Biomass Syngas Production Technology by Gasification for Liquid Fuel and Other Chemicals

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Mitsubishi Heavy Industries, Ltd. (MHI) has been working to develop a variety of commercially viable technologies to support biomass energy. This report describes technology for the thermochemical gasification of biomass to obtain gas, i.e., syngas, which can be used to produce other chemicals such as methanol and urea (fertilizer). The technology is applicable to a wide variety of biomass feedstock, including inedible lignocellulose and waste, and can be used for large-scale production. It should help to reduce greenhouse gas emissions and to establish a secure liquid fuel source for Japan, which currently relies on imported materials.

1. Introduction

Biomass is a renewable energy source. Western countries and others have been developing technologies to use biomass and promote its practical applications. Japan has also been working on ways to reduce greenhouse gas emissions and establish secure energy sources. Through 2001 to 2004, Mitsubishi Heavy Industries, Ltd. (MHI) demonstrated once-through operation of woody biomass gasification to methanol synthesis process with a daily biomass throughput of 2 tons. [1] MHI is continuously promoting the development of practically applicable gasification technologies, adaptability to various kinds of biomass such as agricultural waste biomass and woody biomass, gas-purifying techniques for minimizing tar, and the reduction of power consumption.

To hasten practical application of biomass gasification, we propose the integration of biomass gasification/gas-purification process with existing large capacity chemical synthesis plants such as methanol or urea (fertilizer) synthesis. This would allow the effective production of liquid fuel and other chemical products.

2. Technology for the Use of Biomass

Table 1 shows a list of technologies for biomass utilization.

Table 1 List of technologies for biomass utilization

Principle	Thermochemical conversion		Bioconversion		Direct combustion
System	Gasification Chemical synthesis	Carbonization system	Fermentation Ethanol production	Fermentation Methane production	Existing thermal plants Exclusive- and co-firing
Raw material	Woody or herbaceous biomass	Wood waste Sewage sludge Others	Cereals (grains) Cellulose	Garbage Sewage sludge Others	Any vegetation
Product	Methanol, DME*, urea	Pyrolysis coke	Ethanol	Methane	Electricity Steam
Energy conversion efficiency	High (liquid fuel and other chemical products)	High (solid and gas fuels)	Low–medium (liquid fuel)	Low–medium (gas fuel)	High (electricity)
Large-scale deployment	Applicable	Possible	Not applicable	Not applicable	Applicable
Technical development	Demonstration level	Practical level	Practical level (Demonstration level for cellulose)	Practical level	Practical level

* DME (dimethyl ether)

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To spread biomass energy applications, MHI is promoting the development of various technologies in accordance with the needs of end users.

The process of biomass gasification involves generating a high-temperature zone (800–1,200°C) by burning part of the raw material and using oxygen and steam as gasifying agents. The heat produced converts biomass into syngas, which is primarily comprised of H_2 and CO. The syngas is then used to synthesize liquid fuel and other chemicals.

The advantages of our technology include the possible use of both woody and herbaceous raw materials such as forest residue, inedible crop parts, and wood waste. A large-scale plant can be established in a small space due to the high yield of heat energy and an increased reaction rate.

3. Biomass Gasification Technology to Obtain Syngas for the Production of Liquid Fuels and Other Chemicals

MHI successfully performed once-through operation of woody biomass gasification to methanol synthesis process at our demonstration plant with a throughput of 2 tons per day. This was conducted as part of a project with Chubu Electric Power Co., Inc. and the National Institute of Advanced Industrial Science and Technology from 2001–2004 and was commissioned by the New Energy and Industrial Technology Development Organization (NEDO). Since this project, MHI has continued to participate in NEDO-commissioned projects and joint research projects to develop component technologies for highly efficient conversion of biomass and other energy sources. This report describes the utilization of agricultural biomass waste and the gas-purifying technique, which are adaptable to existing catalytic chemical synthesis processes.

3.1 Gasification of agricultural biomass waste in an entrained-flow gasifier

(1) Characteristics of our entrained-flow gasifier

The entrained-flow gasifier developed by MHI can quickly gasify pulverized biomass, allowing the gasifiers to be compact, yet capable of treating large amounts of biomass. Because no bed materials are needed, the gasifier has no upper gasification temperature limit to prevent the melting of bed materials, so the gasification process can take place at high temperatures. In a fluidized bed type gasifier, the gasification temperature must be maintained at or below 850°C, while MHI's gasifier allows gasification to occur at or above 1,000°C. As a result, less tar is produced, making tar treatment at the end of flow easier. Our gasifier also provides advantages associated with fluidized bed type gasifiers. As shown in **Figure 1**, the cross-sectional area at the lower part is smaller than the area at the upper part of the gasifier.

This design results in a high gas velocity zone at the lower part of the gasifier, preventing large particles from falling to the bottom while allowing only small particles to move upward along the gas flow due to the low gas velocity at the upper zone. Despite the broad particle size distribution of the pulverized biomass, unreacted large particles and raw materials that require relatively long reaction times are kept inside the gasifier until the reaction is completed, thus achieving high carbon conversion efficiency.

(2) Gasification of agricultural biomass waste

Palm residue (an unused agricultural waste) can be used as a large volume and stable biomass raw material supply. If palm residue can be gasified, the commercial use of biomass energy is expected to become more common. We examined the applicability of palm residue to MHI's entrained-flow gasifiers. The basic gasification characteristics were obtained by measuring the gasification reaction rate of char (a product of pyrolysis of raw materials). The gasification performance in the entrained-flow gasifier was assessed using a gasification test facility with a throughput of 240 kilograms per day. Two types of palm residue were used: empty fruit bunches (EFB), which are fibrous, and palm kernel shells (PKS) consisting of a rigid core and fine fibrous particles. The char reaction rate indicates that EFB reacted almost as quickly as Japanese Cedar, but that of PKS was slower.

Figure 2 shows the results of gasification tests conducted on EFB and PKS using a facility with a throughput of 240 kilograms per day. The carbon conversion efficiency of EFB was approximately 98% and that of PKS was 94%; both showed excellent results. The results demonstrate that the advantages of MHI's entrained-flow gasifier enabled even PKS particles, which have a slow reaction rate, to be kept inside the gasifier until the reaction was complete, thereby achieving high carbon conversion efficiency.

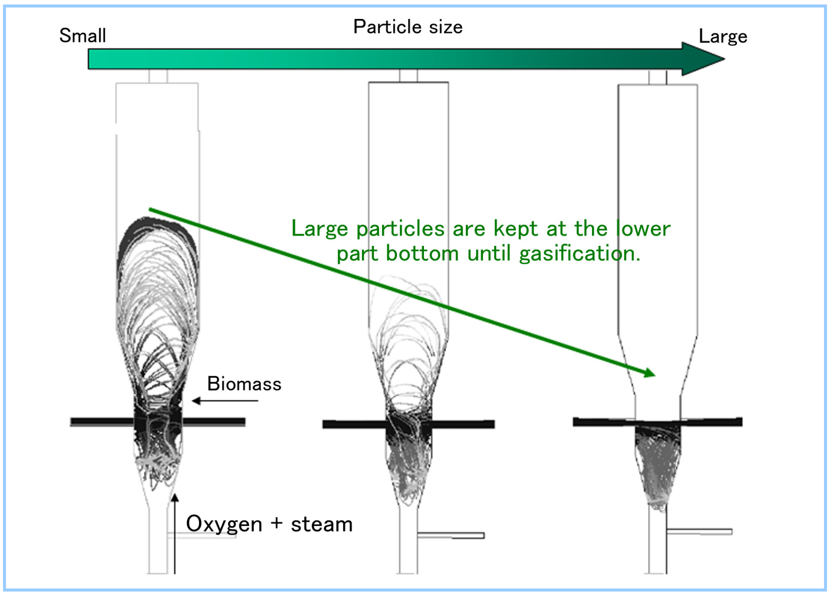

Figure 1 Trajectories of biomass particles inside a gasifier
Gradual change in the shape of the gasifier enables biomass particles with a wide range of sizes to be circulated inside the gasifier without falling or being blown away because of the relationship between gas flow rate and terminal velocity of the particles. Particles can remain inside as long as required for gasification.

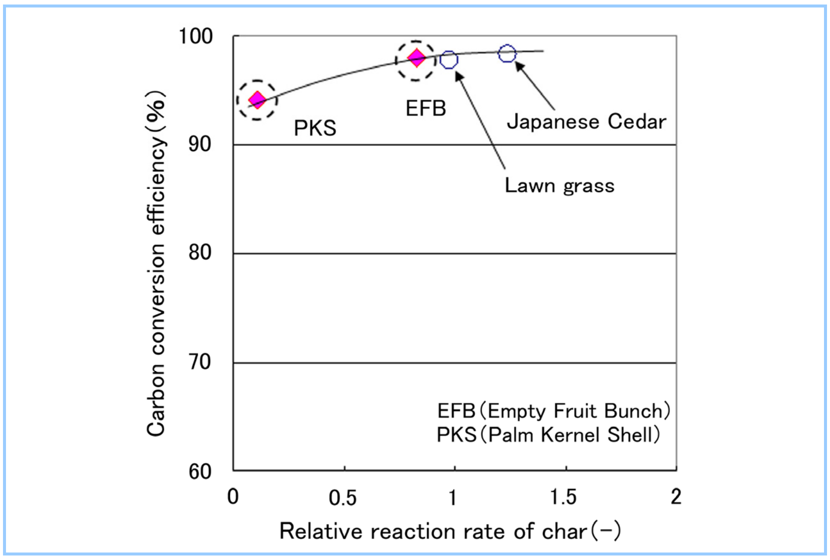

Figure 2 Relationship between carbon conversion efficiency and char reaction rate
With the gasifier design shown in Figure 1, PKS (palm residues) can achieve a carbon conversion efficiency of approximately 94%, despite its low gasification rate.

3.2 Technology for purifying syngas

As shown in **Figure 3**, the syngas obtained through biomass gasification can be used to synthesize various kinds of liquid fuels and chemicals by connection with existing chemical processes. Methanol, a chemical that can be produced from syngas, is a very versatile material. It is essential to C1 chemistry and is used as a starting material for various synthetic processes. It is also vital to methanol fuel cells, which are becoming a practical technology, as well as esterification in the synthesis of biodiesel fuels BDF, which have already been introduced in Europe.

Sophisticated purifying techniques are needed[2] for the catalytic synthesis process of methanol and other chemicals to protect the catalyst from poisoning due to the presence of hydrogen sulfide or aromatic hydrocarbons.

MHI has developed a gas-purifying system to remove these catalyst-poisoning substances. As illustrated in **Figure 4**, the syngas will be roughly purified using carbonaceous adsorbents in a multicomponent adsorption tower before undergoing an advanced purifying process in which hydrogen sulfide is removed by adsorbents and aromatic hydrocarbons are decomposed by catalysts.

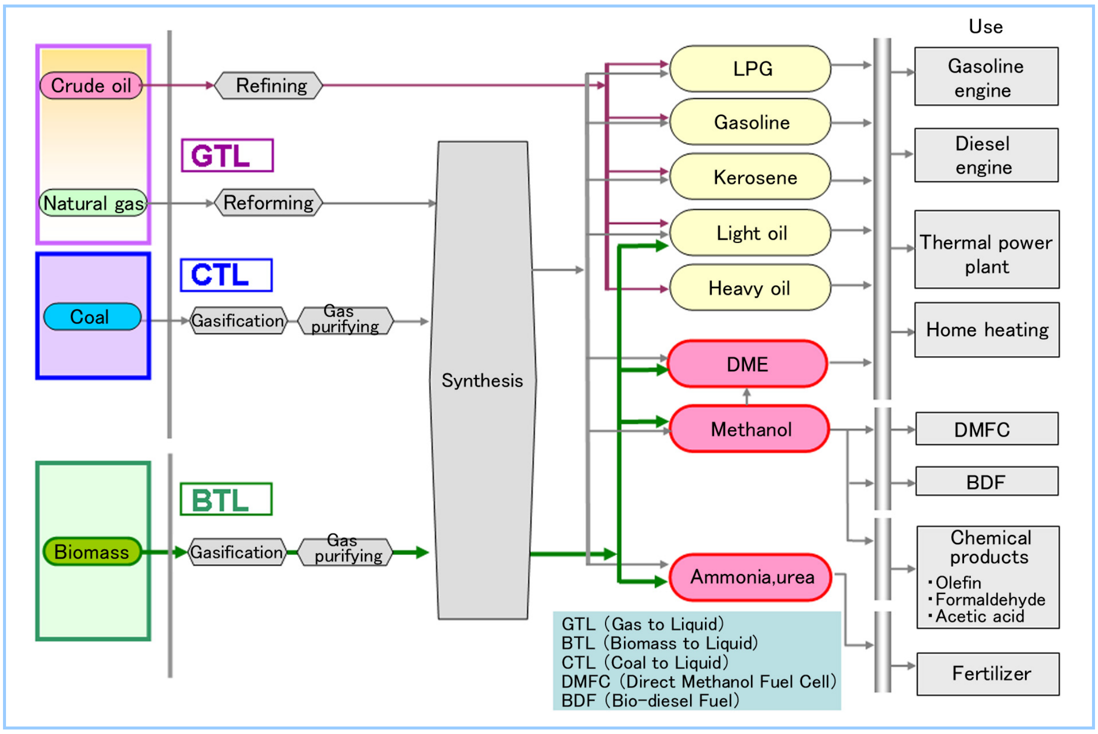

Figure 3　Liquid fuel and chemical synthesis processes using syngas
Syngas is used to synthesize chemicals that are used in various fields.

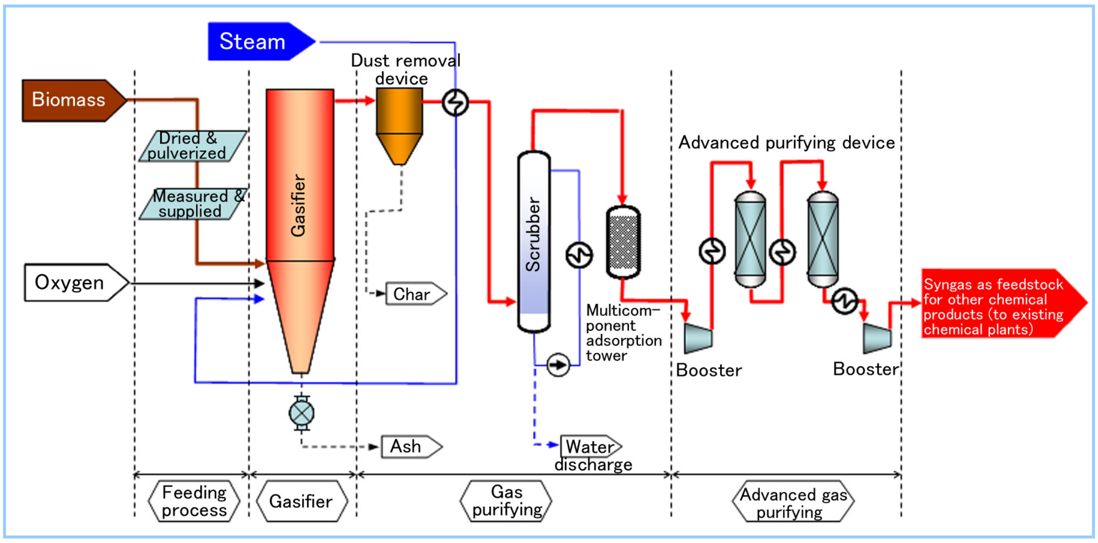

Figure 4　Diagram of the biomass gasification and syngas purifying system.
A diagram of the system used to carry out a series of processes from biomass gasification to gas purifying before supplying the refined syngas to existing chemical plants.

In this system, polycyclic aromatic hydrocarbons and monocyclic aromatic hydrocarbons, both of which are known to poison synthetic catalysts, are removed completely. The removal rate of each catalyst poison via the gas-purifying process is shown in **Figure 5**.

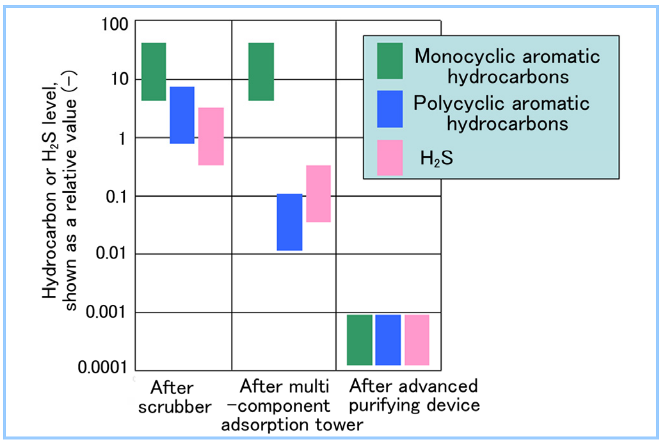

Figure 5　Multicomponent gas-purifying system
Aromatic hydrocarbons and H2S are roughly removed in the multi-component adsorption tower. More thorough removal is performed using the advanced purifying device.

For the multicomponent adsorption tower of carbonaceous adsorbents, MHI has developed an adsorption technique in which biomass char (a byproduct of biomass gasification) is effectively used to reduce the cost of commercial activated charcoal. The effectiveness of the multicomponent adsorption tower for the preliminary removal of H_2S and aromatic hydrocarbons was confirmed.

4. Integration with Existing Chemical Plants

We propose integrating our biomass gasification and syngas purifying plant with methanol or fertilizer synthesis plants where natural gas is used as feedstock. Natural gas (methane) used for synthesis can be partially replaced by syngas (**Figure 6**).

The integration of existing chemical synthesis facilities offers notable advantages over independent systems that require all the processes necessary to produce chemicals from biomass, including the distribution and usage of the chemical products. By the combination of gasification/purification technologies with MHI's expertise in chemical plants, the practical and widespread use of biomass can be expected.

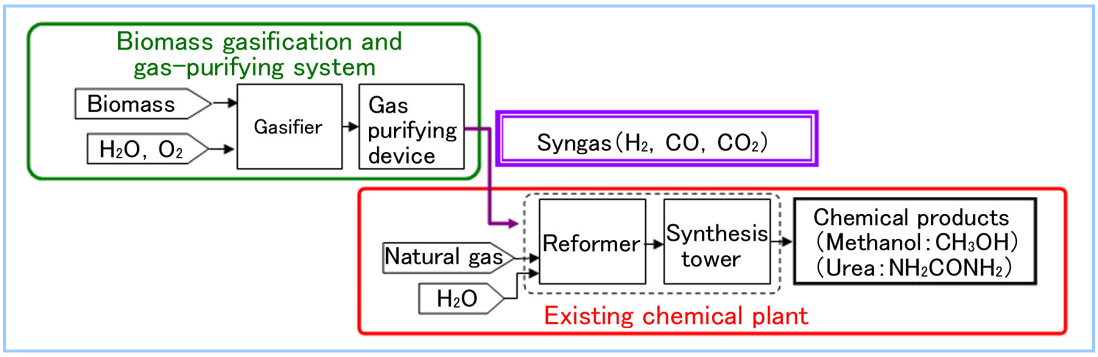

Figure 6 Example of biomass gasification and the gas-purifying system combined with an existing chemical plant
Natural gas, which is used to produce chemical products at existing plants, can be partially replaced by syngas comprised of H_2, CO, and CO_2

5. Conclusions

This report introduced the technologies developed by MHI for biomass gasification and subsequent syngas purifying, making syngas available as feedstock for other chemical products such as methanol. The practical and widespread use of our technology will enable carbon-neutral biomass to be used as an alternative to fossil fuels and therefore help reduce greenhouse gas emissions and improve energy security in Japan. The introduction of our technology to developing countries will also help reduce greenhouse gas emissions worldwide.

Securing a stable supply of biomass is an obstacle to implementing this technology and has brought us to a virtual standstill. However, rapid developments in Western countries cannot be ignored. Considering the revitalization of Japanese agriculture and forestry, our responsibility lies in the steady development of technology. We plan to continue to contribute to our country's development by promoting practical applications in close coordination with the concerned Japanese government agencies.

References

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