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Current Situation and Future Scope of Biomass Gasification in Japan

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In this study, we investigated current situation of biomass gasification plants in 5 cities (c.a. Murayama City, Chichibu City, Ueno Village, Oshu City and Yamaguchi City) in Japan, and make R&D policy proposals to expand the biomass gasification plants. Four cities have commonly promoted the efficient heat utilization such as snow melting, drying the wood and supplying hot water into mushroom bed and hot spring. However, heat utilization is limited in a small area because heat loss is generated during the long-distance transportation. In order to obtain energy forms suitable for the long-distance transportation, such as hydrogen gas and electricity, the R&D of biomass gasification with hydrogen production or combined with Solid Oxide Fuel Cell (SOFC) should be promoted in the future.

Keywords: biomass gasification, CHP, hydrogen energy.

1. Introduction

Ever since the industrial revolution, humanity has consumed a huge amount of energy and thus global energy demand in 2040 is predicted to increase 37%

higher than the current level¹⁾. This massive energy consumption has caused various issues such as climate change, greenhouse gas emissions and the depletion problem of fossil fuels.²⁾ As a result, recently the interest in renewable energy is increasing, and in particular

Table 1: Biomass process technology options classification.⁴⁾

Conversion process	Final products	Advantages
Direct combustion	Steam Heat Electric energy	Most often-used conversion process
Biochemical	Bioethanol Biogas	Useful method for moisture content biomass
Agrochemical	Biodiesel	Simple production process
Gasification	Steam Heat Electric energy Fuel gas	High efficiency using combined-cycle gas turbine systems
Pyrolysis	Char-coal Fuel gas Bio-oil	Conversion to various types of fuels

biomass utilization has received broad attention due to its CO₂ neutral property. Currently, the percentage of biomass energy in world's total primary energy consumption is approximately 10%, and this will be increased especially in developing countries during the next 30 years³⁾.

Advantage of biomass utilization is that biomass resources can be used in various types of energy application, including electric and heat generation for industrial facilities and homes. Biomass conversion technologies to such useful energies can be separated into four process technologies: direct combustion process technology, biochemical process technology, agrochemical process technology and thermochemical process technology.⁴⁾ The final energy products and the advantages of these process technologies were listed in Table 1. Direct combustion technology is the main process to convert biomass resources into heat, mechanical power and electricity. This system is available in the size range from a few MW up to more than 100 MW⁵⁾. Biochemical processes, using fermentation, converts biomass into biological hydrogen gas and ethanol via acid/enzymatic hydrolysis. Biomass resources with high-moisture content, such as the herbaceous plant sugarcane, are more economically suited to biochemical process which is 'wet/aqueous' conversion⁶⁾. Agrochemical processes are the mechanical extraction method to produce bio-diesel energy form. For instance, bio-diesel is directly extracted by crushing seed crops containing a high percentage of oil^{7,8)}. Thermochemical processes are able to be subdivided into gasification and pyrolysis. Gasification converts biomass with a low moisture content (*e.g.* wood chips) into syngas products, such as hydrogen (H₂), carbon monoxide (CO) and methane (CH₄). The syngas is converted into both electricity and heat in gas engine. Biomass gasification has been developed commercially

owing to two main factors: a higher level of electricity and heat generation efficiency even in small-scale plant, and a lower level of exhaust emissions of major air pollutants. Pyrolysis is the thermochemical conversion process in absence of air to produce a bio-oil, a charcoal and a syngas.

In Japan, various types of research and development (R&D) related with biomass utilization has been performed owing to the oil crisis in the 1970s. In the trend of bioenergy utilization, the Japanese government has developed several strategies for biomass utilization in Japan. In June 2002, a committee was established to develop the strategies, and half a year later "Biomass Nippon Strategy⁹⁾" was developed by the cabinet. The goal of this strategy was to expand biomass utilization and develop the relating technologies. The strategy mentions the four reasons to promote biomass utilization: (1) creation of a regional employment, (2) activation of forestry, fishery, and agriculture industries, (3) reduction of greenhouse gas emission, and (4) fostering and promotion of venture companies.

The biomass utilization has been promoted by developing "Biomass Nippon Strategy", increasing R&D funds, and easing various regulations. However, a big barrier toward the expansion of biomass utilization is that the amount of practically available biomass resource is predicted to account for only 5% of total primary energy supply in Japan¹⁰⁾. Thus, the idea is needed for small-scale utilization suitable for scarce biomass resources. Biomass gasification has attracted the most attention because this process can be operated with high efficiency even in small-scale plant¹¹⁾. Biomass gasification seems to be suitable as a decentralized and small-scale region like Japan. In this study, we investigated current situation of biomass gasification plants (*e.g.* gasifier types and heat utilization), and make policy proposals to create the technological innovations

Table 2: Biomass gasification plant in Japan¹²⁾.

Company	Gasifier type	Location	Capacity [kW]
Takuma Co.,Ltd	Circulating fluidized bed	Misato City, Saitama	200
Kawasaki Heavy Industries, Ltd.	Fluid bed	Niyodogawa Town, Kochi	150
Burkhardt	Up-draft	Ueno Village, Gunma	165
JFE Engineering Corporation		Murayama City, Yamagata	2000
TSUKISHIMA KIKAI CO.,LTD.	Down-draft	Ishikawa City, Ishikawa	2000
		Chichibu City, Saitama	115
Yanmar Holdings Co., Ltd.	Down-draft	Senboku City, Akita	360
		Oshu City, Iwate	35
Chugai Ro Co., Ltd.	Rotary kiln	Koshu City, Yamanashi	35
		Aso City, Kumamoto	180
		Iwakuni City, Yamaguchi	180
		Yamaguchi City, Yamaguchi	176
		Sakai City, Osaka	15
		Takayama City, Gifu	50

and to expand the biomass gasification plants in Japan.

2. Biomass gasification plants in Japan

Table 2 lists biomass gasification plants in Japan¹²⁾. According to table 2, various types of gasifier has been introduced and the electric capacities in the gasification plants are in the range of 10 kW to 2000 kW. Here, we investigated current situation of biomass gasification plants in 5 cities (*c.a.* Murayama City, Chichibu City, Ueno Village, Oshu City and Yamaguchi City) in which different types of gasifiers, such as up-draft, down draft and rotary kiln types, has been introduced. We selected these 5 cities to examine the effect of gasifier types on the operational situation and heat utilization in each cities. Furthermore, we discussed keys toward successful operation of biomass gasification.

2.1. Murayama City, Yamagata

The gasifier used in Murayama city is up-draft type (see Fig. 1) having a higher efficiency. In this gasifier, the biomass fuel falls from the top zone of the reactor, and the oxygen or air is inserted into the bottom zone. The fuel slowly comes down by gravity and passes sequentially through drying (moisture evaporation), pyrolysis (release of a solid char residual and volatiles such as gases and aromatic compounds), reduction and oxidation zones (heterogeneous reactions of char with O₂, CO₂, H₂O). Simultaneously, the generated volatiles is carried upward along with the up flow of heated gas products. Ashes as the solid remains are removed at the bottom of the gasifier. The tars with aromatic compounds in the volatiles come out from the reactor along with the gas products. The up-draft gasifier generates high tar content, which accounts for up to 20% of the pyrolysis products, and thus requires substantial clean-up to remove this tar. The updraft gasifier can handle fuels in the particle size range of 5 – 100 mm and containing much amount of moisture; thus, it is suitable for a wide variety of fuel sizes and moisture content. In contrast to the downdraft gasifier, there is no upper limitation with respect to the size. There are two main advantages of updraft gasifiers: the high thermal efficiency and simple construction.

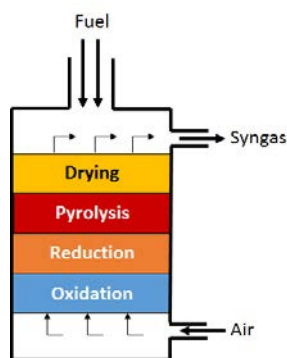


Fig. 1: Up-draft type gasifier

The capacity of the gasification plant in Murayama city is 2000 kW, which is larger scale compared to the other types of plants as shown in Table 1. This plant supplies electricity and heat to 11 communal facilities such as hospital, school and so on. In Yamagata there is much amount of biomass resource (130,000 Tone)¹³⁾ and especially fruit trees such as cherry, apple, pear accounts (39,000 Tone)¹³⁾, thus the gasification plant is available for input of 60 t/day. This gasification plant has been operated by Yamagata Green Power Corporation and financed from local farming community. Although the disadvantage of up-draft gasifier is high content of tar in the syngas, the generated tar is effectively used as heavy oil. In Murayama city, there is a lot of snow in winter. In the future, heat generated from biomass gasification is expected to be utilized for snow melting¹⁴⁾.

2.2. Chichibu City, Saitama

Chichibu city has used the down-draft type gasification plant (see Fig. 2) available for input of 1.5 t/day¹⁵⁾, which was smaller than that of Murayama city. Chichibu city installed the down-draft type due to its feature of a very small tar generation.

The down-draft type gasifier was originally developed to gasify high volatile fuels. The fuel is carried out into the top zone of the reactor and the gases flow concurrently with descending packed bed of solids. In the middle section of oxidation zone, the oxygen or air/steam is inserted. The volatile products are intimately mixed with char solids in the turbulent high-temperature oxidation region around throat, and thus the tar cracking occur mostly in this high-temperature region. In the bottom, there is a system to recover the solid product, such as the ash and char. The feature of fixed bed down-draft type gasification is reliable process due to a high conversion of the pyrolysis tars and hence producing relatively clean gases. This configuration is favored for fuels containing more than 25 wt% moisture and a low proportion of coarse and fine particles, preferably particle size range of 10 – 300 mm. This gasification is generally suitable for small-scale electricity generation, owing to the low content of tars. Because the particle size and throat diameter is limited physically, the maximum capacity of this configuration is approximately 500 KW_e.

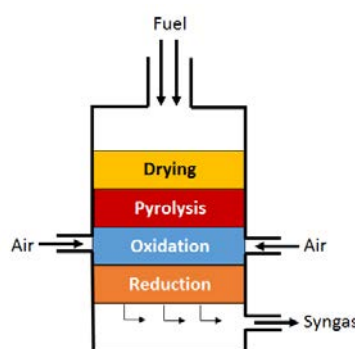


Fig. 2: Down-draft type gasifier

The biomass gasification plant was operated by Chichibu city government and the generated electricity was supplied to the destination such as hotel, leisure facility, and so on. However, this plant was stopped in 2015 due to the fire disaster, and the resumption of operation is not planned¹⁵.

2.3. Ueno Village, Gunma

Ueno Kinoko Center Corporation produces 500 tons/year of Chinese Mushroom, and creates an estimated 60 jobs¹⁶. For Chinese Mushroom production, the room temperature in the facility was needed to be maintained at 20 °C, and thus the heating and cooling system operated by electricity supplied large amount of heat to adjust the room temperature. However, electricity prices has been increased since the Great East Japan Earthquake of March 11 in 2011. As a result, biomass gasification plant with combined heat and power (CHP) manufactured by Burkhardt Company in Germany was introduced into this village. This gasifier is up-draft type with 165 kW.

Heat has been mainly utilized for mushroom bed and air-conditioning equipment. Before the introduction of the biomass gasification plant, a hot-water boiler using a waste mushroom as a fuel (350 kW) and an electrical heating and cooling system (cooling capacity: 1,210 kW, and heating capacity: 1,540 kW) had been utilized for heat supply¹⁶. After the introduction of biomass gasification with CHP supplying hot water, the operating rate of the electrical heating and cooling system has been cut leading to the reduction of electrical utilization.

2.4. Yamaguchi City, Yamaguchi

Yamaguchi city installed rotary kiln gasifier (as illustrated in Fig. 3) to produce high quality of gases. Rotary kilns contain a slowly rotating cylindrical chamber. The contact between gases and solid occurs owing to the rotation of the drum. The heat and matter are not very effectively exchanged between the solid and the gases, and thus the longer reaction time is required compared with the other gasification technologies. The contact between solid and gases contact might be improved by introducing several barriers inside the drum, which handles the solid material more effectively and increases the contact area with the gas phase. The most general type is countercurrent type, where biomass fuel is inserted into the top of the reactor and the oxidizing agent into the bottom side. The main advantage of rotary kiln gasifier is providing gas of sufficiently high quality.

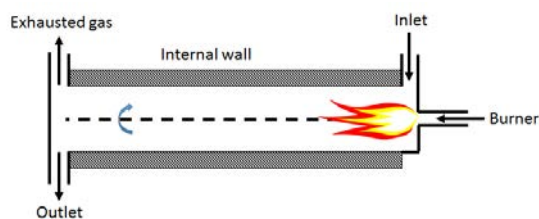


Fig. 3: Rotary kiln type gasifier

Biomass rotary kiln gasification plant (25 – 100kW) is set in sawmill, and was built by Chugai Ro Corporation for the first time in Japan. Not only timbers from forest thinning such as Japanese cedar, cypress and bamboo but also residue generated in the sawmill are chipped and used as a biomass fuel. 5.0 tons / day has been supplied into the gasifier (rotary kiln), and the generated syngas has been converted into electricity (180 kWh) and heat in gas engine¹⁷. Heat has been used to dry the wood in sawmill.

2.5. Oshu City, Iwate

In order to promote the regional activation in Oshu city in Iwate, biomass gasification plant with CHP was built in March, 2010. The gasifier is small-scale down-draft type (35 kW) with the low production of tar¹⁸. Heat and power generated with CHP are effectively utilized in facility of Kurotaki Hot Springs. The introduction of the gasification plant reduces the cost of electric power by 50% and of heating oil by 30%.

Although in Chichibu city the biomass gasification plant has already been stopped, the gasification plants in Murayama city, Ueno village, Yamaguchi city and Oshu city were successfully operated. These four cities have commonly promoted the effective heat utilization such as snow melting, drying the wood and supplying hot water into mushroom bed and hot spring. In order to expand biomass gasification all over Japan, not only heat utilization for local area but other utilization should be considered.

3. Future prospect of biomass gasification in Japan

As described previously, heat utilization improves the total efficiency and leads to the successful operation. However, heat loss is generated during the long-distance transportation, and thus heat utilization is limited to the surrounding area. In order to overcome this problem and expand biomass gasification in Japan, it is argued that two technologies, biomass gasification with hydrogen production and SOFC will be crucial in the future. In the following section, we examine the current situation on these technologies.

3.1. Biomass gasification for hydrogen society

The “hydrogen economy” has been paid attention due to sustainable, stockable and transportable properties. Japanese government aims to establish the hydrogen infrastructure in Tokyo by 2020. Biomass resource is expected to be utilized as one of the most important sources producing hydrogen gas. In Toshu city in Fukuoka, biomass gasification plant for producing hydrogen gas has been operated since 2011, and has handled biomass feedstocks of 847 kg/day¹⁹.

The hydrogen gas obtained by biomass gasification is relatively expensive compared with natural gas steam

reforming. In renewable energy, on the other hand, biomass gasification is the most cost-effective process producing hydrogen gas.

Hydrogen gas can be produced combining the gasifier and steam reforming process as shown in Fig. 4. One of the big problems in biomass gasification producing hydrogen gas is the generation of tar formed during the process. The tar may cause deactivation of Ni catalyst used in steam reforming. The operation conditions, such as temperature, reaction time and percentage of gasifying agent should be optimized to reduce the tar formation²⁰. Therefore, further research is needed to overcome the problem of tar formation.

Additionally, we must overcome a lot of social and economic problems, such as a lack of international visibility, a small market, a hydrogen gas utilization regulation, and so on.²¹

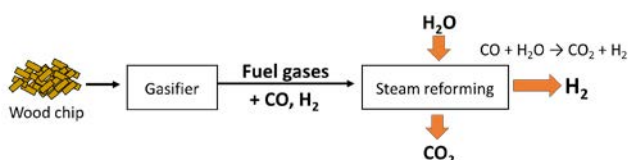


Fig. 4: Biomass gasification process for producing hydrogen gas.

3.2. Biomass gasification with solid oxide fuel cell

The gas engine cannot achieve high electrical efficiency in small-scale gasifier systems. In order to increase the electricity output from the gasification process, the gas engine should be replaced with a Solid Oxide Fuel Cell (SOFC) as shown in Fig. 5. However, this replacement means that the gasifiers must reduce the tar formation and provide gas of sufficiently high quality because tar impurities cause the clogging in SOFC system²². CO as well as H₂ generated from the gasifier can be directly converted to the electricity output in a SOFC if the tar impurities in the gas is sufficiently reduced. Therefore, further R&D is needed to develop the gasifier providing gas of sufficiently high quality.

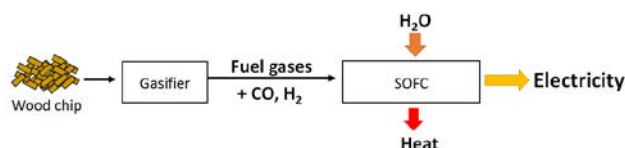


Fig. 5: Biomass gasification process with SOFC system.

In order to optimize the operation parameters, such as temperature, gasifying agent and residence time and in the gasifier, a better understanding the tar formation at molecular level is crucially important. Thus, further research should address a computational approach based on a detailed chemical kinetic model (DCKM), which can elucidate the tar formation mechanism and predict gas quality at molecular level.²³⁻²⁵ However, the DCKM is not sufficient to describe full phenomena caused by

biomass gasification because of the lack of a kinetic database on the thermal decomposition processes of several heavy aromatic compounds. In order to improve the DCKM, future computational work should estimate these kinetic parameters based on *ab-initio* calculation and transition state theory.²⁶ In addition, Japanese government needs to boost the R&D funding relating to the computational research.

In terms of economical viewpoints, we must consider strategies of expanding biomass utilization without feed-in tariff (FIT), which have been proven to make electric power companies purchase electricity from renewable energies at a price of 40 yen/kWh.²⁷ In 2005 the installed electrical capacity for biomass power generation was 2.2 GW.²⁸ After the introduction of FIT in 2012, the capacity has been increased and will probably reach to 3.33 GW by 2020.²⁸ In order to expand biomass utilization even after the termination of FIT, the cost of hydrogen storage systems and fuel cells should be reduced through the R&D.

4. Conclusion

In conclusion, we investigated current situation of biomass gasification plants in 5 cities (c.a. Murayama City, Chichibu City, Ueno Village, Oshu City and Yamaguchi City). Although in Chichibu city the biomass gasification plant has already been stopped, the gasification plants with CHP in Murayama city, Ueno village, Yamaguchi city and Oshu city were successfully operated. These four cities have commonly promoted the efficient heat utilization such as snow melting, drying the wood and supplying hot water into mushroom bed and hot spring. However, heat loss is generated during the transportation, thus heat utilization is limited to the surrounding area. In order to obtain energy forms suitable for the long-distance transportation such as hydrogen gas and electricity, biomass gasification with hydrogen production or SOFC should be promoted in the future. Improving the gas quality is an important step towards the commercialization of these two technologies.

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