

## Case Report

# An Analysis of the Current Status of Woody Biomass Gasification Power Generation in Japan

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**Abstract:** Forests cover two-thirds of Japan's land area, and woody biomass is attracting attention as one of the most promising renewable energy sources in the country. The Feed-in Tariff (FIT) Act came into effect in 2012, and since then, woody biomass power generation has spread rapidly. Gasification power generation, which can generate electricity on a relatively small scale, has attracted a lot of attention. However, the technical issues of this technology remain poorly defined. This paper aims to clarify the problems of woody biomass gasification power generation in Japan, specifically on the challenges of improving energy utilization rate, the problem of controlling the moisture content, and the different performance of power generation facilities that uses different tree species. We also describe the technological development of a 2 MW updraft reactor for gasification and bio-oil coproduction to improve the energy utilization rate. The lower heating value of bio-oil, which was obtained in the experiment, was found to be about 70% of A-fuel oil. Among the results, the importance of controlling the moisture content of wood chips is identified from the measurement evaluation of a 0.36 MW-scale downdraft gasifier's actual operation. We discuss the effects of tree species variation and ash on gasification power generation based on the results of pyrolysis analysis, industry analysis for each tree species. These results indicate the necessity of building a system specifically suited to Japan's climate and forestry industry to allow woody biomass gasification power generation to become widespread in Japan.

**Keywords:** gasification; Japanese technology development; woody biomass

## 1. Introduction

### 1.1. The Current State of Japanese Woody Biomass

In recent years, concerns have grown about the increase in energy consumption and air pollution and the depletion of natural resources that have resulted from the ballooning global population and its use of fossil fuels. In Japan, woody biomass, which is in abundant supply, has been attracting attention regarding its use in power generation projects. By using otherwise unutilized wood materials as fuel, woody biomass power generation has been positioned as a carbon-neutral method for power generation. The enforcement of the Feed-in Tariff (FIT) Act in 2012 led to the start of the operation or planning of numerous woody biomass power generation projects in Japan. Woody biomass is a renewable energy that is characterized by being produced and consumed locally, so it is expected to have a stimulatory effect on the local economy [1]. In reality, however, the self-sufficiency rate of wood materials in Japan is only about 20%, which is caused by such factors as the difficulty in transportation, since many of the forests in the country are found on steep hills. Therefore, it is hard to say that domestic woody biomass resources are being utilized effectively [2]. Furthermore, a growing number

of plans to build large-scale power generation projects rely on imported fuel, ignoring the ability of the regions in the country to supply woody biomass [3].

The number of small-scale power generation projects that were rolled out increased in 2015, as a result of the hike in the selling price of electricity under 2 MW, whose use of woody biomass fuel derived from sustainable wood can cost anywhere from 32 yen/kWh to 40 yen/kWh. Small-scale woody biomass gasification power generation and combined heat and power (CHP) have garnered great attention because, even after the end of the buying period through FIT, if all the heat from a 0.165 MW gasification CHP unit is sold, it would still be possible to obtain about the same profit as that which is gained during the FIT period [4], and there are cases where this kind of project has led to the revitalization of local communities [5]. The results of modeling analysis by Sérgio et al. [6] show that the quality of gas produced via gasification of brewers' spent grain was sufficient for use in energy production. From the results, it can be confirmed that power generation efficiency can be improved by gasification. In addition, according to a study by Famoso et al., gasification of citrus peel (178,971 tons) can generate 66.7–74.6 GWh of electricity, and it shows the effectiveness of agro-industrial residues [7]. Their paper argues that renewability analysis based on exergy data is needed. While a growing number of small-scale gasification units from overseas are being rolled out in Japan, their performance does not match that of their overseas counterparts because of tar and clinker generation. Efforts to elucidate the causes have been lacking [8].

Research on gasification for power generation in foreign countries has encountered numerous challenges, such as regarding the improvement of wastewater treatment resulting from gasification by Gabriele et al. [9]. On the other hand, many research studies on gasification power generation in Japan focus on moisture content ratios and improving the efficiency of exhaust heat recovery [10]. Endo et al. showed that the moisture content ratio must be under 15% as a result of changing the moisture content ratio of raw materials for downdraft-type gasifier and measuring the temperature inside the gasifier and the tar concentration of the gas [11]. In addition, research studies on the pyrolysis characteristics of woody biomass fuel include those that focus on the components of wood materials [12] and those comparing wood materials with gramineous plants [13]. Other research studies, such as those by Yamazaki et al. [14] and Sasauchi et al. [15], suggest the possibility that Japanese woody biomass fuel is not appropriate for use in gasification units from Europe, but they did not identify the relevant technical problems. As an attempt to contribute to the current limited literature availability, in this report, we will summarize the diffusion state of woody biomass power generation and the technical problems related to gasification power generation in Japan. Particularly, our focus is on the results of technological development projects and empirical research conducted by us for this review.

### 1.2. The Creation of Japanese Woody Biomass Power Generation Projects Database and Trend Analysis

A database of examples of Japanese woody biomass power generation projects was created, and I present the trends in power generation projects by scale. In particular, we consolidated data by focusing on the power generation methods of small- to medium-scale power generation projects and attempted to understand their trends. The database contains overviews of 236 woody biomass power generation projects that were announced from 1 January 2003, to 31 May 2020. We studied the effect of the enforcement of the FIT Act in 2012 and the impact of the changes in the FIT electricity sales price in 2015. In addition, we added details of the scales of woody biomass power generation projects under 2 MW, as well as information regarding their types, and analyzed their trends.

The collected cases were organized into seven classifications by the scale of power generation: <1 MW, <2 MW, <5 MW, <10 MW, <50 MW, <75 MW, and  $\geq 75$  MW. Categorizing by scale and type, the mainstream systems are gasification for <2 MW, wood combustion for <10 MW, palm kernel shell (PKS) combustion for <75 MW, and co-combustion of wood and coal for  $\geq 75$  MW.

Figure 1 shows changes in the number of woody biomass power generation projects according to power generation scale. Here, the assumption is that planning and building require two years. From this figure, it can be confirmed that the number of woody biomass power generation projects has

been increasing significantly since 2014, two years after FIT enforcement. Amidst the construction of over 20 projects annually, the trend in the power generation scale has changed drastically. We attempted to capture the trend of woody biomass power generation projects by comparing the ratio of power generation scale for each period: before FIT enforcement (2003–2013), after FIT enforcement (2014–2016), the change in FIT sales price (2017–2021), and after (2020–2022) (Figure 2). After FIT enforcement, the number of wood combustion projects with a capacity below 10 MW was at the highest level in 32 cases. After the change in the FIT sales price, gasification power generation projects under 2 MW exceeded 40%. Gasification power generation, which is effective even at a small scale, drew attention because of electricity's high sales price and the decrease in the supply of local materials due to the rise in large-scale woody biomass power generation projects. However, only one small-scale 1 MW project is being planned for construction in or after 2020, and more plans are being drawn up for the construction of large-scale power plants with a capacity of 50 KW and above fueled by imported PKS.

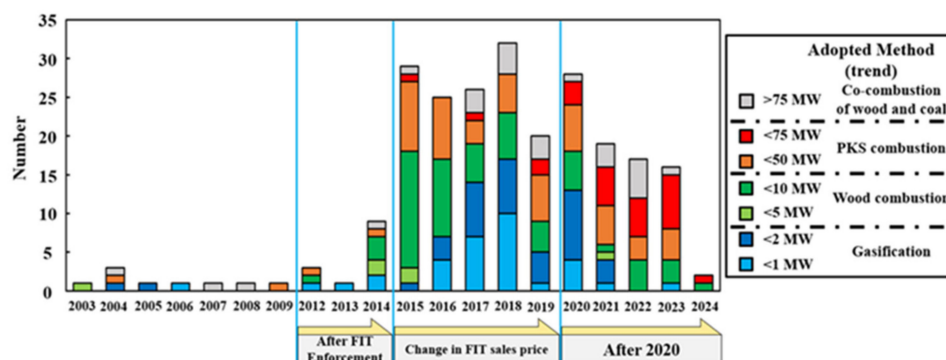


Figure 1. Number of woody biomass power generation projects by scale.

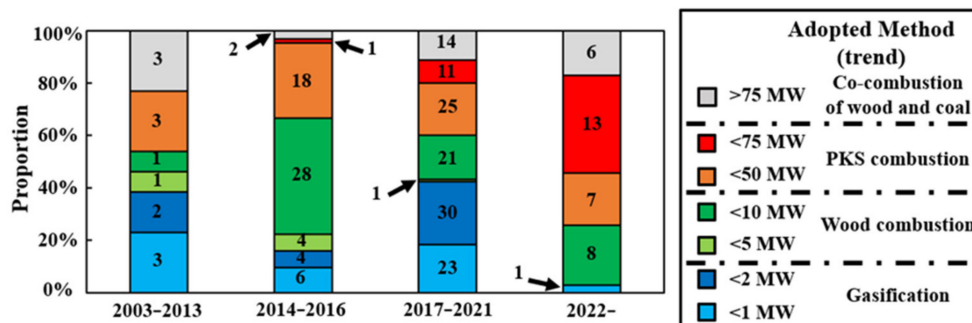


Figure 2. Proportion of woody biomass power generation projects by scale.

From the analysis of the trends in woody biomass power generation projects, we attempted to determine the transition in these projects of less than 2MW, which have the largest fluctuation in terms of the number of projects. We divided the woody biomass power generation projects of less than 2 MW into four classes according to the power generation scale, comprising <0.2 MW, <1 MW, <1.5 MW, and <2 MW, and into two methods, comprising gasification power generation and direct combustion. Figure 3 shows the details of the scale of woody biomass power generation projects of less than 2 MW. It can be confirmed in the figure that, after the change in the FIT sales price, more than 10 medium-scale 1–2 MW power generation projects were built with each method: gasification and direct combustion. Meanwhile, it can be confirmed that for ultra-small-scale power generation of less than 0.2 MW, gasification is mainstream. Although there are many plans to introduce gasification in 2022 and beyond, there is only one plan for a power generation project of less than 1 MW: direct combustion.

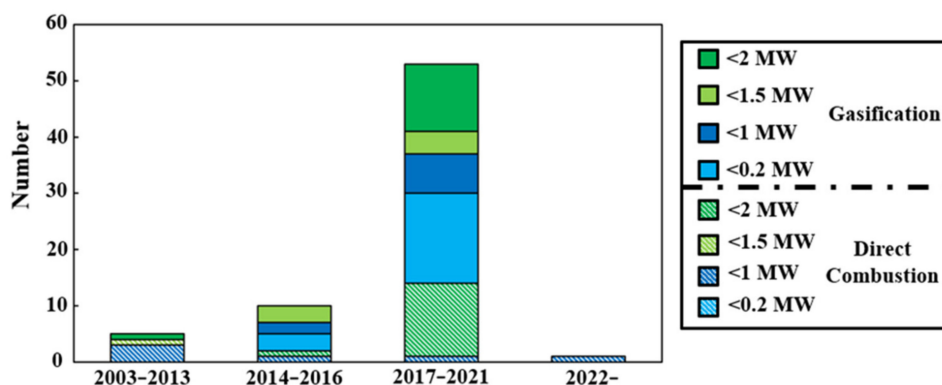


Figure 3. Details of woody biomass power generation projects of less than 2 MW.

As a result of consolidating the number of woody biomass power generation projects in Japan, we saw that the number of projects, mainly those in the 5 MW to 10 MW scale, increased significantly after FIT enforcement in 2012, and there is an increasing number of projects under 2 MW following the change in the FIT sales price in 2015. Additionally, we confirmed that the number of projects over 50 MW that are planned for operation in and after 2020 would increase. With power generation projects under 2 MW, in particular, we confirmed that, while there is a growing trend for introducing ultra-small-scale gasification power generation under 0.2 MW, there are no planned gasification power generation projects for 2020 and beyond. Based on these results, it can be concluded that small-scale gasification power generation has not yet reached the diffusion stage in Japan.

In the next section, we discuss what caused this state of diffusion based on technological development projects and empirical research. First is technological development related to the improvement of the energy utilization rate by gasification and bio-oil coproduction with a 2 MW updraft reactor. It was shown that the updraft reactor can accept wood chips with high moisture content, and by selling bio-oil—which is a byproduct—as a fuel alternative, there is high potential for commercialization. However, this process has not yet become widespread throughout the nation, due to difficulties associated with collecting sufficient wood chips equivalent to 2 MW, as well as in tar treatment. The second is the evaluation of a 0.36 MW small-scale gasification power generation plant, in which the results show that it was not working well due to its high moisture content. The third is the thermal analysis and proximate analysis by tree species. The results suggest that the gasification process is affected by tree ash content.

The results obtained in this research will contribute to the improvement woody biomass gasification power generation in Japan by addressing technical problems.

## 2. Materials and Methods

The analysis presented here summarizes the main results of an experiment carried out to understand the problems of woody biomass gasification power generation in Japan. The first is technological development related to the improvement of energy utilization rate by gasification and bio-oil coproduction using a 2 MW updraft reactor, the second is the measurement evaluation of a 0.36 MW small-scale gasification power generation plant, and the third is the thermal analysis and proximate analysis of tree species.

### 2.1. Gasification and Bio-Oil Coproduction System of a 2 MW Updraft Reactor

This project was conducted in connection with a policy that promotes the diffusion of renewable energy, led by Saitama Prefecture, which neighbors Tokyo. Chichibu, a city in western Saitama, and its surrounding areas are known as hilly and mountainous regions. Forestry revitalization through the application of woody biomass has been identified as a necessity for the local community. This region has a high demand for heat, mainly due to its cement industry, which has pushed it to consider the

social implementation of a high-efficiency energy transformation system that simultaneously produces gasification with woody biomass and bio-oil.

This project was implemented from 2011 to 2013 with the support of the Ministry of the Environment. When studying the early start of the operation, we selected an improvement approach with the help of an updraft reactor, which has shown good performance in Japan [16,17]. This system is mainly characterized by its ability to take in Japanese wood chips, with a high moisture content of 50–60% [18]. Originally, it was designed as a process for generating power through woody biomass gasification, with the suppression of tar generation in existing plants in mind. However, the heavy tar (called “bio-oil”) that was generated was found to be effective as a fuel substitute for heavy oil, so we studied the design conditions that would increase the yield of bio-oil without reducing the gas production ratio. As a result, we confirmed that, by changing the height of the wood chips inside the reaction chamber, we could obtain a maximum of 22% of bio-oil (Figure 4).

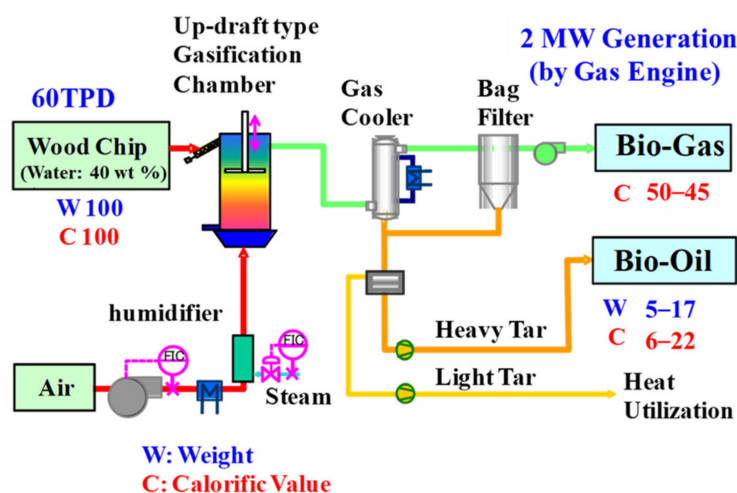


Figure 4. Summary of a gasification and bio-oil co-production process using an updraft reactor.

Figure 5 shows the exterior of the combined combustion test equipment for bio-oil and A-fuel oil that was set up at a human waste treatment facility in Chichibu. A stainless-steel bio-oil supply line was installed in consideration of the pH level of 2.5, and bio-oil was directly sprayed into the combustion chamber rather than mixing it with A-fuel oil in advance.



Figure 5. Bio-oil and A-fuel oil co-combustion test equipment.



## 2.2. The Measurement Evaluation of 0.36 MW Small-Scale Gasification Power Generation Plant

We discuss the actual measurements of a woody biomass gasification power generation system installed as a commercial plant through the FIT. The experiment's target facility is a downdraft gasification power generation system with 0.18 MW output  $\times$  2 lines (0.36 MW) and 11 t/D chip usage (Figure 6). At this facility, the entire process, up to feeding the wood chips into the gasifier, starts with delivering the wood chips to the chip yard from the chip center. Wood chips that have been accumulated and kept for about a week are then dried at approximately 230 °C in a hot-air dryer. Next, the chips are fed into the gasifier through the storage hopper at a temperature of 80 °C.

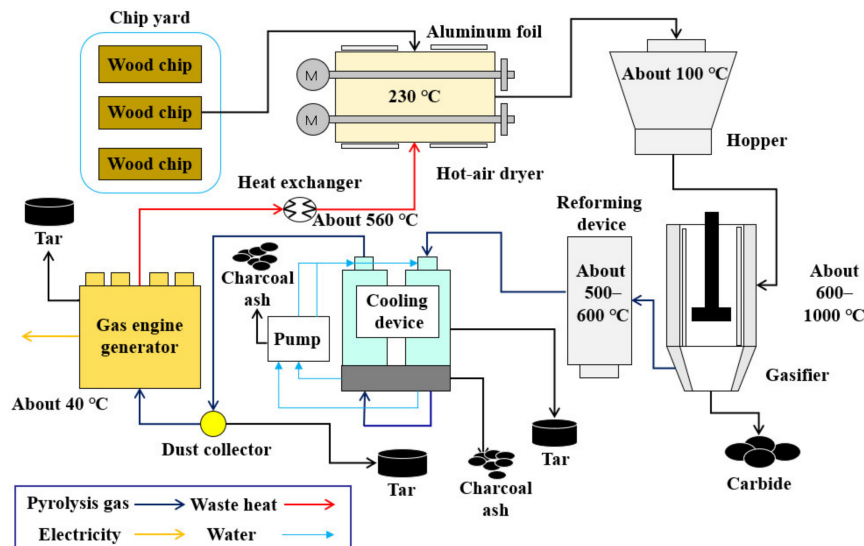


Figure 6. Gasification process flow in a power plant.

To evaluate the gasification power generation process, we consolidated the on-site operations data, analyzed the wood chips' moisture content, calculated the heat balance, and computed the heat generation of gas [19].

## 2.3. Pyrolysis Characteristics of Japanese Tree Species

Even in commercial plants other than the one introduced above, clinker trouble has been reported in facilities in Japan that have introduced European gasification systems [20]. Therefore, it is necessary to investigate the possibility that Japanese tree species are not suitable for European gasification systems. We thought that we could grasp the issues faced by gasification power generation through the quantitative and relative evaluation of the pyrolysis characteristics of various Japanese tree species. In this report, we conducted a thermal and proximate analysis of four types of wood pellets: Japanese cedar, Japanese cypress, pine tree, and *Quercus serrata*.

## 3. Results and Discussion

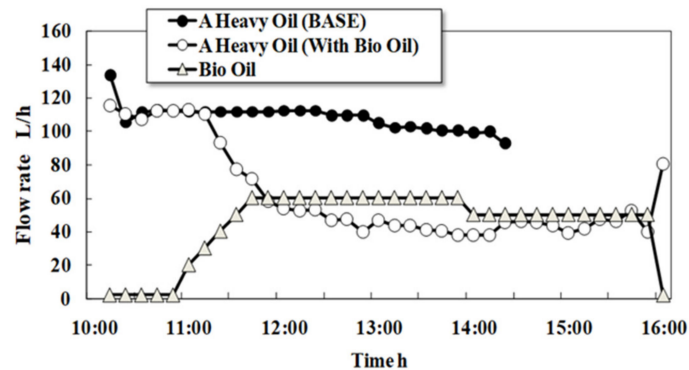
The results of experiments and evaluations carried out to understand and improve the problems of woody biomass gasification power generation in Japan are shown below. Based on these results, we will examine the reasons that have precluded the widespread use of woody biomass gasification power generation in Japan.

### 3.1. Gasification and Bio-Oil Coproduction System of a 2 MW Updraft Reactor

Table 1 shows the properties of bio-oil, while Figure 7 shows the combustion test results. The lower heating value of bio-oil is about 70% of A-fuel oil, proving that it can substitute for A-fuel oil, since it has roughly the same heat value.

**Table 1.** Properties of bio-oil.

Item		Analysis Results		Analysis Method
Proximate analysis	Microcontaminants	(wet wt.%)	0.37	JIS K 2276
	Residual carbon content	(wet wt.%)	11.5	JIS K 2270
	Water	(wet wt.%)	6.7	JIS K 2275-3
	Ash	(wet wt.%)	<0.01	JIS K 2272
	Volatile matter	(wet wt.%)	91.2	JIS M 8812
Heating value	Fixed carbon	(wet wt.%)	2.1	JIS M 8812 calculation method
	Higher heating value	(MJ/kg)	30.97	
	Lower heating value	(MJ/kg)	29.34	JIS K 2279
	value	(kcal/kg)	7400	
Elemental analysis	C	(dry wt.%)	69.46	JIS M 8819
	H	(dry wt.%)	7.22	
	N	(dry wt.%)	0.16	
	O	(dry wt.%)	23.06	Calculation method
	S	(dry wt.%)	0.03	Postcombustion—ion chromatography and gravimetric methods
Density	Cl	(dry wt.%)	0.07	Postcombustion—ion chromatography
	15 °C	(g/cm <sup>3</sup> )	1113	
	15 °C	(g/cm <sup>3</sup> )	1104	JIS K 2249
	50 °C	(g/cm <sup>3</sup> )	1091	
pH		(-)	2.5	Compliant with JIS K 2252 and glass electrode method
Flashpoint		(°C)	111.0	JIS K 2265-4
Temperature (°C)		Viscosity (mPa·s) (cP)		Kinematic viscosity (mm <sup>2</sup> /s) (cSt)
15		658		591
30		267		242
50		190		174

**Figure 7.** Results of bio-oil and A-fuel oil co-combustion test equipment.

The amendment of the FIT sales price for under 2 MW significantly boosted the possibility of commercializing this system. We previously confirmed that, by selling the byproduct bio-oil as a fuel substitute, the system's feasibility as a business would drastically improve [21]. However, it was not commercialized in Chichibu City, for the following reasons:

- Notably, 2 MW-scale power generation requires 60–70 TPD of wood chips, and it was found that it would be difficult to collect them at Chichibu City.
- There was no engineering, procurement, and construction (EPC) service provider that could construct the plant. This was, in part, because most plant manufacturers had to prioritize receiving orders for large-scale, direct combustion projects at that time.
- At that time, the energy input of solar light power generation drastically increased due to FIT, and restrictions on system interconnection started to emerge.

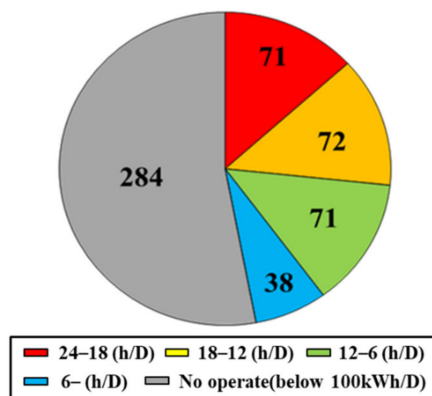
- The issues with this system are that initial running costs for the gas engine are high, and a treatment process for light tar is required. The cost of the gas engine had to be covered by the FIT sales price, but no specific measures regarding light tar treatment could be found.

The updraft reaction chamber method of woody biomass power generation was commercialized in Nagai City, Yamagata Prefecture, and has been reported to generally be running smoothly since it started operating in 2017 [22]. With the current FIT sales price, this system would be profitable even without the use of bio-oil, so the issue of strengthening the combustion process equipment for light tar has been resolved.

There are currently several regions that are considering the effective utilization of woody biomass. Unfortunately, not many are considering the introduction of this system as a prerequisite. One of the reasons for this is that there are now fewer regions that can supply the required raw materials, which is greatly affected by the attention that is being received by gasification power generation at a smaller scale. However, one major advantage of this system is its ability to accept wood chips with high moisture content. In light of this, we expect there to be more studies on gas-generated heat used outside of the power generation business, the enhanced value of making bio-oil a raw material for chemical products, etc.

### 3.2. The Measurement Evaluation of 0.36 MW Small-Scale Gasification Power Generation Plant

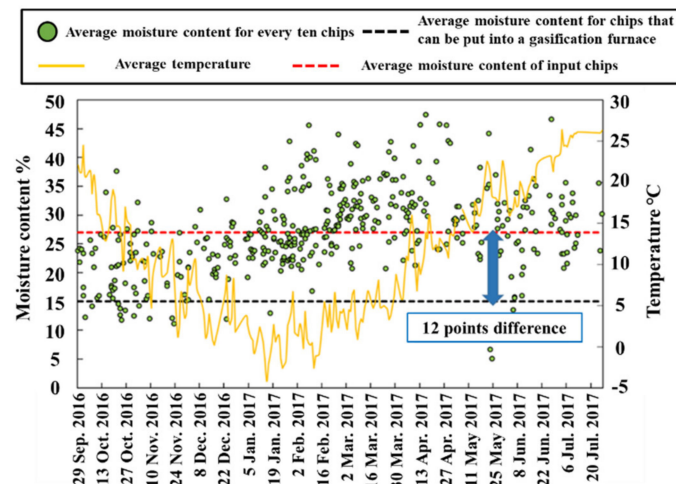
Figure 8 shows the operational status of this facility. It was only operational for 13.25% of the time, even though it was turned on for 18–24 h/day for 536 days (from 18 October 2016 to 13 July 2017, 2 lines) of the survey, so we learned that it was not operating stably. In addition, we found that it was not operational for over half of the survey period, due to repairs, maintenance, difficulty in procuring raw materials, etc.



**Figure 8.** Continuous operation situation (from 18 October 2016 to 13 July 2017). Reprint with permission; JSME, 2020 [19].

Figure 9 shows the moisture content (from 29 September 2016 to 26 July 2017) of the wood chips in the storage hopper. Compared with the updraft method, the downdraft method is known to be more restrictive in terms of chip moisture content. However, we confirmed that the moisture content among wood chips was inconsistent, and a very small number of samples satisfied the 15% requirement, which is the design value of this facility. We also observed that the average moisture content of the input wood chips was 27%, indicating a 12-point difference with the design value. The trend in the average temperature at the site is also shown in the diagram, but we found no correlation with the moisture content. This suggests that there are problems in the drying process itself.



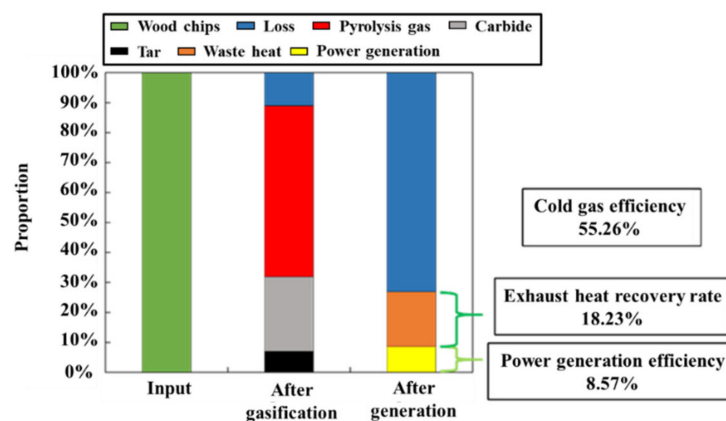


**Figure 9.** Moisture content of wood chips inside the storage hopper (from 29 September 2016 to 26 July 2017). Reprint with permission; JSME, 2020 [19].

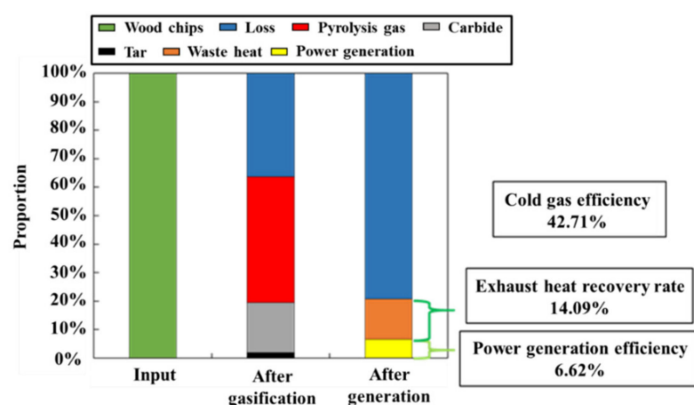
To understand the energy balance and cold gas efficiency of this facility, we calculated the heat balance of the gasification process. We performed the calculation here for two periods, 27 February 2017 to 28 February 2017 and from 30 May 2017 to 4 June 2017, which are when we were able to confirm the wood chip input amount. Table 2 shows the operational status during these periods, and Figures 10 and 11 show the energy balance.

**Table 2.** Calculation condition of thermal substance. Reprint with permission; JSME, 2020 [19].

Continuous Operating Period		From 27 February 2017 to 28 February 2017	From 30 May 2017 to 4 June 2017
Item	Unit	Value	
Wood moisture	(%)	33.65	27.67
Wood input (WB)	(t)	17.04	19.62
Power generation output	(kWh)	5558	5392
Operating time	(h)	39	41.5
Heat recovery amount	(kWh)	11,821	11,466



**Figure 10.** Heat balance of gasification process (from 27 February 2017 to 28 February 2017). Reprint with permission; JSME, 2020 [19].



**Figure 11.** Heat balance of gasification process (from 30 May 2017 to 4 June 2017). Reprint with permission; JSME, 2020 [19].

Based on the results of energy balance for the entire gasification process, the power generation efficiency and exhaust heat recovery rate from 27 February 2017 to 28 February 2017 were 8.57% and 18.23%, respectively, while from 30 May 2017 to 4 June 2020, they were 6.62% and 14.09%, respectively. Cold gas efficiency was 55.26% and 42.71% from 27 February 2017 to 28 February 2017 and from 30 May 2017 to 4 June 2020, respectively. The cold gas efficiency of the downdraft CHP unit from a different manufacturer was approximately 75%, so we found that, in both cases, the actual measurements of cold gas efficiency were at lower levels.

We computed the lower heating value of pyrolysis gas at this facility. Upon comparison of the actual measurements on the analysis target date and the literature values [23,24], we found that, whereas the average literature value of the lower heating values was 7.78 MJ/Nm<sup>3</sup>, the average of the actual measurements was 3.96 MJ/Nm<sup>3</sup>, which was 50.90% of the literature value. The heat value is likely low because the moisture content of the input chips did not satisfy the criteria, and this led to the temperature in the gasifier not reaching its target temperature, which then resulted in the poor generation of flammable gas.

The 0.36 MW-scale downdraft gasification power generation system was not operational for most of the survey period, mainly due to maintenance problems. In addition, we confirmed that the heat balance and gas heat in the gasification process did not reach values reported in the literature. The results suggest the importance of managing chip moisture content in small-scale gasification power generation facilities such as the above. When it comes to downdraft gasifiers, the strict management of moisture content is required, so we think that building a drying system that suits the hot and humid climate of Japan would be needed for further improvements.

### 3.3. Pyrolysis Characteristics of Japanese Tree Species

Figure 12 shows the results of the thermal analysis. We assumed the presence of pyrolysis layers in the gasifier and experimented with a nitrogen atmosphere. We then calculated the slope of the major pyrolysis section [25] of the obtained thermogravimetric (TG) curves. Given the tendency for the gasification rate to be faster as the slope of the TG curve becomes steeper [26], it can be confirmed that the gasification ratio varies depending on the tree species. However, when compared to bark, which generates clinker when burned because of the large amount of ash [27], the difference between tree species is not so significant.

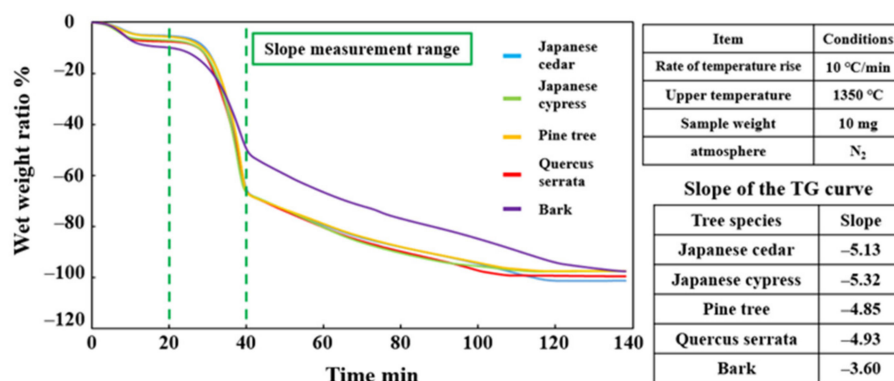


Figure 12. Results of thermal analysis.

Table 3 shows the results of the proximate analysis. The criteria for one gasifier manufacturer were for moisture content of 6–8% and ash of  $\leq 0.4\%$ , but we found that, among the four types of trees in the study, only pine trees satisfied the criteria for moisture content and only the Japanese cypress satisfied the criteria for ash. The maximum difference in lower heating value was only 3%.

Table 3. Results of proximate analysis.

Item		Unit	Japanese Cedar	Japanese Cypress	Pine	Quercus serrata
Proximate analysis	Lower heating value	(MJ/kg)	19.66	19.71	19.25	19.08
	Water	(%)	8.30	9.85	7.94	9.98
	Ash	(%)	0.41	0.37	0.76	0.75
	Volatile matter	(%)	82.7	83.8	84.6	83.1
	Fixed carbon	(%)	16.9	15.8	14.7	16.1

Based on the results of the thermal analysis, we found no significant differences in tree species. On the other hand, the results of the proximate analysis showed that, although there was no difference in terms of the lower heating value, there was no tree species that satisfied the manufacturer's criteria for moisture content and ash. Above all, we suspect that ash harms gasification power generation. In the future, we plan to analyze the properties of ash in tree species by region, and subject them to a more detailed examination. Even today, there are attempts to stabilize the quality of the input chips and pellets by conducting preprocessing through torrefaction [28]. However, unless the level of ash is controlled, this would not ultimately provide a solution to the problem.

#### 4. Conclusions

In this paper, we have discussed the introduction of woody biomass power generation in Japan and its status following FIT enforcement, and presented issues surrounding the diffusion of woody biomass power generation based on technological developments and experimental evaluation projects in which we were involved. Our findings are summarized below.

We consolidated the number of woody biomass power generation projects in Japan and found that, despite the demand for <2 MW small-scale gasification power generation, the number of planned projects is in decline, owing to the high degree of technical difficulty. The updraft reaction chamber gasification and bio-oil co-production process project that the authors were involved in was shown to be highly feasible as a business, because the system could accept wood chips with high moisture content, and the byproduct, bio-oil, is sold as a fuel substitute. Be that as it may, this system has not spread in Japan, because an increasing number of regions are finding it difficult to collect the amount of wood chips required for operating at 2 MW, and the processing of light tar is technically and financially inefficient.

We evaluated the actual measurements in a commercial plant using a 0.36 MW downdraft gasification power generation system. We found that the average moisture content of input wood chips was 27%, 12 points higher than the design value, and that the moisture content was not being controlled. As a result, the cold gas efficiency rate was low, at approximately 40–50%, and the lower heating value of pyrolysis gas was 3.96 MJ/Nm<sup>3</sup>, approximately 50% of the literature value. Hence, we pointed out that control of moisture content would require building a drying system that is appropriate for the hot and humid climate of Japan.

There were reports of clinker trouble in small-scale gasification power generation systems using gasifiers from a European manufacturer, so we studied the pyrolysis characteristics according to tree species and conducted an proximate analysis. Regarding the pyrolysis characteristics, we confirmed the differences in each tree species, but found no significant difference that would affect the gasification process. We also verified that none of the tree species satisfied the manufacturer's criteria for moisture and ash. As for ash, there may be differences depending on the region, even for the same tree species. Hence, we plan to conduct a detailed investigation on this matter, including an analysis of the ash properties.

As shown above, the FIT might have stimulated the market for woody biomass power generation in Japan, but the market still faces various problems such as an imbalance between the possible supply of raw material and the project plans, as well as the operation of commercial plants not being based on any technical evidence. Regions in Japan have high expectations regarding the potential for small- to medium-scale energy utilization of woody biomass, so it is necessary to amass knowledge to solve these issues and build a system that is compatible with Japan's climate and forestry industry.

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