CHAPTER 1

INTRODUCTION

1.1 Background Remarks

One of Thailand's energy strategies is to promote the utilization of renewable energy from the present 7.8% to 20.3% of the national energy consumption by the year 2022 (NEPO, 2011). The government has established the renewable energy development plan in the country. It consists of variety actions including import tax exemption on energy-efficient equipment, and tax exemption for energy-efficient industry, setting up the Energy Service Companies (ESCO) fund to promote energy-efficient investment, and promoting "adder" incentive for renewable-based electricity sold to the national grid. Electricity generated from renewable source can be sold and distributed back to national grid. This is governed by the Provincial Electricity Authority. There are non-firm and firm contracts where the latter has to be guaranteed and, hence, offers higher price.

Biomass is a renewable energy that the royal Thai government targets and expected 4,000 MW to be utilized, there are examples of biomass used around the world especially in small community. The city of Santa Fe, New Mexico uses local woody biomass from forest-thinning industry and woodcraft industry, the municipal waste from landfills and waste transfer stations to produce 32.7 MW residential heat. The $23.7 million system currently serves local households within 30 km radius and costs 0.061 $/kWh. Santa Fe Community College employs 5.1 MW heating system for which 22% of woody biomass is used as the substitute fuel with $1.2 million additional investment. The production costs 0.029 $/ kWh which is well below the cost of city residential heat available (NRCS, 2005). Another example is in Sri Lanka. Locating 10 km away from the national grid's distribution line, a small power plant in Endagalayaya Village was built and currently supplies 3.5 km of electricity generation for its own community. It can supply 50 households within

1.5 km radius and, hence, improve living standards of villagers. However, no actual social and environmental impact is reported (Jayasinghe et al., 2006). In Cambodia, 30 kW biomass power plant is installed and operated by cooperative community called Community Electricity of Rakar Ar (CERA) and it distributes electricity for 150 households. Wooden fuel is provided from 4 ha. community public area as a plantation. (DEDE, 2008)

In a village of Chaingmuan district in Payao province, Thailand, the demand for electricity production is not large. It has been reported as approximately 12 kW for 171 households (Khambunrueng et al., 2006). Most rural communities in Thailand are agricultural-based and consume small amount of energy in comparison with the urban communities. After harvesting season there are agricultural wastes and residues available. These are suitable for fuel to convert to energy or even electricity and present great potential.

However, real challenges are eminent on the technology. Two of common technologies are small steam-powered and gasification systems. At this small size for community use, the steam power technology is penalized by its low efficiency (Hofbauer, 2005). However, it is relative easy and reliable for community operation and most of the components can be manufactured by the domestic companies. This is the reason why there have been components available for small steam power system in the commercial market. On the contrary, gasification system prevails because of its higher efficiency (Basu, 2010). The community-based systems are experimented and deployed in various part of the world, for example, in China (Leung et al., 2004). It is reported that gasification is suitable for a community with less than 300 kWh demand and it can be modified to work with common diesel engines for energy conversion (Velez and Valle, 2007). As the reactor is a key component in the gasification process, to produce fuel gas for generating electricity in the engine, research for higher efficiency and waste reduction is still in research community's interest. There are investigations focusing on high temperature air supply for the rector, a multi-stage design for the downdraft reactor to reduce tar, and improvement of the volatile yields (Solantausta and. Kurkela, 1995, Pian and Yoshikawa, 2001). There are also researches on auxiliary systems such as heat recovery system. Boonnasa (2007) worked on the economizer designed for a retrieval of 242 °C exhaust gas from a 10

MW power plant powered by rice husk. Exhaust heat is used to warm feed water for a system which can reduce 10.5% of energy cost. Additional investment is posed with a payback period of just seven months.

The continuity of fuel supply for biomass-powered system is crucial for the community-scaled power plant especially when the fuel is from agricultural residues which is various, seasonal, and fluctuated in terms of quality and quantity. Fuel management has to be well planned. If the fuel is not sufficient, the operation is not sustained and it cannot meet the demand or earn decent purchasing contract. Type of fuel has to be carefully selected. Criterion might include fuel property, supply potential, and, certainly, market price. Sajiakulnukit et al. (2005) reported that 812.4 PJ energy is available from agriculture wastes in Thailand and there is high possibility that some amount of these can generate electricity especially for the community who owns those wastes. However the disadvantages of agricultural wastes exist which include the difficulty in collecting and transportation. Logistics should be carefully planned as the location of biomass sources are surely scattered and the further-away locations cost more. Sources of biomass can be varied such as rice fields, rice mills, and furniture or handicraft factories. These locations are main sources of agricultural waste collection. Community-scaled biomass power plant can be at one of these locations to minimize the transportation. The locals within the radius of the power plant will gain more income from converting agricultural waste into energy or electricity.

Plantation of biomass fuel is also possible to secure the amount of feed. If woody plantation is chosen, selection of plant species becomes crucial. Ease of nurturing and its properties including biological and thermodynamic are important. To maximize the community benefit, the selected plant has to grow fast and yet, possibly, be resistant to drought and infertile soil, and it should has relatively higher heating value. Examples of potential fast - growth plants are *Eucalyptus camaldulensis* Dehn., *Acacia mangium* Wild., and *Leucaena Leucocephala* (Viriyabancha et al., 2007). In India with annual average rainfall of 50 - 1000 mm, Singh and Torgy. (1994) plant various kinds of fast-growth trees. Plant spacing is reported as 0.6 m x 0.6 m. Large production is found on *Leucaena Leucocephala* and *Eucalytustereticornis* where their yields are between 29-33 ton/hectare/year (Singh and Torgy, 1994). Thailand is in similar geographic area and climate with even more amount of annual rainfall which is between 900 - 1,200. Growing these species is possible in most parts of Thailand. Viriyabancha et al. (2007) studied the fast growing trees for power generation in the community. Due to 12-hour daylight, photosynthesis of plants are effective for rapid growth of fast-growth plants in short period of time. *E Eucalyptus camaldulensis* Dehn. *Acacia mangium* Wild. and *Leucaena Leucocephala* are suggested with great potential. When planted in 1x1 m. spacing, highest yield is between 21.9 to 47.5 tons of fresh/hectare/year (Viriyabancha et al., 2007). With this amount, the plantation for electricity generating is then possible.

However, to commission the power plant within the vicinity of residential community, environmental impact assessment is necessary to ensure community's quality of living, quality of surrounding environment, and sustainability. Several ways of assessments are available and Life Cycle Assessment (LCA) is currently in our interest from which the results are expressed in terms of their potential impacts including Global warming and Acidification. LCA is a measure based on the international standard ISO 14040. The assessment starts from the inventory of materials and energy used to produce designated product or activity along with its waste and corresponding emission. The results of the evaluation were converted into standardized units of $CO_{2\text{-}eq}$/kWh. This implies that the emission reduction is one of the possibilities to control the environmental impact.

Investigation by Jungmeier (2000) compared the environmental impacts of electricity generation from biomass and fossil fuel in Austria and the amount of corresponding CO_2, CH_4, and N_2O are reported. The results of the study were found that electricity generated from natural gas affected the environment 7 times than worse that generated from biomass (Jungmeier, 2000). Similar work is available in several countries such as Egypt (EI-Kordy et al., 2001) and Japan (Widiyanto, 2002). There is work in Thailand as well. Suramaythangkoor and Gheewala (2008) depicts a potential of generating electricity with the use of rice straw and assesses its life cycle in central Thailand. Annual mount of rice straw is 8.5-14.3 Mt/year. From all is burnt away, greenhouse gas (GHG) emission would be equivalent to 5.0–8.6 $MtCO_{2\text{-}eq}$/years but, if rice straw is used to produce electricity, the capacity is reported as 786-

1,325 MW of electricity. natural gas of 1 to 1.8 million meter cubic per year is then preserved which is equivalent to monetary saving of 39-66 Million US dollars per year. As a remarkable result, greenhouse gas emission of 7.8–13.2 $MtCO_{2\text{-}eq}$ per year is also reduced. Similar work is available including work by Koomey and Krause (1997).

1.2 Literature Review

1.2.1 The potential of biomass

Thailand is an agricultural-based nation. The agricultural products and wastes have high potential to be used as source for energy. According to the research of Sajiakulnukit et al. (2005), Potential of 6 biomass sources such as agricultural residual, feedstock, and waste water, etc. is reported as in Table 1.1. The use of biomass for renewable source in Thailand grows recently which support national strategy to increase the use of biomass from current value to 20.3 percent by 2022 (EPPO, 2011). Thanes et al. (2007) comparatively assessed the biomass energy potential in Thailand and the policy of energy strategy. The result of the study is shows that the agricultural residues from biomass plants and industrious waste water alone can be converted to energy and cover the target of national goal. Sugar cane and paddy are the biomass energy source with largest potential. There has been a number of biomass power plants both in private and government sectors. The information of biomass power plants in Thailand was published in August, 2011 by the National Energy Policy and Planning Office (EPPO), Ministry of Energy. Biomass-powered electricity generation is very well under the government support especially for very-small power producer (VSPP) whose generating capacity is less than 10 MW.

Table 1.1 Residue product ratio and heating value of biomass in Thailand.

Product	Residue	Moisture (%)	RPR	Energy use factor	Surplus availability factor	LHV (MJ kg^{-1})
Sugarcane	Bagasse	50.00	0.250	0.793	0.207	6.43
	Top & trash	50.00	0.302	0.000	0.986	6.82
Paddy	Husk	8.83	0.230	0.531	0.469	12.85
	Straw (top)	8.17	0.447	0.000	0.684	8.83
Oil palm	Empty bunches	8.81	0.428	0.030	0.584	16.44
	Fiber	10.11	0.147	0.858	0.134	16.19
	Shell	13.00	0.049	0.588	0.037	17.00
	Frond	48.34	2.604	0.000	1.000	7.97
	Male bunches	13.82	0.233	0.000	1.000	14.86
Coconut	Husk	12.53	0.362	0.289	0.595	14.71
	Shell	11.79	0.160	0.413	0.378	16.48
	Empty bunches	13.03	0.049	0.144	0.843	13.94
	Frond	11.21	0.225	0.159	0.809	14.55
Cassava	Stalk	-	0.088	0.000	0.407	16.99
Maize	Corn cob	8.65	0.250	0.193	0.670	16.63
Groundnut	Shell	-	0.323	0.000	1.000	11.23
Cotton	Stalk	9.33	3.232	0.000	1.000	13.07
Soybean	Stalk, leaves, shell	-	2.663	0.007	0.760	18.00
Sorghum	Leaves & stem	-	1.252	0.118	0.648	17.80

With adder incentive, there are 63 agriculture-residue-powered VSPP reported with the total 808.98 MW generations in 312 power plants. 2,515.65 MW more is in a progress of construction. However, these power plants are small and they use either gasification or steam-powered system. (EPPO, 2012).

For the provision of fuel supplies, not only agricultural residues are used but plantation of fast growing trees are also possible to ensure a feedstock. Using fast growing trees as fuel are found in many places such as India and Cambodia. Sukkasem et al. (1994) had confirmed the growth and productivity of multipurpose trees grown in Chiang Mai in the north of Thailand and identified *Leucaena Leucocephala* and *Acacia auriculiform* is as the potentials. These fast growing trees are planted with spacing of 2 x 2 m and growing within a period of three years. The results showed that *Leucaena Leucocephala* grows well and its yield reaches 62.31 ton/Hectare. They are feedstock for making pulp, using for construction, fuel wood and fodder in the dry weight of leaves, and flowers and fruit. Viriyabancha et al. (2007) reported the potential of fast growing trees to support recent Thailand's energy policy and identified *Eucalyptus camaldulensis* Dehn., *Acacia mangium* Wild., *Cassia siamea* Lam, and *Leucaena Leucocephala* as potentials. Their properties are reported in Table 1.2. The heating value and the yield range between 15.91-20.10 MJ/kg and 29.81-192.18 ton/hectare, respectively, for 1-4 year period of rotation. Velez and Valle (2007) show the figure of fast growing planted in Columbia. The study reports the influence of plantation spacing to stem size of fast growing plant. The rate of survival of *Leucaena Leucocephala* and *Eucalyptus camaldulensis* Dehn. is 85% *(*Khompis et al., 2009).

1.2.2 Application geographic Information System (GIS) and logistics

GIS are tools to analyze spatial data of the different characteristics at specific locations. The relationship of these data will be linked to the reference coordinate system with a surface area of the world (Jirakajohnkool, 2009). GIS is used for various application. For assessment of natural resource, Department of agricultural (2006) uses GIS and develop a mathematical model for rubber production in district level. The result of study was presented in a form of graphical data which can show restrictions of plantation or even productive prediction of latex on monthly basis, and the amount of expected wood ready to be utilized, etc. Rattansriwong et al. (2006) applies GIS to locate the sugar cane production in the northeast of Thailand.

Table 1.2 Species and yields of fast-growing trees.

Species	HV (MJ/kg)	yield (ton/ha)	yield (ton/rai)	Spacing (m)	Years (years)	Source
LeucaenaLeucocephala	15.91	99	15.84	1 x 1	3	Singh and Torgy (1994)
		112	17.92	0.6 x 0.6	4	Kuntong et al. (2002)
		47.5	7.6	1 x 1	1	Viriyabancha et al. (2007)
		62.31	9.97	2 x 2	3	Sukkasem et al. (1994)
*Acacia mangium*Willd.	16.72	38.1	6.1	1 x 1	1	Velez and Valle (2007)
Acacia auriculiformis	6.48	40.75	6.52	2 x 2	3	Sukkasem et al. (1994)
*Cassia siamea*Lam.	20.1	87.44	13.99	3 x 3	2	Kuntong et al. (2002)
*Eucalyptus camaldulensis*Dehn.	18.71	192.13	30.74	1 x 2	3	Kuntong et al. (2002)
		29.81	4.77		1	Arjharn et al. (2008)

Sugar cane production is then presented in graphical data. Sorawut and Rattansriwong (2006) develops the map of potential cassava production in the northeast. Data available on the map such as planting duration before harvesting, plant spacing, yield, etc. are taken into account to suggest suitable species of cassava to the other appropriate areas. Laemsak et al. (2007) creates the database of the fast growing plants areas and draws potential areas to encourage the planting fast growing trees in 19 provinces of the Northeastern Thailand. The geographic information system (GIS) was applied to collect the biomass database. According to the analysis required to evaluate and to classify graphical images, Global Positioning System (GPS) was used to collect information useful to various accordance with the references. The targeted research areas are in Tambon Udomsub of Wangnamkheo district, Nakhon Ratchasima province. The Global Positioning System (GPS) device is a surveying tool to assess the reference data which include information in a geographical map, database of economic plants and economic forest from both public and private sectors, surveying information from field work and interpretation of SPOT-4, SPOT-5 satellite photographs at a resolution of 10 meters and a map of the interpretation. The result of study found that potential areas for planting fast growing trees, Eucalyptus, is estimated as 4.03 percent of the total areas of the Northeast. The suitable area for growing those trees was the lower parts of the Northeast of Thailand because there were many supporting factors including unused areas, transport, and logistics system.

The location of the power plant has to be carefully plan as it is crucial to the construction and operations of the biomass power plant in terms of energy consumption in its logistic. In general, main factors are density of energy source and transportation systems. Krukanont and Prasertsan, 2004 studied the potential of rubber woody waste as fuel to generate electricity in the southern part of Thailand. This research offers a decision support system and relates mathematical model is formulated. The GIS was applied to suggest the rubber plantation areas. Planting areas of rubber trees is rechecked for accuracy of data by comparison with the data registered with the Rubber Research Institute, Department of Agriculture (RRIT).The main700-kilometer long highway was designated as a transport system route. The assessment relied on road networks in GIS system. The results of this study showed that 8 locations of the power plant are suggested with 186.5 MW installation as shown on Figure 1.1.

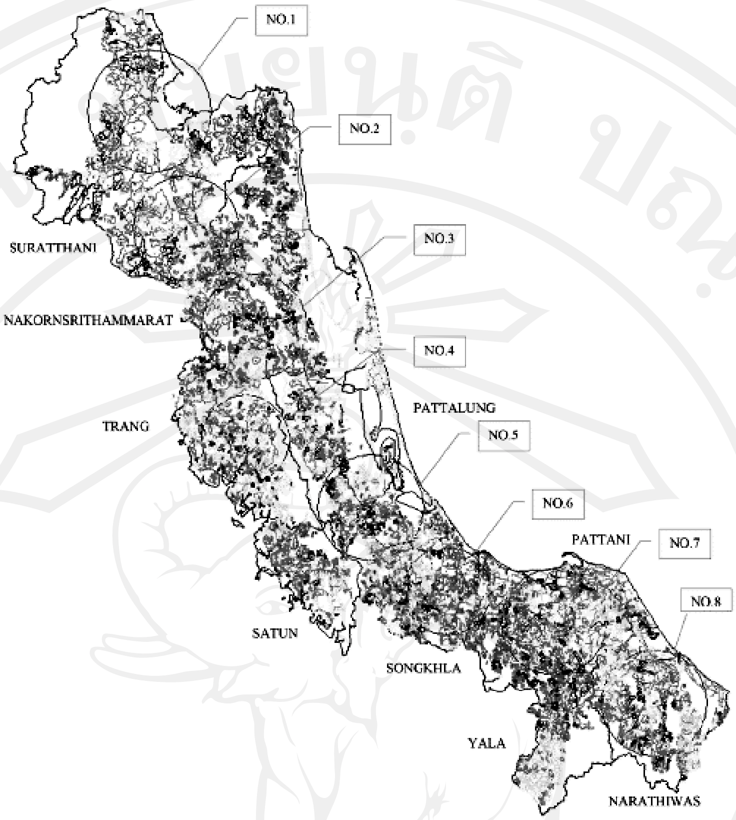

Figure 1.1 The positions result of power plant in the southern part of Thailand. (Source: Krukanont and Prasertsan, 2004)

Pheomphanbun and Emaruji (2008) had used GIS to find the appropriate location of power plant fueled by cob and used cooking in Phayao Province. The size of the power plant is suggested to be 10 MW. Caputo et al. (2005) studied the biomass as a substitute for fossil fuels to produce electrical in Italy . However, cost for electricity production the fact that from biomass is rather costly because the technology was still limited including and the overall efficiency of the system is relatively low. Biomass is seasonal and it location is distributed over large area. This research was to study the feasibility of producing electricity from biomass by the combustion process and gasification process with 5-50 MW to be installed. The economic evaluation was divided into three parts: the investment, income from the sale of electric energy, and cost of operations. The results of this study found that logistics affecting to income of the plant biomass. Logistic factors included the price of the vehicles in transport, the loading capacity of vehicle, the price of biomass, and the distribution of biomass resources. These variables must be taken into account to create the conditions of logistics making a reasonable profit.

Perpina et al. (2009) developed the strategy of the logistics and transportation of biomass. The location of power plant is determines a many biomass source varied from agriculture waste and forestry. GIS was used to provide data on the distribution of agriculture waste. The target area was divided 1 km grid. Network analysis was applied with the factors of economic, technological, environmental aspect, and social regulations. Results from this study are potential mapping and the suggested location for the power plant for community in Valencia, Spain. Rentizelas et al. (2008) carried out similar worth in Thessaly, Greece for electrification community heating and cooling. Decision support system for afferent local biomass are studied with suggested was of the return on investment (NPV). Assisted with GIS, Fiedler et al. (2007) had proposed the planning and modeling on biomass transport in the form of mathematical models. The importance of location of biomass power plant and biomass properties are also emphasizes.

Allen et al. (1988) studied the chain of supply and price of woody biomass including coppice wood, straw, and grass used as fuel for large power generation. Logistics system is crucial for supply chain management of biomass in the United Kingdom.

1.2.3 Technology for generating electricity

Two main technologies for converting solid fuel into power are gasification and the rankine system. Typically, smaller system has less efficiency than the large system as shown at Figure 1.2 (Hofbauer, 2005). Efficiency of 100 kW gas engine technology is at 26% but efficiency of 1,000 kW gas engine technology was at 32% shown at Figure 1.3

Gasification technology converts a solid fuel into gas in limited condition of oxygen. Producer gas from the process mainly compose of CO, H_2 and CH_4. This size of gasification system is in range of 10 kW to 1,000 MW. As most agriculture community has energy demand. If community-based power plant is to be established, small downdraft gasifier is suitable option. (Basu, 2010).

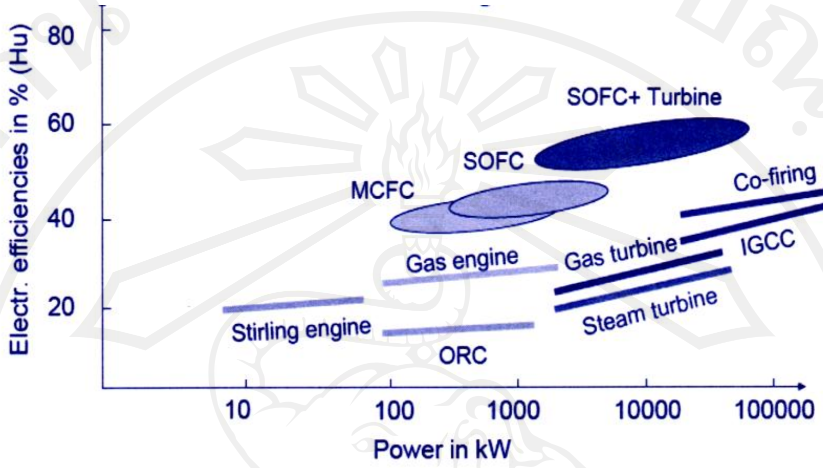

Figure 1.2 Comparison of electrical efficiencies of different technology (Source: Hofbauer, 2005)

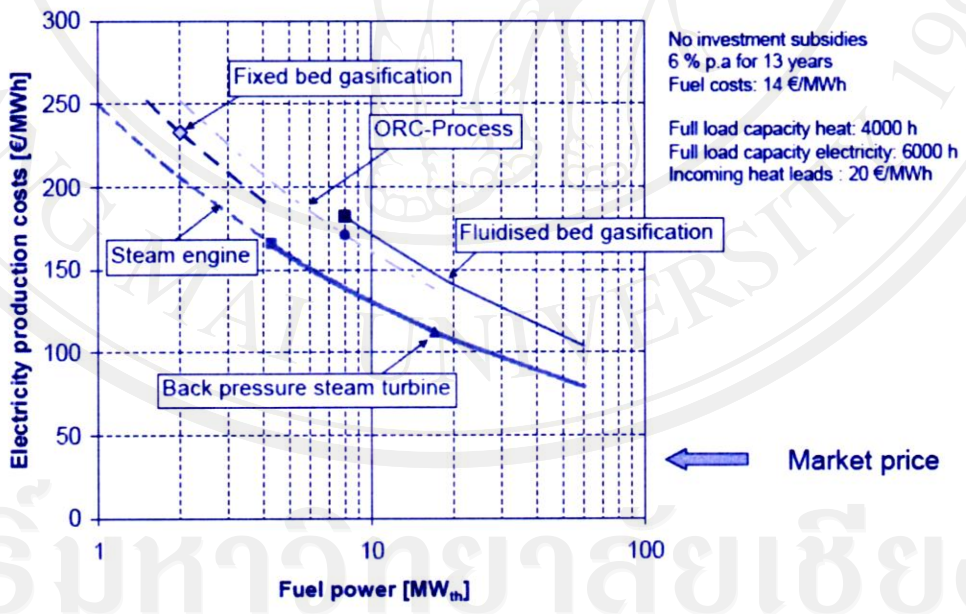

Figure 1.3 Electricity production costs of different power. (Source: Hofbauer, 2005)

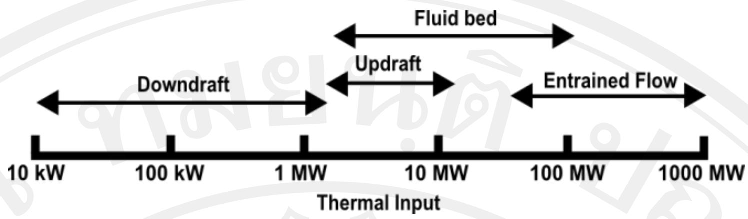

Figure 1.4 Range of applicability for biomass gasifier types**.** (Source: Basu, 2010)

The system cost is report as 0.8 to 1.5 million dollars/1 MW. The operation of the system requires expertises. Gasification technology research and development is commonly found in Thailand. Waewsak et al. (2007) designed and built gasification system using husk and sawdust from rubber wood processing industry in Phatthalung. 10 kW downdraft gasifier with generation is built along with mathematical models. Fuel's moisture content of 15%, input rate of 20 kg/hr are prescribed. The result of the study found that the system could produce gas fuel with components of 14 % of CO, 16.2% of CO_2, 2% of CH_4, 26.9% of H_2 and heating value of fuel gas at 5,382 kJ/Nm^3. For larger installation, Great Agro (2010) is interested in electricity generation from rice husks residues from the mill, based on the concept of zero waste for the community. The capacity is 200 kW_e. Gasifier is designed as 3-staged system. Generated electricity is utilized on location and also sold. It is also report that domestic gasifier cost half of the imported. The efficiency of performance system is approximated to 25%. The total investment in the construction system was 2.91 million baht. The system operates for times 24 hours a day and 300 days/year. The overall efficiency of the gasifier is reported to be highly suitable for power production systems in community (McKendry, 2002).

Performance of the gasifier was determined by the quality of syngas components. Each fuel type affected the quality of the fuel gas. Rajvanshi (1986) analyzed the composition of the syngas by downdraft gasification system. Agricultural waste materials such as rice husk, corn and woody had been tested. The component of syngas with heating value of fuel combustion was between 3.25 - 7.20 MJ/m^3. Other details were shown in Table 1.3.

Table 1.3 Composition of syngas from various fuel burning

Fuel	Gasification method	Volume Percentage					Calorific Value MJ/m^3
		CO	H_2	CH_4	CO_2	N_2	
Charcoal	Downdraft	28-31	5-10	1-2	1-2	55-60	4.60-5.65
Wood with 12-20% moisture	Downdraft	17-22	16-20	2-3	10-15	55-50	5.00-5.68
Wheat straw pellets	Downdraft	14-17	17-19	-	11-14	-	4.50
Coconut husks	Downdraft	16-20	17-19.5	-	10-15	-	5.80
Coconut shells	Downdraft	19-24	10-15	-	11-15	-	7.20
Pressed Sugarcane	Downdraft	15-18	15-18	-	12-14	-	5.30
Charcoal	Downdraft	30	19.7	-	3.6	46	5.98
Corn cobs	Downdraft	18.6	16.5	6.4	-	-	6.29
Rice hulls Pelleted	Downdraft	16.1	9.6	0.95	-	-	3.25
Cotton stalks cubed	Downdraft	15.7	11.7	3.4	-	-	4.32

(Soure: Rajvanshi, 1986)

However, the choice of appropriate technology to the local biomass fuels is important. The form of the fuel downdraft gasification was used to determine the characteristics of the fuel for each consisted of following parameters: energy content of the fuel, bulk density, moisture content, dust content, tar content, ash and slagging characteristic. For example, woody fuel should processed into wood blocks with 5 cm, a density of 256 kg/m^3 and this wood fuel was put into downdraft gasification. Tar content and ash content were 3.24 g/m^3 and 0.2%, respectively. The preparation of fuel above was excellent. Details are shown as Table 1.4.

Small power plant with the production capacity of 100 kW for a community was imported. Arjharn et al. (2009) studied the power plants used biomass fuel from the local area of Nakorn rachasima provice. 80 kW open top downdraft gasification biomass Gasification technology was installed and tested for optimum operation. Producer gas consisted of 18-22% Of CO, 18-20% of H_2, and 1-2% of CH_4 and yields average heating value of 4.5 to 5.5 MJ/m^3. 1.34 kg (15%MC)of wood chip is used for kWh of electricity The total efficiency to correct the biomass into electricity is 17.31% and from the gas is 46.45% and the cost of electricity equal to 3.25 Baht/kWh, which was close to the purchase price of the Thai government (NEPO, 2011).

Table 1.4 Gasification characteristics of various fuel.

Fuel	Treatment Bulk density Moisture (m.c)	Tar Produced (g/m^3)	Ash Content %	Gasifier	Experience
Alfalfa straw	Cubed 298 kg/m^3 m.c.=7.9%	2.33	6	downdraft	No slagging, some bridging
Bean Straw	Cubed 440 kg/m^3 m.c.=13%	1.97	10.2	downdraft	Severe slag formation
Barley straw (75% straw; 25% corn fodder and 6% orza binder)	Cubed 299 kg/m^3 m.c.=4%	0	10.3	downdraft	Slag formation
Coconut shell	Crushed (1-4 cm). 435 kg/m^3 m.c. = 11.8%	3	0.8	downdraft	Excellent fuel. No slag formation
Coconut husks	Pleces 2-5 cm, 65 kg/m^3	Insignificant tar coconut	3.4	downdraft	Slag on grate but no operational problem
Corn cobs	304 kg/m^3 m.c. = 11%	7.24	1.5	downdraft	Excellent fuel. No slagging
Corn fodder	Cubed, 390 kg/m^3 m.c. = 11.9%	1.43	6.1	downdraft	Severe slagging and bridging
Cotton stalks	Cubed, 259 kg/m^3 m.c. = 20.6%	5	17.2	downdraft	Severe slag formation
Peach pits	Sundried, 474 kg/m^3 m.c. = 10.9%	1.1	0.9	downdraft	Excellent fuel. No slagging

Table 1.4 Gasification characteristics of various fuel (continued).

Fuel	Treatment Bulk density Moisture (m.c)	Tar Produced (g/m^3)	Ash Content %	Gasifier	Experience
Peat	Briquettes, 555 kg/m^3 m.c. = 13%	-	-	downdraft	Severe slagging
Prune pits	Air dried, 514 kg/m^3 m.c. = 8.2%	0	0.5	downdraft	Excellent fuel
Rice hults	Pelleted, 679 kg/m^3 m.c. = 8.6%	4.32	14.9	downdraft	Severe slogging
Safflower	Cubed, 203 kg/m^3 m.c. = 8.9%	0.88	6.0	downdraft	Minor slag formation
Sugarcane	Cut 2-5 cms, 52 kg/m^3	Insignificant	1.6	downdraft	Slog on hearting Bridging
Walnut shell	Cracked, 337 kg/m^3 m.c. = 8%	6.24	1.1	downdraft	Excellent fuel. No Slagging
Walnut shell	Pelleted.	14.5	1.0	downdraft	Good fuel
Wheat straw	Cubed, 395 kg/m^3 m.c. = 9.6%	-	9.3	downdraft	Severe slagging, Bridging, Irregular gas production
Wheat straw and Corn stalks	Cube (50% mix) 199 kg/m^3 m.c.= 15%	0	7.4	downdraft	Slagging
Wood blocks	5 cm cube 256 kg/m^3 m.c. = 5.4%	3.24	0.2	downdraft	Excellent fuel
Wood chips	166 m^3 m.c. = 10.8%	6.24	6.26	downdraft	Severe bridging And slagging

(Source: Rajvanshi, 1986)

1.2.4 Life cycle cost (LCC) and Life Cycle Assessment (LCA)

Design of construct a power plant generally is based on the economic aspect of the project and depends a number of factors such as payback period and expected unit cost of electricity. The cost assessment is determined in several ways and the common approach is to evaluate the life cycle cost. Life Cycle Cost Analysis (LCC) is determine the total production cost of electricity throughout the project. Rukvichian (1999) estimation of the electricity cost of photovoltaic (PV) in Thailand was achieved by LCC. The objective is to determine the efficiency of the system, and potential feasibility of economic and social impact of the system. LCC was applied to estimate the cost of the system with lifespan of 20 years. LCC of the PV system was reported as 35.58 Baht/kWh, which is relatively expensive. Similarly, Arjharn et al. (2009) analyzed the cost of electricity from biomass 100 kW power plants for the community as woody fuel plantayion of fast growth tree is used as fuel. The cost of electricity had been found that it was 2.5 baht/kWh more than70-80% is the cost of biomass feed into the system, Mahapatra and Dassappa. (2012) carried out the study between LCC of electricity generated from decentralized renewable energy sources and grid extension. Systems of power generation compared were off-grid solar photovoltaic, biomass gasifier based power generation and conventional grid extension for remote village. Those are considered from their benefits of reducing carbon emissions. The cost of electricity of off-grid solar photovoltaic is the highest in all cases. Carbon dioxide emission factor of biomass gasifier is reported as 0.81 kg/kWh. The biomass gasifier system is maintained with higher cost than the conventional grid.

However, the condition of living for the communities surrounding the power plant should be factored into the decision of power plant project too, even in the remote area which is far away from the grid. With this reason, LCC analysis is not enough for generating electricity to be used in the community. Adding the consideration for environment the analysis will reveal the environmental impact from all activities involved in electrification. Assessment of environmental impacts is evaluated in several ways. Life Cycle

Assessment (LCA) is one of the methods that are generally accepted. The assessment of environmental impact when the impact is converted to economic value called externality cost which will directly reflect to the cost in order to reach sustainable development. Example of study of the externality cost are found a number of previous investigations. In Egypt, El-Kordy et al. (2001) used the LCC and LCA on the generation of electricity from various fuels. All electricity costs were included with externality resulted from plant's emissions. Environmental impacts and environmental costs were shown in Table 1.5 and the LCC of power generation plant types shown in Table 1.6. It reveals that cost of solar energy is the highest due to the initial investment. The cost of electricity from fossil fuels is the lowest and better than wind energy converter. This is when externality cost is excluded. However, when the cost of electricity includes the environmental cost, it is more expensive than the cost of electricity from wind energy. Widiyanto et al. (2002) conducted the LCA and LCC of electricity in Japan. Jungmeier (2000) had assessed life cycle and also the environmental impacts of energy generating from biomass and fossil fuel in Austria. This study was based on ISO 14040 to compare the greenhouse gas (GHG) from various technologies in $CO_{2\text{-}eq}$/kWh. The results found that the use of biomass fuels produces less greenhouse gas than that of fossil fuels. Environmental impact in terms of $CO_{2\text{-}eq}$/kWh of woody fuel conversion is reported as low as one-seventh of the impact from nature gas conversion.

Table 1.5 External cost ($/kWh) of renewable fuel power plants.

Pollutant type	Externality($/kg)	Emissions (g/MWh)	
		PV	wind energy converters
SO_x	5.666	126.124	19.575
NO_x	2.294	115.603	62.76
TSP	3.306	7.457	2.074
CO_2	0.018	68,600	18,060
External cost ($/kWh)		0.00224	0.00059

Source : EI-Kordy et al. (2001)

Table 1.6 Cost Factors and Life Cycle Cost for Different System (cent/kWh).

System	Cost Factors and Life Cycle Cost (Cent/kWh)					
	Capital Cost	Maintenance Cost	Fuel Cost	Externality Cost	Total Cost No External	Total Cost with External
Conventional Steam Fuel Oil Fired	0.5969	0.1371	0.8924	3.8328	1.5928	5.4256
Conventional Steam Natural Gas Fired	0.4974	0.1217	0.7843	1.0496	1.3804	2.43
Gas Turbine Diesel Oil Fired	0.751	0.5124	1.6318	2.5829	2.8438	5.4266
Gas Turbine Natural Gas Fired	0.751	0.5124	1.2918	1.5047	2.5038	4.0085
Combined Cycle Natural Gas Fired	0.5333	0.2797	0.6977	0.8749	1.4807	2.3555
Photovoltaic	13.3515	1.1817	0	0.1792	13.782	13.9612
Wind Energy Converter	1.6689	0.1865	0	0.0469	1.7616	1.8085

Source : EI-Kordy et al. (2001)

Similarly, the research of Pamela et al. (1998) compared the environmental impact of electricity generation by fuel, coal and biomass fuels in terms of emissions of carbon dioxide. The results showed the emissions is 46 g/kWh from the biomass electrification. As biomass is from plants which survive from its photosynthesis from which the carbon dioxide emission is recycled back. This is arguably the net zero emission. Surmaythangkoor Gheewala (2008) assessed the potential of rice straw to generate electricity in the central region of Thailand. LCA was applied to determine the greenhouse gas (GHG emission). The result of study shows that rice straw has the potential to produce energy from 8.5-14.3 Mt/year. The environmental impact in terms of GHG reduction is reduced is emphasize the fact that reduced from 7.8-13.2 $MtCO_{2\text{-}eq}$/year. These previous studies, electricity generated from renewable energy posed less environmental impact than the electricity from the fossil energy. Similar is due from Koomey and Krause (1997). They suggested to use of the results were found that studied system had emissions of sulfur dioxide, which is very high environmental cost. The solution of this problem was to prevent the environment from pollution by installation equipments or devices, or removal of pollutants. Increased costs were environmental costs taken into account. In this study, the environmental cost was equal to the cost of removing sulfur dioxide (Flue Gas Desulfurization Equipment).

Sundqvist and Soderholm (2002) reviewed the externality cost research in the during 1988-2000 and suggests that the popular method of evaluating the impact was mostly bottom-up damage cost approach since 1995. The calculation of damages or consequent damages was done as function of the impact occurring in the different damage function and impact pathway. Electricity generated by fossil fuels particularly oil and coal would send out more externality cost than other renewable fuels. Externality cost was mainly studied in civilized countries especially in Europe. For developing countries, it was found very few.

Sundqvist (2002) reported that externality cost of the biomass was the lowest value at 0 US cents/kWh and the maximum value at 22.09 US cents/kWh. Full detail was shown in Table 1.7 Externality cost was found that the wider differences as a result of the methodology and factors, so the externality cost was determined by the limitation of the range by cutting the maximum and minimum value of data distribution to the level of 25% as shown in Figure 1.5. The distribution of each externality was narrow to show the closeness of the results of studies. In generally, the application of mathematical average (Mean) must have no difference in the quality of the data, so the average of externality cost of electricity generation by different fuels levels was in 0.31-14.04 US cents/kWh.

Reference the previous studies of Externality cost is necessary to adjust the externality cost reasonable and consistent with condition of the country. Adjustment to reflect the differences is done in many ways such as national income, gross national product (GDP).

Table 1.7 Range of external cost estimates in power generation.

(US Cent/kWh)	Coal	Oil	Gas	Nuclear	Hydro	Wind	Solar	Biomass
Min	0.004	0.03	0.003	0.0003	0	0	0	0
Max	67.72	39.93	13.22	64.45	26.26	0.88	2.2	22.09
Difference	16930%	1331%	441%	214833%	-	-	-	-
Mean	14.01	12.32	4.61	7.12	3.36	0.31	0.84	4.95
Median	6.38	9.11	2.62	0.81	0.32	0.32	0.76	2.68
Std. Dev.	15.99	12.45	4.58	16.96	7.59	0.24	0.74	5.57
N	36	20	31	21	16	18	11	22

Sources: Sundqvist and Soderholm (2002).

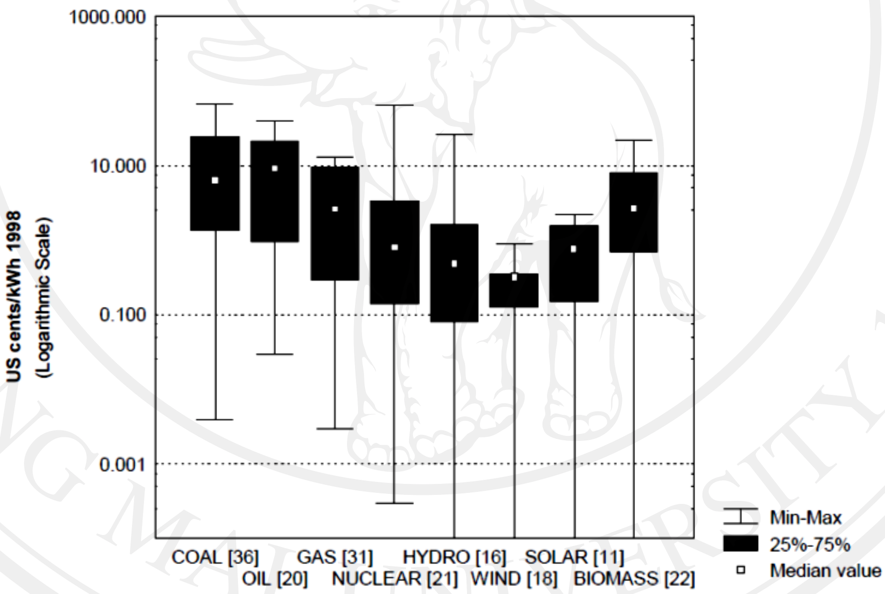

Figure 1.5 Range of external cost estimates in power generation

(Sources: Sundqvist, 2002)

Vorayos (2005) applied the externality cost to evaluate the ethanol solar distillation system throughout the life cycle of the system. The external costs or environmental impact cost were included in the life cycle cost (LCC) due to the aspect of sustainable development as:

$$LCC = C_{pw} + M_{pw} + F_{pw} + R_{pw} - S_{pw} + X_{pw}$$

Where C_{pw} is capital cost, M_{pw} is operating and maintenance costs, F_{pw} is fuel costs, R_{pw} is replacement costs, S_{pw} is salvage value and X_{pw} is externalities cost and subscript $_{pw}$ is present worth. The externalities result from the harmful impact on the environment. It can be estimated from the quantity of emissions and their monetization as:

$$X = \sum (C_i x\ VED_i)$$

Where: C= amount of emission (kg) VED = Value of environment damage of substance i (baht/kg)

The Externality cost in Thailand has been studied. Sakulniyomporn et al. (2011) assumed reference the externality cost of power generation of the country .The database was based on the period between 2006 and 2008. Externality cost was accessed by impact pathway approach which health-based assessment. The main criteria pollutants considered in the analysis comprised of sulfur dioxide (SO2), nitrogen oxides (NO_X), and particulate matter (PM). Externality cost is found and shown in Table 1.8.

Table 1.8 Specific health damage cost per ton of emitted pollutants (US$/ton).

Fuel type	SO_2	PM_{10}	NO_x
All types	3,767	5,883	286
Coal	3,718	3,964	296
Lignite	1,775	2,084	259
Oil/gas (w/o FGD)	6,379	6,637	348
Oil (W/o FGD)	11,463	11,773	403
Oil (with FGD)	994	1,058	98
Diesel	5,832	2,316	163
Gas	5,438	6,405	302

Source: Sakulniyomporn et al. (2011)

Also, in Thailand, Ministry of Finance has been preparing Act. of economic instruments for environmental management. Pollution tax must be collected from the industry sectors in reference of its releasing water (BOD and total suspended solids) and of air pollution (SO_2, NO_x, and total particulate). The aims were to control pollution affected to environmental impact. The proposed pollution tax is shown Table 1.9.

Table 1.9 The pollution tax of draft of Act of economic instruments for environmental management.

pollutant	minimum (Bath/ton)	maximum (Bath/ton)
SO_2	1,000	2,000
PM10	1,500	2,500
NO_x	1,000	2,000

Source: Ministry of Finance, 2012

Hence, the purpose of this study is to analyze the feasibility of producing electricity in small communities considering the impact to the environment, electricity cost, sources of fuel and the logistic effect. Potentials includes fast-growth wood plantation and biomass waste in designated local area as a case study. Selected technologies are either small downdraft gasification or small rankine system.

1.3 Objective of the Present Study

The objectives of the research program are:

1.3.1 To analyses the potential of biomass in the form of graphical (spatial) map and their attributes.

1.3.2 To develop a community-scale electricity generation model from biomass under constraints of logistics, technology, cost and environment impact.

1.4 Scope of the Study

1.4.1 To establish a energy center for appropriate power capacity of the community in the north of Thailand at least 1 province with quantity potential of biomass from agricultural waste.

1.4.2 To apply the GIS to evaluate the optimal location for the plant in term of logistic management and the cost of electricity.

1.4.3 The steam power system and biomass gasification were technologies considered for electricity generation, both of which have a power capacity less than 10 MW (VSPP Very Small Power Producer) covered by the Provincial Electricity of Authority (PEA).

1.4.4 The environmental impact of the electricity generated was assessed by LCA.

1.5 Benefit of this Study

1.5.1 The application of GIS can be used to guide the analysis of the biomass potential.

1.5.2 The results can be used to guide management of the logistics for the collection of biomass for energy production and related factors.

1.5.3 The results can be used to help the gasification system and the steam power system for small communities as well as to improve the overall efficiency of these systems.

1.5.4 The results can be used to promote renewable energy in the form of biomass fuel, which is a priority of the government to help solve the current energy crisis.

1.5.5 The result can be used to make information decisions and to compare the alternatives with regards to the energy cost and the total cost of environmental impact.