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JOURNAL REVIEW

A study on the economic analysis and optical project model of woodchip cogeneration systems

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Abstract−Woody biomass has long been used to make heat. Recently, there has been a renewed interest in wood-fired energy production because woody biomass is carbon free and it is an abundant energy source in the world. The past 20 years have witnessed an exciting growth in the numbers of wood-fired heating plants, but compared to conventional fossil fuels, its portion in our energy mix is rather insignificant. To promote the use of woody biomass as well as giving a guideline for woody biomass-based energy system, technological and economic feasibility analyses of wood-fired cogeneration facilities and equipment are necessary. The objective of this study is to evaluate the potential of a cogeneration system and to perform reliable economic analysis of an optimal business model. Work should be initiated to establish a multilateral network, taking into consideration institutional infrastructure, scientific capabilities, and cost effectiveness.

Key words: Woodchips Cogeneration Systems, Economic Analysis, Biomass Energy

INTRODUCTION

Commercialization of energy production system from biomass has been a very interesting research and development topic since the energy crisis of the 1970s. Various environmental and economic benefits have been claimed for the application of biomass such as energy security, reduction of greenhouse gas emissions, and availability of a renewable source for increasing energy demand. Especially, forest residues are a viable option because they are abundant, relatively cheap and not edible [1,2]. The recovery of forest residues reduces the chance of forest fires, increases forest health by reducing competition for resources, generates additional revenue by utilizing forest by-products, and reduces the burden of disposal of waste material [3-5,13]. In spite of such benefits, industries have been relatively slow to process renewable energy from forestry residues. The sluggish development has been due to financing, reluctance to adopt new technology, and resource uncertainty concerning biomass feedstock supply, production costs, and economic impacts [4-6]. Thus, accurate assessments of the availability and production costs of woody biomass feedstock can help spur the use of biomass as fuels. Recently, some advanced countries have believed that use of woody biomass from forest thinning and sawmill waste is competitive with petroleum fuels in certain locales [6,7]. Thus, there have been numerous projects for economical and environmentally friendly use of forestry biomass as a fuel source. In European countries, a cogeneration system using woody biomass is emerging as a central policy response to the convention on climate change [14]. European and many other advanced countries are treating woody biomass as a strategically important sustainable renewable energy resource [15]. A benefit of using fuel and power generated from woody biomass in place of fossil fuels is that CO_2 emissions are cut as a result [16]. Also, it can enhance economic opportunities for forestry and timber industries locally. The use of woody biomass for energy cogeneration can be a good opportunity for utilization of a new energy resource. In view of these global trends, the potential for wood fuel generated from a cogeneration system has been identified for proposing an optimal project plan through a reliable economic analysis.

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ANALYSIS METHOD

This study was performed based on an averaging cost accounting method, as represented in Fig. 1. Three different modules were designed and implemented while focusing on estimating cost accounting for power generation. The first module is a surface analysis module, which utilizes the technical and economic indicators for evaluation and identification. The second is a power input module that is based on major economic indicators to evaluate and perform financial and cash flow analysis. The third is an input variation module, where change in indicators and sensitivity of its effect on the energy production cost is schematized. Life cycle cost analysis (LCCA) was used for economic analysis in this study. The cost of woodchip

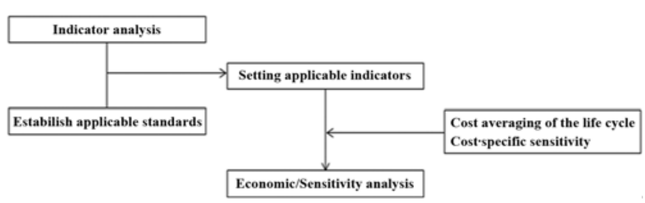

Fig. 1. The schematic flow of economic analysis procedures.

Table 1. Investment for wood biomass based power plant [8] (Unit: Million Won[a])

Classification			District heating corp.	Operator A	Operator B
Generation method			Cogeneration	Generation pnly	Cogeneration
Generator type			Steam turbine	Gas engine	Steam turbine
Capacity			8,700 kW	180 kW	1,100 kW
Direct expanses	Initial cost	Generator	8,450	82.7	1,865
		Gasification unit	-	98.7	-
		Steam/Boiler	26,147	-	9,841
		Substations		120.0	
		Others			3,327
		Subtotal	34,597	301.4	15,033
	Construction cost	Civil/Construction		38.0	5,399
		Grid connection		8.0	
		Subtotal		46.0	5,399
	Subtotal		34,597	144.7	20,432
Overhead	Design		1,176		1,368
	Inspection/Test run/Management		2,042		448
	Land		3,642	53.0	
	Transportation			25.0	360
	Tariff/Interest			22.4	878
	Others (Contingency etc.)			1.9	2,549
	Subtotal		6,860	102.3	5,603
Total			41,457	449.7	26,035
Initial cost (Ten thousand Won/kW) (Before Sep. of Heat part)			476	250	2,367

Note: Initial cost indicators are from each operator's planned figures
[a]Won is the basis of Korean currency (1000 Won=1 USD)

cogeneration energy production was estimated; an original S/W was designed and implemented for the sensitivity analysis.

ECONOMIC ANALYSIS

1. Input Indices

1-1. Cost of Facilities

As a representative case, District Heating Corp. (Daegoo, Korea) currently has a woody biomass cogeneration facility in operation and several reviews are underway for gasification plant of woody biomass. Table 1 shows the investment cost of the company for a wood biomass based power plant. In Korea, the facilities and facility cost indicators for currently reviewed plans are very different depending on equipment configurations and procurement methods. Therefore, it is difficult to set standard cost indicators. On the other hand, there are relatively high requests for a biomass energy system and commercial examples in advanced countries. Generally, these countries are using direct combustion systems (mainly cogeneration type using steam turbine), and gasification type (mainly using gas engine generators). Generally, the investment cost is variable depending on the type being used and the venation range is relatively high. Table 2 shows the list of initial cost for the biomass power generation methods in Japan, England, US, and other countries. Approximately, the cost ranges from $2,000 to $3,000 per kW. In these cases, cost allocation for each heat and power generation was ignored.

Table 2. Initial cost for biomass energy generation in advanced countries [10-12]

Classification		Initial cost ($/kW)	Facility size (MW)
Japan	Resource and energy dept.	2,546	10.3
England	ITC	3,018	5.3
US	Oregon	2,096-2,400	5-50
	Kettle falls wood-fire plant	2,000	42.5
Others	World bank	2,975	1

Index Calculation

A. Calculation Standard

Regarding the power generation with biomass, there are few cases of application examples in Korea. To estimate the appropriate energy production cost from biomass, the investment costs from domestic project under planning and foreign data, applicable for Korea, are used. Wood biomass from forestry waste and thinning is considered for the main fuel of a CHP plant. The heat will be used for local heating and the electricity will be connected to the grid. This plan is the basis for the estimation of the standard equipment cost.

B. Calculation Process

The following is the calculation process of initial equipment cost allocation between heat and power generation equipment. The bio-

Table 3. Cost allocation for biomass energy generation [8] (Unit; thousand Won/kW)

Item	Components	For electricity	For heat	Total	Remarks
Direct investment	CHP Equip.	971	0	971	Equipment cost related to electricity generation is 24.4% of total direct investment cost
	DH Equip.	0	1,638	1,638	
	HOB	0	330	330	
	Main piping	0	311	311	
	Distribution piping	0	727	727	
	Subtotal	971	3,005	3,977	
Overhead		90	280	370	Electricity related cost ratio of 24.4% is applied to the total common cost
Land cost		102	316	419	
Interest during construction		26	82	108	
Total		1,190	3,683	4,873	

Note: Base equipments standard was CHP 8.7 MW (heat load tracking method)

mass cogeneration equipment being operated by Korea District Heating Corp. uses a direct combustion cogeneration system using woodchips. For the system, production cost of heat and power can be separately calculated. For example, the equipment cost related to electricity is separated from the total. The common costs for power generation are calculated by the ratio of the equipment cost related to power generation and total cost. As shown in Table 3, the cost directly related to heat generations, such as boiler and piping equipment, is about three million Won per kW. The cost directly related to power generation is 0.971 million Won per kW, which corresponds to about 24% of the total equipment cost. Therefore, the common costs, such as overhead, land cost, interest during construction period etc., multiplied by 24.4% results in the portion of power generation in the total common costs. By using this relation, we can calculate the cost for power generation in the common costs: 0.218 million Won/kW. Consequently, the total equipment cost for power generation becomes about 1.2 million Won per kW.

C. Indices Calculation

The indicator for energy production from biomass was estimated by reviewing domestic and foreign examples. As mentioned earlier, the equipment cost of power generation is approximately 24.4 percent of the total cost. In most foreign cases, the cost of heat generation is included for cost calculation and, approximately 30% is assumed for the equipment cost of power generation. This consequently implies the equipment cost for power generation will be between \$600 and \$900. According to the domestic and foreign examples, the standard equipment cost for power generation is set about 1.1 million Won per kW. An alternative standard cost that takes price volatility of market growth into account was set at 1 million Won per kW and will be also used in the analysis.

1-2. Equipment Utilization Rate

In Korea, there are few examples of energy system using woody biomass, which makes it difficult to collect utilization and performance data of power generation equipment. Regarding the woody biomass infra of Korea, waste woodchips are the primary resource and supply of the feedstock can highly affect to the utilization rate of the plant. In Table 4, limited information of combined heat and power generation system of Korea District Heating Corp. is presented. The equipment utilization rate of the biomass cogeneration facility is approximately 55% due to the short supply of feedstock. In foreign cases, the utilization rates of biomass power plant are different depending on the process of the plants and feedstock status. Until now, due to various reasons the equipment utilization rate of the cases was around 30-40 % (Table 5).

Table 4. Equipment utilization of biomass power generation in Korea [8]

Classification		Production of sales level		Equipment utilization
		Elec. Ge. cost	Sales cost	
Cogeneration equipment	Electricity (MWh)	45,275	42,106	55.2%
	Heat (MWh)	125,764	120,743	-
Boiler for heat (MWh)		29,620	28,435	-

Note: Heat load tracking methods, 8.7 MW standard

Table 5. Equipment utilization of biomass power generation in other countries [8]

Classification	Location	Equipment utilization (%)	Facility size (MW)
Denmark	Haslev	32.8	5
Sweden	Sandvik II	40.7	38
	Kraft	30.8	35
US	DOE	32.0	50

Indices Calculation

Cost calculation was conducted by comprehensive review of the foreign application data and Korean domestic wood biomass power generation project of District Heating Corp. The power generation process was direct combustion of biomass with a steam turbine. The equipment utilization rate of 55% was used as the basis and an alternative equipment utilization rate was chosen as 90% of the basis, which was 50%. This was because the currently operating foreign wood biomass power generation units have lower equipment utilization rate than the domestic basic design type's values.

1-3. Cost of Operation

Regarding the information from Korea District Heating Corp., the operation retention to facility investment is about 6%. This cost

Table 6. Foreign examples of operation retention ratio for biomass energy generation in Japan [12]

Classification	Position	Operation retention ratio (%)	Facility size (MW)
Japan	Resource and Energy dept.	16.7	10.3
Others	World bank	2.9	1.0

is a proportion of the sum of costs involved with operation of the plant, repair and maintenance cost etc. from the total initial equipment investment. It excludes costs related specifically to cogeneration equipment in determination of operation maintenance cost. Due to the nature of the biomass power generation, the initial equipment investment cost can differ depending on the process. The operation retention ratio, which is dependent on this initial equipment investment cost, also shows significant differences. The assessment has to be made using comprehensive information on generation methods. However, availability of this information is very limited. From the available information attained from foreign power generation examples, the operation retention ratio was found to be around 3% and some were as high as 17% (Table 6).

Indices Calculation

A. Calculation Standard

Operational maintenance costs were determined using pre-feasibility study resources from the wood biomass cogeneration system that is currently in operation domestically. This value was used for setting a standard ratio with the initial equipment investment cost for power generation.

B. Calculation of Standard Cost

The operation maintenance cost consists of labor, repair maintenance, taxes etc., and itemized operation maintenance costs for 8 MW cogeneration facility are shown in Table 7. The domestic operation maintenance cost was used as the basis. However, the foreign examples and data were also put into consideration. The operation retention ratio of 6% is used for analysis.

1-4. Cost of Fuel

Domestic wood chips and pellets being processed from the forestry wastes have been produced for special purposes rather than for the power generation. Therefore, domestic supply infra has not set up yet and the feedstock costs are rather expensive. However, if the supply infra is set up, the feedstock cost will be considerably

Table 8. Amount collected forestry wastes by utilization [14]

(Unit: m^3)

Classifications	1999	2000	2001	2002
Sawdust	36,714	36,845	29,848	13,059
Bulky feed	919	941	504	539
Round treated timber	1,845	7,287	5,147	4,086
Timber sales	37,945	43,381	30,952	20,799
Forestry fuel	42,801	42,618	42,312	28,038
Total	120,224	131,072	108,763	66,521

Table 9. Standard operation maintenance cost for fuel cell system for power generations

Classification	Cost (Yen[a]/Ton)	Remarks
Cost of timber from forest thinning	5,900	
Cutting down and collection cost	4,000	- Thinning subsidy: 13,500 Yen/ton
Transport cost (trading site)	3,100	
Transportation cost (to final consumer)	5,300	
Total	18,300	

[a]Yen is the basis of Japanese currency (117.8 Yen=1 USD)

lowered in the future. Current usage of forestry wastes includes sawdust, bulky feed, round treated timber, timber sales, forestry fuels etc. As shown in Table 8, the amount of forestry waste collected in 2002 was 67,000 m^3, of which forestry fuel (42.2%) and timber sales (31.3%) take up 70% of the usage. Other usages include sawdust (19.6%), round treated timber (6.1%) and bulky feed (0.8%). The production cost of woodchips consists of transporting forest thinning material to timber access roads (From afforestation projects), freight and loading cost of sending the waste to crusher, wood crushing cost, and finally cost to transport the woodchips to the actual consumer. The domestic market for woodchips has not been systemized and therefore has different price forecasts. In reality, the price of woodchips is high. In case of the foreign woodchip market, depending on the country's production and trading system, the price can differ greatly. In Japan, the total cost from forest thinning to the

Table 7. Standard operation maintenance cost for biomass cogeneration [14]

Classification	Cost (Million Won)	Remarks
Labor	600	- 20 Workers (for 8 MW) - 1 person x 3,0 Million Won/year per person (Consideration for Qualified manpower)
Repair Maintenance Cost	8	- Total Repair Maintenance Cost is Allocated to Electricity and Heat Gen. separately - 25% level of total cost
Other Costs	24	- Tax - Insurance
Subtotal	632	- Equipment Cost (1.1 Million Won/kW) - Operation Retention Rate: 5.75%

final consumer is about 18,300 Yen per ton (Table 9).

Indices Calculation

A. Calculation Standard

In Korea, biomass power generation is likely focused on utilizing forestry wastes. The feedstock cost for analysis was the current market price of domestic woodchips. Woodchips that are currently being traded in Korea are mostly for special usages. The price is relatively high but it is expected to decrease considerably when stable large scale supply systems are formed. Actually, businesses and operators who are evaluating the energy generation using woodchips base the price forecast on the same expectations and rationales. In this study, a fixed type crushing method for waste wood chip production was chosen as a basis for estimating the price.

B. Index Standard

Wood chips price was assumed as 40,000 Won per ton in the analysis. This was under the assumption that a supply system has been set up with a stable supply and demand.

2. Indices Calculation

2-1. Cost of Unit Facilities

The equipment investment cost was set at 1.1 million Won per kW, based on domestic and foreign examples. As an alternative case, 1 million Won per kW, which included consideration on price volatility due to market growth, was chosen as an alternative basis.

2-2. Operation Retention Ratio

Biomass power generation using wood or agricultural residue is not yet commercialized in Korea. However, biomass power generation has been widely used in Japan and Europe. Input index for the retention ratio was determined from foreign data and the equipment was reviewed by using planning stage data from domestic projects.

2-3. Equipment Utilization Rate

The input indicator for the equipment utilization rate was determined as 55%, based on domestic project basis data. Alternative was set at 50%.

ECONOMIC AND SENSITIVITY ANALYSIS

1. Scenario Set-up

Table 10 presents the setup of a scenario for the power generation production cost determination, based on key input indicators. Based on the equipment cost (1.0 Million Won/kW, 1.1 Million Won/kW), the operation retention rate (5%, 6%), and the equipment utilization rate (50%, 55%), a total of eight combinatory scenarios were applied to the analysis. Other than the previously mentioned input indicator, the other common wealth index was placed under the same conditions.

Table 10. Case set up for determination of biomass energy generation production costs

Classification	Equipment cost (Ten Thousand Won/kW)	Operation retention ratio (%)	Equipment utilization (%)
Case 1	110	6.0	55.0
Case 2	110	6.0	50.0
Case 3	110	5.0	55.0
Case 4	110	5.0	50.0
Case 5	100	6.0	55.0
Case 6	100	6.0	50.0
Case 7	100	5.0	55.0
Case 8	100	5.0	50.0

2. Cost Accounting for Electricity

Based on input indicators for each scenario, production cost for electricity were determined as follows. The production cost for each of the input index combinations was between 63.09-72.82 Won/kWh. The production cost for each of the input index combinations

Table 11. Prosecution cost of electricity in biomass power generation for each case

Scenario	Electricity production cost (Won/kWh)	Scenario	Electricity production cost (Won/kWh)
Case 1	68.99	Case 5	65.50
Case 2	72.82	Case 6	68.99
Case 3	66.33	Case 7	63.09
Case 4	69.90	Case 8	66.33

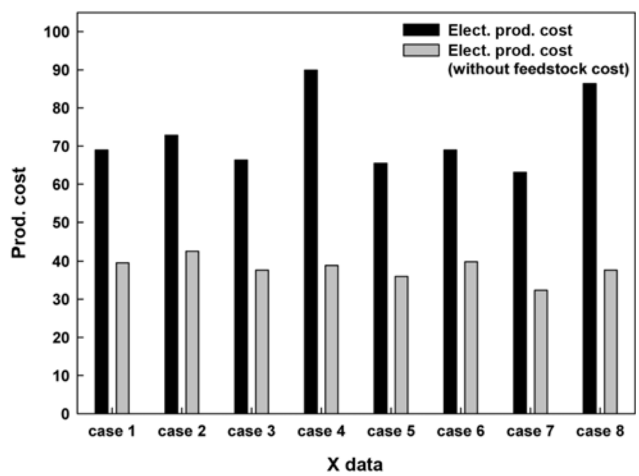

Fig. 2. The production cost of electricity in biomass power generation for each case.

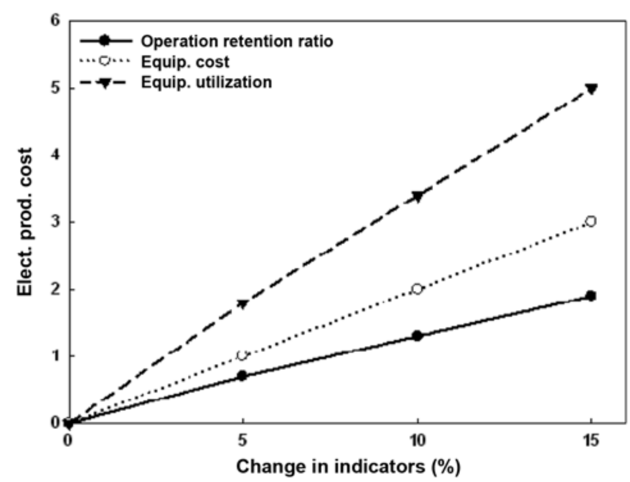

Fig. 3. Single variable sensitivity.

were presented in Table 11 and Fig. 2.

3. Sensitivity Analysis

To analyze the production cost sensitivity of biomass power generation, the equipment cost, operation retention ratio, and base index for equipment utilization were changed by 5%, 10% and 15% (Fig. 3). The effects of these changes on the power generation cost were investigated. For case 1, 5% change in the above=mentioned parameters results in the electricity production cost sensitivity of 1.83 Won/kWh, which is the highest in relation to the equipment retention ratio. Other significant results are equipment cost of 1.12 Won/kWh and the operation retention ratio of 0.80 Won/kWh. In other words, the order of variables that affects to the power generation cost in biomass power generation is equipment utilization rate>equipment cost>operation retention ratio.

CONCLUSION

Energy conversion system using woody biomass has not been fully developed compared to the conventional fossil fuel or nuclear power generation system. The commercialization of this technology has been rather slow because the power generation cost is rather expensive and the uncertainties of the newly developed system which is not as familiar as the conventional ones. However, emergence of new technologies and future possible developments will possibly enable biomass energy conversion systems to become a new and important renewable energy production system. Possible plans for lowering the investment and operation cost of biomass cogeneration system are as follows. First, design optimization can reduce investment cost. Installation of appropriate-sized equipment and facility can further reduce the cost and increase effectiveness and productivity. Also, the energy loss and breakdown in equipment can be minimized by appropriate placement of equipment in accordance with the wood fuel's innate characteristics. Second, additional processing costs can be saved by choosing a conversion system that can utilize various wood fuels with different physical characteristics. Finally, designing of continuous systems and efficiently scheduled management can also reduce cost.

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