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Economic analysis of anaerobic digestion—A case of 3 MW Electricity Generation from Wastewater, Decanter cake and Elephant Grass of Palm Oil Mill industry in Thailand

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ABSTRACT

The main objective of this study is to analyze economical possibility of 3 MW electricity generation power plants fuelled by biogas produced from 3 types such as the wastewater, decanter cake and elephant grass from palm oil industry by discount rate on investment in case of non subsidy and 20% subsidy. The analysis includes capital investment, operation costs, profitability and revenues of the very small power plant, where, this scenario analysis is carried out based on the data from the survey sample palm oil mill to identify possibility project that optimize electricity production. This economic performance biogas plant based on NPV, IRR and PBP concepts. The findings of the analysis indicate that HCD system of the wastewater is financially feasible. The results obtained indicate a positive NPV and acceptable IRR and a PBP of less than 5 years and it's generally no cost. The CSTR co-digestion of decanter cake can yield an IRR of approximately 11.3% but PBP more than 14 years. Elephant grass biogas system is impossible. The analysis suggests that industrial that further support mechanisms from the government in terms of investment subsidies, soft loan, crop pricing scheme and special subsidies of feed in tariff (FIT) of adder are financially crucial to project survival.

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INTRODUCTION

Biogas is a renewable energy which is known as a potential alternative to fossil fuel. It is deemed as a vital alternative energy for Thailand. So far, factories, farms, communities and companies with capacity to produce biogas have been encouraged and supported to install biogas system for heat and electricity generation as alternative to oil and natural gas consumption. These endeavors, under the responsibility of Energy Policy and Planning Office (EPPO) (2014) and Department of Alternative Energy Development and Efficiency (DEDE) (2014), have proven to be a great success. Therefore, the AEDP determines that within 2021, 600 megawatt (MW) of electricity, 1,000 ktoe of heat should be generated from biogas and Excluding Elephant grass 3,000 megawatt (MW) and Compressed liquid gas (CBG) 1,200 tons/day Twarath (2012).

Presently, a number of factories, farms, communities and companies nationwide have already installed the biogas production system to provide alternative source of energy. To ensure effective monitoring and evaluation, there is a strong need for updated information on status and potentials for biogas production. A centralized and modern information and database system for biogas production will enable effective formulation of policy, strategy, guidance and measures to enhance efficient use of biogas as well as optimizing promotion of available alternative energy. Consequently, DEDE has created information and database system which monitors and evaluates the production of biogas in all facilities nationwide to keep pace with biogas generation status (produced amount of energy, amount serving as alternative energy for electricity and heat generation). Under this database, a report has been set to report energy production potential from all sources as following, RSU (2014),

1) Waste / wastewater from industry
2) Waste / wastewater from livestock and other similar farm.
3) Food waste / waste / sewage from communities and other establishment.
4) 8 types of agricultural waste, straw, leaves and stems of sugarcane leaves, corn leaves, bean leaves

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and stems, cassava roots, empty fruit bunch, pineapple and rubber scrap.

5) Energy plant, for example, elephant grass grown in vacant land or communal land used by communities such as deserted paddy fields, abandoned farm and natural grassland

Currently biogas steadily increases and stimulates several vital researches and development which is directly attributed EPPO (2014) and DEDE (2014).

In this study , simple feasibility of 3 MW electricity generation is Thailand is the very small power producer (VSPP) from Electricity Generating Authority of Thailand: EGAT (2011). This biogas plant are the Hybrid channel digester (HCD) of wastewater from palm oil plant and Completely Stirred Tank Reactor (CSTR) co-digestion of decanter cake and elephant grass with wastewater, lots of wastewater from palm oil industry are available as main feedstocks for biogas, however some wastewater are preferable as watering agricultural areas for the palm oil plant. The decanter cake is wasted form palm oil plant are available as outgrowth materials, however some decanter cake are preferable food for farm animals. Elephant grass is growing form neighborhood area, Overview of the Wastewater, Decanter Cake and Elephant Grass in Palm Oil pant is presented in Fig.1. these is represented a new energy crop which offers prominently high yield annually (90-120 tons fresh per 1600 m^3-year or equivalent to 227.6 - 303.5 tons fresh per acres-year) RSU (2014).

Elephant grass for calculation, it can be used directly for mono digestion and co-digestion with wastewater mixed. Otherwise, growing elephant grass is environmental benefits because of the reduction of agricultural inputs. Nevertheless biogas technology is considered to be appropriate with the climate in Thailand. Completely Stirred Tank Reactor: CSTR anaerobic digester is broadly used especially in the country where waste management is provided. Peer literature studied methane potential from grass silage depending on characteristics of grass species and location of source. The results showed that methane potential (CH_4) from grass varied values; it is depended form type of reactor or scale of research and feedstock mixed. So biogas from energy crops like elephant grass may be concluded that, Phichi (2014)

- Methane Yield (280 m^3 CH_4/ ton-vs) (VS is valentine solid)
- 1 ton of fresh elephant grass contains 204 kg VS, where VS 1 ton shall contain 4.9 tons fresh elephant Grass. Therefore, 4.9 tons fresh of elephant grass can produce 280 m3 methane or can produce bio gas for = 280/0.55 = 509 m^3

In addition, related research investigated efficiency and economic analysis of thermophilic CSTR anaerobic digester in treating swine wastewater. The results verified the comparison between thermophilic CSTR operated at high efficiency other available systems. The economic analysis showed that CSTR operated with solely swine wastewater was not economically feasibility in pilot scale due to low organic loading rate. It would rather operate with stuff that holds high organic loading rate such as straw and grass ERDI (2012).

The aim of this study is to assess biogas production simple feasibility for small-scale 3 MW electricity generation from Hybrid channel digester (HCD) of wastewater from palm oil plant , and CSTR of anaerobic co-digestion of decanter cake and elephant grass with wastewater. The analysis includes capital investment, operation costs, profitability and revenues of the very small power plant. Eventually suggestion will be made on subsidy supporting scheme such as subsidy, Adder for financial survival of the projects such as net present value (NPV), Internal rate return (IRR)and payback period (PBP).

Fig. 1: Overview of the Wastewater, Decanter Cake and Elephant Grass in Palm Oil Mill plant RSU (2013)

1. *Process methodology:*

2.1 Overview of the biogas system form palm oil mill:

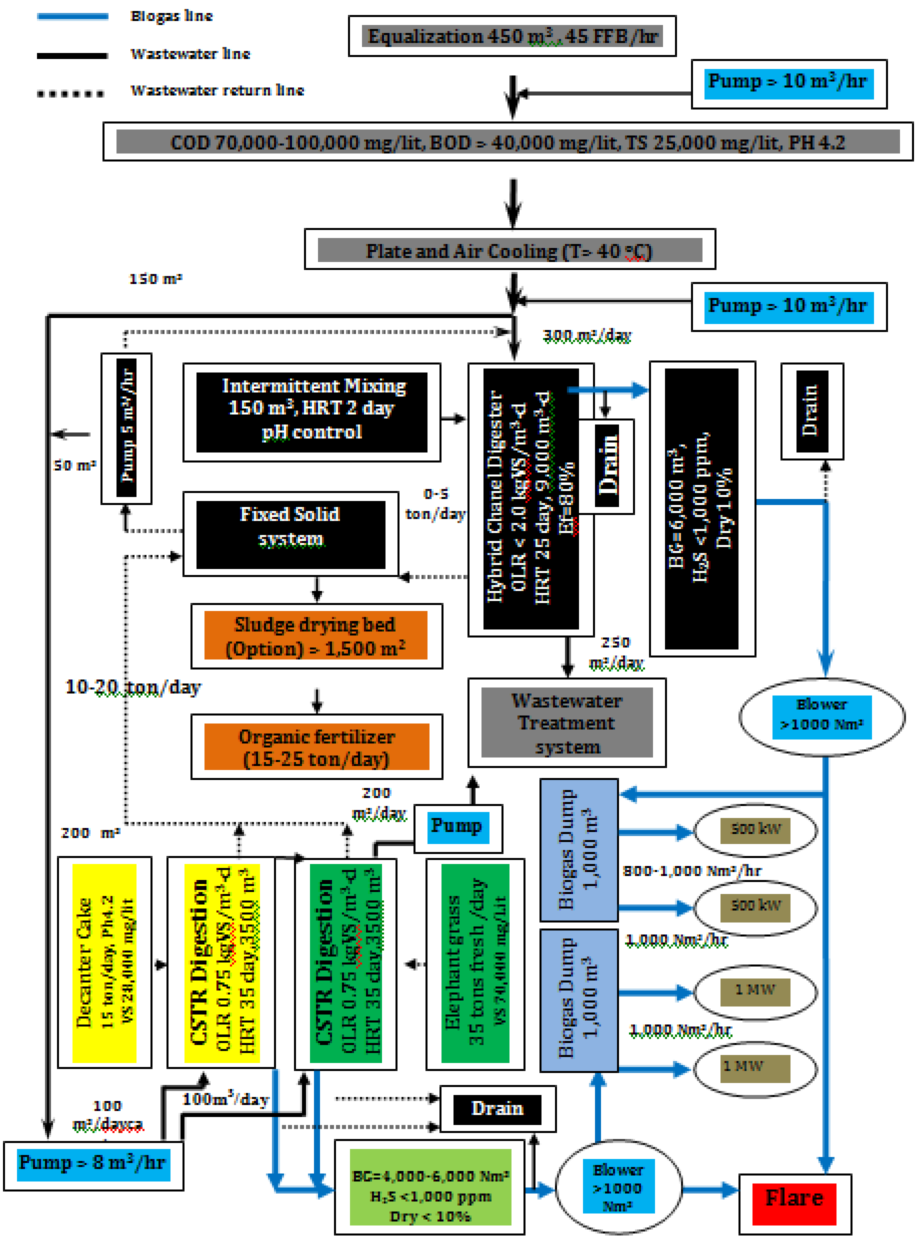

Fig. 2: Overview of the biogas system form palm oil mill industry.

(Hybrid channel digester and CSTR digester) and the electricity generation process RSU (2013) Assessing a feasibility of small-scale electricity generation from 2 scenarios of anaerobic co-digestion system, the first scenario is an anaerobic hybrid channel digester (HCD) (9,000 m^3) of wastewater from palm oil mill plant, it may be concluded the calculation parameters that, 300 m^3/day (COD 70,000-100,000 mg/lit, BOD > 40,000 mg/lit, TS 25,000 mg/lit, PH 4.2), for HCD system, OLR < 2.0 kg.VS/m^{3}-day HRT 25 day Efficiency 80%, biogas generation = 8,000 Nm3 (CH_4 <55%), H_2S<1,000 ppm, H_2O < 10%. As the second scenario are completely stirred tank reactor (CSTR) co-digestion (3,500 m^3) of decanter cake (15 tons/day, VS 28,000 mg/l, pH 4.2) and elephant grass (35 tons fresh/day, VS 70,000 mg/l) respectively with wastewater from palm oil mill plant 150 m^3/day, and from HCD system about 50 m^3/day, these may be concluded the calculation parameters that, OLR < 0.75 kg.VS/m^{3}-day, HRT 35 day, Efficiency 70%, biogas generation = 4,000-6,000 Nm^3 (CH_4 <55%), H_2S<1,000 ppm, H_2O < 10%. Overview of the Biogas and electricity generation process is presented in Fig.2.

Initial process of financial analysis in this study are investigation and construction estimation from engineering drawing of biogas production system of palm oil mill wastewater [6] and to quote standard cost from Ministry of Energy, Thailand by Energy Policy and Planning Office (EPPO)(2014), where Energy Research and Development Institute-Nakornping Chiang Mai University (ERDI)(2012) is a research, design system and project management previously ERDI (2012) and [10]. Properties of elephant grass, wastewater of palm oil, decanter cake and elephant grass were analyzed of DEDE. Operating conditions and processes input/output used in this work are suggested by ERDI (2012).

In case, 3 MW generator are installed to work with Volumetric of HCD = 9,000 m^3 (1 MW) and Volumetric of CSTR = 7,000 m^3 (2 MW) proposed and invested by the somewhere palm oil mill plant in Thailand. Consequently, the information above would contribute the capital investment, annual cost, and revenues. These values are continued to analyze the project feasibility with the basic methods for considering the present worth method, the internal rate of return method, and the payback period method Sullivan (2013) which underlying the financial assumptions. Overview of the electricity generation process is presented in Fig.2.

1.2 Assumptions on Biogas Production from HCD Digestion and CSTR Co-Digestion:

The amount of daily input of wastewater of palm oil mill plant, decanter cake and elephant grass are quoted and derived from DEDE (2014), where properties of feedstocks are tested. In addition, anaerobic (HCD, CSTR) co-digestion in completely construction biogas plant is carried out there to acquire the optimized sizing and condition to increase highest biogas yield. A 3,000 kW-biogas generator model which 1.2 kWh/Nm^3 of biogas generation consumption rate is specified for 3-8 hours operation in this study. Operational parameter of anaerobic HCD, CSTR plants are presented in Table 1.

Table 1: Operation parameters from Palm oil mill industrial 45 ton FFB/hr of Wastewater, Elephant Grass and Decanter Cake biogas plant of 3 MW electricity capacities, RSU (2013)

Operational Parameters	HCD digestion (1MW) Palm Oil mill Wastewater	CSTR digestion (1 MW) Elephant grass	CSTR digestion (1 MW) Decanter Cake
Feedstock Input	• 300 m^3/day from palm oil mill industry	• 35 tons /day fresh Elephant grass	• 15 tons /day Decanter Cake
Biogas System	• OLR 2.0 kg.VS/m^{3}-day • HRT 25 day • Eff = 80%	• OLR 0.75 kg.VS/m^{3}-day • HRT 35 day • EF = 70%	• OLR 0.75 kg.VS/m^{3}-day • HRT 35 day • EF 70%
Digester Volume	• 9,000 m^3	• 3,500 m^3	• 3,500 m^3
Accessories Biogas System	• Intermittent Mixing by pump (150 m^3/day@4) • Scrum jet	• stirred blade 10kW@3 • Premix Tank 250 m^3 • Fixed solid system	• stirred blade 10kW@3 • Premix Tank 250 m^3 • Fixed solid system
Accessories Biogas	• Scrubber & Dump	• Scrubber & Dump	• Scrubber & Dump
Input co-Digestions (wastewater)	-	• 75 m^3/day from palm oil mill industry • 25 m^3/day from HCD	• 75 m^3/day from palm oil mill industry • 25 m^3/day from HCD
Biogas Production	• 6,000 Nm^3	• 2,000-3,000 Nm^3	• 2,000-3,000 Nm^3
Plant factor (4-8 hr)	• 39%	• 12.5%	• 12.5%
BG Engine-Gen eff.	• 35%	• 35%	• 35%
Electricity	• 7,200 kWh/day	• 3,000 kWh/day	• 3,000 kWh/day
Digestate	-	• 35 tons/day (wet)	• 15 tons/day (wet)
Operating Days	• 330 days	• 330 days	• 330 days

2.3 Assumption on Financial Analysis:

The capital investment of 9,00+7,000 m^3 volumetric of HCD-CSTR co-digestion comprises of construction cost, machinery cost, and biogas generator cost. Feedstocks include, elephant grass (700 THB/ton of fresh), decanter cake of palm oils (250 THB/ton of wet wastewater of palm oil), and liquid waste (as a by-product of waste is at no cost). Annual costs include biogas plant operation and maintenance, generator maintenance and labor costs are 4.5% and 1.5% of total investment respectively. Annual revenues organic fertilizer sales are 100 THB/ton of digestate (elephant grass & decanter cake) RSU (2014). In the Old Regulations, revenues from electricity sales supply to the grid according to Electricity Generating Authority of Thailand: EGAT to purchase electricity from VSPPs at TOU rate during peak period at 3.80 THB/kWh including Ft and during off peak period at 2.00 THB/kWh including float time (Ft) and additional purchasing price or adders are set at 0.50 THB/kWh applied through the first 7 year of project service life Sullivan (2013). But in this feasibility study used average value of new regulations, revenues from electricity sales supply to the grid basic feed-in tariff (FIT_{new}) is 5.35 THB/kWh during applied through the first 7 year of project service life by except for the value of peak period, the off peak period and adders . Key assumptions of this study include 20 years project life span at 7.0% discount rate EGAT (2013).

Discussions:

Table 2 shows variable of capital investment and revenues. These tables illustrate that incremental revenue such as total investment costs, total annual costs and total annual revenues. As for non subsidized projects, the results obtained indicate a impossible net present value and unacceptable the internal rate of return and the payback period of more than 20 years and it's generally cost of decanter cake and elephant grass. This digestate of CSTR co-digestion needs investment subsidy more 20% of its capital investment while wastewater of HCD digestion does not percentage of its capital investment for financial viability. Nonetheless, nonsubsidized projects but they offer good feed-in tariff and adder; both projects are able to achieve financial viability with 10-20 % (FIT_{new}) reduction from input material cost Projects have certainly undergone variable capital investment and revenues and it is necessary to consider couple factors. Rules and suggestions of projects financial analysis of the very small power producer (VSPP) were established by EPPO (2014) and DEDE (2014). Its context imposes the government project specification of internal rate of return at 9-12%. The most stable system of non subsidy is the project of wastewater of HCD digestion Therefore, it is considered internal rate of return at 57% and payback period is 4.5 year, in this project is possible biogas system from palm oil mill industry (owner 100%). This project gets involve with this regulation when takes 20% of investment subsidy combines with the feed-in tariff (FIT_{new}) of revenues, As a result, the PBP is less than 4.5 year and it is the most stable system, whereas CSTR co-digestion project takes 20% of investment subsidy combines also with it is the most stable project growth of revenues. As a result, the payback period and net present value is remaining risk system, it is the unstable project.

The verification strongly suggests to promote renewable energy in country, the government world subsidize at least 20% of the capital only investment for decanter cake CSTR co-digestion and elephant grass co-digestion respectively. It also clearly shows favorable payback period may be within 7-9 years. If the construction such as structural-civil, mechanical-sanitation systems, electrical- control with EPC is managed by owner (Palm Oil Mill Industry), as the result of reduce investment cost may be more than 20% and help to reduce the simple payback period. It is estimated that producing 3 MW of renewable energy is the resulted in environmental, it is approximately equivalent to reducing 1.95 tones of CO_2 emissions, it was established by EPPO (2014) and DEDE (2014). We may install biogas plants in area side of palm garden (palm sector) where gas or electricity is not available and feedstock is presented in large amount. However, the anaerobic co-digestion process may result in increased nutrient value in the digestate. Therefore, approval from Thailand Environment Agency and more testing during land application may be required.

Considering wastewater HCD system and decanter cake with elephant grass CSTR co-digestion in assumed commercial scale of non subsidy, the cash flow indicates internal rate of return 29.9 % with project payback period more than 13.62 years whereas the commercial scale of 20 % subsidy (owner 80%) wastewater HCD system and decanter cake with elephant grass CSTR co-digestion , The cash flow determines internal rate of return 20.19 % with project payback period more than 10.9 years. Similarly, these indications are not economic acceptability. Reconsidering each project cash flow, it is found that material costs are quite high compared to the other annual costs. Thereby besides the sensitivity analysis of capital investment and revenues, it is necessary to account sensitivity analysis of input material cost as well. Economic power plant of cash flow general financial of non subsidy is illustrated in Table 3 and Table 4.

Table 2: Economic power plant of general financial of both scenarios RSU (2013) RSU.

Parameters	Value (million THB)		
	HCD digestion Palm Oil Mill Wastewater	CSTR digestion Elephant grass	CSTR digestion Decanter Cake
Investment costs (owner)			
• Structural and Civil	8.00	5.00	5.00
• Mechanical and sanitation systems	13.00	9.00	7.00
• Electrical and control	3.00	3.00	3.00
• Gas Engine VS Gen	10.00	10.00	10.00
• Gas treatment system	5.00	5.00	5.00
• Consult	2.85	3.41	2.55
• 7% VAT	3.15	2.59	2.45
Total investment costs	45.00	37.00	35.00
Annual costs			
• Input material/year	0.00	8.09	1.24
• Biogas plant O&M/year	2.03	1.67	1.58
• Labor/year	0.68	0.56	0.53
Total annual costs	2.71	10.32	3.35
• Annual revenues			
• Electricity sales (5.35 THB/kWh)	12.71	5.30	5.30
• Organic fertilizer sales/year	0.00	1.16	0.50
Total annual revenues	12.71	6.46	5.80

Financial Analysis (owner 100%) • Simple Net present value (NPV) • Simple Internal Rate Return (IRR) • Simple Payback Period (year)	66.0 57.33 % 4.50	- - -	12.33 11.43 % 14.29
Total Financial Analysis (owner 100%)			
• Net present value (NPV) • Simple Internal Rate Return (IRR) • Simple Payback Period (year)	81.37 29.91 % 13.62		
Total Financial Analysis 20% subsidy			
• Net present value (NPV) • Simple Internal Rate Return (IRR) • Simple Payback Period (year)	68.3 27.48% 3.6	29.3 7.51 % >20	
Total Financial Analysis 20% subsidy			
• Net present value (NPV) • Simple Internal Rate Return (IRR) • Simple Payback Period (year)	97.7 20.19% 10.90		

Conclusion:

The typical simple payback for a biogas plant may be about six years as long as the existing government incentive program is available and biogas energy is produced continuously without interruption except for scheduled regular maintenance. Even though anaerobic co-digestion is a very old process, implementation of this process successfully on the commercial scale for producing energy is still evolving. Emergency shut down in the process shows that the technology and process related knowledge still have to improve. Despite these drawbacks, the potential for gases energy trading and increased consumer awareness regarding practicing environmentally (wastewater/waste) and sustainable agricultural (elephant grass) production methods will certainly add to the benefits of continuing to work with this technology.

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Table 3: Economic 3 MW biogas power plant of general wastewater, elephant grass and decanter cake.

Assumptions :	Value	Unit
Total Project Costs	117,000,000.00	Baht
(exclude Land & Development cost)		
Debt Leverage	100.00	%
Interest Rate	7.00	%
Tenor of Loan	7.0	Years (+1 year Grace period)
Plant Factor	30.14	%
Sale Price per kWh	5.3500	Baht
Construction Period	1.0	Year
Interest During Construction (IDC)	4,095,000.00	Baht
Annual EE (net) Production	4,356,000	kWh/year
Elephant grass consumption per year	11,550	Tones
Elephant grass supply Price per ton	700	Baht

Table 4: Cash Flow Analysis 3 MW biogas power plant of wastewater, elephant grass and decanter cake, the discount cash flow method was used to find out the IRR.

Project Expenses\Year		0	1	2	3	4	5	6
• Estimated Interest during construction period	4,095,000							
• Interest Expenses		7,458,750	6,288,750	5,118,750	3,948,750	2,778,750	1,608,750	438,750
• Loan Payment		16,714,286	16,714,286	16,714,286	16,714,286	16,714,286	16,714,286	16,714,286
• Total Expense	4,095,000	24,173,036	23,003,036	21,833,036	20,663,036	19,493,036	18,323,036	17,153,036
• Project Income								
• Electricity Sales Income		23,304,600	23,304,600	23,304,600	23,304,600	23,304,600	23,304,600	23,304,600
• Total Income		23,304,600	23,304,600	23,304,600	23,304,600	23,304,600	23,304,600	23,304,600
• Cash Flow	-4,095,000	-868,436	301,564	1,471,564	2,641,564	3,811,564	4,981,564	6,151,564
• Accumulated Cash Flow	-4,095,000	-4,963,436	-4,661,871	-3,190,307	-548,743	3,262,821	8,244,386	14,395,950
• IRR								
• Discount factor	0.935	0.873	0.816	0.763	0.713	0.666	0.623	0.582
• NPV (at DF)	-3,827,103	-758,525	246,166	1,122,649	1,883,399	2,539,806	3,102,268	3,580,266
• Project Expenses\Year	8	9	10	11	12	13	14	15

• Estimated Interest during construction period								
• Interest Expenses								
• Loan Payment								
• Total Expense	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
• Project Income								
• Electricity Sales Income	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00
• Total Income	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00
• Cash Flow	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00
• Accumulated Cash Flow	37,700,550.00	61,005,150.00	84,309,750.00	107,614,350.00	130,918,950.00	154,223,550.00	177,528,150.00	200,832,750.00
• IRR								
• Discount factor	0.544	0.508	0.475	0.444	0.415	0.388	0.362	0.339
• NPV (at DF)	12,676,158.30	11,846,876.91	11,071,847.58	10,347,521.11	9,670,580.47	9,037,925.68	8,446,659.51	7,894,074.31
Project Expenses\Year	16	17	18	19	20			
• Estimated Interest during construction period								
• Interest Expenses								
• Loan Payment								
• Total Expense								
• Project Income								
• Electricity Sales Income	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00			
• Total Income	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00			
• Cash Flow	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00	23,304,600.00			
• Accumulated Cash Flow	224,137,350.00	247,441,950.00	270,746,550.00	294,051,150.00	317,355,750.00			
• IRR								
• Discount factor	0.3166	0.2959	0.2765	0.2584	0.2415			
• NPV (at DF)	7,377,639.54	6,894,990.22	6,443,916.10	6,022,351.49	5,628,365.88			

REFERENCES

Energy Research and Development Institute-Nakornping Chiang Mai University (ERDI), Biogas Production from Anaerobic Digestion of Elephant grass and Poultry Wastewater of palm oil, ERDI Internal Report.

Energy Research and Development Institute-Nakornping Chiang Mai University (ERDI), 2012. Biogas Production from Anaerobic Digestion of Elephant grass and Swine Waste, ERDI Internal Report.

Energy Research and Development Institute-Nakornping Chiang Mai University(ERDI), 2012. Studying Optimization of Biogas Production from Various Types of Grass in Thailand, ERDI Internal Report.

Energy strategy, 2014. Energy Policy and Planning Office (EPPO), Ministry of Energy, Thailand, Department of Alternative Energy and Efficiency (DEDE), 2014. Ministry of Energy, Thailand.

Nizami, A.S., A. Orozco, E. Groom, B. Dieterich and J.D. Murphy, 2012. How much gas can we get from grass?. Applied Energy, 92: 783-790.

Phichi Tinsuntisook, 2014. From Jatropha to Napier Grass: The Difference Is Policy, 2014 MODERN MANUFACTURING MAGAZINE, February, 11(132): 68-70.

Ransit University (RSU), 2014. Final Report, The Study of Compatibility and Guideline of Biogas Production, Department of Alternative Energy and Efficiency [DEDE], Ministry of Energy, Thailand.

Sullivan, W., E. Wicks, J. Luxhoj, 2013. Engineering Economy. 12th ed., Pearson Education, December, 2013. (U.S.A), Electricity Generating Authority of Thailand (EGAT), 2011.

Twarath Sutabutr, 2012. Alternative Energy Development Plan : AEDP 2012-2021, International Journal of Renewable Energy, 7(1): 1-10.