2012: Design a CHHP System for a University Campus Using Local Resources

Kyushu University

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Faculty advisor
Prof. Megumi Takata
Executive summary

We propose a system that is not just a closed jewelry box filled with sparkling hopes for a new energy based society using biomass and CHHP but also a system which holds the key to inspire people to open it by them and deserve the benefits in a futuristic world.

Biomass resources such as raw garbage, sewage water, cattle manure and timber from forest thinning are easy to access in our neighborhood. Among these options, raw garbage and cattle manure are already utilized as fertilizer in agriculture industry. Sewage water is also retrieved in a broad scale for reuse. In contrast, thinned timber is rarely used as a biomass resource.

However, there are unforeseen merits we can gain by utilizing thinned timber.

The background of present situation could be described as follows. Artificial forests cover about 40% of the total forest areas in Japan and this proportion is especially high in our community area, resulting a value of 55%. In the past huge amount of wood was required for Japan’s economic growth. The then-government took steps to reforest stripped mountains densely in order to increase yield. After almost half a century, at present the forests have been unable to grow due to condensed plantation and as a result the CO$_2$ absorption rate has begun to decline.

If there is an opportunity to use thinned timber as a biomass resource, the forests would gain enough space for the growth of their trees. Therefore the utilization of thinned timber could contribute to the absorption of a great amount of CO$_2$ from the atmosphere, not just the reduction of CO$_2$ emission from fossil fuel.

In the proposed system, a gasification furnace is chosen because thinned timber cannot be fermented naturally. In Japan there is a gasification furnace which is currently in operation. This furnace is a fluidized-bed which is able to carry out gasification and combustion simultaneously. This system is used to gasify thinned timber directly, and is capable of feeding the produced gas into DFC and extracting the enormous heat generated during combustion simultaneously.

The three key elements produced by the proposed system are ‘Electricity’, ‘Heat’ and ‘Hydrogen’. The electricity will be sold to the university at a unit cost of 28.2cent/kWh determined by regulations. Generated heat is used for numerous purposes such as desiccating thinned timber, residual heating of gasification system, ice skating rink cooling and bio diesel fuel production. Hydrogen will be supplied to different transport modes such as Fuel Cell Vehicles (FCV), thinned timber collecting trucks and fuel cell powered buses.

The proposed system will definitely make an impact on enhancing its area’s tourism and education. The Fukuoka city holds the second most number of international conferences in Japan after Tokyo. The reason is not only that it is geographically close to Korea and China but also the existence of Kyushu University, which plays a leading role in the development of Japan’s science and technology. This latest carbon free system will be a prominent landmark for visitors and advertised as an attraction facility which implements the coexistence with forests and which practically could be introduced any place on earth. Concurrently Itoshima peninsula, where the Kyushu University is located, is a popular resort area in Fukuoka city and the proposed system will be used as a facility to enhance tourism education for resort customers.

Our proposing system would contribute immensely towards the region’s economy, education and environment by utilizing biomass, and a prominent overall performance could be anticipated.
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1. Feedstock analysis

1.1 The area of feedstock analysis around Kyushu University

Kyushu University is located on the boundary between Fukuoka city and Itoshima city, both of which are parts of Fukuoka prefecture. Fukuoka city is divided into seven sectors as wards. The area where Kyushu University belongs is called the Nishi ward (Fig 1.1-2).

Feedstock analysis is conducted for these two administrative districts because the campus is located on the center of these two areas. The radius is about 10km from the campus. One feature of this region is the humid climate with temperature suitable for plantations. Table 1.1 shows the general details of the two areas. 68% of the total area consists of forests and plantation areas. Another feature is that this region belongs to Fukuoka metropolitan area, which holds the 4th strongest economy of Japan.

1.2 Research approach and results

1.2.1 Research approach

The feedstock analysis was conducted using two methods. The first is to gather information for the feedstock by making inquiries at some offices, and each feedstock data was obtained. The other method is estimation of the amount of feedstock from population, the number of livestock, areas etc. In the following sections, explanations are given on the conducted feedstock analysis.

1.2.2 Result of feedstock analysis

According to a survey 23 variants of biomass resources exist in our area. Those are shown in Table 1.2. Biomass can be classified into 3 groups as fermentable, un-fermentable and bio-oil. Fig. 2.1 shows the results of feedstock analysis in Itoshima city and Nishi-ward of Fukuoka city. “Used amount” means that the amount of biomass is already used and “Available amount” indicates the amount unused at present.

---

Table 1.1 General details of Itoshima city and Nishi Ward of Fukuoka city

<table>
<thead>
<tr>
<th></th>
<th>Itoshima City</th>
<th>Fukuoka City Nishi Ward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>100,000</td>
<td>189,000</td>
</tr>
<tr>
<td>Area (km²)</td>
<td>216.15</td>
<td>83.83</td>
</tr>
<tr>
<td>Cultivated acreage</td>
<td>60.36</td>
<td>16.59</td>
</tr>
<tr>
<td>Forest Area</td>
<td>98.26</td>
<td>31.78</td>
</tr>
<tr>
<td>Residential Area</td>
<td>15.80</td>
<td>11.32</td>
</tr>
<tr>
<td>Others</td>
<td>41.73</td>
<td>23.69</td>
</tr>
</tbody>
</table>

Table 1.2 Types of Biomass in this area

<table>
<thead>
<tr>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermentable biomass</td>
<td>Unfermentable biomass</td>
<td>Others</td>
</tr>
<tr>
<td><em>Kitchen waste</em></td>
<td><em>General waste of tree chips</em></td>
<td><em>Waste Edible oil</em></td>
</tr>
<tr>
<td><em>Food garbage</em></td>
<td><em>Industrial waste of tree chips</em></td>
<td></td>
</tr>
<tr>
<td><em>Milk cow excreta</em></td>
<td><em>Lumber scrap tree chips</em></td>
<td></td>
</tr>
<tr>
<td><em>Beef cow excreta</em></td>
<td><em>Mowed grass</em></td>
<td></td>
</tr>
<tr>
<td><em>Frog manure</em></td>
<td><em>Oyster shell</em></td>
<td></td>
</tr>
<tr>
<td><em>Layers dirt</em></td>
<td><em>Rice straw</em></td>
<td></td>
</tr>
<tr>
<td><em>Rosin dirt</em></td>
<td><em>Chaff</em></td>
<td></td>
</tr>
<tr>
<td><em>Dehydrated sewage sludge</em></td>
<td><em>Straw barley</em></td>
<td></td>
</tr>
<tr>
<td><em>Septic tank sludge</em></td>
<td><em>Pruned branch of orange</em></td>
<td></td>
</tr>
<tr>
<td><em>Water hyacinth</em></td>
<td><em>Lumber from thinning</em></td>
<td></td>
</tr>
<tr>
<td><em>Mandarin orange residue</em></td>
<td><em>Burn beer</em></td>
<td></td>
</tr>
</tbody>
</table>
Information regarding the amount of kitchen waste, food garbage (from business activities), dehydrated sewage sludge, human waste, waste of septic tanks, and lumber scrap wood were obtained from the city office and prefectural government. There were also data of unique types of garbage such as the amount of mowed grass, water hyacinth, oyster shells, rice straw, chaff, straw barley, mandarin residue, pruned branches of mandarin, lumber from thinning, and bamboo. In addition, the amount of livestock, other feedstock and cultivated acreage were acquired from city office.

In Fig. 1.3, dehydrated sewage sludge stands for the state after sewage purification and dewatering. The amount of sewage water before purification was counted at a total of 54,110,155 t/year in Nishi ward of Fukuoka city, and 5,321,799 t/year in Itoshima city. This sewage water facility lacks an anaerobic digester system. 65.2% of dehydrated sewage sludge is sold as a soil stabilizer and over 30% for cement related use.

### Office inquiry

Information regarding the amount of kitchen waste, food garbage (from business activities), dehydrated sewage sludge, human waste, waste of septic tanks, and lumber scrap wood were obtained from the city office and prefectural government. There were also data of unique types of garbage such as the amount of mowed grass, water hyacinth, oyster shells, rice straw, chaff, straw barley, mandarin residue, pruned branches of mandarin, lumber from thinning, and bamboo. In addition, the amount of livestock, other feedstock and cultivated acreage were acquired from city office.

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### Estimation

The amount of feedstock, which was not obtained by inquiries, was decided by estimation. In this estimation, the amount of livestock excreta, waste oil, industrial waste of wood chips etc. were estimated. Estimation formula is shown in the appendix.

The amount of livestock excreta was estimated from the number of livestock including beef cattle, dairy cattle, pigs, and birds. For example, dairy cattle were categorized in terms of weight and breed. The amount of each feces and urine per day were assorted by weight or condition. At present in Itoshima city, almost all livestock excreta are converted to compost and being utilized in own and neighboring farms. As a result, available amount to be used as a bio mass resource is low.
The amount of industrial wood chips was estimated from the total amount of tree chips in Fukuoka prefecture by calculating from the ratio of this city’s population. The amount of general waste of wood chips was estimated by analyzing combustible waste at the incineration plant. Comprehensive survey of environmental biomass in Itoshima city shows that 78.4% of total industrial waste of wood chips is used as fuel, pulp material, bedding material etc. The unused waste are burned and compressed. On the other hand, general waste of wood chips is all combusted at the incineration plants in both cities. This might be an opportunity to collect those wood chips to make methane gas.

Regarding as mowed grass, water hyacinth, oyster shell, rice straw, chalk, straw barley, mandarin orange residue, pruned branches of mandarin, timber from forest thinning, and bamboo in Nishi ward were determined by formula (1) which is shown in appendix. This feedstock from Itoshima city was acquired by inquiring the city office.

Waste oil from food factory, supermarket and restaurant were estimated by inquiring those facilities. The amount of recoverable and loss oil per household were estimated at 0.003 t/year and 0.005t/year respectively. Total amount of waste oil was estimated from multiplying the amount of waste oil per unit by the number of those facilities. Waste oil from industrial activities is collected by the recycle service company and recycled as biodiesel and fertilizer. On the other hand, waste oil from household is almost burned at incineration plants.

1.3 Feedstock for the system

To choose feedstock for the system, it is necessary to consider how to use and collect the biomass. In our community area, about 250,000t of biomass is produced annually. However 60% of total biomass is already used. Especially the feedstock, which are categorized as Group A achieves 75% for utilization. The other 25% are so hard to use that those are not utilized at present. On the other hand, the biomass in Group B isn’t effectively used. Ratio of utilization is less than 30% and there is enough amount of heat quantity to produce heat, Hydrogen and electricity by DFC1500.

The feature of Group B is that it is difficult to produce the energy by fermentation because main feedstock of Group B is tree chips and timber from forest thinning. Before the industrial revolution those were used to be combustible fuel but at present the value of fuel is lower than fossil fuel. Both of them are produced from forests.

In Japan, 40% of the total forest areas are artificial forests, and the percentage of our community area is higher, results at 55%. In the past huge amount of timber was required for economic growth of Japan. The then-government took steps to reforest stripped mountains densely in order to increase yield. After an almost half a century, at present the forests have been unable to grow due to condensed plantation. To encourage trees to grow better, every 4% of all artificial forests are thinned annually. Yet it is essentially necessary to trim wider because more than half of all artificial forests were planted during the same decade about 50 years ago (Fig. 6.2).

For these reasons, the proposed system mainly uses feedstock belongs to Group B. Table 1.3 shows the feedstock chosen for the system. Wood transforms to energy by gasification. The biomass for the CHHP plant is collected by the staff of plant operating company using fuel cell trucks. Furthermore waste oil, which belongs to Group C, is used for producing bio-diesel oil. Waste oil collecting projects are already in process at elementary school but are insufficient. Therefore new projects will be commenced to collect waste oil. This is also expected to enhance the education of children.

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Amount (ton/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General waste of tree chips</td>
<td>23,709</td>
</tr>
<tr>
<td>Industrial waste of tree chips</td>
<td>1,823</td>
</tr>
<tr>
<td>Lumber scrap tree chips</td>
<td>1</td>
</tr>
<tr>
<td>Mowed grass</td>
<td>6,295</td>
</tr>
<tr>
<td>Pruned branch of orange</td>
<td>224</td>
</tr>
<tr>
<td>Timber from forest thinning</td>
<td>18,057</td>
</tr>
<tr>
<td>Bamboo</td>
<td>6,695</td>
</tr>
<tr>
<td>Total</td>
<td>56,804 (159 ton/day)</td>
</tr>
</tbody>
</table>
2. **CHHP System Technical Design**

2.1 **Structure of the CHHP System**

We propose a CHHP system which is mainly composed of a gasification unit for biomass and DFC1500.

The gasification unit mainly consists of a gasification furnace and heat exchangers. Generally, there are several types of gasification furnace in the market. We adopt fluidized-bed gasification furnace which is operated as a demonstration furnace at present in Japan. The gasification furnace produces not only gas for the DFC1500 but also CO$_2$ and heat. The CO$_2$ is used for nurturing the plants. The heat is used for feedstock drying, gasification unit preheating, as a heat source for the air-conditioner of an Ice Skating Rink and for production of bio diesel fuel.

Kyushu University possesses a photovoltaic generation unit and a wind turbine generator unit. At the initial phase of introducing the CHHP system, the electricity generated by these units is utilized for campus use. In a case that the demand for Hydrogen exceeds the amount of Hydrogen generated by DFC1500, required amount of Hydrogen is generated by electrolysis of water with the renewable energy. Hydrogen is supplied for FCVs, FC trucks for lumber collection and FC buses.

Fig. 2.1 shows the flow diagram of the proposed system.
Fig. 2.2 Overview of CHHP system from North West direction

Fig. 2.3 Overview of CHHP system from South West direction
Fig. 2.4 Side view of the CHHP system

Fig. 2.5 Concept of the Ice Skating Rink interior
2.2 CHHP System and peripheral Systems

2.2.1 CHHP System

Fig. 2.6 illustrates the distribution diagram of CHHP system. Table 2.1 provides the required energy for operating the system and output energy. As mentioned in the previous section, the proposed system mainly consists of two components. In this section, we will discuss details of each component.

![Fig. 2.6 Schematics of the CHHP system](image)

Table 2.1 Input and output energy for the system

<table>
<thead>
<tr>
<th>Element</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong></td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>160t/day</td>
</tr>
<tr>
<td>Water</td>
<td>224.4t/day</td>
</tr>
<tr>
<td>Air</td>
<td>709t/day</td>
</tr>
<tr>
<td><strong>Output</strong></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>0.99MWh</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.88t/day</td>
</tr>
<tr>
<td>Heat</td>
<td>1.69MW</td>
</tr>
</tbody>
</table>
2.2.2 Gasification Unit

There are several types of gasification furnace such as fixed-bed, fluidized-bed, and entrained-bed furnace. Table 2.2 shows the characteristics of these gasification furnaces. We adopted the fluidized-bed furnace because its biomass amount scale is suitable for the proposed system. In addition, EBARA Co., manufactured fluidized-bed gasification furnace which we adopt for the proposed system is not required an input feedstock of wood chips.

<table>
<thead>
<tr>
<th>Table 2.2 Types and specifications of gasification furnaces</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial cost</strong></td>
</tr>
<tr>
<td>Biomass amount scale</td>
</tr>
<tr>
<td>60t/day</td>
</tr>
<tr>
<td>Amount of tar</td>
</tr>
<tr>
<td>Down : draft low</td>
</tr>
<tr>
<td>Size of wood chips</td>
</tr>
</tbody>
</table>

The gasification furnace manufactured by EBARA Environmental Plant Co. LTD. consists of a gasification chamber and a combustion chamber. Common fluidized-bed furnace generates tar. However, the gasification furnace does not generate tar because tar is burned out in the combustion chamber. Timber, water and air are required for gasification and two types of gases are generated. One is the produced gas and the other is combustion gas. The produced and combustion gases are used for operating DFC1500 and preheating water and air, respectively. Table 2.3 shows the components of the exhaust gas and their quantities. Each amount is estimated from references.

<table>
<thead>
<tr>
<th>Table 2.3 Components of the exhaust gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LHV (MJ/kg)</strong></td>
</tr>
<tr>
<td>CH₄</td>
</tr>
<tr>
<td>H₂</td>
</tr>
<tr>
<td>CO</td>
</tr>
<tr>
<td>N₂</td>
</tr>
<tr>
<td>CO₂</td>
</tr>
<tr>
<td>O₂</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
We designed a gasification furnace which treats 160t of biomass per day (56,804t/year, excluding a periodic check span of one week) by referring to the demonstrated gasification furnace which is manufactured by EBARA environmental plant co. LTD. The amount of biomass treated by proposed gasification furnace was decided based on the input energy to DFC1500. Fig. 2.7 and 2.8 illustrate the demonstration of gasification furnace.

Vapor and air are supplied to operate the gasification furnace. Vapor and air flow into the gasification chamber and to the combustion chamber, respectively. The amount of input vapor and air are determined by the used amount of timber from forest thinning. That is, the ratio of weight of input vapor to timber from forest thinning is 1:1, and input air to timber is 1:4. The ratio was requested from the EBARA Environmental Plant Co. LTD. Thus, the amount of input vapor and air is 160t and 640t per day, respectively. We assumed that air consists of 20% of Oxygen and 80% of Nitrogen.

By operating the gasification furnace, two types of gas (produced gas and combustion gas) and water are generated. The amount of produced gas is estimated from the ratio of components of the gas and their densities. According to the estimation, the amount of produced gas is 34.1 t/day.

The amount of discharged water is estimated from a reference. It states that 95% of input vapor is discharged. Hence, we estimate that 148 t/day of water is discharged.

The amount of the combustion gas is estimated from the mass balance of the gasification furnace. The combustion gas consists of Nitrogen, Oxygen and CO₂. First, the amount of Nitrogen in the combustion gas is 504 t/day since the amount of input Nitrogen is 512.38 t/day and the amount of Nitrogen contained in produced gas is 8.38 t/day. Oxygen is partially used for combustion. According to the reference, 23% of input Oxygen is exhausted from the gasification furnace. Thus, the amount of Oxygen in the combustion gas is estimated at 28 t/day.

The amount of CO₂ is obtained from the following equation.

\[
\text{(The amount of CO}_2 = \text{total mass of input} - \text{the amounts of produced gas, discharged water, Nitrogen and Oxygen in the combustion gas})
\]

From the equation, the amount of CO₂ is estimated at 265.9 t/day.

Fig. 2.7 Conceptual drawing of the fluidized-bed gasification furnace

Fig. 2.8 Demonstration of fluidized-bed gasification furnace manufactured by EBARA environment co., LTD
Heat balance for the gasification furnace is calculated. Heat quantity of the input biomass is 20.5 MW. Lower heating value of the timber from forest thinning is assumed as 11 MJ/kg. For gasification of timber, temperatures of water and air have to be increased up to 750°C and 450°C, respectively. Thus, pre-heating processes are set up to raise these temperatures to 200°C. In these processes, heat of the combustion gas from the gasification furnace and a part of 20.5 MW of input heat quantity is used. Three heat exchangers are used in these processes, and we describe these heat exchangers as HEX1, HEX2, and HEX3 according to the order of high temperature. All the heat exchangers are convectional. Specifications of these heat exchangers are given in Table 2.4. The water temperature is raised from 15°C to 210°C in three steps. First, water flows through HEX3 to the inside of gasification furnace. As the water needs a large amount of heat to evaporate, heat in the gasification furnace is used. The technology concerned with utilization of the heat in gasification furnace is the patent of EBARA Environment Plant Co. LTD. and further details of the patent are provided on the appendix. After flowing through gasification furnace, the water flows through HEX2. Flow volume of the water is 210 t/day. 160 t/day of water is used for the gasification and remaining water is used for the lately discussed skating rink. Air temperature is raised from 15°C to 200°C through HEX1.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HEX1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixture gas</td>
<td>450</td>
<td>290</td>
<td>780</td>
<td>1.39</td>
<td></td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>Air</td>
<td>15</td>
<td>200</td>
<td>640</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEX2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixture gas</td>
<td>280</td>
<td>230</td>
<td>780</td>
<td>0.25</td>
<td></td>
<td>500</td>
<td>9.8</td>
</tr>
<tr>
<td>Water</td>
<td>110</td>
<td>200</td>
<td>216</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEX3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixture gas</td>
<td>230</td>
<td>110</td>
<td>780</td>
<td>0.68</td>
<td></td>
<td>500</td>
<td>15</td>
</tr>
<tr>
<td>Water</td>
<td>15</td>
<td>90</td>
<td>216</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside of the furnace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>90</td>
<td>170</td>
<td>210</td>
<td>5.83</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2.4 Specifications of the heat exchangers
All of heat exchangers are manufactured by Nekken Sangyo Co. LTD. Fig. 2.9 and 2.10 illustrate the schematics of the heat exchangers. Fig. 2.11 illustrates the location of heat exchangers in the gasification unit. Table 2.5 contains their specifications.

<table>
<thead>
<tr>
<th>Type</th>
<th>HEX1</th>
<th>HEX2</th>
<th>HEX3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>plate-type</td>
<td>plate-type</td>
<td>plate fin-type</td>
</tr>
<tr>
<td>L(mm)</td>
<td>1,140</td>
<td>710</td>
<td>1,855</td>
</tr>
<tr>
<td>W(mm)</td>
<td>1,305</td>
<td>1,480</td>
<td>1,400</td>
</tr>
<tr>
<td>H(mm)</td>
<td>1,480</td>
<td>1,305</td>
<td>250</td>
</tr>
<tr>
<td>cost(USS)</td>
<td>43,882</td>
<td>25,411</td>
<td>13,764</td>
</tr>
</tbody>
</table>

The produced gas and the combustion gas include ash and dust. To remove these ingredients, a cyclone separator manufactured by Aco Co. LTD. is adopted into the CHHP system. 6MC-9 and 6MC-81 are employed. The specifications and costs are shown in table 2.6. Schematic drawing is illustrated in Fig. 2.12.

<table>
<thead>
<tr>
<th>Type</th>
<th>For produced gas</th>
<th>For combusted gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>6MC-9</td>
<td>6MC-81</td>
</tr>
<tr>
<td>L(mm)</td>
<td>540</td>
<td>1,620</td>
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<tr>
<td>W(mm)</td>
<td>540</td>
<td>1,620</td>
</tr>
<tr>
<td>H(mm)</td>
<td>1,670</td>
<td>3,450</td>
</tr>
<tr>
<td>cost($)</td>
<td>15,294</td>
<td>67,058</td>
</tr>
</tbody>
</table>
2.2.3 DFC system

We adopt DFC1500 for the proposed system. DFC1500 produces 1.0MW of electricity from 3.0MW of input fuel in LHV. 92.95 ton per day of combustion gas at 370℃ is also produced. In addition, 0.88 t/day of Hydrogen is generated. The amount of generated heat is 105,680MJ/day.

Fig. 2.14 illustrates the process of changes of input gas.

Exhaust gas from the gasification furnace contains Oxygen. Oxygen is needed to be removed from the gas before supplying to DFC1500. Oxygen is removed at the pre-processing unit which is a part of DFC1500, by the following chemical reaction.

\[
\text{CH}_4 + 2\text{H}_2 + 2\text{CO} + 4\text{O}_2 \rightarrow 3\text{CO}_2 + 3\text{H}_2\text{O} \quad (1)
\]

In the proposed system, produced gas from the gasification furnace is used at the anode side. Therefore, the anode reaction is not the same as usual. We discuss the reactions of each inlet gas below.

1. CH\(_4\)

All of CH\(_4\) is reformed as follows.

\[
\text{CH}_4 + 2\text{H}_2\text{O} \rightarrow 4\text{H}_2 + \text{CO}_2 \quad (2)
\]

65% of the produced H\(_2\) in equation (2) is consumed at the anode.

\[
2.6\text{H}_2 + 2.6\text{CO}_2^2- \rightarrow 2.6\text{H}_2\text{O} + 2.6\text{CO}_2 + 5.2e^- \quad (3)
\]

The remaining 35% of the H\(_2\) and CO\(_2\) react according to the following equation.

\[
1.4\text{H}_2 + 0.47\text{CO}_2 \rightarrow 0.93\text{H}_2 + 0.47\text{H}_2\text{O} + 0.47\text{CO} \quad (4)
\]
Combining the products from equations (2) ~ (4) yields,
\[
\text{CH}_4 + 2\text{H}_2 \text{O} + 2.6\text{CO}_3^{2-} \rightarrow 0.93\text{H}_2 + 3.07\text{H}_2 \text{O} + 3.13\text{CO}_2 + 0.47\text{CO} + 5.2e^- \quad (5)
\]

II. CO

All of CO is reformed as follows.
\[
3.16\text{CO} + 3.16\text{H}_2 \text{O} \rightarrow 3.16\text{H}_2 + 3.16\text{CO}_2 \quad (6)
\]
65% of the produced \( \text{H}_2 \) in equation (6) is consumed at the anode.
\[
2.05\text{H}_2 + 2.05\text{CO}_3^{2-} \rightarrow 2.05\text{H}_2 \text{O} + 2.05\text{CO}_2 + 4.10e^- \quad (7)
\]
The remaining 35% of the \( \text{H}_2 \) and \( \text{CO}_2 \) react according to the following equation.
\[
1.11\text{H}_2 + 0.37\text{CO}_2 \rightarrow 0.74\text{H}_2 + 0.37\text{H}_2 \text{O} + 0.37\text{CO} \quad (8)
\]

Combining the products from equations (6) ~ (8) yields,
\[
3.16\text{CO} + 3.16\text{H}_2 \text{O} + 2.05\text{CO}_3^{2-} \rightarrow 0.74\text{H}_2 + 2.42\text{H}_2 \text{O} + 4.84\text{CO}_2 + 0.37\text{CO} + 4.10e^- \quad (9)
\]

III. \( \text{H}_2 \)

65% of the produced \( \text{H}_2 \) is consumed at the anode.
\[
0.68\text{H}_2 + 0.68\text{CO}_3^{2-} \rightarrow 0.68\text{H}_2 \text{O} + 0.68\text{CO}_2 + 1.36e^- \quad (10)
\]
The remaining 35% of the \( \text{H}_2 \) and \( \text{CO}_2 \) react according to the following equation.
\[
0.37\text{H}_2 + 0.12\text{CO}_2 \rightarrow 0.25\text{H}_2 + 0.12\text{H}_2 \text{O} + 0.12\text{CO} \quad (11)
\]

Combining the products from equations (10) ~ (11) yields,
\[
1.05\text{H}_2 + 0.68 \text{CO}_3^{2-} \rightarrow 0.25\text{H}_2 + 0.80\text{H}_2 \text{O} + 0.56\text{CO}_2 + 0.12\text{CO} \quad (12)
\]

From equations (5), (9) and (12), the reaction formula of our system is developed as following.
\[
\boxed{
\text{CH}_4 + 3.16\text{CO} + 1.05\text{H}_2 + 5.16\text{H}_2 \text{O} + 5.33\text{CO}_3^{2-} \rightarrow 1.92\text{H}_2 + 6.29\text{H}_2 \text{O} + 8.53\text{CO}_2 + 0.96\text{CO} + 10.66e^-
}
\]

In addition to \( \text{H}_2 \) and \( \text{CO}_2 \), \( \text{CO} \) and \( \text{H}_2\text{O} \) (650℃) are generated from anode exhaust gas due to imperfect combustion. Thus, using CO shift reaction unit consists of a low temperature shift reactor, PROX reactor, and heat exchanger and is designed by Cosmo Engineering Co., CO is completely removed. CO removal can be implemented in two ways. One is the CO shift reaction which is occurred in low temperature CO shift reactor. Second is the selective oxidation which is occurred in two PROX reactors. In the former reaction, about 90% of CO is shifted to \( \text{H}_2 \) and 10% of CO is combusted in the latter device. Reaction formula can be written as following.
\[
0.9\text{CO} + 0.9\text{H}_2\text{O} = 0.9\text{H}_2 + 0.9\text{CO}_2 \quad (14)
\]
\[
0.1\text{CO} + 0.05 \text{O}_2 = 0.1\text{CO}_2 \quad (15)
\]

CO shift reaction unit is shown in APPENDIX A

CO\(_2 \) generated in anode reaction and CO shift reaction unit is used for cathode reaction. CO shift unit humidity is removed by using absorption dehumidification designed by Shirakawa Seisakusho Co., because the PSA should be kept out of humidity. The air which flows through the heat exchanger in
CO shift reaction unit is utilized for cathode gas. In AGO, $\text{H}_2$ is combusted which passed through PSA in a small amount. Cathode reaction is shown in the following equation.

$$\text{CO}_2 + 0.5\text{O}_2 = \text{CO}_3^{2-} \quad (16)$$

Here, $\text{O}_2$ included in the air which is heated in CO shift reaction unit, is utilized for generating $\text{CO}_3^{2-}$ at cathode reaction. The exhaust gas from DFC1500 flows into biomass storage and BDF manufacturing plant for preheating and esterification reaction heating, respectively.

### 2.3 Peripheral systems

#### 2.3.1 Biomass storage room

A storage room for biomass is built by Techno House Co., According to Techno House, it costs 135,000 US$ to build a prefabricated steel-frame (length: 25m, width: 25m, height: 3.5m). Floor heating system is introduced in the prefab by utilizing waste heat from DFC1500 in order to warm and dehumidify the wood. The room temperature is kept at 40 °C by utilizing 0.5MW of waste heat, and the room humidity is lowered down by using a ventilation fan. Although seasonal differences should be considered, the water content of wood is expected to decrease from about 60% which is the condition before storing takes place. In this way, the energy for dehumidification in the gasification unit can be reduced. Hence this system contributes to operations with high-efficiency.

![Fig. 2.15 Biomass storage room](image1)

![Fig. 2.16 Solar panel in campus](image2)

![Fig. 2.17 Wind turbine](image3)

#### 2.3.2 Solar panel

Solar panel is located at the campus (Fig.2.16) and the current generating capacity is 200kW. This electricity is used as part of CHHP plant’s electricity requirement (162.5kW).

#### 2.3.3 Wind turbine

Kyushu University carries out active research on wind turbines (Fig.2.17) and possesses an advanced use of wind power. The current generating capacity is 196kW. This electricity is used as part of CHHP plant’s electricity requirement (162.5kW).
2.3.4 Electrolyzer

SL66D from Shinkou Kankyou Solution Co. is adopted as an electrolyzer. This device is operated using electricity produced from solar and wind power. This electrolyzer is not introduced to the system at its initial stage. The electrolyzer will be introduced when the demand for Hydrogen increases in the future. It produces Hydrogen, which is compressed by a compressor located at the Hydrogen station and then is stored in the pressure accumulator. As a result, the system becomes flexible to meet the increasing demands for Hydrogen in the future.

Fig. 2.18 Electrolyzer
3. **End use**

3.1 **Heat use**

3.1.1 **Refrigeration of an Ice Skating Rink**

It is considered that the Kyushu University will be donated with an Ice Skating Rink by Mr. Robert T. Huang who is a former graduate of Kyushu University. He established the SYNNEX Co. and accomplished listing on the New York Stock Exchange in 2003. He is also the founder of Kyushu University Ice Hockey Club. All these events finally resulted as reasons for this consideration. This project is, however, hadn’t carried out due to the difficulty of managing the maintenance cost. The size of the rink considered is 30\times60m conforming to the international standards and it means that 420\text{Mcal/h} of energy is necessary to refrigerate. If it operates 24 hours a day and 365 days a year and if electricity covers all of this energy, it would cost around 588,000 US$ (1\text{kWh}=0.119 US$). Therefore, in order to cover the energy requirement, we use an Ammonia absorption refrigerator utilizing surplus steam produced by the gasification unit. This gives us the advantage to achieve a reduction in electricity production.

AUL200 from Daikin Applied Systems Co. is adopted as the refrigerator. This refrigerator generates ice by using 43.2 t/day of steam (160\text{°C}, 0.517\text{MPaG}).

![Fig. 3.1 AUL200](image)

3.1.2 **Esterification unit**

Although a wide variety of biomass such as cattle manure is used in our area, waste oil is yet to be actively utilized. Hence waste oil is collected from our area and is utilized in the proposed system. BDF productive device from Biomass Japan Co. is adopted for reforming waste oil into BDF. 126 t/year of waste oil is planned to collect and convert to BDF by using two devices which can process a total of 400L/day. Waste heat produced from CHHP system substitutes for existing heater of this
device. The existing heater consumes 60kWh of electricity in each time of use and utilizing waste heat results in reduction of electricity consumption. By resolving the problem of electric consumption of heater which is a disadvantage of BDF production, further expansion of BDF is expected. As a marketing strategy produced BDF will be sold at the same market price of diesel oil (1.53 US$/l) with the objective of gaining a profit at the business.

![BDF production device](image1) ![Green house in campus](image2)

**3.1.3 Green House**

Department of Agriculture of Kyushu University is currently under construction at Ito campus. In the Department of Agriculture located at the old campus, a lot of plants are grown in green houses which kept warm and have a CO₂ rich atmosphere by using oil fired boilers. In our system, the exhaust gas from DFC1500 and gasification unit includes highly concentrated CO₂ and heat. Utilizing these exhaust gases, the room can be kept warm and the plants are given the opportunity to grow faster. At the Agricultural Department in Ito campus, 114,994kWh of electricity is planned to use for green houses, but the total amount of electricity is unnecessary because CHHP system’s exhaust gas meets the demand of heat and CO₂. The way to supply heat and CO₂ is installing pipes to each green house and turn on directly into the room.

**3.2 Electricity use**

The electricity generated by DFC1500 is 0.99MW and is supplied to the facility in campus. From the solar and wind power generation units, electricity at a magnitude of 396kW is generated and is used for the CHHP system’s operation.

The details on the use of electricity are discussed thoroughly in the Economic Plan.

**3.3 Hydrogen use**

Hydrogen filling station is already introduced at Kyushu University and we will utilize this after completing a necessary upgrade. Though the amount of hydrogen supply is 10Nm³/h at present, building equipment is designed for preparing to extend hydrogen supply to 500Nm³/h.

Hydrogen is generated by DFC1500 and purified up to 99.999% by Iwatani Co. manufactured PSA. Pipe line enables Hydrogen to be carried to Hydrogen filling station from PSA. At the station, Hydrogen is compressed to 40MPa by using two compressors which have a compressing capability of
200Nm$^3$/h. Hydrogen storage tank is composed of three banks, and each bank has six pressure accumulators. Each accumulator has a capacity of 100 liters, so each bank can store up to 25kg of Hydrogen. The tanks of two FCVs can be filled with Hydrogen simultaneously, due to two dispensers in the Hydrogen filling station.

Table 3.1 Specifications of the Hydrogen filling station

<table>
<thead>
<tr>
<th>Specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Refueling pressure</td>
<td>35MPa</td>
</tr>
<tr>
<td>Compression capacity</td>
<td>880kg-H$_2$/day , (9.778Nm$^3$/day)</td>
</tr>
<tr>
<td>Hydrogen purity</td>
<td>99.999% or more in volume (CO:1ppm or less in volume)</td>
</tr>
<tr>
<td>Refueling capacity</td>
<td>Capable of refueling two passenger vehicles at the same time (35MPa)</td>
</tr>
<tr>
<td>Main components</td>
<td>Compressor (200m$^3$/h×2sets), Storage cylinders (656Nm$^3$×3 sets , 41MPa) , Dispenser</td>
</tr>
</tbody>
</table>

In this system, it is assumed that trucks which retrieve biomass demand 40kg of Hydrogen per day (four trucks, each with a requirement of 10kg of Hydrogen per day). In addition, 60kg of Hydrogen per day is required for supplying buses (six buses, each with a requirement of 10kg Hydrogen per day) and is assumed to be possible. For FCVs, it has the ability to supply Hydrogen for 260 units (3kg per a FCV).

![Fig. 3.4 Hydrogen station flow chart](image-url)
4. Safety Analysis

We considered 4 factors for each component of this system (Gasification furnace, DFC, Pre heating room, BDF plant, Hydrogen station and Ice Skating Rink) as shown below.

a) Hardware breakdown  
b) Fire or combustion  
c) Operation error  
d) Electrical power shortage

To ensure the safety, a pressure-resistant design, leak prevention, fire extinguishing system and periodic maintenance are considered. Details are shown as follows.

4.1 The complete system

In Japan, there are many disasters occur which can damage the entire system. As the Kyushu University is located on the top of a hill, we must consider two main disasters that might affect the infrastructure; earthquake and thunder.

To prevent any fatal destruction by earthquake, large facilities such as Gasification furnace and DFC should possess a vibration isolation system. If, as a result any component such as a compressor or a sensor stops suddenly, it may cause a gas explosion or burst of pipes. Therefore just after an earthquake early warning is given, we switch to backup power plant in order not to lose the power source. After activating the backup power source, valves are closed in turn to stop combustion and chemical reaction gradually. It is important that we suspend the system safely.

To deal with disasters cause by thunder, a lightning rod is installed.

4.2 Gasification furnace

Gasification furnace is a complicated system which has several critical features such as operating several heat exchangers and treating CO which is highly toxic for humans.

Compressor malfunction, pipe fracture, melting and human error are considerable accidents related with the air inlet pipe. As a solution for a possible pressure increase in pipes due to these accidents, pressure detectors are installed. If it detects anything suspicious, the relief valve is opened to let the gas exhaust. The same procedure is taken when pipes are choked with dust or at a compressor malfunction during a power shortage.

The same procedure applies to the water/steam line inlet pipe, but boiler needs to be considered as another problem. The boiler is installed inside the gasification furnace to apply its generated heat for boiling. Fig. 4.1 shows the structure of gasification furnace. Protection wall is set nearby the boiler not to be damaged by the large sand particles which are used as a heat insulator in the gasification furnace.

One of the problems of the unit itself is the increase of temperature and pressure caused by the excess of fuel supply. To prevent this thermometers and pressure gauges are installed in the unit. If they detect anything unusual, the relief valve is opened. Incidentally, the gas from the relief valve has a possibility to contain CO, so the system lets the gas pass through a catalyst before discharge. Another possible problem is a gas leak from a crack on pipe. Although it is important to detect CO leaks and exclude exactly, it is difficult to find an exact leak point because of the unit’s scale. So we install several CO sensors around

![Fig. 4.1 Gasification furnace](image_url)
the unit, and ventilate by blowing air upwards from the ground continuously.

In preparation for a case of combustion unit malfunction, Oxygen sensor is installed near the DFC and if the sensor detects an unusual level of Oxygen, valve would be closed to prevent Oxygen from infiltrating into DFC.

Generated gas from the gasification furnace contains CO. Therefore taking necessary measures to prevent a possible leakage is important. Therefore double pipes are used to adopt nitrogen purge for a safe flow pass. In this pipe, nitrogen gas is flown in the outer valve where the generated CO gas is flown in the inner valve. Even a CO leakage occurs this system dilutes the strength of the toxic gas. Additionally CO sensors are installed on the outer valve that we can detect CO leaks and close valves before the outer pipe breaks.

4.3 DFC plant

We adopt MCFC for DFC plant. MCFC has an advantage which holds a temperature gradient between CH₄ and CO at the anode. This occurs because reformed gas provides an endothermic reaction where anode provides an exothermic reaction. Yet there are two more problems. If quantity of input gas increases suddenly, a large amount of heat will begin to move and results in a breakdown at the electrode. Therefore, a regulator is installed to control input flow. Another problem is the life-time of nickel catalyst. The generating efficiency decreases due to consumption of nickel. We maintain it annually by cleaning or changing the catalyst.

If the water gas shift reactor or CO remover starts to malfunction, CO would flow into PSA. To prevent this CO sensor is installed and valves are closed as soon as sensor detects CO. In addition, nitrogen purge will be applied to the flow pass from combustion unit to PSA as same as the gasification furnace.

4.4 Biomass storage room

It is very important to prevent from a fire breakout because there are dry wood inside the cabinet. In the building using fire is strictly prohibited and fire extinguishers such as sprinklers are installed.

4.5 BDF plant

If a fire breaks out in the BDF plant and burn bio diesel oil, extinguishing with water could cause the fire to spread rapidly. Therefore CO₂ fire-fighting system is chosen.

4.6 Hydrogen station

In Japan there are several strict regulations for a Hydrogen filling station. The system is fully compliant with those regulations. For example, there is no object within 8m from Hydrogen dispenser and protection barriers are chosen around Hydrogen storage tanks.

Furthermore in order to reduce damage from a Hydrogen explosion, concrete barrier surrounds in four directions, and the top is covered with a thin roof. In this way, an impact from an explosion escapes to the outer atmosphere. A Hydrogen detector and a pressure gauge are installed on the outside of pipe. In a case of gas leakage or an increase in pressure exceeding a limited value, valves are closed and Hydrogen is released to the outer atmosphere through relief valve.
5. **Economic/Business plan analysis**

5.1 **Business model**

There are mainly two organizations related to this proposed system. One is Kyushu University in which the system is located. In Kyushu University there are various facilities. For instance, the Inamori Foundation Memorial Hall is used for domestic and overseas conferences, and a restaurant is attached to it so that many participants of conferences are able to enjoy delicious cuisine. Then Ice Skating Rink is contemplated being operated as a new facility. (The green labeled facilities in Fig. 5.1 are in possession of Kyushu University).

Another is a managing company of the proposed CHHP system. As a management system, it is contemplated to be entrusted by Kyushu University and adopt the PFI (Private Finance Initiative) system. This company not only carries out operation management of the CHHP system including collection of timber from forest thinning using FCV trucks but also manages fuel supply (In Fig. 5.1, the three enclosed facilities, with CHHP as the core facility are managed by this company). Balancing the gained profit on this company is an important issue. Incidentally, this company suspends the system for annual maintenance for a period of one week.

![Fig. 5.1 CHHP system and the facilities of Kyushu University](image)

5.2 **Source of profit**

As shown in Fig. 5.1, CHHP system supplies (1) Heat, (2) Hydrogen and (3) Electricity. The usage of each product is shown in detail as follows.

5.2.1 **Profits from selling Heat**

The enormous amount of exhaust heat from CHHP system is utilized at Kyushu University building, Ice Skating Rink, greenhouses and BDF as an energy source. Exhaust heat is supplied to greenhouses and BDF free of charge, but for the Ice skating rink the supply comes with a price. If the unit cost is set at 5.88 US$/t, Kyushu University would pay 105,300 US$/year to the management company.

In case of usual maintenance of an Ice Skating Rink, it costs a vast sum of money;
2,000,000US$/year is estimated if electricity is fully used. Therefore utilization of exhaust heat can attain a large amount of reduction in electricity usage.

In addition, BDF operated by utilizing exhaust heat can produce 143kl/year of bio diesel fuel. As for raw materials, waste oil supplied by local residents is utilized. Therefore there is no cost for purchasing material. The bio diesel fuel is planned to be sold at 1.53US$/l, at the same market price.

5.2.2 Profits from selling Hydrogen

It is necessary to use buses or FCVs as modes of transportation because Kyushu University and its surrounding area are located on the top of a small hill.

Fig. 5.2 shows the transition of hydrogen cost by year. As a measure for spread of FCV, we propose that the fuel expenses will be increased in a step-by-step system within ten years since this system is initialized, then finally set at 5.88US$/kg which makes fuel efficiency of FCV equal to that of a hybrid car at present. By saving the fuel expenses, an increase in FCV usage is expected. As a result, it is conceivable that Kyushu University attains the aim to create new FCV users by involving in Hydrogen business.

40kg/day of hydrogen is used for material trucks out of 880kg/day produced so that 840kg/day can be supplied to the general market. This system can refuel 280 cars a day and further up to 50 cars with the application of an electrolyzer.

5.2.2 Profits from selling Electricity

Electricity from CHHP system is supplied to related facilities in Kyushu University. The amount of electricity supplied from CHHP system is 24,000kWh/day. Kyushu University pays 3,388US$/day at a unit cost of 28.2cents/kWh determined by regulation.

5.3 Expenditure

5.3.1 Initial investment

Table 5.1 shows the initial investment of our proposed system. Listed price is calculated based on exact market price. The cost which includes 10% of facility cost and 10% of design cost is shown in at the bottom of the table. In this estimation, Hydrogen filling station and Ice Skating Rink are considered already existing facilities. FCV trucks used for feedstock transportation of CHHP system are included in the initial investment.
### Table 5.1 Capital cost summary

<table>
<thead>
<tr>
<th>Classification</th>
<th>Equipment</th>
<th>Quantity</th>
<th>Total cost (US$ Millions)</th>
</tr>
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<td>DFC</td>
<td>DFC1500</td>
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<td>3.24</td>
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<tr>
<td></td>
<td>Compressor</td>
<td>2</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>cyclone</td>
<td>1</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>HEX1</td>
<td>1</td>
<td>0.04</td>
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<td>0.04</td>
</tr>
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<td></td>
<td>HEX3</td>
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<td>Pump</td>
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<td></td>
<td>Dehydrator</td>
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<td>Gasification plant</td>
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<td>Relief valve</td>
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<td></td>
<td>Mass flow controller</td>
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<td>Mass flow meter</td>
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<td></td>
<td>Gas holder</td>
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<td>Valve</td>
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<td>FCV station</td>
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<td>Pressure accumulator</td>
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<td>Kyushu Univ.</td>
<td>Electrolysis apparatus</td>
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<td>1.88</td>
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<td></td>
<td><strong>Equipment Total</strong></td>
<td></td>
<td><strong>28.58</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Design and construction cost</strong></td>
<td></td>
<td><strong>5.72</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td><strong>34.29</strong></td>
</tr>
</tbody>
</table>

#### 5.3.2 Management cost

Management cost is shown in Table 5.2. The charge of water and electricity required for continuous operation of the system is calculated based on the rate of industrial use in Fukuoka city. The rate of electricity is 6.78 US$/kW, and the charge of water is calculated as following formula.
Also in Japan a consumption tax of 5% is added to these charges.
It is considered that employing 16 workers is sufficient for a stable operation of the gasification plant, feedstock transportation etc. As the maintenance cost, 2% of initial investment is added.

Table 5.2 Operating cost

<table>
<thead>
<tr>
<th>Classification</th>
<th>Consumption</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water use (m³/year)</td>
<td>75180 m³/year</td>
<td>0.50</td>
</tr>
<tr>
<td>Electricity (MWh/year)</td>
<td>58.2 MWh/year</td>
<td>0.23</td>
</tr>
<tr>
<td>Employment (people/year)</td>
<td>16 people/year</td>
<td>1.68</td>
</tr>
<tr>
<td>Maintenance</td>
<td>2% capital cost</td>
<td>0.69</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>3.10</strong></td>
</tr>
</tbody>
</table>

Table 5.3 shows the annual production of Hydrogen, exhaust heat, electricity and BDF from our system and their annual sales. Due to the fluctuation of Hydrogen cost as mentioned above, the sales are calculated as an average of a 20-year depreciation period.

Table 5.3 Total income

<table>
<thead>
<tr>
<th>Classification</th>
<th>Generation</th>
<th>Total income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (t/year)</td>
<td>315 t/year</td>
<td>1.34*</td>
</tr>
<tr>
<td>Heat (t/year)</td>
<td>17,900 t/year</td>
<td>0.11</td>
</tr>
<tr>
<td>Electricity (MWh/year)</td>
<td>8,592 MWh/year</td>
<td>2.82</td>
</tr>
<tr>
<td>Oil (l/year)</td>
<td>143,200 l/year</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>4.49</strong></td>
</tr>
</tbody>
</table>

*Average value of total income in a 20-year depreciation period.

5.4 Desirable economic effect

While expecting to be a base point of Hydrogen fuel supply, the families of conference participants are expected to visit together because of the existence of Ice Skating Rink in the campus. If the usage fee is priced at 11.7US$, it will be a fine stable income. In Fukuoka city, more than 200 international conferences with more than 50 participants are held annually. Therefore at least 10,000 participants are estimated to visit Fukuoka city every year. Furthermore having the system located in the famous resort destination Itoshima peninsula with attractive beaches, café etc. will definitely be an added feather to the cap.

This system is expected to promote family activities and to make a huge influence on the economy.
6. Environmental analysis

6.1 Energy saving and CO\textsubscript{2} reduction with CHHP system

The CHHP system generates heat, Hydrogen and electricity power by using biomass, which is normally left unused which is already discussed in chapter 1. Wood grows up by absorbing CO\textsubscript{2} and therefore we can call this bio mass fuel operated system as a “zero emission system”. The CHHP system contributes a great service to the environment because it is able to reduce fossil fuel consumption at present facilities. Unless the CHHP system is installed at the campus, alternative energy needs to be bought or produced using other resources to meet the requirements.

However, few resources such as water and electricity are acquired from outside to operate this system. Table 6.1 shows the required input energy for the system.

Wood is collected by fuel cell trucks as to avoid fossil fuel consumption in any means. Water is mainly used for the gasification plant. Electricity is used for the Hydrogen compressor to increase pressure up to 40MPa and for the operation of peripheral equipment.

<table>
<thead>
<tr>
<th>Energy Input</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woods</td>
<td>160 (t/day)</td>
</tr>
<tr>
<td>Water</td>
<td>224.4 (t/day)</td>
</tr>
<tr>
<td>Electricity (kWh/day)</td>
<td>3,900 (kWh/day)</td>
</tr>
</tbody>
</table>

Table 6.1 Energy input for system

<table>
<thead>
<tr>
<th>Energy Output</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>880 (kg/day)</td>
</tr>
<tr>
<td>Electricity</td>
<td>24,000 (kWh/day)</td>
</tr>
<tr>
<td>Heat for greenhouses</td>
<td>0.78 (MW)</td>
</tr>
<tr>
<td>Steam (250°C)</td>
<td>1.67MW</td>
</tr>
<tr>
<td>Bio Diesel Fuel</td>
<td>400(l/day)</td>
</tr>
</tbody>
</table>

Table 6.2 Energy output from system

In sections 6.1.1 and 6.2.2, the estimation is carried out to calculate the saved fuel and CO\textsubscript{2} emission by introducing the proposed CHHP system. The output from the CHHP system is shown in Table 6.2. All output energies from the system are compared to the fuel use from conventional energy sources. In addition, to quantify the total fuel saving, the fuel consumption and CO\textsubscript{2} emission by the CHHP system must be considered.

6.1.1 Fuel saving

In order to calculate the amount of the fuel saving, the following expression is used.

\[ F_s = (F_T + F_G + F_H + F_B) - F_{CHHP} \]

\( F_s \) stands for total fuel savings, \( F_T \), \( F_G \), \( F_H \) and \( F_B \) stand for fuel use from avoided on-site thermal production, purchased grid electricity, energy services provided by Hydrogen and gasoline usage of car, respectively. \( F_{CHHP} \) is the amount of fuel used by the CHHP system.

To calculate \( F_s \), the boiler with natural gas is replaced. \( F_G \) needs the grid loss of electricity and in Japan, the value stands at 5%. \( F_H \) is the heat quantity of gasoline which could be calculated with a hypothesis that all Hydrogen produced by CHHP is used for passenger vehicles. \( F_B \) is the fuel use from avoided bio diesel provided by CHHP. The resulted equation can be shown as follows as our proposed system does not use fuel.

\[ F_s = (80,995 + 30,856 + 84,530 + 4843) - 0 = 201,224 \ [\text{MMBtu/year}] \]

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>0 kWh/day</th>
<th>0.0 MMBtu/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woods</td>
<td>107.7 kWh/day</td>
<td>0.4</td>
</tr>
<tr>
<td>Electricity</td>
<td>3,900 kWh/day</td>
<td>13.3</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>4,895 MMBtu/year</td>
</tr>
</tbody>
</table>

Table 6.3 Fuel saving from CHHP system (\( F_{CHHP} \))
6.1.2 CO₂ emission saving

Similarly to fuel saving, CO₂ emission saving is calculated with the following expression.

\[ C_S = (C_T + C_G + C_H + C_B) - C_{CHHP} \]

\( C_S \) is the total amount of CO₂ savings. \( C_T, C_G, C_H \) and \( C_B \) stand for emissions from avoided on-site thermal production, purchased grid electricity, Hydrogen utilization and gasoline usage of car, respectively. \( C_{CHHP} \) is the total amount of CO₂ emission from the CHHP system.

In order to determine \( C_{CHHP} \), the calculation should be carried out for generated CO₂ emission by input water and electricity. The required electricity to purify a 1m³ of water is 0.48kWh. The required electricity for the system operation including CHHP plant and Hydrogen station is only generated by wind power and photovoltaic power in the University as mentioned in chapter 2. The amounts of CO₂ emission at electricity generation from photovoltaic power and wind power are 0.016 lb/MWh and 0.012 lb/MWh, respectively. Table 6.4 shows the amount of CO₂ emission at the generation of 1kWh of electricity. Table 6.5 shows the results of estimation using the figures in Table 6.4.

\( C_T \) is the exhausted CO₂ emission when natural gas corresponds to \( F_T \) is burned to generate the thermal energy. \( C_G \) is estimated by using Japan mix generation because the amount of CO₂ emission differs with the primary energy used for electricity generation. \( C_H \) is the amount of CO₂ emission which is exhausted when the gasoline corresponds to \( F_H \) is burned. The same could be considered for \( F_B \). In conclusion, the result is shown as follows.

\[ C_S = (4,330 + 3,670.4 + 6,540 + 374) - 11.5 = 14,903 \text{ [t/year]} \]

Table 6.4 CO₂ emissions by primary resources

<table>
<thead>
<tr>
<th>Electricity</th>
<th>CO₂ emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan mix generation</td>
<td>811.66 lb-CO₂/MWh</td>
</tr>
<tr>
<td>Photovoltaic generation</td>
<td>0.016 lb-CO₂/MWh</td>
</tr>
<tr>
<td>Wind power generation</td>
<td>0.012 lb-CO₂/MWh</td>
</tr>
</tbody>
</table>

Table 6.5 CO₂ exhaust from CHHP system (\( C_{CHHP} \))

<table>
<thead>
<tr>
<th>Woods</th>
<th>160 t/day</th>
<th>0 kg-CO₂/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>224.4 t/day</td>
<td>0.9 Photovoltaic generation</td>
</tr>
<tr>
<td>Electricity</td>
<td>3,900 kWh/day</td>
<td>31.2 Photovoltaic generation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32.1</td>
</tr>
<tr>
<td>Total (Max.)</td>
<td></td>
<td>11.5 t-CO₂/year</td>
</tr>
</tbody>
</table>

6.2 The beneficial use of potential timber

In Japan, the devastation of forests is continued due to wood at cheaper prices entering the market from foreign countries overcoming domestic products which has resulted ignorance in forest care (Fig. 6.1). The effective approach to prevent the devastation is forest thinning. Proper forest thinning provides a solution for over-crowded woods where the remaining woods would be able to grow up healthy. However, timber from forest thinning is small in size and is not worth to use as lumber. Due to this reason, a system for collecting the thinning has been constructed to make effective use of them as the biomass resource.

Fig. 6.2 shows the age distribution of trees in artificial forests. In fact, over twenty-year-old woods should be thinned out periodically because their growth decreases gradually. At present 75% of the total artificial forests are in need of this treatment. Digenesis by thinning is an effective solution against the devastation of forests.
There is another reason why forest thinning is selected as the biomass resource. Table 6.6 indicates the amount of CO₂ absorption by forests before and after thinning. Apparently, just after thinning takes place, the absorption of CO₂ would decrease, but within a term of 20 years, thinned forests absorb 1.3 times of CO₂ greater than the amount absorbed by un-thinned forests. Fukuoka city and Itoshima city have an area of 130.04km² of forest and 55% of it are artificial forests. In addition, the objective of thinning is an annual area of 2.86km², 4% of the total artificial forests.

At present the amount of CO₂ absorption at the thinned forests is 547,800t per 20 years. In case thinning is not conducted, the amount would decrease by 61,300t per 20 years. On the other hand, in case the thinning area is extended up to 5%, the amount would increase by 15,300t per 20 years. The annual CO₂ absorption would further rise by 760t, which corresponds to 5% of the results of CO₂ emission saving calculation at section 6.1.2.

If 4% of the artificial forest is thinned annually, the amount of CO₂ absorption will increase by 61,800t per 20 years compared to the case in which no thinning has implemented. It could be assumed that the value of 4% increases to 5% by our proposal. In that case, the amount of CO₂ absorption will increase by 77,400t per 20 years compared to the case of no-thinning. This explains that by expanding the ratio of thinning by 1%, the amount of absorption would increase by 15,600t per 20 years in the total considered area (Fig. 6.3). By implementing this strategy, an additional annual absorption of 760t, in other means, 5% of the total absorption of CO₂ at section 6.1.2 can be achieved from our proposal.

<table>
<thead>
<tr>
<th>CO₂ absorption</th>
<th>ton-CO₂/km²/20years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before thinning</td>
<td>6,860</td>
</tr>
<tr>
<td>After thinning</td>
<td>8,850</td>
</tr>
</tbody>
</table>

Table 6.6 CO₂ absorption

Fig. 6.3 Comparison of CO₂ absorption
7. **Marketing and Education Plan**

7.1 **Marketing plan**

7.1.1 **Potential of Fukuoka city**

Table 7.1 shows the data record on rankings or hosting an international convention. In 2010, Fukuoka prefecture hosted 216 international conventions. This ranks at 2nd place after Tokyo which stands at 1st place by hosting 492 international conventions. Table 7.2 displays the total number of foreign immigrants at each port in year 2010. Fukuoka ranks as the 3rd major city in Japan opening its gateways to the foreign world. 0.76 Million people travel to Fukuoka city by using either Fukuoka airport or Hakata port which numbers larger than the visitors using the Tokyo International airport.

Fukuoka airport and Hakata port are located closely to downtown Fukuoka. Visitors could arrive at Kyushu University within one hour by bus or subway from the airport or port. Someone using a vehicle could reach the university within a half an hour from the center of Fukuoka by using the recently upgraded city expressway. A large convention center is also located close to the Hakata port (Fig. 7.1).

Due to this reason various international conferences are held at the convention center or Kyushu University. For example, an opening ceremony and key lectures would take place at the convention center where the small workshops and seminars would take place at the university. The university possesses several conference halls and other required facilities (Fig. 7.2).

On the other hand, the university is located at Itoshima peninsula which is a popular resort destination in Fukuoka city. One can find sparkling beaches and relaxing cafes along the coastline and an annual open-air festival with a participation of more than 15,000 people is held here. Itoshima area is a place where someone can gain leisure and entertainment to suit their needs.

---

**Table 7.1 Number of international conferences**

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokyo</td>
<td>498</td>
<td>440</td>
<td>480</td>
<td>457</td>
<td>472</td>
</tr>
<tr>
<td>Osaka</td>
<td>134</td>
<td>134</td>
<td>134</td>
<td>134</td>
<td>134</td>
</tr>
<tr>
<td>Fukuoka</td>
<td>158</td>
<td>158</td>
<td>158</td>
<td>158</td>
<td>158</td>
</tr>
<tr>
<td>Nagoya</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Yokohama</td>
<td>109</td>
<td>109</td>
<td>109</td>
<td>109</td>
<td>109</td>
</tr>
</tbody>
</table>

**Table 7.2 Foreign immigrants at airports and ports**

<table>
<thead>
<tr>
<th>Airport / port name</th>
<th>Location</th>
<th>(Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narita airport</td>
<td>Chiba</td>
<td>4.2</td>
</tr>
<tr>
<td>Kansai airport</td>
<td>Osaka</td>
<td>1.75</td>
</tr>
<tr>
<td>Haneda airport</td>
<td>Tokyo</td>
<td>0.75</td>
</tr>
<tr>
<td>Osaka airport</td>
<td>Osaka</td>
<td>0.51</td>
</tr>
<tr>
<td>Hakata port</td>
<td>Fukuoka</td>
<td>0.28</td>
</tr>
<tr>
<td>Naha airport</td>
<td>Okinawa</td>
<td>0.14</td>
</tr>
<tr>
<td>Kumamoto port</td>
<td>Fukuoka / Yumaguchi</td>
<td>0.11</td>
</tr>
<tr>
<td>Fukuoka airport</td>
<td>Fukuoka</td>
<td>0.28</td>
</tr>
</tbody>
</table>
7.1.2 Target and marketing plan

It is considered that a massive influx of people could be created towards the Kyushu University by this proposal. The main target is not only the conference participants but also tourists who visit resorts in Itoshima peninsula. To encourage periodic utilization of campus facilities, two main ideas are proposed.

The first idea is about utilization of H₂ which is supplied from the CHHP plant. Public transportation is vital to meet the conditions of facilitation site. Expansion of bus lines is planned to provide a reliable mode of transportation for facility users. For sightseeing around the campus facility, FCV renting is available. FCV and FC buses are also used for mobile publicity campaigns as they are constantly driven around the campus.

The second idea is about utilization of Ice Skating Rink. It is assumed that people from different age periods and gender would use this facility. One example would be that children playing in the Ice Skating Rink also having an opportunity to join a CHHP plant tour with parents. Regular users are encouraged to use the facility frequently by providing an annual free pass.

7.2 Education plan

7.2.1 CHHP plant tour

School and social tour courses will be arranged to provide necessary education for visitors on the importance of CHHP plant system including visits to the plant itself and Ice Skating Rink. Students in Kyushu University play a main role in coordinating these tour courses. The tour route is decided according to the purpose and level of knowledge of the visitors on this field. Kyushu University students will be benefited by earning course credits for coordinating these field trips inside the campus. The students will also get an opportunity to enhance their knowledge on the CHHP plant and increase awareness on the environment by serving as tour guides. For kids this will definitely be one of the role models for their bright future. Children and parents would listen to the explanations and have a chance to use a part of the system. Children would provide their impressions towards the university student guides while parents advise the student guides with valuable feedback. This kind of process will help the university students to help their management skills by receiving inspirations and feedback simultaneously.

As the final objective, an environment friendly sustainable energy system will be established which will not only provide energy, but also help to accumulate and circulate knowledge and ideas.

7.2.2 Collecting waste oil project

At present there are several waste oil collecting projects carried out in our community area. Yet it stands below 60% of total waste. This should be promoted as waste oil is so easy to reuse as bio-diesel fuel. Waste oil retrieving project is conducted at elementary schools by asking its’ students to bring their home waste oil. This leads to improve conscience of saving and effective utilization for not only elementary school students but also their house members. If this action becomes a custom, students will be motivated to carry this out even after graduation.
biomass changes
APPENDIX

APPENDIX A

Fig. A.1 shows the CO shift reaction unit, a package product of Cosmo Engineering Co. This unit is a part of DFC1500 for conversion of CO into H₂ by shift reaction. The heat exchange calculation of this unit is shown in Table A.1.

![Fig. A.1 CO shift reaction unit](image)

Table A.1

<table>
<thead>
<tr>
<th></th>
<th>Inlet temp. [℃]</th>
<th>Outlet temp. [℃]</th>
<th>Mass flow rate [t/day]</th>
<th>Exchange heat [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEX4</td>
<td>Mixture gas</td>
<td>600</td>
<td>180</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td>15</td>
<td>500</td>
<td>69</td>
</tr>
<tr>
<td>HEX5～7</td>
<td>Mixture gas</td>
<td>260</td>
<td>40</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>15</td>
<td>85</td>
<td>200</td>
</tr>
</tbody>
</table>

Cooling tower of the cooling water circulation is used to cool down the exchanged heat as shown in Fig. A.2.

![Fig. A.2 Cooling tower](image)
Fig. A.3 displays several components of the PSA unit. This unit is installed in DFC1500.

The mixed gas will be compressed to 1MPaG before inserting into the CO₂ separating tank. CO₂ will be fluidified and separated inside this tank. The gas passed through the tank flows towards the Hydrogen separation film. The film distinguishes Hydrogen and let it pass through. After this process, the concentration of Hydrogen rises to 98%. This quantity of Hydrogen flows into PSA and is further purified up to 99.999%. PSA and Hydrogen separation film are manufactured by Iwatani Co. and Ube Kosan Co., respectively.

Fig. A.4 The model of Hydrogen separator film

Fig. A.5 Pressure Swing Adsorption (Manufacturer: Iwatani Co.)
Fig. B.1 Schematic of the Hydrogen station
Estimated respective amount of feedstock

\[ = A \times B \times \frac{\text{the area of Fukuoka city Nishi ward}}{\text{the area of Fukuoka city}} \]

A: The amount of each feedstock per unit area (t/m²) estimated by reference data of Itoshima city.
B: The planted area of each feedstock in Fukuoka city (Courtesy: City Office).
The utilization amount of Fukuoka city Nishi ward is provided according to the report of Itoshima city.
APPENDIX E

Fig. E.1 Material flow in CHHP system

Fig. E.2 Heat flow in CHHP system
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Greenhouse
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(45) Hydrogen pumps of Kaji Tec Co.
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(47) TOKICO: hydrogen dispenser
(48) JHFC demonstration experiment data

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(49) Age distribution of artificial forest

(50) Forestry Agency (paper)

(51) Ikko-sha PRO
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