www.serd.ait.ac.th/reric

Bio-ethanol in Thailand: A Life Cycle Assessment

J. Martchamadol* and A. Dutta[+1]

Abstract – *Thailand has a plan to supply 3.0 million liters per day of ethanol to replace MTBE (methyl tertiary-butyl ether) in Unleaded Gasoline 95 and to substitute some Unleaded Gasoline 91 by the end of year 2011. Presently, 45 ethanol factories have received the permit from the National Ethanol Board to produce ethanol as a fuel with the total capacity up to 11.115 million liters per day. However, there still exist a number of limitations; such as raw material supply, raw materials price, yield of ethanol production, efficiency of conversion technology etc.*

In this research, a life cycle assessment (LCA) of bio-ethanol production through three possible routes was made. In each route, it estimated the energy consumptions and emissions during the processes; which included farming, conversion, transportation and vehicle operation stages. The feedstocks used for this study were sugarcane, cassava, and lignocellulosic materials.

It was found that bio-ethanol production from sugar feedstock with 80 Bar co-generation (steam and electricity) system using bagasses as the fuel provide the best result in term of reduction in fossil fuels consumption compared to cassava feedstock for all the cases studied under this research. In addition, these scenarios provided the added benefit of CO_2 reduction due to the use of biomass for electricity and steam production. However, emission of N_2O, VOC, CO, NOx, PM10, and SOx are higher compared to conventional gasoline.

For the case of bio-ethanol productions from lignocellulosic materials (herbaceous and woody), it was found that a fermentation process with electricity co-production provide the best result in terms of less fossil fuels consumption and less emission compared to other cases investigated. Even though, it showed the negative impacts by increasing VOC, CO, NOx, and PM10, compared to conventional gasoline but predict a positive result on GWP and SOx reduction.

Keywords – Bio-ethanol, energy crops, energy and emissions, LCA, lignocelluloses.

1. INTRODUCTION

Thailand has a plan to supply 3.0 million liters per day of ethanol to replace MTBE (methyl tertiary-butyl ether) in Unleaded Gasoline 95 and to substitute some Unleaded Gasoline 91 by the end of year 2011 [1], [21]. Presently, 45 ethanol factories have received the permit from the National Ethanol Board to produce ethanol as a fuel with the total capacity up to 11.115 million liters per day [2].

Presently, fermentation process is mainly used in Thailand. The feedstocks used for this process are sugarcane, cane molasses and cassava, which are also considered as food crops [1], [21]. This is one of the reasons for companies facing the problems with sustainable supply of raw materials, and a consistent raw materials price. The other barriers that companies still facing are, yield of ethanol production, and efficiency of conversion technology.

Of late, a number of researchers propose lignocellulosic materials as being one of the potential raw materials for ethanol production. The use of lignocellulosic materials is expected to provide the benefits as non-food crops, short-cultivation and harvesting cycle, requires less agrochemical or fertilizer inputs, and utilizes biomass waste to energy [3]. Researchers proposed a number of pathways to produce the bio-ethanol from lignocellulosic material such as; fermentation of cellulosic biomass through hydrolysis process, fermentation of cellulosic biomass through gasification/pyrolysis process. As the result, agri-residues could be used as feedstock for bio-ethanol production, which are not limited to only sugar or starch crops [3], [4], [5].

To identify and propose the suitable pathway for bio-ethanol production in Thailand, one needs to analysis all the possible pathways in term of total energy consumption and emissions during the bio-ethanol production processes such as farming, conversion, transportation and vehicle operation stages.

Nakarit et al. [7] reported that ethanol production from molasses is not suitable in terms of net energy for the existing case in Thailand. They have reported that to produce a liter of anhydrous ethanol (99.5%), it consumes 40 MJ energy which is more than the calorific value of ethanol (about 21 MJ/liter). Recently, Nguyen *et al.* [8], [9] has conducted the same for ethanol production from cassava. They have reported a positive net energy value is 10.22 MJ/liter (labor energy not included) for the existing case of Thailand.

In this research, life cycle analysis for energy consumptions and emissions of two possible pathways for bio-ethanol production were performed by using the modified GREET version 1.7 model [6]. The first pathway considered the fermentation process for both sugar cane and cassava as the raw materials. The second pathways considered the synthetic bio-ethanol production through

---

[*] Energy Field of Study, Asian Institute of Technology, PO Box 4, Klong Luang, Pathumthani 12120, Thailand.

[+] Engineering Department, Nova Scotia Agricultural College, PO Box 550, Truro, Nova Scotia, B2N 5E3, Canada.

[1] Corresponding author;
Tel: +1 902 893 6711; Fax: +1 902 893 1859.
E-mail: adutta@nsac.ca

hydrolysis process from lignocellulosic materials (woody and herbaceous). The gasification/pyrolysis process and synthesis ethanol by bacteria is the interesting process but it in the state of research and development. Therefore, in this study does not evaluate this process [4], [6].

2. METHODOLOGIES

Consolidated bio-processing involved hydrolysis, fermentation, cellulase production, and separation to produce biofuel.

2.1 Assumptions

Main keys assumption for calculating and evaluating energy consumption and emissions are provided in Table 1.

Distance covered by truck for transportation and distribution of fertilizer was estimated as 480 km. In case of sugarcane, cassava and lignocellulosic material (LM), this distance was estimated as 100 km.

Cargo payload of heavy-duty trucks for all biomass and fertilizers were considered as 20 tons and 23 tons; respectively.

In conversion stage, energy consumption and emissions were calculated based on efficiency of production process or conversion factor or secondary data as shown in Table 1. Some conversion processes produce steam and/or electricity as co-product. The energy and emission values of those were deducted from the total energy consumption and emissions.

The distance for conversion plant to refueling pump was estimated as 600 km radius with 25 tons cargo payload of heavy-duty truck.

In vehicle operation stage, the passenger car of 10.54 km per gasoline equivalent liter was used. The benefit on low SO_2 and CO_2 credit were accounted for blended ethanol in gasoline (called “gasohol”).

The consumption of primary and secondary energy was important for calculating energy consumption and emissions of ethanol, and conventional gasoline (CG). Low sulfur diesel (LSD) was considered as the secondary fuel which is mainly used for transportation purpose as shown in Figures 1, 3 and 4.

The average resources for electricity generation in Thailand are residue oil 6.30%, natural gas 72.90%, coal 17%, biomass 3.8%, and others 0.1%. Therefore, total energy consumption and emissions of electricity production are based on the conversion efficiency of each type of power plant [10], [20].

Moreover, crude oil, conventional gasoline, conventional diesel, residue oil, and natural gas were imported. The average distances for ocean tank transportation were calculated from the main exported countries to Thailand [11], [12]. And also pipeline is the main means of transporting natural gas from Thai’s gulf which is estimated as 2,652 km [13].

2.2 Output of the Analysis

The output of the analysis was separated in two sections. First is Well-to-Pump (WTP) analysis. The boundary of this analysis encompasses biomass farming, transportation, bio-ethanol processing and transportation to the refueling pump. The second is Well-to-Wheel (WTW) analysis. The boundary of that analysis encompasses the Well-to-pump and vehicle operation analyses [6].

At present, E10 (10% of ethanol blended in 90% of gasoline) is available at the refueling pump in Thailand. Therefore, WTW analysis was done for E10 and it was compared with conventional gasoline.

Table 1. Conditions for LCA evaluation

No.	Raw Material	Process/Technology	Co-product
Base case	Crude oil	Oil refinery	No
1st Case	Sugarcane	Fermentation	No
2nd Case	Sugarcane	Fermentation	Electricity at pressure 20 Bar from bagasse
3rd Case	Sugarcane	Fermentation	Electricity at pressure 80 Bar from bagasse
4th Case	Cassava	Saccharification and Fermentation	No
5th Case	Cassava	Saccharification and Fermentation	Electricity generation from biogas of solid waste
6th Case	Cassava	Saccharification and Fermentation	Steam generation from biogas and solid waste
7th Case	Woody	Hydrolysis and Fermentation	Electricity
8th Case	Herbaceous	Hydrolysis and Fermentation	Electricity

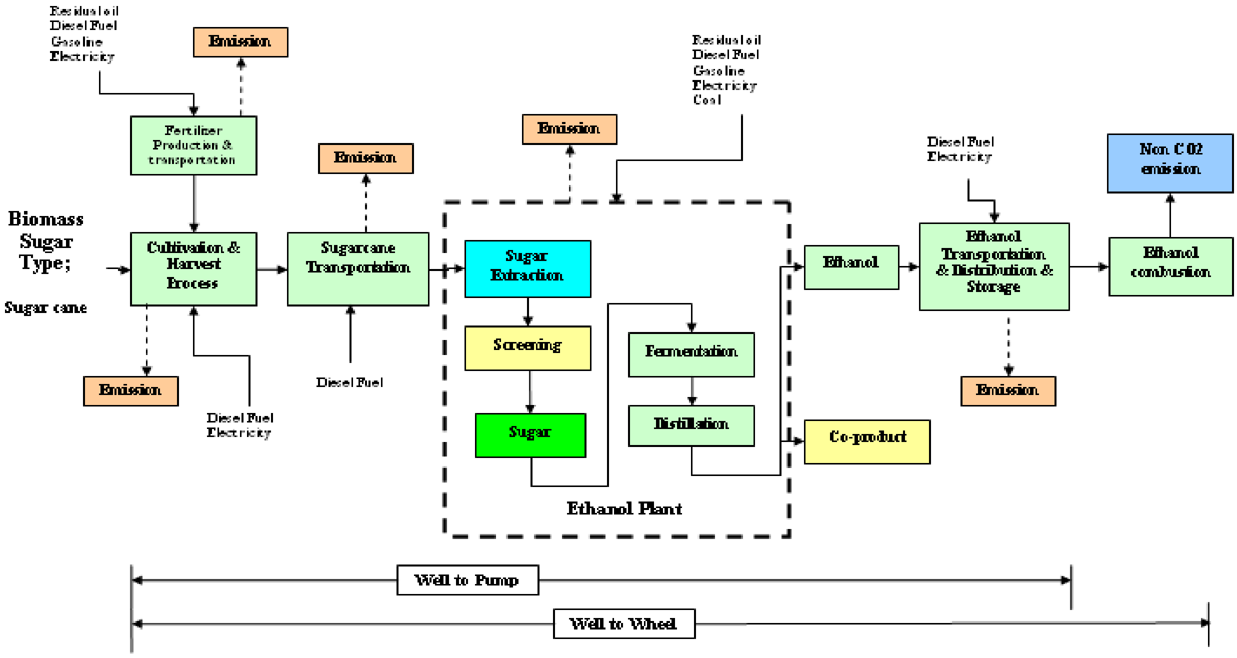

Fig. 1. Bio-ethanol production from sugarcane by fermentation process

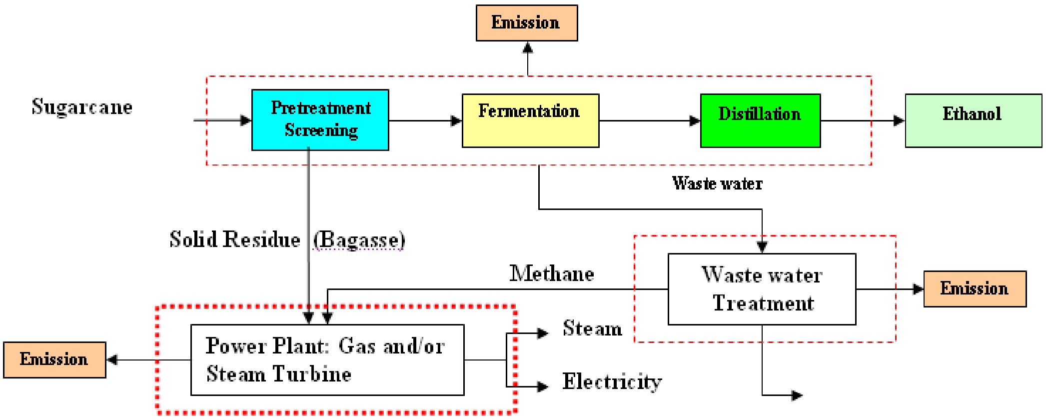

Fig. 2. Flow diagram of ethanol production from sugar through biological process with heat and electricity cogeneration

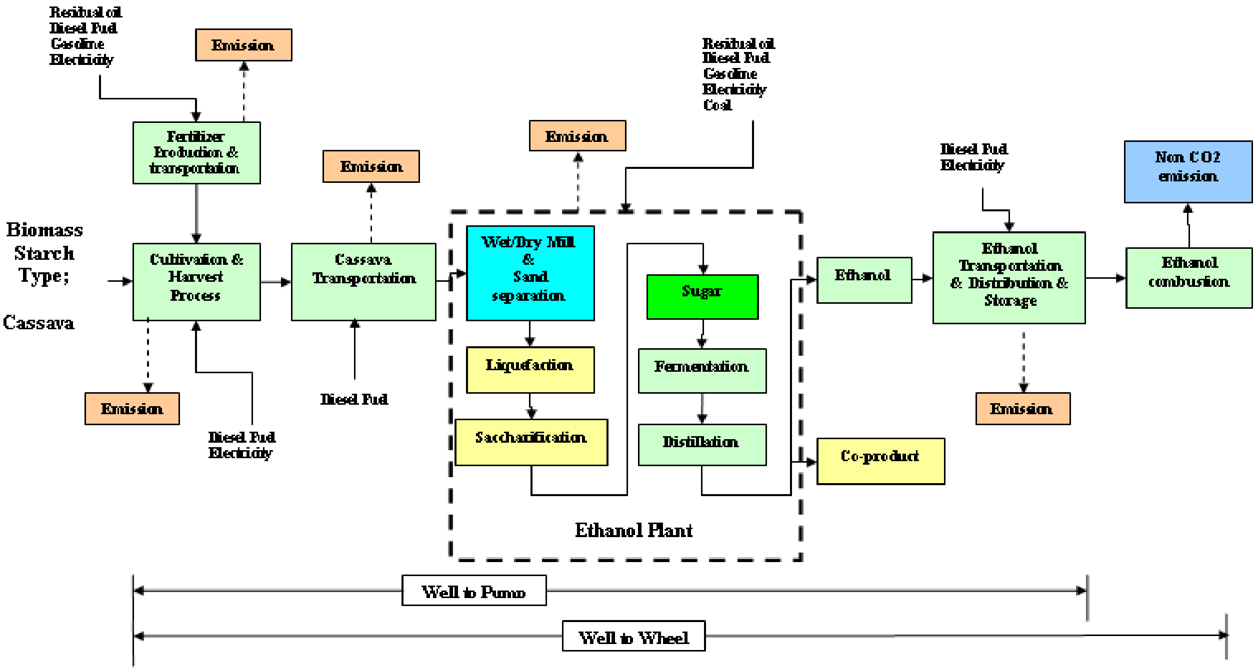

Fig. 3. Bio-ethanol production from cassava by hydrolysis and fermentation process

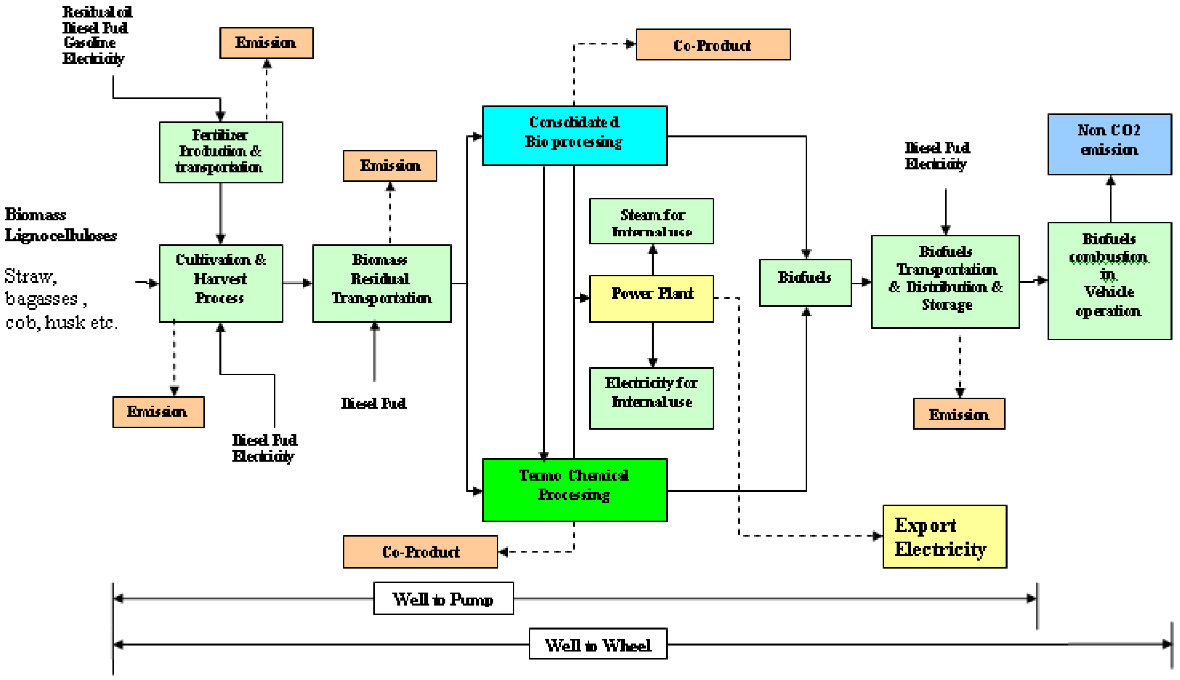

Fig. 4 Boundary for biofuel Production from cellulosic biomass (Source: Wu M.et.al., 2005)

Table 2. Scenario control and key input parameters of feedstock for ethanol production

Feedstock for Ethanol Production	Sugar cane per dry ton	Cassava per dry ton	Woody Biomass per dry ton	Herbaceous Biomass per dry ton
N_2O Emissions: N in N_2O as % of N in N fertilizer	1.50%[6]	1.50%[6]	None	None
Farming Energy Use: MJ	19.90[7]	243.63[26]	None	None
Fertilizer Use				
Grams of Nitrogen	1,500[7]	2,500[14]	None	None
Grams of P2O5	1,500[7]	1,167[14]	None	None
Grams of K_2O	1,500[7]	3,000[14]	None	None
Grams of Herbicide	40[7]	-	None	None
Grams of Insecticide	-	-	None	None
CO2 emissions from land use change (grams)	-48,500.00[6]	-48,500.00[6]	-112,500.00[6]	-48,500.00[6]
Harvest period	10-12 months[15]	8-12 months[14]	None	None
Energy Use for Ethanol production: MJ/liter	16.27[7],[15]	15.55[19]	30.9[6]	22.2[6]
Ethanol yield: liters per dry ton of biomass	69.99[16]	180.00[16]	340.69[6]	359.61[6]
Biogas Credit: MJ/liter of ethanol		-1.79[16]		
Solid waste Credit: MJ/liter of ethanol		-8.67[16]		
Electricity credit: kWh per liter of ethanol		-0.24[16]	-0.30 [6]	-0.15 [6]
pressure 20 Bar	-0.32[17]			
pressure 80 Bar	-1.71[18]			

Remark:
1. The Electricity generation mix (Thailand Case) was displaced by co-produced electricity in biomass-based EtOH plants for export.
2. Woody Biomass and Herbaceous Biomass were considered as residues. Therefore energy consumption and emissions at farming stage were not counted.
3. Biogas was produced 0.08 m^3/liter of ethanol and CV of biogas is 65% of CH_4 =22,400 kJ/m^3 (DEDE, 2006)
4. Energy of solid residue = 0.088(RPR) * 17,736.55 (MJ/ton of cassava) / 180 (liter of ethanol per dry ton of cassava) = 8.67 MJ/ liter of ethanol

3. RESULTS AND DISCUSSION

This section presents the results of the analysis of each case mentioned in Table 1. The results for Well-to-Pump (WTP) analysis are shown in Tables 3, 4, 5, and 6.

3.1 Energy Consumption of Well-to-Pump Bio-ethanol Production

The analysis on energy consumptions in unit of MJ per million MJ of ethanol for all pathways (eight cases) and conventional gasoline (CG) found that;

- Cases 1st, 2nd, 4th, 5th, 7th, and 8th were found to be consuming energy higher than 1 million MJ for producing 1 million MJ of ethanol. The main source of this energy consumption was from fossil fuel except for the cases of 7th and 8th (renewable energy from biomass residues) is the main source. Therefore, case 7th and 8th show significantly reduction of fossil fuel consumption.
- Cases 3rd and 6th are consuming energy lower than 1 million MJ for producing 1 million MJ of ethanol. The main source of total energy consumption is from fossil fuel, and more than 50% of fossil fuel consumed is petroleum.

The WTP efficiency (Table 3) of all cases (1st-8th case) is lower than CG. This is because biomass is difficult to transport compared to liquid or gas and consume more energy. As an example, 20 tons of sugarcane / truck consumed energy 5,210.2 MJ which only produce 1,400 liters of ethanol.

Table 3. WTP efficiency of bio-ethanol production in different pathways and conventional gasoline (CG

Case	Base	1st Case	2nd Case	3rd Case	4th Case	5th Case	6th Case	7th Case	8th Case
WTP efficiency	78.72%	27.89%	41.18%	54.90%	43.76%	45.86%	57.09%	41.23%	48.67%

Note: WTP Efficiency = $10^6 / (10^6 + \text{Total WTP energy consumption})$

3.1.1 Specific Analysis for Sugarcane

The 3rd case (Sugar: Electricity Production at pressure 80 Bar) consumes the lowest energy compared to other cases of sugarcane feedstock (1st case and 2nd case) as shown in Table 4. This is because bagasse can generate steam and electricity for the conversion process and the excess electricity can be exported to the grid. This case results in reduction in fossil fuel consumption for electricity and steam generation in ethanol plant. It is the one option to improve the WTP efficiency from 28% up to 55%. However, fossil fuels (mainly petroleum) consumed in this case is higher than CG. This is because transportation stage consumes 78% of total petroleum consumption.

3.1.2 Specific Analysis for Cassava

Cassava with biogas co-production (6th case) consumed the lowest energy and less fossil fuels compared to other cases of cassava feedstock (4th case and 5th case) as shown in Table 5. The main reason is that during conversion process of ethanol from cassava, steam consumption is 51.4% compared to electricity, which is only 19% (base on Lurgi technology). Therefore, using biogas and solid waste for steam generation significantly reduce fossil fuel consumption and improve the overall WTP efficiency from 44% up to 57%.

However, fossil fuels (mainly petroleum) consumed in this case is higher than CG. This is because ethanol production process consumes 44.5%, cassava farming consumes 22%, and transportation consumes 32% of total petroleum consumption.

3.1.3 Analysis for Woody and Herbaceous Biomass

Ethanol production from woody biomass (7th case) and herbaceous biomass (8th case) by fermentation process consumed higher energy; more than 4.3 and 2.9 times of CG energy consumption respectively (Table 6). However, this co-energy mainly comes from biomass residue and solid waste from the process itself. As the result, these pathways can help to reduce fossil fuel consumption significantly about 100% and 93% respectively.

3.2 Emissions of Well-to-Pump Bio-ethanol Production

The analysis shows that VOC, CO, NOx, and PM10 of all ethanol production pathways are higher than CG production, because of following reasons;

- Fossil fuels are the main energy sources of all stages of ethanol production. Therefore, the emissions from this quantity of fossil fuels are accounted.
- Even though, some pathways use the concept of waste to energy utilization such as 2nd, 3rd, 5th, 6th, 7th, and 8th case but the emission factor of biomass combustion is higher than residue oil (VOC, CO, CH_4, N_2O) [6]. As the result, it produces more of those emissions.

The 3rd, 6th, 7th and 8th cases give the benefit on the reduction of SOx, CH_4, and CO_2 because of the utilization of solid waste and agriculture residue for producing energy and supply that energy in the ethanol production process. However, higher N_2O is produced during farming stage because of fertilizer used.

Table 4. Summary of energy consumption and emissions: WTP bio-ethanol production from sugarcane compare to CG

	Base case	1st Case	2nd Case	3rd Case
	Energy consumption (MJ/mmMJ)			
Total energy	270,254	2,584,951	1,428,163	821,368
Fossil fuels	238,496	2,525,389	1,375,754	796,841
Petroleum	122,939	1,271,926	294,441	257,800
	Emission (kg/mmMJ)			
VOC	26.107	63.022	55.005	50.498
CO	18.525	104.801	77.031	57.473
NOx	46.143	358.508	183.898	144.459
PM10	6.882	104.877	55.535	34.308
SOx	21.371	404.927	181.667	120.442
CH_4	100.182	269.131	165.185	89.126
N_2O	0.593	28.412	27.736	26.701
CO2	17,217	152,490.142	61,537.852	22,205.103
VOC: Urban	15.227	17.134	15.211	14.601
CO: Urban	5.798	17.397	14.664	9.699
NOx: Urban	17.302	38.608	32.596	23.618
PM10: Urban	0.913	1.791	1.329	0.830
SOx : Urban	10.018	36.881	29.015	14.578

Table 5. Summary of energy consumption and emissions: WTP bio-ethanol production from cassava compare to CG

	Base case	4th Case	5th Case	6th Case
	Energy consumption (MJ/mmMJ)			
Total energy	270,254	1,285,134	1,180,501	751,650
Fossil fuels	238,496	1,266,085	1,166,256	732,977
Petroleum	122,939	826,447	820,073	318,007
	Emission (kg/mmMJ)			
VOC	26.107	60.519	80.384	61.785
CO	18.525	105.149	398.673	156.219
NOx	46.143	283.151	701.58	352.16
PM10	6.882	61.466	106.753	69.371
SOx	21.371	152.594	157.899	149.521
CH4	100.182	123.168	124.879	82.136
N2O	0.593	17.97	60.313	25.903
CO2	17,217	80,805	74,553	77,623
VOC: Urban	15.227	15.62	15.515	14.686
CO: Urban	5.798	9.55	8.694	8.717
NOx: Urban	17.302	24.07	22.522	22.002
PM10: Urban	0.913	0.962	0.876	0.781
SOx : Urban	10.018	14.718	12.23	12.338

Table 6. Summary of energy consumption and emissions: WTP bio-ethanol production from woody and herbaceous compare to CG

	Base case	7th Case	8th Case
	Energy consumption (MJ/mmMJ)		
Total energy	270,254	1,425,506	1,054,518
Fossil fuels	238,496	-16,404	16,275
Petroleum	122,939	92,579	68,760
	Emission (kg/mmMJ)		
VOC	26.107	39.968	38.254
CO	18.525	83.68	62.956
NOx	46.143	137.466	103.535
PM10	6.882	19.562	18.335
SOx	21.371	-6.779	-1.854
CH4	100.182	-3.816	1.011
N2O	0.593	10.568	7.906
CO2	17,217	-15,720	-4,540
VOC: Urban	15.227	13.428	13.379
CO: Urban	5.798	3.051	3.301
NOx: Urban	17.302	10.199	10.325
PM10: Urban	0.913	0.163	0.189
SOx : Urban	10.018	-2.112	-0.768

3.3 Gasohol (E10): Well-to-Wheel

This section represents the result of energy consumption and emissions for Well-to-Wheel analysis. Total energy consumption (MJ/km) and emissions (grams/km) are calculated by weighted average method of different amount of bio-ethanol blended in CG. CO_2 emission is calculated by including CO_2 credit on burning bio-ethanol, which is based on the percentage of blending. Therefore, gasohol (E10), which is 10% of ethanol blended with 90% gasoline, is presented in this section. This result is compared with CG and can be seen in Table 7. The key points of this analysis are presented below;

3.3.1 Energy Consumption

The result is separated in three sections depending upon the feedstock types: sugarcane, cassava, woody and herbaceous;

Sugarcane

Gasohol (E10) gives positive result by reducing 3.10% of petroleum consumption in case of electricity co-product at 20 bar (2nd case) and 3.31% in case of electricity co-product at 80 bar (3rd case) on per km basis.

Cassava

Gasohol (E10) produced by utilizing biogas and solid waste as fuel for steam production (case 8th) gives the positive result by reducing 0.9% of fossil fuels consumption on per km basis.

Woody and Herbaceous

Gasohol (E10) produced by herbaceous and woody as feedstock give the positive result by reducing 4.7% and 4.9% of fossil fuels consumption respectively on per km basis.

3.3.2 Emissions

Similarly, the results of Well-to-Wheel emissions from bio-ethanol production are also separated in three sections by type of feedstock.

Sugarcane

Only the case that produces electricity at 80 Bar shows the positive result. This case reduces GWP 1.4% lower than CG.

The combustion of gasohol (E10) during vehicle operation stage generated less SOx compared to CG. However, LCA shows negative result. This is because it consumes fossil fuel during production stage and the efficiency is lower than CG. Therefore, reduction of fossil fuel consumption and use high efficient technologies could be considered for reducing the harmful effect on environment.

Cassava

It shows negative result on all emissions compared to CG.

Woody and Herbaceous

It shows the positive result by reducing GWP 4.71%, 3.99% respectively. Reduce SOx about 7.35%, 5.88% respectively. But VOC, CO, NOx and PM10 generated are higher than CG.

3.4 Sensitivity Analysis

The sensitivity was done by ± 10% changing of energy consumption of each stage: farming stage, fertilizer production and transportation stage, transportation of feedstock stage, ethanol production stage, and ethanol transportation and distribution stage. The results are shown in Figures 5, 6, 7, and 8. The sensitivity analyzed for the best case of each feedstock; 3rd, 6th, 7th, 8th case.

The result shows that the significant factor that affects the WTP efficiency is energy consumption during ethanol production. This factor has effect for all type of feedstock. Other significant factor is the transportation.

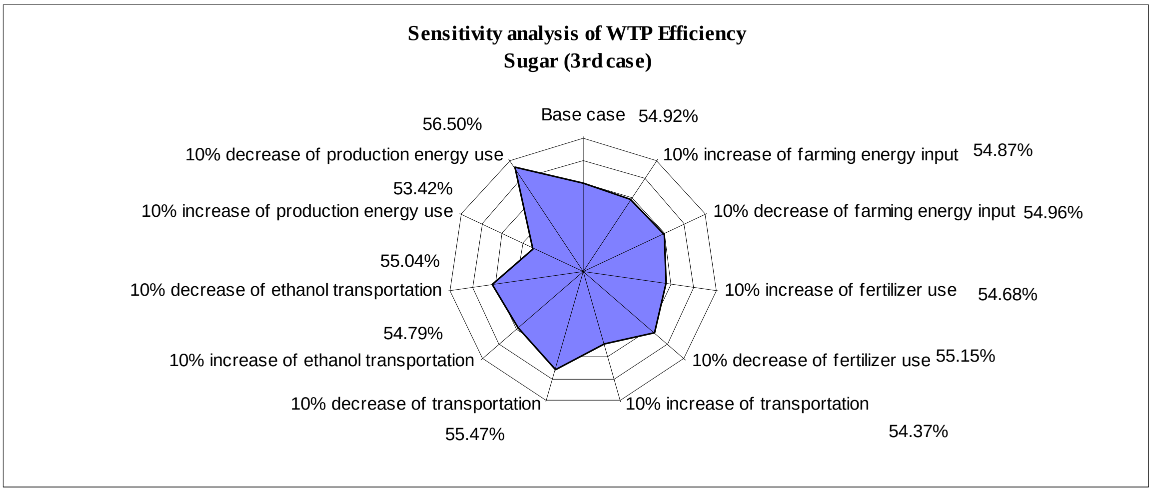

Fig. 5. Sensitivity analysis of WTP efficiency of the best case of sugarcane as feedstock.

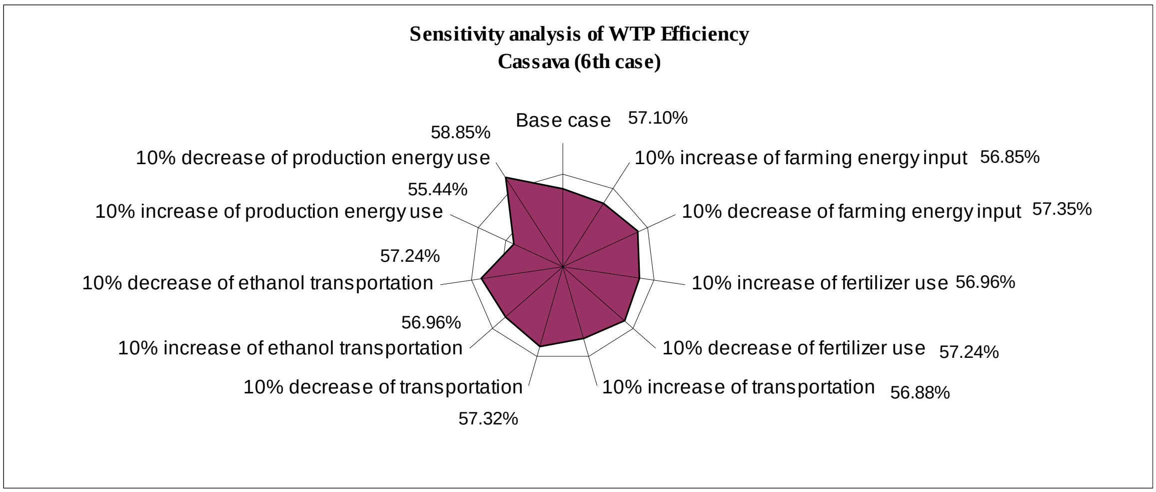

Fig. 6. Sensitivity analysis of WTP efficiency of the best case of cassava as feedstock.

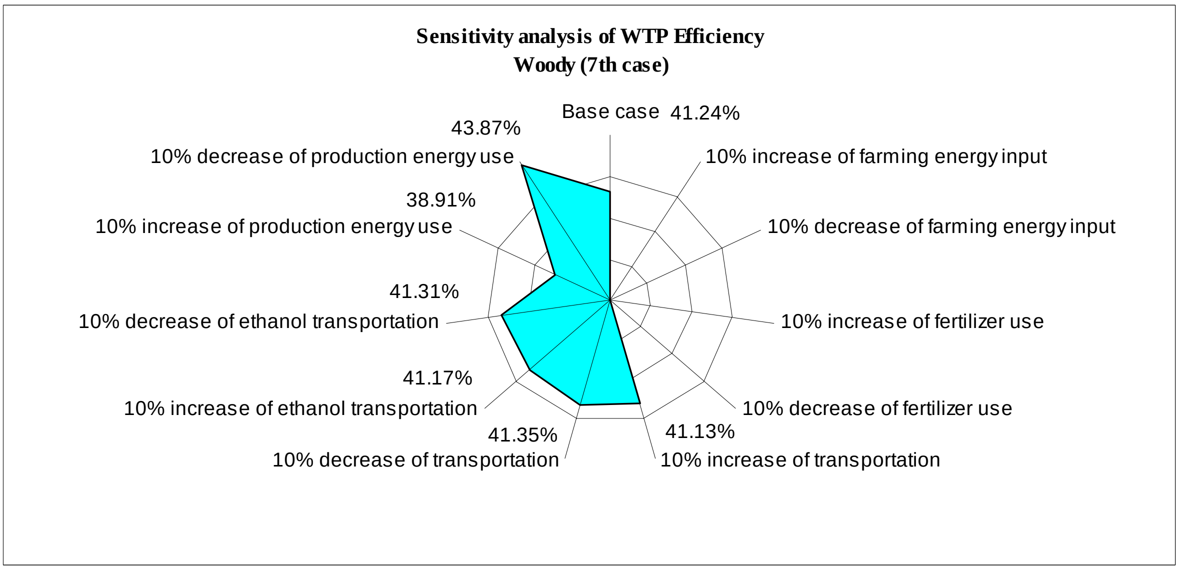

Fig. 7. Sensitivity analysis of WTP efficiency of woody biomass as feedstock.

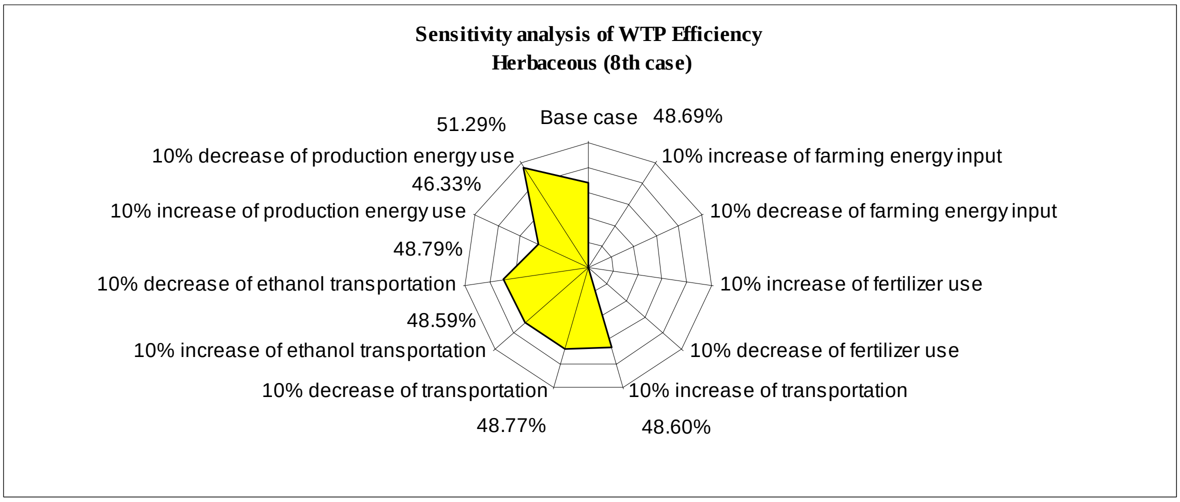

Fig. 8. Sensitivity analysis of WTP efficiency of herbaceous biomass as feedstock.

Table 7. Summary of energy consumption and emissions: Well-to-Wheel bioethanol production from all cases compare to CG.

	CG	1st Case	2nd Case	3rd Case	4th Case	5th Case	6th Case	7th Case	8th Case
	Energy Consumption (MJ per km)								
Total Energy	3.856	4.226	3.999	3.880	3.971	3.951	3.867	3.999	3.926
Fossil Fuels	3.697	4.014	3.789	3.675	3.767	3.748	3.663	3.516	3.522
Petroleum	3.346	3.434	3.242	3.235	3.347	3.345	3.247	3.203	3.198
	Emission (Grams per km)								
CO2	266	286	269	261	272	271	272	254	256
CH4	0.313	0.347	0.326	0.311	0.318	0.318	0.310	0.293	0.294
N2O	0.009	0.014	0.014	0.014	0.012	0.020	0.013	0.010	0.010
GWP	276	299	280	272	283	285	283	263	265
VOC: Total	0.191	0.197	0.195	0.195	0.197	0.200	0.197	0.193	0.192
CO: Total	2.383	2.395	2.389	2.386	2.395	2.452	2.405	2.391	2.387
NOx: Total	0.228	0.280	0.246	0.239	0.266	0.348	0.279	0.237	0.230
PM10: Total	0.039	0.057	0.047	0.043	0.048	0.057	0.050	0.040	0.040
SOx: Total	0.068	0.144	0.100	0.088	0.095	0.096	0.094	0.063	0.064
VOC: Urban	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116
CO: Urban	1.465	1.467	1.467	1.466	1.466	1.466	1.466	1.465	1.465
NOx: Urban	0.107	0.111	0.110	0.108	0.109	0.108	0.108	0.106	0.106
PM10: Urban	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
SOx: Urban	0.033	0.038	0.037	0.034	0.034	0.033	0.033	0.030	0.031

4. CONCLUSION

The energy consumptions and emissions of ethanol production for all cases studied are higher than energy consumption and emissions from CG production. Bio-ethanol from sugarcane with electricity co-generation at 80 bar showed higher efficiency and predicted significant reduction of fossil fuels consumption and lower emissions compared to 20bar pressure. Cassava feedstocks with steam co-production predicted positive result in both of fossil fuel reduction and lower emissions than electricity co-production. Woody and herbaceous feedstocks with electricity co-production showed significant reduction in fossil fuel consumption; though higher emissions compared to CG are predicted.

In order to improve the performances, crops farming with less machinery and with less fertilizer and pesticide requirements could improve the environmental and energy balance of bio-ethanol. It will also be necessary to introduce the use of bio-diesel into the agricultural machinery. Moreover, the study on plant breeding and organic farming concept should be more deeply considered. Simulation and sensitivity analysis of the key parameters for transportation to obtain the optimum transportation strategies should be done to reduce energy consumption and emissions. It will also be required to introduce the use of bio-diesel into the heavy-duty truck during transportation stage. The evaluation of new technologies of lignocellulosic material to produce bio-ethanol is still in the research and development stage and requires high investment cost. Therefore, an overview relating to these technologies and its cost benefits analysis should be more deeply considered. There is a competition between biomass residues for electricity and heat production and bio-ethanol for the transport sector. To align this, a suitable strategy will be required to ensure the synergy of the development. To select the suitable technologies in Thailand, a thorough analysis on socio-economic impacts should be done. Finally, other environmental and social impacts; such soil erosion and soil degradation, water use and water contamination, and human health and other social impacts need to assess for bio-ethanol production.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of Mr. Seksan Papong of National Metal and Materials Technology Center (MTEC) and Mr. Komkrit Chuawittayawuth of Department of Alternative Energy Development and Efficiency (DEDE) for their suggestions and information, which proved to be very useful in this work.

REFERENCES

[1] Department of Alternative Energy Development and Efficiency (DEDE). 2004. *Thailand alternative energy situation 2004.* Ministry of Energy, Thailand. Retrieved from website www.dede.go.th.

[2] Department of Alternative Energy Development and Efficiency (DEDE). 2007. *Current and Project of Ethanol Production Capacity in Thailand.* Retrieved from website www.dede.go.th. on January 26, 2007.

[3] Girard, P., and Fallot, A. 2006. Technology state-of-the-art: Review of existing and emerging technologies for the large scale production of biofuels and identification of promising innovations for developing countries. Background Paper for the

GEF-STAP Liquid Biofuels Workshop. CIRAD, Montpellier. Retrieved from website http://stapgef.unep.org/activities/technicalworkshops/biofuels on January 11, 2007.

[4] Øyvind, V. 2005. Biofuels from lignocellulosic material - In the Norwegian context 2010 – Technology, Potential and Costs. Faculty of Information Technology, Mathematics and Electrical Engineering, Department of Electrical Engineering, Norwegian University of Science and Technology.

[5] Demirbas, A. 2007. Progress and recent trends in biofuels. *Progress in Energy and Combustion Science* 33: 1–18.

[6] Argonne National Laboratory. 2005. GREET version 1.7 Model. Office of Energy Efficiency and Renewable Energy, Department of Energy (DOE). USA. Retrieved from website http://greet.anl.gov.

[7] Nakarit, J. and Wattanavichien, K. 2004. 323 Life Cycle Energy and Environmental Impacts of the Ethanol 95% and 99.5% Production from Molasses for Thailand Transportation. Internal Combustion Engine Research Laboratory, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand.

[8] Nguyen, T.L.T. Gheewala, S.H., and Garivait, G. 2006. Life cycle cost analysis of fuel ethanol produced from cassava in Thailand. The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand.

[9] Nguyen, T.L.T., Gheewala, S.H., and Garivait, S. 2007. Full chain energy analysis of fuel ethanol from cassava in Thailand. The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand.

[10] Department of Alternative Energy Development and Efficiency (DEDE). 2005a. *Annual Report of Electricity Power in Thailand 2005*. Ministry of Energy, Thailand.

[11] Department of Alternative Energy Development and Efficiency (DEDE). 2005b. *Annual Report of Oil and Thailand 2005*. Ministry of Energy, Thailand.

[12] Department of Energy Business (DOEB). 2006. *Report on Production, Import Export of Oil product*. Ministry of Energy, Thailand. Retrieved from website www.doeb.go.th.

[13] Thai Petroleum Pipeline Co., Ltd. www.thappline.co.th.

[14] Department of Agriculture (DOA). 2006a. *Cassava*. Retrieved from website http://www.doa.go.th/power_oil/cassava/index.htm. March 1, 2006.

[15] Department of Agriculture (DOA). 2006b. *Sugarcane*. Retrieved from website http://www.doa.go.th/power_oil/WebSugarcaneNew/index.html. March 1, 2006.

[16] Department of Alternative Energy Development and Efficiency (DEDE). 2006. *Utilization of the waste from Ethanol Industry*. Ministry of Energy, Thailand.

[17] Sugar Factory Ang Vien (Ratchasima) Company limited. 223 Moo 1, Nivetrat Road Amphur Kangsanamnang Nakornratchasima, Thailand.

[18] Coelho, S. 2005. Brazilian Sugarcane Ethanol: Lessons Learned. CENBIO-The Brazilian Reference Center on Biomass.

[19] Lurgi AG. www.lurgi.com.

[20] Electricity Generating Authority of Thailand (EGAT). www.egat.co.th.

[21] Dutta, A. 2006b. ProBIOS: Promotion of Biofuels for Sustainable Development in Thailand. Asian Institute of Technology (AIT), Thailand.

[22] Ministry of Transportation, Thailand. www.mot.go.th.

[23] PTT Public Company Limited. Natural gas Transportation System.

[24] Thai Oil Public CO., LTD. www.thaioil.co.th.

[25] Watcharejyothin, M. 2000. Natural gas transportation in Thailand: price regulation and productive efficiency analysis. Energy field of study. Asian Institute of Technology (AIT), Thailand.

[26] Chamsing, A., Salokhe, V., Singh, G., 2006. Energy consumption analysis for selected crops in different regions of Thailand. Agricultural Engineering International: the CIGR Ejournal, EE 06 013. Vol. VIII.