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Economic analysis of biomass power generation schemes under renewable energy initiative with Renewable Portfolio Standards (RPS) in Korea

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ABSTRACT

An economic analysis of biomass power generation was conducted. Two key technologies—direct combustion with a steam turbine and gasification with a syngas engine—were mainly examined. In view of the present domestic biomass infrastructure of Korea, a small and distributed power generation system ranging from 0.5 to 5 MW_e was considered. It was found that gasification with a syngas engine becomes more economically feasible as the plant size decreases. Changes in the economic feasibilities with and without RPS or heat sales were also investigated. A sensitivity analysis of each system was conducted for representative parameters. Regarding the cost of electricity generation, electrical efficiency and fuel cost significantly affect both direct combustion and gasification systems. Regarding the internal rate of return (IRR), the heat sales price becomes important for obtaining a higher IRR, followed by power generation capacity and electrical efficiency.

1. Introduction

As the world's 10th largest energy consumer, Korea consumes 2% of world energy and imports 97% of its energy needs. In 2009, Korea spent 91 billion US dollars on energy imports, which corresponded to 28% of total imports. Increasing energy security and renewable energy resources is the greatest problem facing Korea. For decades, Korean energy policy has focused on securing a socially balanced supply of energy. Since the Korean government introduced a feed-in tariff (FIT) program in the power sector in 2006, power generation from renewable energy sources has been growing steadily. However, this increment has failed to meet government targets, and only 1% of Korea's electricity has come from renewable resources over the recent years, as shown in Fig. 1 (Lee, 2010).

Concerns over climate change and heavy dependence on imported fossil fuels have resulted in the introduction of a new policy of "low carbon, green growth" in Korea. Recently, there was a dramatic change in Korea's renewable energy initiative to promote renewable energy technologies (RETs) from FIT to Renewable Portfolio Standards (RPS). Under the RPS system, the economic feasibilities of the RETs become important. The new policy instrument is mandated for retail electricity suppliers (or, alternatively, electricity generators or consumers) to source a minimum percentage of their electricity needs from eligible renewable resources, and thus ensures that a minimum amount of renewable energy is included in the portfolio of electricity resources. In order to promote the use of renewable energy and to add flexibility and reduce the cost of meeting the requirements, tradable renewable energy certificates (REC) can be used (Wiser and Langniss, 2001).

According to the recently announced RPS, which will be enacted in 2012, electricity suppliers are required to include 2% renewable energy by 2012 and 10% by 2022, as shown in Table 1. The program will mandate 16,481 GW h of additional renewable energy per year through 2015 and 50,248 GW h per year through 2022. Each renewable resource has its own multipliers that will mitigate the gap of economics between the resources. The multipliers are presented in Table 2. They are expected to contribute to the spread of RPS with a focus on large-scale energy providers because a renewable energy generator (unregulated) is able to sell REC multiplied by its resource's multiplier. Among the many renewable resources, dedicated woody biomass combustion (including gasification) has the highest multiplier after offshore wind, tidal power, and fuel cells. The multiplier for power generation using biomass combustion or gasification is 1.5.

Although 6,370,000 ha of land (i.e., 63.8% of the nation's total land area) are covered with forest, there have been few examples of biomass power generation in Korea. This is because biomass supply infrastructure and utilization technologies have not yet been fully developed in Korea. Biomass resource availability is the most important issue in terms of economics and long-term project sustainability, as it allows projects that can utilize a reliable

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and onsite supply of fuels (Bruhn et al., 2011; Peterson and Haase, 2009). From the perspective of energy security and controllability of power generation, biomass appears to be an extremely promising renewable fuel. Various studies forecast an increase in its contribution to the future energy supply, at both regional and global levels (Yamamoto et al., 2001).

Biomass conversion technologies for heat and power can be classified into two categories: direct combustion with a steam turbine and gasification with a gas engine. Direct combustion is a common method of converting biomass resources into heat, power, or a combination of both (CHP: combined heat and power). The direct combustion system burns biomass to generate hot flue gas and steam in a boiler. The steam provides heat for industrial processes or district heating, and a steam turbine can be used to generate power. Biomass combustion facilities that produce electricity through a steam turbine have a conversion efficiency between 10% and 35%, depending on the size and manufacturer; a CHP system can have an overall system efficiency of up to 85% for large facilities (Bridgwater, 1995; Energy Nexus Group, 2002; Schmidt et al., 2011).

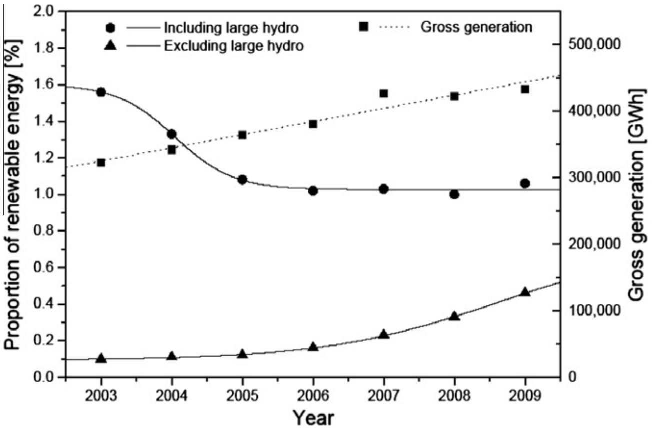

Fig. 1. Gross generation and renewable energy portion with and without large hydroelectric power generation in Korea.

Table 1
Annual amount of renewable energy supply obligations in Korea (Unit: GW h).

Year	Gross generation	Reference power generation	Amount of supply obligations	
			Duty rate (%)	Amount of duty
2011	463,810	450,344		
2012	473,377	459,800	2.0	9007
2013	481,686	464,366	2.5	11,495
2014	489,343	470,893	3.0	13,931
2015	497,819	476,877	3.5	16,481
2016	507,340	484,574	4.0	19,075
2017	512,713	486,869	5.0	24,229
2018	517,141	491,297	6.0	29,212
2019	521,335	495,491	7.0	34,391
2020	524,360	498,456	8.0	39,639
2021	528,324	502,480	9.0	44,861
2022	531,977	506,133	10.0	50,248

Biomass gasification, which is a rather recent technology, is being used to improve the efficiency of biomass energy conversion and reduce the investment costs of biomass electricity generation (Hemmes et al., 2003; Mathieu and Dubuisson, 2002; Sharma, 2008; Wu et al., 2002). It has advantages for distributed power generation systems that are appropriate for widely distributed biomass resources with low energy density (Demirbas, 2001). On the other hand, synthetic fuels such as substitute natural gas (SNG), dimethyl-ether (DME), and Fisher–Tropsch (F–T) diesel can be generated from the product gas of biomass gasification with further synthetic processes. These possibilities provide additional motivation for the development of the gasification process and research into this area (Jie and Wennan, 2011; Lv et al., 2007; Shie et al., 2011). Gasification systems convert biomass into the mixture of combustible gases and byproducts consists of hydrogen, carbon monoxide, carbon dioxide, methane, tar vapor, and ashes. The product gas can be burned directly in a boiler to produce steam and heat or alternatively, the product gas can be used for gensets such as gas engine, gas turbine, or other application requiring high-quality gas after removing the impurities (Ajay et al., 2010; Peterson and Haase, 2009; Warren et al., 1995).

According to an internal report, there are about 10–20 sites that can supply 50–300 tons of woody biomass per day in Korea, and several small-scale biomass CHP systems can be operated at each site. At this stage, guidelines are necessary for building strategies of using biomass resources to meet RPS. In this study, we selected two technologies: CHP using direct combustion of biomass with a steam turbine and biomass gasification with a gas engine. Although fundamentally different in their principles and characteristics of operation, each of these technologies has its own merits. Moreover, they are already commercialized so as to meet the demands of electricity suppliers. Thus far, no direct comparison of the two systems has been performed by considering various parameters including REC weights and prices. Therefore, it is of great interest to investigate the impact of adopting these technologies and the economic feasibility of each system.

2. Methods

2.1. Model description

A model is developed to analyze the economical feasibilities of biomass energy conversion technologies. The energy conversion system of the model may be a power generation facility or a CHP system. The most recent data of a Korean power company (Korea

Table 2
REC multipliers for renewable energy resources in Korea.

Category	REC multiplier	Subject energy and standards		
		Installation type	Category of land type	Capacity standards
Solar energy	0.7	Buildings, etc., when not using existing facilities	5 EA categories of land (farm, paddy field, orchard, lot for ranch, forest land)	
	1.0		23 other EA categories of land	Excess 30 kW$_e$
	1.2			Under 30 kW$_e$
	1.5	Buildings, etc., when using existing facilities		
Renewable energy	0.25	IGCC, Surplus gas		
	0.5	Waste, Reclaimed land gas		
	1.0	Hydro, Wind power on land, Bio energy, Dedicated RDF combustion, Waste gasification, Tidal power (with seawall)		
	1.5	Dedicated woody biomass combustion, Offshore wind (under linkage distance of 5 km)		
	2.0	Offshore wind (exceeding linkage distance of 5 km), Tidal power (no seawall), Fuel cell		