remote forestry district where a few petrol stations currently exist. This city has one of the greatest availability of woody biomass in the Kanto district.

Calculating for woody biomass, we find:

$Q_w = \Sigma Q_i$
$= 1,384.21$ (forest cuttings)
$+ 12.42$ (sawmill scrap)
$+ 25.36$ (orchard pruning)
$+ 0$ (park pruning)
$= 1,421.99$ tons/year (wet base)
$S = 225.69$ km^2
$N = 5$ (locations)
$\rho = 10\%$

Thus, where

$$q = Q/ [(N\rho/100)360]$$

the volume of utilizable woody biomass q per hydrogen station location will be

$$q = 7.90 \text{ tons/day}.$$

Utilizing steam gasification and PSA refining using the data of reference [5] in Table I, this biomass would yield 230 m^3/h of hydrogen.

Therefore, this district may be estimated to have well enough potential to develop a hydrogen station business based on production of hydrogen from woody biomass.

The maximum biomass transport distance will be

$$L = 10(s/N\rho\pi)^{1/2}$$

and thus,

$$L = 11.99 \text{ km}$$

Transport cost comes to 2,418 yen per ton, and the ratio of transport cost B is calculated as 15.7%. The advantage over co-generation (about 30%) is evident. One may expect a reduction in transport costs of close to 15%.

V. BIOMASS HYDROGEN STATION OPPORTUNITIES IN THE KANTO DISTRICT

As discussed above, we find that the production of hydrogen from biomass and the filling of FCVs at hydrogen stations is a more promising approach than co-generation with biomass.

This section considers the application of this approach in municipalities throughout the Kanto district.

Fig. 4 shows the relationship, in 398 municipalities in the district, between the volume of hydrogen production and biomass transport distance, using provisional calculations for the same conditions as employed above.

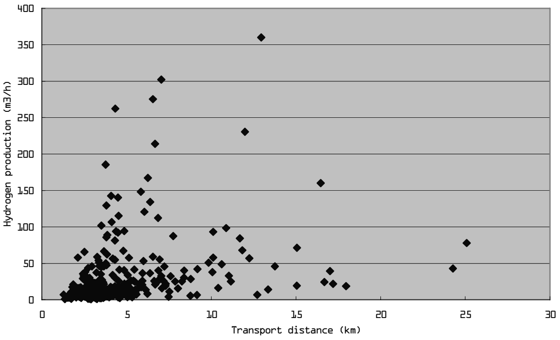

Fig. 4 Relationship between Biomass Transport Distance and Hydrogen Production Volume
(Woody Biomass)

It can be noted from Fig. 4 that hydrogen stations are required at no more than six locations to satisfy the requirement of minimum hydrogen station production volume of 200 m3/h for practical woody biomass applications.

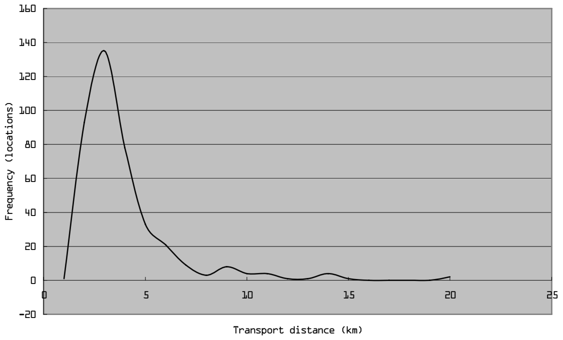

Fig. 5 Relationship between Transport Distance and Service Locations (Woody Biomass)

Fig. 5 describes the relationship between transport distance and the number of station locations. Since a majority of stations (373 of 398 locations, or 93.7%) are located within a transport distance of 10 km, allowing large reductions in transport costs, it is possible to increase the number of stations capable of achieving practical application by further expanding the collection area for woody biomass to optimize economies.

Fig. 6 plots the data for livestock excreta under the same conditions. It shows about 15% (53 of 359 locations) of all stations achieving 200 m3/h or more and that production of hydrogen from livestock excreta is the more feasible method.

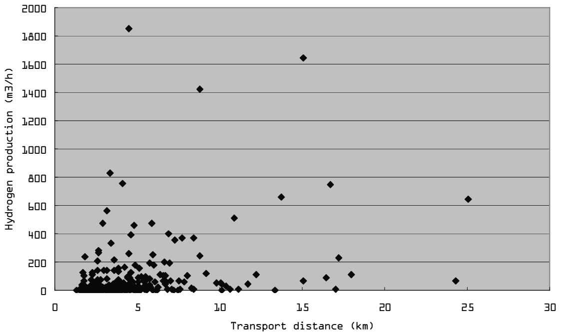

Fig. 6 Relationship between Biomass Transport Distance and Hydrogen Production Volume (Livestock Excreta)

VI. CONCLUSION

This paper examines approaches to the utilization of biomass by means of producing hydrogen from biomass and filling FCVs at hydrogen stations.

The following conclusions have been reached.

1) It was shown that hydrogen production from biomass allows large reductions in biomass transport costs below those for co-generation with biomass. In Okutama city, the transport costs may be reduced by as much as 15% of collection and transport costs for co-generation.

2) There are no more than a few sites in the Tokyo area capable of hydrogen production of at least 200 m^3/h - the scale that is required for a hydrogen station to be operationally practical using woody biomass.

3) In the case of livestock excreta, it was shown that 15% of the municipalities in the Kanto district are capable of securing sufficient biomass to be operationally practical for hydrogen production. It was found that the differences in feasibility of practical operation depend on biomass type.

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