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COMPETE

Competence Platform on Energy Crop and Agroforestry Systems for Arid and Semi-arid Ecosystems - Africa

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Report on Task 3.2 and 4.3

By

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Table of Content

Task 3.2: Energy and Environment Assessment of Biomass Energy Systems in Thailand

1. Introduction

Thailand's total energy consumption has been rising in a dramatic manner since the 1980s. Strong economic growth and rapid industrialization are considered both the cause and effect of large expansion in energy consumption. Lacking an abundant supply of domestic fossil-based energy resources, Thailand is obligated to import a large amount of crude oil to meet domestic demand. Not only does oil consumption cost the country a huge amount of foreign currency, arising with it is a concern about environmental quality. Apart from a rise in GHG emissions which contribute to global warming, increased level of air pollution adversely affects public and ecosystem health.

Currently, attention has been paid to biomass as a substitute for fossil fuels in Thailand due to environmental and social-cost benefits **[1].** Thailand is an agro-industrial based country where various kinds of crops are produced and there is a large amount of agricultural residues annually. In the year 2001, the potential of agricultural residues could be accounted for as follows; 20 million ton of rice husk, 2.2 ton of palm oil residues, 50 ton of bagasse and 5.8 ton of wood waste, while available residues were 0.15%, 0.26%, 0.057% as well as 0.31% of each potential waste. The utilization rates as energy source were, 0.0005%, 0.006%, 0.0003% and 3×10^{-7}% of each potential **[2].** These data clearly indicate that the potential of agricultural residues is much higher than the rate of utilization.

Today, various kinds of biomass have been used for energy in Thailand, viz., cassava, sugar cane, jatropha, oil palm, rice husk and rice straw. Energy conversion of biomass differs by sources, conversion options, end-use applications and infrastructure requirements. It can be used as solid fuel by combustion process or used as liquid fuels, biofuels, through appropriate conversion processes. The production and use of biofuels has recently emerged as a critical issue in response to world oil shortages and environmental concerns. However, if we look at the life cycle of biomass, increasing use of biomass for energy purposes may also bring about some potential risks such as net energy loss and GHG emissions, uncompetitive cost of biofuels when compared to fossil fuels and other environmental impacts such as land use and land transformation, water and air pollution, etc. Therefore, it is necessary to evaluate the environmental consequences of implementation of biomass based energy systems in Thailand.

Life Cycle Assessment (LCA) is a tool that can be applied for evaluation of environmental performance and identification of opportunities to improve the environmental efficiency of biomass energy systems. This chapter summarizes several applications of LCA and full chain energy environmental and cost analysis which have been conducted in order to assess biomass for power generation and biofuels for transport in Thailand. The summarized studies consist of the electricity production from rice husk, rice straw-based power generation, biodiesel production from palm oil, biodiesel from *Jatropha curcas L,* fuel ethanol from cane molasses and fuel ethanol from cassava in Thailand.

2. Energy from rice residues

2.1 Electricity production from rice husk [3]

Rice is cultivated in every region of Thailand, the total annual rice production being estimated as 20 million tons **[4].** At the rice mill, rice husk will be removed when passing through the process. Rice husk is the outer cover of rice that accounts for about 20% by its weight **[5, 6].** In the past, rice husk was mostly dumped as waste that caused waste disposal problem for the mills **[5]**. Also, when rice husk is fermented by microorganisms, methane is emitted contributing to global warming **[7].** Rice husk is a fine and light particle and can cause breathing problems **[5].** Hence, the rice mill owner should find the proper way to deal with this waste. Cement industry can use rice husk to add silica in the product itself because rice husk has a high silica content **[8]** and some amount of the waste are used as fertilizer in fields **[5]**. These ways are not enough to significantly reduce rice husk disposal problem. Another way that has been proposed is using the husk for energy purpose **[4, 5]**. Rice husk can be used as solid fuel by combustion process **[9].** Many countries including Thailand use rice husk to produce electricity **[10].** However, only 50-70% of the husk in Thailand is utilized **[11].**

To confirm whether energy production from biomass has lower emissions than conventional fuel production, an environmental assessment was done by the life cycle assessment methodology. All the data, resource use and emissions, in the study were based on 1 MWh of electricity production from the Roi Et Green Project, a pilot plant project of capacity 9.8 MW using rice husk as the feedstock. The plant has been developed as a demonstration project by the National Energy Policy Office (NEPO) for showing the potential of reduction in import of nonrenewable energy sources and also reduced environmental emissions **[6].** The power plant uses 290 tons of rice husk and 1,400 tons of water in one day, and has a power requirement of 1 MW. Net power output is 8.8 MW, which is sold to the Electricity Generation Authority of Thailand (EGAT) for 21 years under the Small Power Producer (SPP) scheme. The raw materials consumed and environmental emissions of energy production from rice husk were determined. System boundary of the life cycle assessment study is shown in **Figure 1** and the characteristics of rice husk from the pilot plant study site are presented in **Table 1**. **Table 2** shows the comparison of air emissions intensities from rice husk power plant (Roi Et Green project) and conventional power plants.

Table 1 Component analysis of rice husk sample **[12]**

Parameter	**Unit**	**Result**	**Basis**
C	%	38.23	dry
H	%	5.80	dry
O	%	40.50	dry
N	%	1.21	dry
S	%	0.041	dry
Total moisture	%	11.94	as received
Ash content	%	14.22	dry
Low Heating Value (LHV)	kJ/kg	13,158.7	as received
High Heating Value (HHV)	kJ/kg	15,217.2	dry
Volatile matter	%	59.87	dry
Fixed carbon	%	18.56	dry

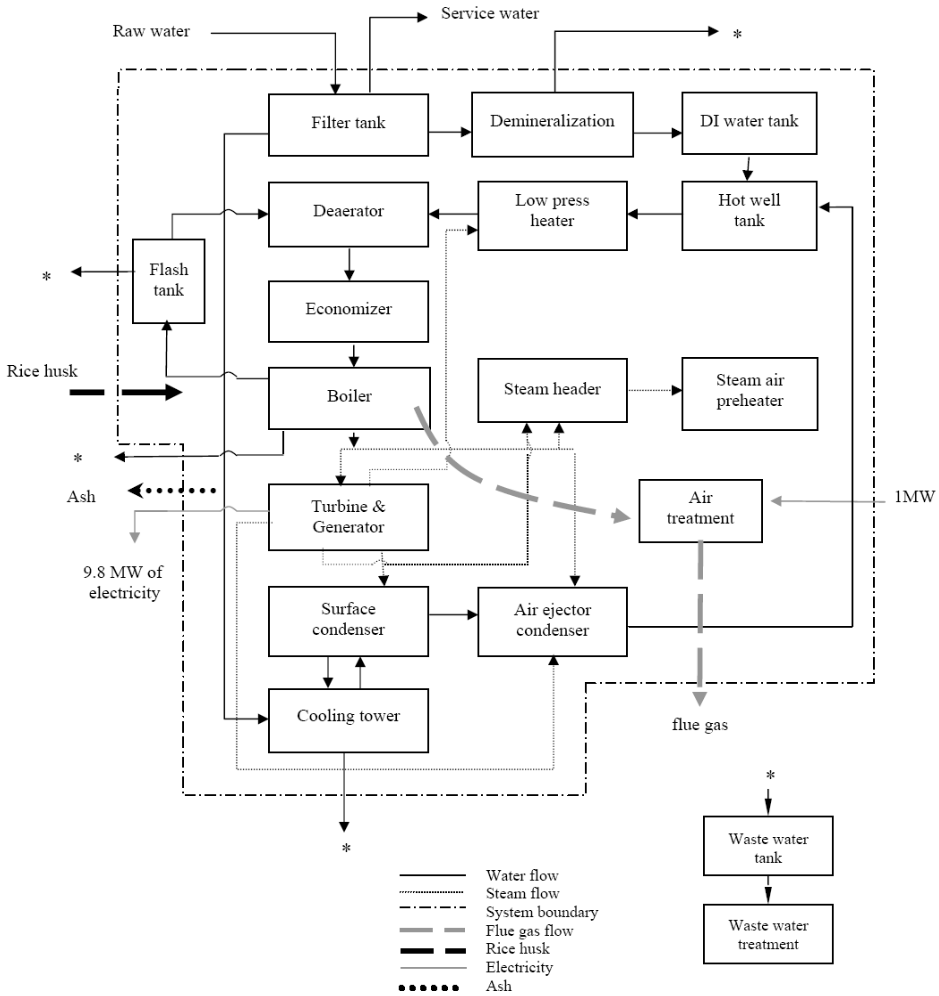

Figure 1 System boundary of rick husk energy production **[3]**

Table 2 Comparison of emission data of Roi Et Green project and conventional power plants **[12, 13]**

Item	Emission (kg/MWh)				
	Roi Et Green	Coal	Oil	Gas	Combined*
CO_2	nearly zero	1.26×10^3	8.1×10^2	5.7×10^2	7.3×10^2
SO_2	0.32	2.8	1.3	3×10^{-4}	0.65
NO_X	2.5	5.8	2.9	1.4	2.4
CO	0.71	0.2	0.27	0.2	0.2
TSP (dust)	8×10^{-2}	3.7×10^{-3}	9.7×10^{-2}	3.6×10^{-3}	3.6×10^{-2}

* Weighted average of coal, oil and gas-fired power plants

CO_2 from the Roi Et Green plant is from biomass combustion and hence, being part of the global carbon cycle, does not contribute to global warming. This is a distinct advantage of biomass-based energy production. The emissions of SO_2 and NO_x are lesser in case of coal and oil-fired power generation even though there are NO_x and SO_x removal equipment installed in the latter, but higher than for natural gas. Both these emissions contribute to acidification and in addition, NO_x also contributes to photochemical ozone formation and nutrient enrichment. Thus, the electricity production from rice husk is better than the conventional electricity production on these counts. CO and dust emissions are slightly higher than conventional power production pointing to need for improving the combustion efficiency of the rice husk power plant. Overall, the study indicates that rice husk is a viable feedstock for electricity production and performs better than fossil fuels (especially coal and oil) from the point of view of environmental emissions.

2.2 Potential of rice straw-based power generation in Thailand [14]

In Thailand, 8–14 Mt of rice straw are open burnt annually after paddy harvest, contributing to local pollution problems **[15-18].** Compared with the quick earnings obtained from the next paddy crop, the higher investment cost of rice straw utilization provides insufficient incentive for farmers to collect it; so, burning is still the most common practice for rice straw disposal **[18-21]**. If properly managed, this rice straw could actually be a valuable resource for energy instead of being wasted by burning. This is especially the case for the central provinces of Thailand which could produce 2–3 crops annually and already have ready-to-use baling machines; these provinces have the highest potential and readiness for development. However, some of provinces in the the North and Northeast have been using rice straw for animal feed because they have only a single crop every year and can utilize the rice straw for livestock feed during the dry season and soil cover.

LCA has been used to evaluate the potential of rice straw power plant implementation in Thailand in terms of GHG emission savings from avoided open burning and from implementing rice straw power production, which can substitute that from natural gas. The system boundary contains activities for paddy cultivation and for power operation; paddy cultivation includes harvesting and production of fertilizers, pesticides and herbicides, whereas power generation includes rice straw collecting, delivery to power plant and power production **(Figure 2).**

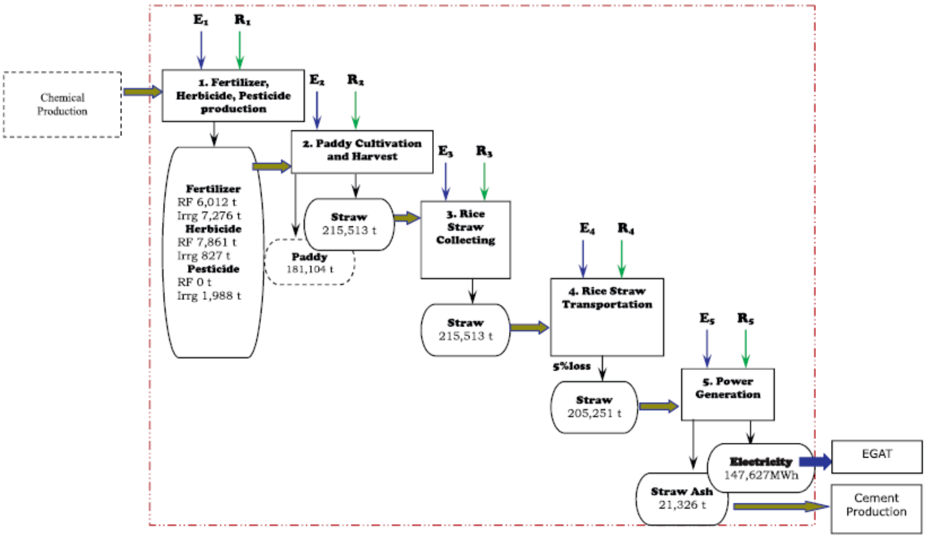

Figure 2 System boundaries of power production from rice straw (RF: Rainfed; Irrg: Irrigated) **[14]**

The life cycle approach for the calculations has thus been applied in the following way. Rice straw is currently being burned in the Central regions of Thailand to quickly facilitate planting the next crop. If power plants were introduced to utilize the rice straw, then the farmers may be motivated not to burn the rice straw and instead sell it to these power plants. The power that would be generated from this rice straw would displace power production from natural gas, which is the marginal feedstock for power production in Thailand. Thus, the avoided GHG emissions from the displaced natural gas power production can be credited. Provincial rice straw availability has been studied and forecasted for 2007–2008 **[15, 16, 17, 20]**. Rice husk power plant conditions are used as assumptions for this study. The plants are assumed to be installed within each province to limit the rice straw supply cost. The provincial potential is evaluated in terms of provincial power generation capacity with GHG emission savings based on the range of plant efficiency and maximum power production capacity.

As a result, provincial potential is classified into 5 groups. The province in Group 1 is unable to have rice straw supply for the entire year, but still has a small potential amount which could support a power plant in a neighboring province. The provinces in Group 2 (Trat, Chonburi, Samut Songkram, Sa Kaeo, Rayong and Samut Sakhon) have low supply potential for very small scale electricity generation. Rice straw in the provinces of this group could be gathered up to develop Very Small Power Plants (VSPP) for sale, or smaller-capacity VSPP for local community use instead of sale to the grid. Those in Group 3 (Prachuap Khirikhan, Samut Prakarn, Nakhon Nayok, Bangkok, Prachinburi and Nonthaburi) have low supply potential for small-scale electricity generation. This group could develop VSPPs and sell electricity to the local grid. Saraburi, Kanchanaburi, Phetchaburi, Pathumthani, Ratchaburi, Lopburi and Ang Thong are classified into Group 4, they have high supply potential for electricity generation to develop many VSPPs. Rice straw from some provinces with smaller potential could be gathered up to develop Small Power Plants (SPP) with higher capacity, reducing the cost per MW. Chachoengsao, Singhburi, Nakhon Pathom, Ayutthaya, Chainat and Suphanburi are classified into Group 5; they have very high supply potential for commercial electricity generation. The provinces in this group have a very high supply potential for commercial electricity generation; each province could develop more than one plant of SPP size. In sum, a total of 25 provinces in central Thailand have potential to generate electricity with a total capacity of 210–292MW (plant efficiency 20–27%), resulting in an annual GHG emission savings of 2.3–2.6 $MtCO_2$-eq, and with a provincial capacity of over 20MW in 6 provinces, 10–20MW in 7 provinces, 1–10MW in 6 provinces and less than 1MW in 6 provinces.

Table 3 Potential in central provinces of Thailand based on rice straw availability

	Identification	Provincial capacity (MW)	No. of provinces	Provincial capacity[a] (MW)	Group total capacity[a] (MW)	Group GWP saving ($MtCO_2$-eq per year)
Group 1	Unable to supply for entire of year	0	1	0	0	0
Group 2	Very low supply potential	<1	6	0.07-0.75	1.6-2.2	0.017-0.02
Group 3	Low supply potential	1-10	6	1.3-9.0	20-28	0.22-0.25
Group 4	High supply potential	>10-20	7	8-20	79-111	0.88-10.0
Group 5	Very high supply potential	>20	6	16-76	163-225	1.78-2.04
		Total	26		263-366	2.9-3.3

Note: Rice straw availability is based on data from Fungtammasan (2005) [16]
[a] Evaluation based on worst case is 20% plant efficiency and best case is 27% plant efficiency and data range is "worst case-best case".

The study shows that rice straw power plant could be a high potential alternative for electricity generation as well as incentive for utilization instead of field burning, which is a waste of a useful resource in addition to contributing to local as well as global pollution. Burning of 8.5–14.3 Mt of rice straw annually contributes to 5.0–8.6$MtCO_2$-eq, which could be avoided if the resource is utilized for power production. The resulting 786–1325MW capacity could save 7.8–13.2 $MtCO_2$-eq annually and yielding an estimated benefit of 39–66 MUS$. The power from rice straw would also result in a savings of about 1–1.8 billion m^3 of natural gas, which is about 4–7% of the amount required for the 18,200MW in Thailand's Power Development Plan 2007.

The study provides a preliminary feasibility of power potential from rice straw in Thailand in terms of fuel supply availability and GHG saving, since fuel is the main factor for biomass power plant feasibility, whereas the other factors are not much different such as development cost, project cost, operating (excluding fuel) cost and maintenance cost. It must however be noted that rice straw will not be used as long as industrial waste (rice straw, wood waste, etc.) is still available because industrial waste, being produced at factories, is centralized and easier to collect. However, industrial waste biomass will already be in short supply by 2010 **[16].** Also, field burning will continue as long as it is not illegal. This is the present situation in Thailand. So, the rice straw for power generation is a combined solution of removing rice straw from field without open burning and being an alternative resource for GHG reduction when enough industrial waste is not available to meet the demand.

3. Environmental assessment of biodiesel

3.1 Environmental evaluation of biodiesel production from palm oil [22]

Biodiesel is one of the most promising alternative fuels for transportation in Thailand. It is a very good candidate for substituting petroleum-diesel in engines because of its similar properties. Obtained from transesterification of fatty materials, biodiesel can be produced from various vegetable and/or animal oils. Regarding raw material supply and production cost, palm oil is found to be a wonderful suitable raw material for biodiesel production in Thailand. However, the production of biodiesel entails emissions to the environment such as fertilizers and herbicides during plantation and emissions from fuel use during oil extraction, transportation, etc. Hence, the environmental implications of biodiesel production need to be addressed.

A life cycle perspective was applied to evaluate the environmental performance of biodiesel production from palm oil. An inventory of relevant inputs and outputs of biodiesel production from palm oil was compiled. To this end, the study was divided into 3 stages: oil palm plantation, palm oil production and transesterification into biodiesel. For each stage, the materials and energy flows were elaborated. The emissions to air, water and soil compartments are inventoried. The emissions such as wastewater discharge, solid waste load, volatile organic compounds and other major air pollutants were also considered in terms of their potential environmental impacts. Relevant data for resource consumption and emissions to air, water and soil were collected for all the stages. The life cycle diagram of biodiesel production is shown in **Figure 3**.

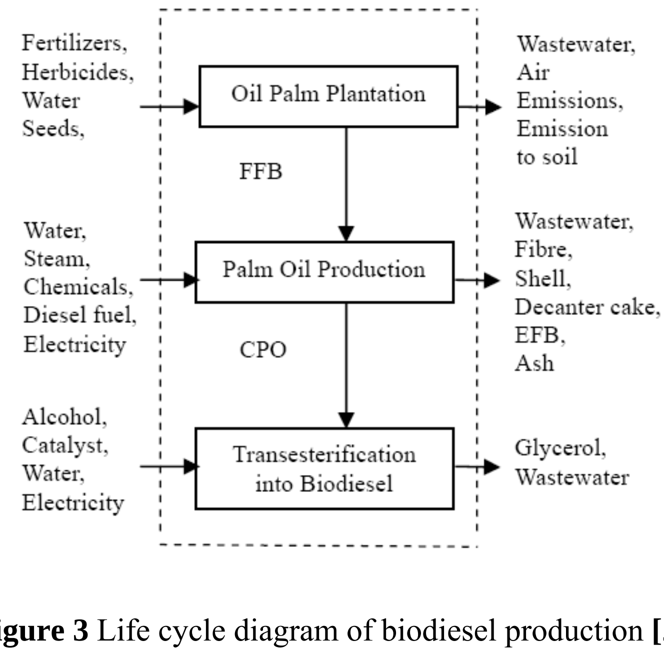

Figure 3 Life cycle diagram of biodiesel production **[22]**

The sites for the data in this assessment are as follows:

- The oil palm plantation is located in the Krabi province, in the southern part of Thailand. Materials and energy: Input data are fertilizers, herbicides, water, and seeds. Output data are emissions to air, soil, and wastewater, and fresh fruit bunches (FFB).

- The palm oil production facility is also located in the Krabi province. Materials and energy: Input data are FFB, water, steam, diesel and electricity. Output data are fibre, shell, decanter cake, empty fruit bunches (EFB), ash, wastewater, air emissions, crude palm oil (CPO) and kernel.
- The biodiesel production (transesterification) facility is located in the South of Thailand. Materials and energy: Input data are palm oil, water, electricity, methanol and sodium hydroxide. Output data are methyl ester (biodiesel), glycerol and wastewater.

Table 4 summarizes the total flows of materials, energy, and emissions from the life cycle of biodiesel production from palm oil. The results show that 1 ton of biodiesel is produced from about 1.14 tons of crude palm oil (CPO) or about 6-7 tons of fresh fruit bunches (FFB). The major water requirement for the production of biodiesel comes from oil palm agriculture. Nitrogen is the largest input from fertilizer although potassium and phosphorus are also significant contributors. Diesel requirements come primarily from agriculture and palm oil production. The transesterification process has the largest demand for electricity (kWh).

Table 4 The inventory list of 1 ton biodiesel production **[22]**

Parameter	Quantity	Parameter	Quantity
Raw Mat.		**Energy**	
Fertilizer (kg)		Steam (m^3)	1.8-3.5
N	265-340	Electricity (kWh)	360-380
P	74-95	**Air Emissions**	
K	190-240	Particulate (kg)	4.2-9.4
Mg	48-61	NO_2 (kg)	1.8-3.3
B	4-5	CO (kg)	1.5-4.1
Paraquat (kg)	0.5-0.9	**Wastewater (m^3)**	3-4
Glyphos. (kg)	1.4-2.2	**Solid waste**	
FFB (ton)	6-7	Fibre (t)	1.6-2.4
NaOH (kg)	6-10	Shell (t)	0.3-0.5
Methanol (t)	0.15	Decanter cake (t)	0.06-0.14
Diesel (L)	5-13	EFB (t)	1.6-2.1
Water (m^3)	6,500-10,000	Ash (t)	0.02-0.07
		Output	
		Biodiesel (t)	1.0
		Glycerol (t)	0.32

For emissions to air, soil and wastewater:

- Emissions associated with the plantation include N-fertilizer, which is applied to oil palm plants in the nursery and field. This emits N_2O to the air which contributes to global warming. Fertilizers may also contribute to nitrate and phosphate leakage to the groundwater, however the excess is not known. The herbicides paraquat and glyphosate are also spread on the soil in the plantation, and the insecticide furadan is applied to the nursery, but these chemicals are less toxic because of photo- and bio-degradability.

- In the steam generation step of palm oil production, emissions are composed of particulate matter, NO_2, and CO (in flue gas), all of which contribute to photochemical ozone formation. In addition wastewater from the palm oil mill process is used to produce biogas which is used for electricity production. Solid wastes such as fibre, shell, decanter cake, empty fruit bunches and ash are used in agriculture and industry.
- In palm oil transesterification into biodiesel, wastewater is produced from washing of methyl esters. Although the water is low in pollution, contaminants may include sodium hydroxide catalyst, methanol, glycerol, palm oil, etc. In addition there are emissions to the air when biodiesel is combusted in diesel engines for transportation which will be considered later.

3.2 Full chain energy analysis of biodiesel from *Jatropha curcas L.*[23]

The Thai government has planned to increase the national renewable energy share from 0.5% presently to 8% by the year 2011 **[24]**. To this end, biodiesel is one of the important renewable energy sources being promoted. Along with oil palm and used oil, ***Jatropha curcas Linnaeus* (JCL)** oil has been considered as a prospective feedstock for biodiesel production, particularly due to the possibility of cultivation in dry and marginal lands. Direct use of JCL oil in one piston engines is promoted by the Department of Agricultural Extension—Thailand because of the good properties of the JCL oil **[25].** However, for use in automobiles, the JCL oil needs to be converted to biodiesel. Currently, transesterification is one of the most selected chemical methods to adjust oil characteristics for use in cars. Before any policy measures promoting a particular renewable energy can be adopted, it is imperative to consider a full chain energy analysis as a first step to address energy gain or loss of renewable energy production **[26]**. To support decision makers in the energy policy sector to make informed decisions vis-à-vis promotion of JCL plantations for biodiesel, therefore, the evaluation of energy balance of Jatropha Methyl Ester (JME) production in Thailand using a life cycle approach was performed. Net energy gain (NEG), the difference between the total energy outputs and total energy inputs, is one of the accepted indices for analyzing the energy efficiency of biofuels **[26]**. In the same way, net energy ratio (NER), the ratio of total energy outputs to total energy inputs, reflects the energy efficiency of the process. Both NEG and NER were used as indicators for investigating the results.

The full chain energy analysis includes JCL cultivation, oil extraction, biodiesel production, and transportation at all stages. JME is the main product and seed cake, crude glycerin, wood, and peel are also counted in the analysis as they are significant co-products. The analysis excludes the assessments of energy consumption associated with facilities construction i.e. manufacturing machines, irrigating structures, vehicles, etc. as well as with manual labor, i.e., new planting, pruning, harvesting, driving etc. The calculations are based on 1 ha of JCL farming area for 20 years. The main result is the estimate of overall energy requirements for best and worst cases. The information is obtained from 14 research sites and 10 practical sites (size of farming area ranges from lower than 1 ha to around 20 ha) in Thailand during the year 2006–2007. The allocation of environmental burdens to co-products is done based on energy. Although parts of the JCL tree can be exploited for a number of uses such as medicine, insecticide, mollusciside, raw material of dye production, raw material of paper production **[27]**, this study views them as co-products used for energy purposes except seed cake that will be considered both for fuel stock and fertilizer because of its high nutrient content. The system boundary of this study is shown in **Figure 4.**

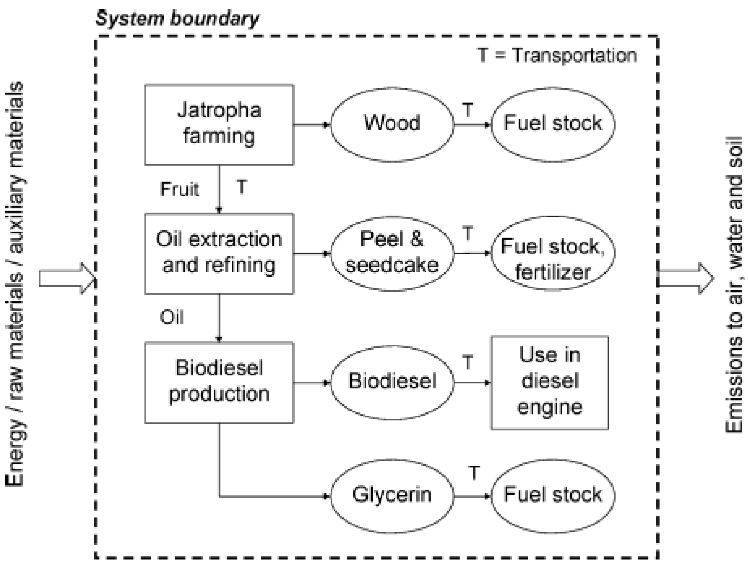

Figure 4 Life cycle scheme for the studied system **[23]**

The average result and two scenarios—best and worst case—are set up to illustrate the range of results due to the variety of management practices. The results of study show a net energy gain from all JME co-products. The net energy gain (NEG) and net energy ratio (NER) of biodiesel and co-products from the life cycle of JCL are 4720 GJ/ha and 6.03, respectively. Even if only biodiesel is considered without coproducts, the NER is 1.42, still higher than 1. It means that the promotion of JME production in community area yields a positive NER for all scenarios considered. With proper planning, an NER as high as 12 can be obtained. **Figure 5** shows energy consumption in each process to produce biodiesel per ha for 20 years. The agriculture phase has the highest average energy consumption and oil refining the lowest. The range of energy consumption for transportation phase is quite high because some sites have to transport products for sale through large distances while some sites operate all activities in their community area. Detailed analysis of the energy output from each phase shows that the highest energy gain is from seed cake as fuel stock because the total weight of seed cake is more than 3 times that of JME. However, due to its high nutrient content it is anticipated that the seed cake will be promoted to be used as fertilizer. When it is used as fertilizer, the energy output is the reduction of energy consumption for producing the chemical fertilizer which it would substitute. The energy gain from the use of seed cake as fuel is about 3 times that of its use as fertilizer. However, this cannot be used as a justification for the use of seed cake as fuel because the air emissions from burning of seed cake as well as environmental benefits of chemical fertilizer substitution should also be considered in addition to energy output. In practice, the selection will also be governed by the market price.

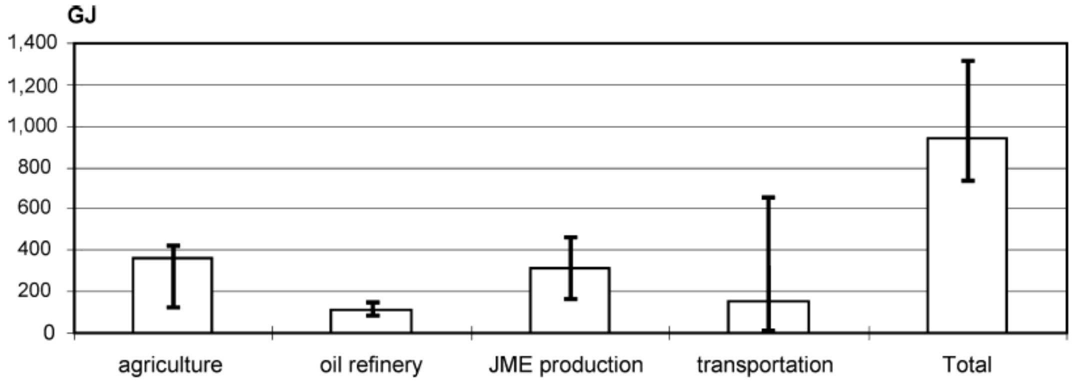

Figure 5 Energy consumption for producing JME and coproducts per ha for 20 years **[23]**

Due to variable conditions, a sensitivity analysis has been done as presented in **Figure 6** to determine the effect of the following factors on NER: biodiesel yield, co-products yield, farm energy inputs, energy consumption in oil extraction process, and energy consumption in biodiesel consumption process. The figure shows that the NER results are most sensitive to a change in co-products yield. A 10% change in co-products yield changes the NER by about 8%. This is reasonable since, as observed earlier, the co=products provide the maximum energy output. The effect of changing all the other factors on the NER is less significant. The results of this study are thus robust.

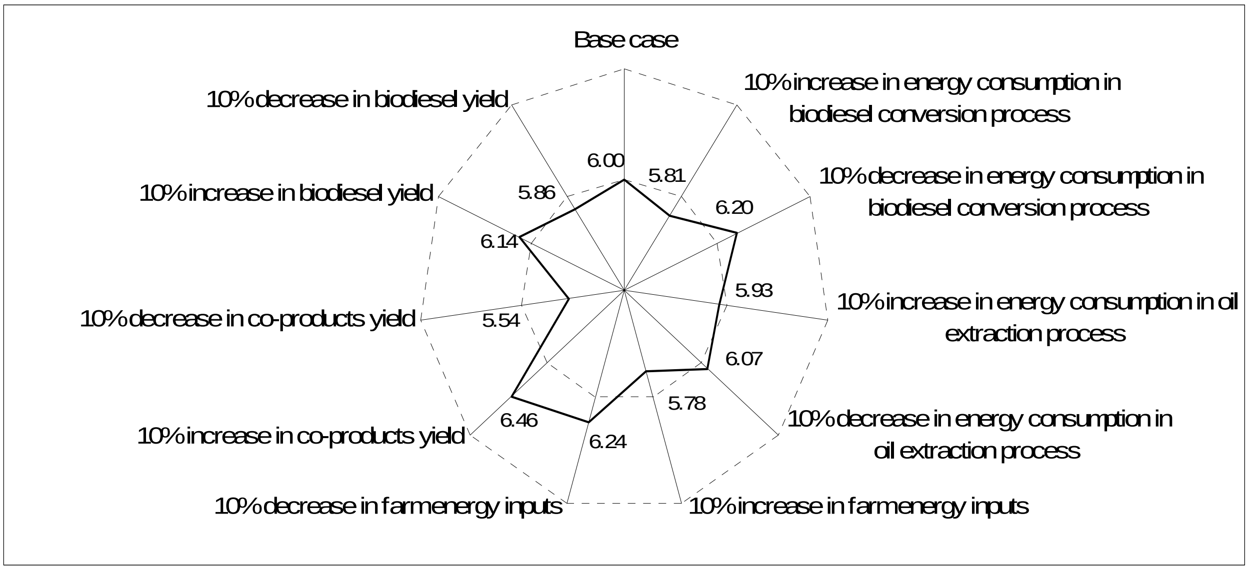

Figure 6 Sensitivity analysis of factors related to NER **[23].**

It should be noted that the calculations in this study are done for a long-term plantation of 20 years. However, this study assesses only energy balance as a first step in evaluating the possibility of JCL as a feedstock for biodiesel. The cost of investment, depletion of resources, environmental impacts, toxicity of JCL, and chemical use should be further studied for an overall assessment. Nevertheless, the results of this study point clearly to the conditions under which maximum benefits of utilizing JCL for biodiesel can be derived. This will serve as a good starting point for policy as well as investment decisions for appropriate infrastructure development and further research needs.

4. Life cycle energy and environmental assessment of fuel ethanol

4.1 Life cycle energy and environmental assessment of fuel ethanol from cane molasses in Thailand [28-31]

After China and India, Thailand is considered another emerging market for fuel ethanol in Asia. In Thailand, three types of raw materials regarded as having high potentials for ethanol production are cassava, molasses and sugar cane. At present, however, ethanol in the country is mainly a fermentation/distillery product of cane molasses. Molasses, a byproduct of the sugar industry with up to 50% fermentables, is considered a common feedstock for the alcohol industry in tropical countries. The Thai government has a policy to encourage fuel ethanol production from molasses, taking advantage of the available supply, simple conversion process as well as existing sugar-based distillery infrastructure. According to **[32**], by 2008, 12 sugar-based ethanol plants with the total output of 1.925 million litres (ML) a day will come on stream in Thailand. The government gasohol E10 policy is most likely an appropriate start and higher blends, e.g., E20, E85, have also just been launched in the market in present year.

In line with rapid development of process technologies involved in ethanol production from biomass, evaluations of ethanol's advantages over gasoline through intensive life cycle assessment (LCA) studies have been conducted to better understand the energy and environmental performance of fuel ethanol. Through LCA procedure, all exchanges of ethanol system with the environment and their potential impacts are examined. Molasses ethanol in Thailand was assessed by life cycle approach in order to present a full chain energy analysis and GHG balance to evaluate whether production and use of the molasses ethanol fuel can help reduce fossil imports and be a reasonable option for national climate policy.

Life cycle energy and environmental performance analysis of molasses-based ethanol as a 10% blend with gasoline as a transportation fuel in Thailand were performed. The functional unit (FU) chosen to compare E10 and conventional gasoline (CG) was 1 L gasoline equivalent consumed by a new passenger car to travel a specific distance. The following parameters were considered:

- Energy use, specified as: (1) net energy use (total fossil and non-fossil energy use, excluding energy recovered from system co-products), (2) fossil energy use and (3) petroleum use
- Environmental impact potentials in four categories: (1) global warming potential (GWP); (2) acidification potential (AP); (3) nutrient enrichment potential (NP); and (4) photochemical ozone creation potential (POCP)

– Land use

The system boundary of the molasses ethanol life cycle is shown in **Figure 7**. Major operating units located inside this boundary are sugar cane farming, molasses generation, and ethanol conversion. Transportation is a component of all operating units. Also included is the production of various items which are energy or energy-related material inputs in sugar cane farming, e.g. fertilizers, herbicides, diesel fuel, and labour. To estimate energy use and emissions associated with molasses input in ethanol conversion, an allocation between molasses and sugar based on their contributions to the economy was set up. The year 2006 marked a significantly increased use of molasses for ethanol production in Thailand compared to 2005 **[33]**. In the Thai product market, average prices over the year 2006 for molasses and sugar were THB 4,000 (US$105) and THB 14,980 (US$394) a tonne, respectively **[34].** About 103.6 kg of sugar and 45.2 kg of molasses are extracted from 1 tonne of sugar cane **[34].** Thus, the relative contribution of sugar and molasses to the economy has the ratio of 8.6:1. Based on this ratio, energy use and emissions from sugar cane and sugar/molasses production (including transportation) were allocated between sugar and molasses at 89.6% and 10.4%, respectively. The ratio is substantially lower than the 15.0:1 for 2005 derived by the same allocation method.

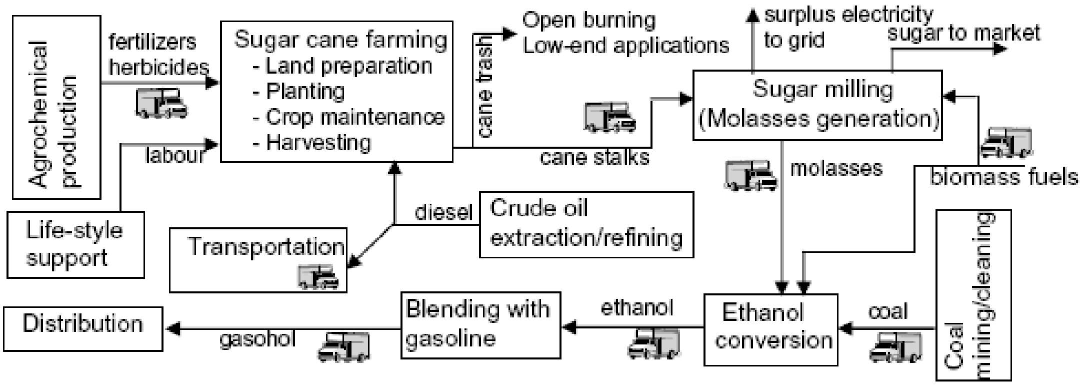

Figure 7 Life-cycle scheme for the molasses based ethanol system **[29]**

4.1.1 Full chain energy analysis [28]

In assessing ethanol's energy performance, net energy value is conventionally a key indicator to identify whether ethanol production and use results in a gain or loss of energy. It weighs the energy content of ethanol against the energy inputs in the fuel production cycle. More specifically, there are three ways in which net energy issue (concerned with ethanol) is being addressed. The first one defines net energy value (NEV) as follows.

NEV = Energy content of ethanol - Net energy inputs (total fossil and non-fossil energy inputs, excluding energy recovered from system co-products, e.g. biogas).

Although energy performance has conventionally been considered using NEV, it may be more meaningful to evaluate a biofuel's contribution to fossil energy use reduction. Such an evaluation should address how much energy is gained when non-renewable fossil fuel energy is expended to produce renewable biofuels. The equations of net (renewable) energy value (NRnEV) and energy ratio (ER), thus, take the following form.

NRnEV = Energy content of ethanol - Fossil energy inputs; and
ER = Energy outputs/Fossil energy inputs.

It is convenient to display net energy value per litre of biofuel. Taking into account price and yield of sugar and molasses in 2006, 10.4% of the energy use in sugar cane farming and sugar milling **(Table 5)** are allocated to molasses. Given the conversion rate of 225 L MoE per tonne molasses or 10.17 L per tonne cane, the steps of calculation to get NEV and NRnEV are presented in **Table 6**.

Table 5 Energy inputs in sugar cane farming and sugar milling **[28]**

Item	Fossil and renewable energy inputs (MJ/t cane)	Fossil energy inputs (MJ/t cane)	Petrol. energy inputs (MJ/t cane)
Sugar cane farming	*465.4*	*441.1*	*212.9*
Diesel fuel (farming operation)	49.6 (10.7%)	49.4	44.8
Fertilizer, herbicide	212.5 (45.6%)	208.3	35.2
Human labour	113.4 (24.4%)	93.8	51.7
Diesel (transportation)	89.9 (19.3%)	89.6	81.2
Sugar milling (Molasses generation)	*410.2*	*4.7*	*4.2*
Bagasse	2117.6	0	0
Rice husk, wood waste and bark	140.8	0	0
Diesel fuel (transportation)	4.7	4.7	4.2
Bagasse as internal energy source	−1852.9	0	0
Electricity output from sugar milling	*−169.4*	*−164.3*	*−8.0*
Net inputs	*706.2*	*281.5*	*209.1*

Table 6 Energy performance of molasses-based fuel ethanol **[28]**

Item	Fossil and renewable energy inputs (MJ/L)	Fossil energy inputs (MJ/L)	Petrol. energy inputs (MJ/L)
Molasses input as raw material	*8.01*	*3.61*	*1.34*
Sugar cane farming	3.85		
Molasses generation	4.16		
Electricity output from sugar milling	*−1.74*	*−1.69*	*−0.07*
Process fuels used for MoE conversion	*18.28*	*11.02*	*0.11*
Rice husk	7.25		
Coal	11.03		
Biogas as an energy input	0.42		
Biogas as internal energy source	−0.42		
Diesel fuel used for transport activities	*2.30*	*2.29*	*2.08*
In sugar cane farming	0.92		
In sugar milling	0.05		
In ethanol conversion and distribution	1.33		
Net inputs	*26.85*	*15.23*	*3.46*
NEV / NRnEV / ER	*−5.67 / +5.95 / 1.39*		
MJ ethanol produced/MJ petroleum inputs	6.12		

Though the net energy (NEV) analysis provides results not in favour of the fuel, molasses ethanol has high potential to improve if co-products, e.g. stillage and cane trash are utilized for process energy in place of fossil fuels. There are iwo possible factors contributing to this unfavourable result. First, the ethanol conversion rate as reported by the factory is relatively low compared to references **[35, 36].** Second is a low contribution (2%) of the energy recovered from stillage treatment to the total energy requirements of the distillery. Among all sub-systems of the MoE production cycle, ethanol conversion is the most energy-consuming one, amounting up to 63.9% of the total energy inputs. The next are sugar cane farming, molasses generation and transportation at 14.6, 13.5 and 8%, respectively. Moreover, there are opportunities for adopting new technologies in ethanol conversion to reduce energy demand by raising ethanol productivity.

Net renewable energy (NRnEV) analysis addressing how much energy is gained when non-renewable fossil fuel energy is expended to produce renewable biofuels gives results in favour of molasses ethanol. For each MJ of fossil energy inputs to produce molasses ethanol, there is a 39% energy gain compared to 19.5% and 15.7% loss for gasoline and diesel fuels, respectively. Even more remarkable is the figure of ethanol energy gain from petroleum energy use, 6.12 MJ/MJ. The findings highlight the positive effect of renewable fuel production in helping to reduce the dependence on non-renewable energy resources, notably petroleum the reserve of which is very near exhaustion.

As per the assessment of supply potential from the surplus molasses, to meet sugar-based ethanol production target, a shift of 8–10% sugar cane produce from its current use in sugar industry to new use for fuel ethanol appears to be a feasible solution. The use of a relatively small portion of the national sugar cane production for ethanol fuel is expected to have minor impact on sugar industry. What is in need to push integrated sugar and ethanol production in Thailand is an appropriate policy favouring a flexible use of sugar cane for ethanol production either directly from sugar juice or indirectly via molasses as a by-product of sugar production. The decision on the degree of substitution between the two commodities, driven by market dynamics, would help farmers and sugar millers get reasonable prices for their produces thus stabilizing their income.

4.1.2 GHG balance **[29-31]**

As indicated by the two sets of results in **Table 7**, substituting MoE for CG leads to a 25.6% or 31.1% increase in GHG emissions, depending on which ratio is used to allocate emissions between sugar and molasses. As a whole, anaerobic pond treatment of distillery spent wash has the highest contribution to total emissions (54.1% with allocation ratio of sugar to molasses (ARSug—Mo) = 8.6 and 56.4% with ARSug—Mo = 15.0), followed by coal use in ethanol conversion (33.3% with ARSug—Mo = 8.6 and 34.7% with ARSug—Mo = 15.0). The net effect of MoE on GHG emissions is likely to be an increase rather than a reduction compared to CG. Main sources of GHG emissions are uncontrolled CH4 emissions from anaerobic ponds treating distillery spent wash and coal used in ethanol conversion, amounting to 87.4% of the overall GHG emissions (base year 2006).

Table 7 Molasses-based ethanol life cycle GHG emissions, scenario 1 (base case) **[29]**

Activity	g CO_2 eq[a]/L ethanol	
	2005: AR_{Sug-Mo} = 15:1	Base year 2006: AR_{Sug-Mo} = 8.6:1
Sugar cane farming	*260.2*	454.6
Fertilizers and herbicides	66.8	116.7
Diesel fuel (farming operation)	21.3	37.3
Labour	38.2	66.7
Diesel fuel (transportation)	39.0	68.2
Soil N_2O	69.4	121.2
Cane trash burning	25.5	44.5
Sugar milling	*5.8*	*10.2*
Bagasse, rice husk and wood waste use as fuels	3.7	6.6
Diesel fuel (transportation)	2.1	3.6
Electricity sold to the grid	*−71.8*	*−125.4*
Ethanol conversion	*3119.4*	*3119.4*
Coal use as fuel	*1150.1*	*1150.1*
Rice husk use as fuel	2.1	2.1
Biogas use as fuel	0.3	0.3
CH_4 emissions from anaerobic pond	1870	1870
Diesel fuel (transportation)	96.9	96.9
Total emissions	*3313.5*	*3458.7*
Gross avoided emissions	*−2638.9*	*−2638.9*
Net increase in emissions	*674.6*	*819.8*
% Increase	*25.6*	*31.3*

[a]The GWPs (time span of 100 years) of CO_2, CH_4 and N_2O are 1, 23 and 296, respectively (IPCC, 2001).

However, the ethanol factory is undertaking the projection of improving overall plant performance from its existing situation. The primary goal is to enhance energy self sufficiency through biogas recovery from the entire volume of spent wash produced. It is assumed that this biogas will substitute for coal to save fossil energy. The substitution would also improve the GHG balance through avoidance of CH_4 emissions from the anaerobic pond and CO_2 emissions from coal use. It is also expected that if coal is totally substituted by biomass, e.g., rice husk, plant performance would be improved further. In Thailand, among various biomass-based energy resources, rice husk is ranked second after bagasse regarding supply availability (NEPO, 2000). To figure out how a substitution of biogas and then rice husk for coal as the process energy source in ethanol conversion would have a positive effect on energy and GHG balance, **Table 8** shows three scenarios that were examined in this study including (1) scenario 1 or base case is the current practice of studied ethanol plant which is used coal, rice husk and biogas recovered from 12% spent wash as energy sources; (2) scenario 2 is the case of substituting biogas recovered from 100% spent wash for coal; and (3) scenario 3 is the case of full substitution of biogas and rice husk for coal.

Table 8 Scenarios of the molasses-based ethanol case study **[29]**

Case	Process energy sources
Scenario 1 (base case)	Coal, rice husk and biogas recovered from 12% spent wash
Scenario 2	Coal, rice husk and biogas recovered from 100% spent wash
Scenario 3	Rice husk and biogas recovered from 100% spent wash

Energy balance (EnB) and GHG emissions of MoE under the two projection scenarios (in comparison with the baseline scenario) for the two periods of interest, 2005 and 2006, are summarized in **Table 9**. Capturing biogas by means of efficient UASB and using it in place of coal results in a shift from a 31.1% increase to a 60.6% reduction in GHG emissions when compare to CG. A complete substitution of biogas and rice husk for coal leads to a very high reduction rate, 22.7% up from biogas substitution alone.

Table 9 EnB and GHG emissions of MoE under base case (scenario 1) and projection scenarios (scenarios 2 and 3) **[29]**

	Scenario 1		Scenario 2		Scenario 3	
	2005	Base year	2005	Base year	2005	Base year
Fossil energy inputs (MJ/L)	14.01	15.25	8.67	9.91	2.91	4.15
EnB (MJ/L)	20.43	19.19	25.77	24.53	31.53	30.29
Total emissions (g CO_2 eq/L)	3313.5	3458.7	894.2	1039.4	295.5	440.7
Gross avoided emissions (g CO_2 eq/L)	−2638.9	−2638.9	−2638.9	−2638.9	−2638.9	−2638.9
Net emission change (g CO_2 eq/L)	674.6	819.8	−1744.7	−1599.5	−2343.4	−2198.2
% change[a]	+25.6	+31.1	−66.1	−60.6	−88.8	−83.3

[a]A negative change denotes a decrease in emissions compared to CG and vice versa.

GHG abatement costs for MoE in Thailand based on the estimates of GHG reduction under mitigation scenarios and current incremental costs exceed the many other climate strategies, which are classified as least-cost options for Thailand. The high price of MoE over gasoline appears to be the main cause of the less favourable cost effectiveness in reducing GHG emissions of the fuel. Governed by market rules, the price may far exceed the real production cost when supply falls short of demand. Balancing supply against demand is the key to the viability of any commodity and ethanol is not an exception. At present, though molasses is the main source of raw material feeding ethanol factories in Thailand, the strategic plan of producing the fuel from the other two feedstock sources, cane juice and cassava, is going on. It is expected that once the demand for MoE is largely offset by cane ethanol as well as cassava ethanol, molasses will no longer be a scarce commodity, the monetary value of which does not reflect its real value in terms of either fermentables or feed protein content. Moreover, the Ministry of Energy, ethanol producers and fuel retailers have recently made an agreement on a pricing formula for ethanol, based on the price in Brazil, plus transportation costs and other expenses **[37]**. This will serve as the reference to control price for domestically produced ethanol.

In short, the biofuel development programme, if properly planned and implemented, does provide net benefits. Nevertheless, not many of these benefits are captured adequately in a conventional cost analysis. An isolated weighing of the incremental cost of ethanol over gasoline against GHG reduction, in most cases, appears to be far from reasonable **[38].** The other external benefits that need to be taken into account are (1) reducing oil import dependence and saving foreign currency, (2) strengthening self-reliance through reducing foreign debt and debt service payment, (3) reducing criteria air pollutant emissions, (4) promoting technological development, (5) encouraging agricultural expansion and boosting domestic markets for agricultural commodities and (6) creating rural employment and improving farm income **[39].** Quantifying all of these benefits to be included in an external benefit and cost weighing analysis would be an important area for future research.

4.1.3 Environmental impacts [30]

For assessing environmental impacts of molasses-based ethanol as a 10% blend with gasoline as a transportation fuel in Thailand. In this study, the **functional unit (FU)** chosen to compare E10 and conventional gasoline (CG) is 1 L gasoline equivalent consumed by a new passenger car to travel a specific distance. As the test results based on Toyota 1.6L/2000, fuel economy compassion reveals that 1 L of E10 is equal to 0.989 L of CG. The two scenarios concerned with process energy sources in ethanol conversion and cane trash burning including E10-a or base case scenario (which uses coal, rice husk and biogas recovered from 12% spent wash and 40% of cane trash burning in fields) and E10-a(nb) (which is the same as E10-a but cane trash burning is outside the system boundary) have been evaluated. **Table 10** presents the life cycle assessment (LCA) characterization results for E10-a and CG. Change represents impacts of substituting the fuel alternative for CG. Negative change implies a reduction in environmental loads compared to gasoline, whilst positive change denotes an increase. The results excluding cane trash burning are also given in columns E10-a(nb) for a comparison with E10-a. Breakdown of E10-a and gasoline life cycle energy and environmental impacts in the three stages (feedstock, fuel and end use) are presented in **Figure 8**.

Table 10 LCA characterization results for 8 impact categories (per functional unit)

Impact category	CG	E10-a		E10-a(nb)	
			% change		% change
Net energy use (MJ)	38.70	39.95	+3.2	39.95	+3.2
Fossil energy use (MJ)	38.59	36.55	-5.3	36.55	-5.3
Petroleum use (MJ)	34.83	32.00	-8.1	32.00	-8.1
GWP (kg CO_2 eq.)	2.99	3.07	+2.8	3.07	+2.7
Acidification (g SO_2 eq.)	3.30	3.30	+0.1	3.20	-3.1
Nutrient enrichment (g NO_3^- eq.)	4.99	5.10	+2.1	4.93	-1.2
POCP (g C_2H_4 eq.)	1.53	1.79	+17.0	1.59	+3.9
Land use (m^2.year)	-	0.02			

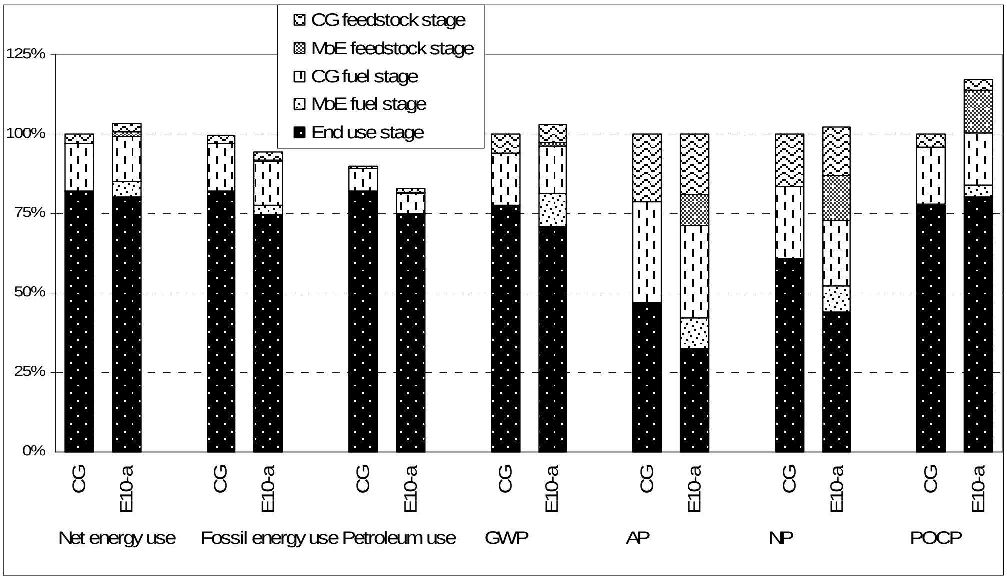

Figure 8 Contributions of stages (feedstock, fuel, end use) to life cycle energy and environmental performance of CG and E10-a

The results show that using MoE in the form of E10 as a gasoline substitute leads to fossil energy and petroleum savings. The savings are mainly due to an avoidance of fossil gasoline consumed when the gasoline–ethanol blend is burned in vehicles. In contrast, using the fuel alternative gives rise to an increase in net energy use relative to CG. Such an increase is contributed primarily by feedstock and fuel stages where higher energy use over CG outweighs lower energy use at the use stage (see **Figure 8**). It can be seen that, MoE feedstock and fuel stages consume more energy than CG. As a result, an addition of MoE to CG to make E10 blend raises energy usage intensity of these stages over CG.

For global warming potential (GWP), photochemical ozone creation potential (POCP) and nutrient enrichment potential (NP), higher impacts from the upstream of E10 govern the net impacts of the fuel life cycle relative to CG. This results in the E10 blend being less environmentally friendly than CG. Considering AP, a higher impact from the upstream of E10 over that of CG is compensated by lower impact from the use stage (see **Figure 8**). Coal used in ethanol conversion is the main source of energy use and environmental impacts. CH_4 emissions from anaerobic pond-treating stillage contribute largely to global warming potential. Capturing this gas and using it for plant energy would bring multiple benefits: saving energy, avoiding environmental impacts of uncontrolled CH_4 emissions and also of CO_2 emissions from coal use. Cane trash open burning in sugar cane farming is a contributor to acidification, nutrient enrichment and, notably, photochemical ozone creation potential.

The sugar industry in Thailand produces approximately 3 million tonnes of molasses a year, 60–70% of which is consumed for liquor and animal feed. The surplus 30−40% is thus feasible to be converted to 0.8 million litres (ML) ethanol a day **[40]**. As such, there is possibly some change in land use to grow crops to substitute molasses in its current use. A rough evaluation of the area of land use for growing feedstock (sugar cane) to produce the ethanol portion in E10 indicates that production of 0.8 ML ethanol a day or 240 ML a year from the surplus molasses corresponds to the use of approximately 43,000 ha of land a year.

4.1.4 Cost performance [31]

One of the concerns arising with an increased use of ethanol is its relatively high price over gasoline **[38]**. This situation is not different for Thailand, a new market for fuel ethanol in Asia. To enhance ethanol's cost competitiveness against conventional gasoline (CG), the government's measures include excise tax exemption and fuel subsidies. In fact, market price is just only one aspect of the biofuels' performance. It would not inform policy makers adequately about potential benefits of biofuels, e.g., fossil oil savings and environmental improvements upon substituting fossil based liquid fuels in transportation. For evaluatation of MoE cost perfermance, the life cycle fossil energy use, air emissions and cost of MoE are the three parameters to be addressed. The cost estimate includes not only the direct production/distribution costs but also the external environmental costs.

4.1.4.1 Cost performance of MoE without externality accounting

As of Jan–Aug 2007, ex-refinery prices (i.e. the prices before all forms of oil fund levy/tax package, marketing margin and value added tax (VAT) are added to make retail prices) for 95-octane unleaded gasoline and gasohol were THB 17.48 and 17.86 L^{-1}, respectively, giving a price gap of only THB 0.38 L^{-1} **[41]**. However, if the difference in fuel economy between CG car and E10 car is taken into account, the gap increases to THB 0.58. For gasohol to be competitive with gasoline, ethanol ex-refinery price has to drop to THB 15.56 L^{-1}, given that 1L ethanol (in the form of E10) is equal to 0.89 L gasoline **[29].** Ethanol ex-refinery price is a sum of the three cost items, production costs, profit margin and transportation/distribution cost. For conventional ethanol, i.e. ethanol from grain and sugar crops, a significant portion of the overall production costs (65–70%) is accounted for by feedstock cost and the remaining (30–35%) is conversion cost **[38, 42].** Molasses market price as high as THB 4000 $tonne^{-1}$ in 2006 pushed ethanol price to THB 25.3 L^{-1} **[43],** which is far above the supposed price to make the fuel competitive with gasoline. In order to make ethanol price drop to THB 15.56, a reduction in molasses price to THB 2023 $tonne^{-1}$ would be the first option. Trend of molasses price drop is most likely in line with a reduced demand, resulting from the promotion of ethanol from the other feedstocks, cassava and sugarcane **[33].**

4.1.4.2 External environmental benefit

An external benefit is a benefit not reflected in the market price of the goods and services, i.e. a benefit not paid for by customers **[44].** By this definition, market price tells nothing about the so-called ''hidden benefits'' of ethanol. To assess biofuels' benefits over conventional fuels, there is a need to quantify external costs and include them in a social cost analysis. The Swedish EPS (Environmental Priority Strategies in product design) **[45]** system is a model that has been used to accomplish this task in Thailand. Default indices are derived for impact category indicators, e.g. resources use and pollutant emissions. Background information is extracted from LCA-based inventory of the process studied and the results are represented via willingness to pay (WTP) of the society.

Since with Thailand, the depletion of the world's oil reserves and environmental degradation due to air pollution are among top national concerns **[46],** external costs for fossil oil resource use and air emissions were considered in this study. To adapt the model to Thailand, it is hypothesized that the WTP is proportional to the per capita income (GDP expressed in terms of purchasing power parity) **[47].** WTP for Thailand is thus presented by the following equation:

$$WTP_{Thailand} = WTP_{Sweden} \times PERCAP\text{-}GDP(PPP)_{Thailand}/PERCAP\text{-}GDP(PPP)_{Sweden}.$$

Information about GDP(PPP) per capita for Thailand and Sweden is available from CIA (2007), based on which the ratio $WTP_{Thailand}/WTP_{Sweden}$ or ''income elasticity of WTP'' is derived. **Table 11** lists the external costs for air pollutants and fossil oil use in THB equivalent/kg after adjustment for Thailand.

Table 11 Environmental costs per unit of pollutants and fossil oil use [31]

External cost	CO_2	CH_4	N_2O	CO	NO_2	SO_2	VOC	PM_{10}	Fossil oil
THB/kg	1.4	34.5	485.0	4.2	27.0	41.9	27.1	457.2	6.4

Table 12 presents three scenarios concerned with process energy sources in ethanol conversion and cane trash burning in fields. The first scenario (E10-a) represents the base case (shown in Fig. 1). The second (E10-b), with the same assumption as in the first in ''cane trash burning'' condition, assumes that the plant's energy demand is met by using biogas recovered from 100% spent wash and rice husk. The third one (E10-c) substitutes cane trash collected from cane fields after un-burned harvesting for rice husk in the second scenario.

Table 12 Scenarios of molasses based gasohol in the study [31]

Case	Process energy source in MoE conversion	% cane trash burned in fields
E10-a	Coal, rice husk and biogas recovered from 12% spent wash	40
E10-b	Rice husk and biogas recovered from 100% spent wash	40
E10-c	Cane trash and biogas recovered from 100% spent wash	0

Table 13 presents the external environmental costs for emissions and fossil oil use estimated from the inventory results for E10 fuels and CG and the cost per unit of air pollutants and fossil oil use. The costs are then added to the ex-refinery price of the two fuels to make total social costs. Ex-refinery price of E10-a (was taken directly from reference **[41]** and the value was used to estimate ex-refinery prices of E10-b and E10-c, taking into account net cost savings potential. As shown in the table, the environmental costs of E10-a, b, c are lower than those of CG. However, with E10-a, the lower external costs for fossil oil use, CO_2 and NO_x emissions cannot compensate for the higher direct production costs and external costs for other emissions, though the price gap between the fuel and CG becomes narrower. In contrast, an addition of lower external costs (resulting from lower fossil oil use and all air emissions except N_2O, VOC and PM_{10}) to the ex-refinery prices of E10-b and especially E10-c makes their

total social costs almost equal to those of CG. The benefits are largely from fossil oil and CO_2 savings.

Table 13 WTP for impacts from emissions, fossil oil use and ex-refinery price of gasohol E10 and CG [31]

Cost item (THB/FU)	Gasoline	E10-a		E10-b		E10-c	
			% Change		% Change		% Change
Environmental costs	471.0	469.1	−0.4	442.5	−6.0	436.8	−7.3
Fossil oil use	240.8	221.6		221.4		221.5	
Air emissions	230.2	247.5		221.1		215.3	
CO_2	196.6	188.2		180.4		179.9	
CH_4	5.9	20.2		5.8		5.6	
N_2O	2.9	4.8		5.0		4.9	
CO	3.5	3.7		3.7		3.0	
NO_x	4.7	4.6		4.5		4.3	
SO_2	1.7	1.9		1.8		1.6	
VOC	3.9	4.7		4.7		4.3	
PM_{10}	11.0	19.4		15.2		11.6	
Ex-refinery price	873.7	902.7	+ 3.3	900.4	+ 3.1	898.7	+ 2.9
Total social costs	1344.7	1371.8	+ 2.0	1342.9	−0.1	1335.5	−0.7

In summary, molasses-based ethanol (MoE) as a 10% blend in gasoline appears to be a good option for substituting gasoline in Thailand in reducing fossil energy use (5.0%) and petroleum use (8.0%). Since E10 contains only 10% ethanol, the magnitude of the reduction as seen is relatively minor. However, taking into account the production target of 0.8ML of MoE or 8ML gasohol a day, a rough estimation can be made that the use of this biofuel would reduce oil use by 140 thousand tonnes a year. This would be translated into foreign currency savings of about US$68 million a year. Promoting E10 as an alternative transportation fuel in Thailand thus helps reduce national fossil fuel and petroleum consumption, and hence improve energy security.

As shown from the scenario analysis, MoE has high potential to be improved if the following measures are implemented: (1) substituting biomass fuels for fossil fuels in ethanol conversion, (2) capturing CH4 from spent wash digestion and using it for energy and (3) utilizing cane trash for energy instead of open burning. The benefits in fossil oil savings considering the production scale according to the government target would be more promising if waste biomass feedstocks are used for energy (scenario c). Apart from that, an analysis of externalities counting the three GHGs (CO_2, CH_4 and N_2O) separately using the EPS model, the benefits of ethanol can also be quantified by addressing GHG savings. Total GHG savings from 8ML gasohol a day substituting gasoline in transportation amount to roughly 0.5 Mt CO_2eq./year. This figure can be translated into an external benefit of US$2.5 million a year, using the lowest Certified Emission Reductions rate for Thailand, US$5/t CO_2eq. **[48].**

4.2 Environmental assessment of cassava based ethanol in Thailand [26, 49-51]

The three types of raw materials regarded as having high potential for ethanol production are sugar cane, cane molasses and cassava in Thailand. The major advantages of cassava over molasses and sugar cane can be listed as follows:

(1) Cassava is well known as a hardy crop having the ability to adapt well to a wide range of growing conditions with minimal inputs. In Thailand, cassava ranks the

third most important cash crop after rice and sugar cane. Various institutions/research centers have conducted cassava improvement research and made the research results relevant to farmers' real conditions, ensuring adaptation as well as adoption by farmers. Due to the introduction of high-yield varieties and improved production practices, an increase in national cassava yield from 13 t/ha in 1995 to 20 t/ha in 2004 was recorded **[52].**

(2) Unlike sugar-based distilleries that are operated seasonally, cassava-based ethanol industry can be put in operation continuously, thanks to the crop's unbound time window for growing and harvesting, plus its capability to be stored as dried chips.

(3) The inadequate Thai cane productivity (60 Mt/yr) compared to sugar mill capacity (75 Mt/yr) implies that very limited surplus stock of sugar cane is available for ethanol production **[36].** The complication of sugar cane and sugar legislation on profit sharing between farmers and millers adds one more disadvantage of sugar cane utilization for ethanol production. With molasses, high demands in both domestic and international market have resulted in supply shortage and, consequently, strong fluctuation in price. In contrast, there is frequently an oversupply of cassava leading to falling prices and incomes for farmers. The ethanol industry once developed would provide a partial solution to the problem. Regarding supply potentials, of the total 20Mt of the annual production of cassava in Thailand, approximately 40% is absorbed by starch industry and another 40% is processed to chips and pellets, mainly for export. The surplus 20% is utilized mainly for low-end applications such as domestic animal feed **[53].** It is reasonable to convert this surplus to 2 million litres (ML) of ethanol per day, ensuring a stable source of feedstock and a neutral impact on starch and chip/pellet industries.

(4) Technical development in ethanol conversion from grains available elsewhere in the world can be readily applied to cassava. This would help to boost input energy efficiency and reduce production cost.

According to the government plan, by 2007 and 2008, the number of cassava-based ethanol (CE) plants in Thailand would amount to 12 with the total output of about 3.4ML per day **[54].** The strategic plan for cassava needs to be revised and reformulated to meet additional demand for ethanol fuel. A decrease in the export of cassava products is mostly a short-term solution. Long-term strategy set up by national cassava policy is improved crop productivity from an unchanged planted area of 1.06 million hectares. It can be achieved by the dissemination of good stake of new varieties and better cultivation/harvest practice. From a current yield of about 19 t/ha, by 2007, the root yield is projected to reach 31 t/ha for a promoted area of about 192,000 ha and 21 t/ha for the rest. The promotion of contract farming is another measure to support the ethanol project **[55].**

To assess the contribution of cassava energy security and climate change mitigation, it is necessary to determine its energy balance (EnB), GHG balance, environmental impacts and cost effectiveness as well as the potential of molasses ethanol. The functional unit (FU) chosen to compare E10 from cassava ethanol and conventional gasoline (CG) is 1 L gasoline equivalent consumed by a new passenger car to travel a specific distance. As shown in **Figure 9**, four main unit processes of the cassavabased

E10/E85 fuel system for the life cycle inventory (LCI) are cassava production, ethanol conversion, transportation and fuel combustion in vehicles. The system boundary also includes various sub-processes associated with the four main processes, viz. agrochemical manufacturing, crude oil extraction/ refining, electricity production and solar energy capturing. The preparation of organic fertilizer used in cassava farming, performed by simply mixing manure with rice husk, was excluded from the system boundary. Also energy costs and environmental loads from the manufacturing of chemicals used in ethanol conversion were considered negligible compared to other inputs and thus not included in the analysis. Solar energy captured by cassava crops and later transformed to the heating value of ethanol was counted as the non-fossil energy consumed when ethanol is burned in vehicles (i.e. use stage).

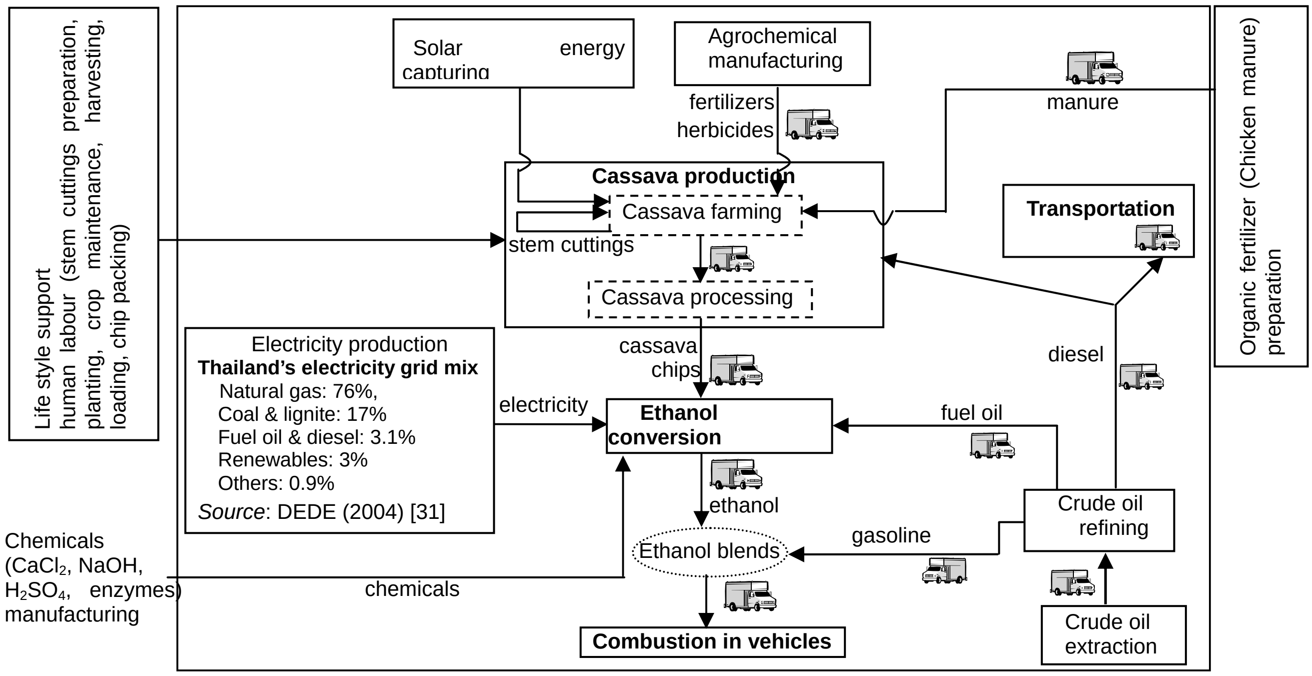

Figure 9 System boundary of the cassava-based E10/E85 fuel life cycle (base case)

4.2.1 Full chain energy analysis [26]

An assessment of net energy and supply potentials was performed to evaluate cassava utilization for fuel ethanol in Thailand. The cassava fuel ethanol (CFE) system involves three main segments: cassava cultivation including processing, ethanol conversion, and transportation. All materials, fuels, and human labor inputs to each segment were traced back to the primary energy expense level. The results in **Table 14** show that CFE in Thailand is energy efficient as indicated by a positive NEV. The NEV found for CFE is 8.80 MJ/L, with human labor energy estimated based on the preferred Life-Style Support Energy (LSSE) method. NEV of 9.95 MJ/L was recorded if human labor is estimated using the Total Food Consumed (TFC) method. Excluding this energy input raises NEV to 10.22 MJ/L. Of the total energy inputs in the CFE system, fuel conversion is the most energy-consuming one, amounting to 64.1%. Following are feedstock cultivation/processing at 26.7% and transportation at 9.2% (LSSE method). Of the three fertilizer elements, N contributes the largest energy consumption in cassava farming. Moreover, about 97.35% of the total energy inputs come from fossil fuels whereas nonfossil energy just makes up a small share (3.65%). Again, the largest contribution of fossil-based energy inputs to the whole CFE production cycle, 55.5%, is due to the ethanol conversion process.

Table 14 also shows a comparison of ethanol's NEV estimate in this study and the three recent NEV estimates [56, 57, 58]. The table presents the detailed accounting of energy inputs in each estimate, displayed as MJ/L ethanol. In fact, it is not an easy task to make such a comparison, mainly due to the differences in (1) assumptions about fuel conversion factors and energy costs of fertilizers and herbicides, and (2) methods used to estimate labor energy and coproduct energy credits.

One important factor contributing to the variation in NEV estimates is the value of the magnitude of farming energy inputs. Notable are fertilizer, herbicide/ insecticide, and human labor inputs. Based on the four NEV estimates, it can be seen that without coproduct energy credits, CFE in Thailand is even more efficient than CFE in China and corn ethanol in the United States. Two reasons make such a favorable performance for CFE in Thailand in comparison with the others. First, cassava farming in Thailand consumes less fertilizers and herbicides. Second, the ethanol conversion stage in Thailand uses far less energy than those in the United States and China. Furthermore, the amount of energy recovered from biogas, a product of stillage treatment, also favors the Thai cassava ethanol's NEV. In comparison with China, cassava farming in Thailand has a much lower labor input, but has a higher direct fuel use. Notably, in spite of lower output per hectare, CFE in Thailand is more efficient than that in China.

Table 14 Comparison of ethanol's NEV estimate in this study and three recent studies

	USDA (2004)	Pimentel and Patzek (2005)	Dai et al. (2006)	this study
Energy use (MJ/L ethanol)				
Farming	*5.19*	*10.34*	*4.34*	*4.24*[a] *(3.09)*[b] *(2.82)*[c]
Seed/stem cuttings	0.06	0.68	0.01	-
Fertilizer	2.84	4.27	1.47	1.22
Herbicides, pesticides	0.31	1.17	1.73	0.55
Direct fuel use	1.80	1.88	0.31	1.05
Custom work/labour	0.17	0.60	0.82	1.42[a] (0.27)[b] *(0)* [c]
Farm machinery	-	1.32	-	-
Irrigation	0.01	0.42	0	0
Ethanol conversion	*6.54*	*13.87*	*8.88*	*6.70*
Electricity and steam	13.86	14.93	15.57[a]	10.15
Process water and equipment	-	0.80	-	-
Energy recovered (biogas)	-	-	-3.67	-3.45
Co-product energy credit	-7.32	-1.86	-3.02	-
Transport, Denaturing, Distribution	*1.03*	*1.57*	*0.50*	*1.46*
Net energy inputs (MJ/L ethanol)	12.76	25.78	13.72	12.40[a] (11.25)[b](10.98)[c]
NEV (MJ/L)	8.51	- 4.50	7.48	8.80[a] (9.95)[b] (10.22)[c]
Ethanol productivity				
Crop yield (kg/ha)	8,739	8,655	33,142	27,046
Conversion rate				
L/ton corn	396	372		
L/ton fresh cassava			190	137
Ethanol output (L/ha)	3,464	3,217	6,313	3,705

Remark
a Labor energy estimated based on Life-Style Support Energy" (LSSE) method recommended by Odum [59]
b Labor energy estimated based on "Total Food Consumed" (TFC) method and a value of 2.3 MJ/h derived for human labor energy equivalent has been used by numerous authors [58, 60, 61].
c Labor energy not included.

4.2.2 GHG balance [49]

As indicated by the results shown in **Table 15**, CE system in Thailand can provide reduction in GHG emissions compared to CG as a base case; the production and use of one litre of CE can avoid 1.6 kg CO_2eq. which corresponds to a 62.9% GHG reduction. Taking into account the production target of 3.4ML of CE per day, a rough estimation can be made that the use of this biofuel would reduce GHG emissions by 2 million tonnes CO_2eq./year or 0.5 million tonnes carbon eq./year.

Table 15 Cassava ethanol life cycle GHG emissions [49]

Items	g CO_2eq/L EtOH[a]	% contribution
GHG emissions due to the use of fossil fuels	839	87.03
Cassava farming/processing	*253*	*30.15*
Fertilizers and herbicides	90	
Diesel fuel	84	
Labor	79	
Conversion	*496*	*59.12*
Bunker oil	472	
Electricity	24	
Transport (diesel fuel)	*90*	*10.73*
Other GHG emissions	125	12.97
Soil N_2O	*123*	
CH_4 and N_2O emissions from biogas burning	*2*	
Total GHG emissions	964	
Gasoline fuel-cycle GHG emissions (excluding CH_4 and N_2O emissions from use phase)	2,918	
Gross avoided emissions	-2,918 x 0.89 = -2,597	
Net avoided emissions	-2,597 + 964 = -1,633	
% reduction	62.9	

[a] The GWP (time span of 100 years) of CO_2, CH_4 and N_2O is 1, 23 and 296, respectively (IPCC, 2001)

Table 15 also shows the distribution of GHG emissions by segments. As expected, fossil fuel use contributes much more GHG emissions than soil N2O emissions plus CH4 and N2O emissions from biogas burning, 87.03% versus 12.97%. Consistent with EnB analysis, again, ethanol conversion is the segment having high contribution of GHG emissions (59.12%) due to high consumption of fossil oil. Following ethanol conversion segment are cassava farming/processing and transportation, accounting for GHG emission contribution of 30.15% and 10.73%, respectively. GHG emissions associated with fossil fuel consumed to support human labor account for almost 31.2% of emissions assigned for cassava cultivation/processing. However, its contribution to the whole system is relatively small, only 8.2% of the total GHG emissions.

4.2.3 Environmental impacts [50]

For environmental impacts of the E10 and E85 blend, it is obvious that sources of energy input in the ethanol conversion process are critical for determining whether the fuel is more environmentally friendly than CG. **Table 16** shows three scenarios concerned with process energy sources in the ethanol conversion stage that have been examined. The first scenario is based on the assumption that the energy used to drive the ethanol conversion process is simply derived from fossil sources. The second scenario reflects the existing situation of ethanol factories in Thailand; process energy source comprises both biomass and fossil fuels. The third one assumes that the plant's energy demand can be met totally by using its co-product (biogas), and biomass, e.g. rice husk, as an external energy source.

Table 16 Scenarios of cassava fuel ethanol study

Case	Process Energy Source
Scenario 1: E10-a, E85-a	Fuel oil only
Scenario 2 (base case): E10-b, E85-b	Biogas and fuel oil
Scenario 3: E10-c, E85-c	Biogas and rice husk

Table 17 summarizes the LCA characterization results for the existing situation of ethanol factories in Thailand or namely E10-b and E85-b and comparing them with CG. Change represents impacts of substituting either of the two alternatives for CG. Negative change implies a reduction in environmental loads compared to CG, whereas positive change denotes an increase. Breakdown of contributions from the three stages (feedstock, fuel and end use) to the life cycle energy and environmental performance of CG, E10-b and E85-b is shown in **Figure 10**.

Table 17 LCA characterization results for 9 impact categories (per functional unit)

Impact category	**CG**	**E10-b**		**E85-b**	
			% change		% change
Total gross energy use (MJ)	38.70	38.78	+0.2	34.02	-12.1
Net energy use (MJ)	38.70	38.48	-0.6	31.57	-18.4
Fossil energy use (MJ)	38.59	36.22	-6.1	14.32	-62.9
Petroleum use (MJ)	34.83	32.65	-6.3	12.58	-63.9
GWP (kg CO_2 eq.)	3.00	2.81	-6.0	1.15	-61.6
Acidification (g SO_2 eq.)	3.30	3.07	-6.8	4.90	+48.4
Nutrient enrichment (g NO_3^- eq.)	5.00	4.38	-12.2	6.67	+33.8
POCP (g C_2H_4 eq.)	1.53	1.54	+0.6	1.27	-17.1
Land use (m^2 in one year)	-	0.27		2.19	

The results show clear advantages of using CE in the form of either E85 or E10 as a transportation fuel over CG in terms of reductions in fossil energy use, petroleum use and GWP. The reductions mainly result from the absence of fossil-based liquid fuel and consequently fossil-based CO_2 emissions from the combustion of ethanol portion in the blends. It is reasonable that the magnitude of the reductions is proportional to the percentage of ethanol mixed with CG. Using E85 is even more advantageous than E10 considering '% change' in total gross energy use and net energy use relative to gasoline. Regarding other environmental impact potentials, e.g. acidification, nutrient enrichment and photochemical ozone creation potential, the results come out in opposite direction for E10 and E85. Along its whole life cycle, E10 produces positive impacts over CG on acidification and nutrient enrichment, but negligible impact on photochemical ozone creation potential. In contrast, the production and use of E85 leads to more severe impacts on acidification and nutrient enrichment but less damaging impact on photochemical ozone creation potential than CG. As illustrated in **Figure 10**, in terms of acidification and nutrient enrichment, lower impacts from the use stage of E10 favour the overall life cycle impacts of the fuel mixture over CG. As ethanol content in gasoline reaches 85%, the net changes in the two impact categories relative to CG are dominated by higher impacts from the upstream of the ethanol fuel life cycle. For POCP, a slightly higher impact from the use stage of E10 over that of CG is nearly compensated by lower impact from the upstream. Improvement appears with E85 where a combination of lower impacts from the fuel stage and use stage completely offset the slightly higher impact from the feedstock stage.

Figure 10 also reveals that a high percentage of energy use and environmental impact potentials is contributed by the combustion of the fuel mixture and the production of the major fuel component, i.e. CG if the mixture is E10 or ethanol if the mixture is E85. Obviously, the environmental impacts from ethanol production cycle play a more dominant role in a high-level ethanol-gasoline blend than in a low-level one.

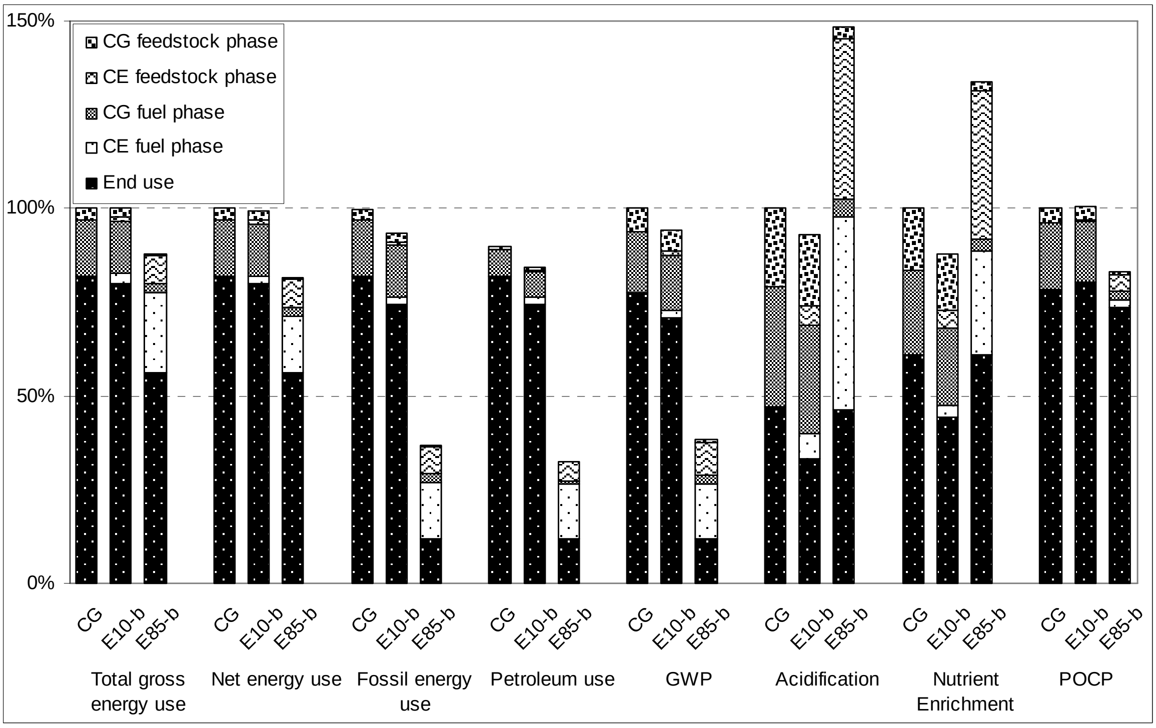

Figure 10: Contributions of stages (feedstock, fuel, end use) to life cycle energy environmental performance of CG, E10-b and E85-b

Based on the results of the study, main conclusions can be drawn as follows:

- Ethanol fuel used in the form of blends in gasoline can help reduce fossil energy use and GHG emissions.
- Using E10 substituting for conventional gasoline also results in less acidification and nutrient enrichment.
- For ethanol production cycle, ethanol conversion is the main source of energy use and most of environmental impacts. It leaves an area for researchers and technicians to work on to maximize ethanol's advantages while minimizing disadvantages. Feedstock cultivation is also a notable contributor to acidification, nutrient enrichment and photochemical ozone creation potentials. A modest rate of energy and energy-carrier inputs in cassava production through appropriate farming practices can help reduce these impacts, i.e. optimising farm inputs.

- Substituting biomass for fossil fuels as the main process energy source in ethanol plants helps improve the fuel's life cycle environmental performance. The substitution has a larger influence on E85 than on E10.
- Human labour, if included in the assessment, increases environmental loads assigned to the two ethanol blends. The increases, however, are not large enough to reverse the direction of the changes (i.e. an increase or decrease) in environmental loads relative to gasoline. For a fair comparison between ethanol production in different countries with different levels of mechanization, human labour input at the farming stage should be included. There is a need, however, to develop a generally acceptable accounting method to quantify labour.

4.2.4 Cost performance [51]

A fair comparison between gasohol and gasoline should be based on their ex-refinery prices rather than retail prices (pump prices). In the first six months of 2007, the ex-refinery prices for gasohol and 95 octane gasoline (ULG 95) in Thailand were around THB 17.9 and THB 17.4 a litre on average **[62-63],** giving a price gap of THB 0.5. However, if the difference in fuel economy between CG car and E10 car is taken into account, the gap increases to THB 0.7. Such price picture fails to reflect the external benefits of ethanol, i.e., benefits not included in its market price and thus not paid for by customers **[44].** There is a need of some assessment technique/hypothesis to convert the amount of resource consumption and air pollutant emissions into a common unit, e.g. monetary value. Various research studies **[64-66]** have tried to quantify these benefits in monetary terms but the task seems not an easy one.

In this study, the external environmental costs of gasohol and gasoline of the three scenarios as mentioned before in **Table 16** were estimated based on EPS 2000 methodology. As **Table 18** shows, the environmental costs of E10-a,b,c are lower than those of CG. However, with E10-a, the lower external costs for both fossil oil use and air emissions cannot compensate for the higher direct production costs, though the price gap between the fuel and CG gets narrower. On the contrary, an addition of external costs to the ex-refinery prices of E10-b and especially E10-c makes their total social costs equal to those of CG. For both CG and E10 fuels, environmental costs contribute about 33-35% of the total social costs; fossil oil use and air emissions having an almost an equal share.

Table 18 WTP for impacts from air emissions, fossil oil use and direct costs of gasohol and gasoline

Cost item (THB/FU)	CG (ULG 95)	E10-a		E10-b (base case)		E10-c	
			% change		% change		% change
Environmental costs	471.0	447.9	-4.9	443.4	-5.9	435.2	-7.6
Fossil oil use	240.8	228.2		225.7		221.3	
Air emissions	230.2	219.7		217.7		213.9	
Ex-refinery price	869.5	909.4	+4.6	903.2	+3.9	894.4	+2.9
Total social costs	1340.5	1,357.3	+2.3	1346.6	+0.5	1,329.6	-0.8

The main message from this externality analysis is that many benefits of ethanol are not reflected in price. EPS is one of the many different valuation models. Varying results are most expected to come out with other valuation models. In addition, potential benefits of biofuels in reducing emissions and fossil oil use are just two besides other benefits that also need to be quantified and included in such a cost/benefit analysis. Some of the important ones can be listed as: (1) saving foreign currency through reduced oil import, (2) strengthening self-reliance through reducing foreign debt and debt service burden, (3) encouraging agricultural expansion and promoting domestic markets for agricultural commodities, (4) creating rural employment and improving farm income.

The results of the study demonstrate that using cassava based E10 substituting for conventional gasoline leads to the following benefits/limitations.

1. Reducing fossil energy (6.1%) and petroleum use (6.3%). As far as an independence from imported oil is of concern, reduction in petroleum use is highlighted.
2. Reducing emissions of CO_2 (6.4%), CH_4 (6.2%), CO (15.4%) and NO_x (15.8%) but increasing emissions of N_2O (25.9%), SO_2 (16.9%), VOC (7.6%) and PM_{10} (2.4%).
3. Generating lower environmental costs (5.9%). It is worth noting that the ex-refinery price of E10 is higher than that of ULG 95 (3.9%), but it is almost compensated by the lower external environmental costs.

From the scenario analysis, it is shown that the substitution of biomass for fossil fuel as the main process energy source in ethanol conversion mostly improves the fuel's life cycle energy, environmental and cost performance.

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Task 4.3: Best Practices – Successes and Failures from Thailand

1. Introduction

This task includes a literature review for documenting best practices, successes and failures on improved agricultural and agro-forestry systems in Thailand. National policies and strategies addressing the implementation of bioenergy and biofuels will be described. Emphasis will be on the promotion of cassava production and utilisation, increase in biomass resource potential and improved energy crop yields. The success of the royal projects in water management and soil improvement will be examples for the best agricultural practice for Thailand.

However, development and deployment of bioenergy is challenging. Technical and non-technical barriers will be listed. Finally, lessons learnt from failures will be given.

2. National policy and strategies addressing the implementation of improved energy crops and agroforestry systems

2.1 Background of national policies and strategies for bioenergy and biofuels

Reserved energy in Thailand has been decreasing due to the marked increase of energy demand especially for transportation and industrial sectors. Approximately half of the country's primary energy demand is imported. It is therefore necessary for the country to develop alternative fuels to compensate the use of fossil fuels in order to help the country to be energy self-reliant. The National Energy Policy focuses on following issues:

1. Establish the regulatory framework for electricity and natural gas industries
2. Enhance energy supply: Energy security (self sufficiency)
3. Promote energy saving and energy efficiency
4. Promote renewable and alternative energy: Reduce imports and diversify fuel types and sources
5. Market-based pricing structure: Reflect true cost in a transparent manner and promote competition
6. Set mandate on clean energy: Alleviate impacts on environment
7. Promote public and private participation in policy formulation

It has been found that bioenergy has the highest potential compared with other renewable energy sources. Biomass which can be used not only for power generation, but also for producing biofuels for transport has also been found to be more cost effective than other types of renewable energy.

As the majority of energy for the transport sector comes from petroleum oil, almost all of which is imported, The Thai government has set ethanol and biodiesel as priority alternative energy sources in its national plan. Measures undertaken to accomplish this goal include monitoring and regulating the pricing of alternative energy, R&D support, and public awareness campaigns. The New Energy Strategy Plan, approved by the cabinet on 17 May 2005, provides for reducing the oil input for transportation by 25 % in 2009 with the use of natural gas, ethanol blended gasoline (gasohol) and biodiesel. By 2011, it is planned to have ethanol contribute with 10 % and biodiesel with 3 % to the fuel consumption of the transport sector. Ethanol and biodiesel are renewable energy, which will not be depleted and which will help increase the prices of agricultural products while reducing oil import and hence saving foreign currency. Moreover, their selling prices are not expensive and these biofuels are clean energy, contributing to reduction of environmental impacts and global warming problems.

In terms of heat and power, apart from the active government campaign in 2005 on several energy-saving and energy-efficiency programs, policy measures to promote renewable energy for electricity production was also implemented, including price incentives, tax benefit and so on.

Details of policies, status of implementation and level of success will be described as followings:

- **Gasohol**

Gasohol is now widely recognized in Thailand and the number of gasohol stations is in rapid expansion. Currently, the gasohol sold in all petrol stations has the volumetric proportion of bio-based ethanol of 10 % or also known as E10, with a more limited number of stations also selling E20 (20 % bio-based ethanol). The gasohol is blended to have the octane number of 95 or it is altogether called gasohol 95. There is also gasohol 91 but with a more limited availability.

In 2004, the Ministry of Energy launched the Gasohol Strategic Plan, though after which some policy measures and targets have been revised. Since then, imported methyl tertiary butyl ether (MTBE) has been phased out and no longer used in unleaded gasoline. The government has also developed specifications for gasohol 95 and performed emission tests on engines. To promote gasohol consumption, following measures have been implemented.

1. Retailed price of gasohol E10 is 2 THB/liter lower than gasoline
2. All government office cars are enforced to be fuelled with gasohol
3. Public relation of warranty of gasohol utilization in all gasoline vehicles that are manufactured since 1995. In addition, public relation campaigns employed by private sector have also helped to successfully raise public awareness and acceptance.

In 2005, the government has set a target that the gasohol consumption would reach 8 million liters/day by the end of 2007 and 20 million liters/day or the ethanol consumption for E10 gasohol of 3 million liters/day by 2011. In 2006, gasohol consumption has reached 1,184 million liters, rapidly grown from 60 million liters in 2004. This is equivalent to the drop of demand for ordinary gasoline (Octane 95) by 34 %, and the rise of gasohol consumption by 83 %. In the same year, the government planned to replace gasoline (octane 95) with gasohol 95 by January 1, 2007, but the full replacement was delayed over concerns that the existing ethanol production capacity would not meet the demand. Finally, from the beginning of 2008, all the petrol stations in Bangkok have stopped the sales of gasoline and have only gasohol 95. The expansion of gasoline replacement to all petrol stations in Thailand is still in progress until 2012 when it is planned that all petrol consumed will be gasohol 95 by law.

Now, it is apparent that ethanol-blended gasohol has gained popularity in Thailand at the expense of ordinary gasoline. With the tax reduction for E20 and E85 cars as a different means to promote the use of ethanol, the lower car prices will make cars fuelled with gasohol or in the future pure ethanol even more attractive. E85 will be an important energy option for Thai people amidst oil price hikes. However, the Ministry of Energy will also keep monitoring the equilibrium between the use of agricultural products for energy production and that for food production.

In addition to the promotion on the users, the fuel ethanol business has been liberalized to encourage the establishment of ethanol plants. As a result, there are now 45 registered ethanol plants with an anticipated production capacity of 10.9 million liters/day. Presently, there are only 8 operating ethanol plants with production capacity of 848,320 liters/day, and 12 additional plants under construction. These facilities are expected to operate at 2.6 million liters/day to be sufficient for the full replacement of gasoline by gasohol 95, as well as gasohol at higher ethanol proportions (i.e. E20 and E85). Most of the facilities produce molasses-based ethanol with a few plants using cassava as raw materials. Exportable supplies of molasses and cassava, which is also used for ethanol production, will tighten over the medium term when all production facilities are fully operational.

- **Biodiesel**

Biodiesel can be produced from palm oil and coconuts as well as other oil plants, like soy beans, peanuts and jatropha. The government plans to have biodiesel widely available as an alternative to pure convention diesel to ease their reliance on imported energy. The biodiesel production for B5 biodiesel has been targeted to reach 4 million liters/day by 2011.

In 2005, a budget of 1.3 billion Baht (or about 32.5 million US$) was approved for biodiesel development during the 8 years' period, from 2005 to 2012. As a first initiative, an agreement has been signed between the Department of Alternative Energy Development and Efficiency (DEDE) of the Energy Ministry and the Thai Military Bank to conduct a 300 million (6 million £) feasibility study on a prototype biodiesel production complex in Krabi (a province in the south of Thailand located the palm oil plantation and processing).

In 2006, diesel consumption was hit by the substitution of natural gas and biodiesel in transportation activities. However, considering the domestic popularity of biodiesel, it is still far behind gasohol due to limited supplies and the lack of clearly defined incentives for biodiesel investment. On April 2, 2007, the Energy Policy Management Committee agreed that all high-speed diesel production must contain biodiesel B100, 2 % by weight, as of April 2, 2008. The Committee will provide a refund, at a rate determined by the Committee, to diesel manufacturers of biodiesel B2. In addition, the government will lower an amount of fee paid for biodiesel B5 manufacturers to the Conservation Fund, which will lower the cost of biodiesel B5 by 0.70 THB/liter.

In order to increase production of raw materials to meet the demand of biodiesel for B2 and in the future B5, the government plans to expand palm plantation by 6 million rai (~0.96 million hectares) by 2012. In addition, the government plans to encourage palm plantations in Laos, Cambodia and Burma on a contract-farming basis. The Cabinet approved a budget allocation of 1,300 million baht (approx. USD 34 million) to promote palm production in 2005. It is estimated that, if the palm oil expansion succeeds, biodiesel production could reach 8.5 million liters/day (3,100 million liter/year) by 2012, which is equivalent to 10 % of total diesel demand. However, current lucrative rubber prices are likely to discourage the replacement of old rubber trees for new palm trees. The Office of Agricultural Economics reported that planted area for oil palm has increased steadily from 344,000 hectares in 2004 to 438,000 hectares in 2007.

Two large petrol companies in Thailand, PTT Public Company Limited (PTT) and Bangchak Petroleum Public Company Limited (BCP), currently owns 511 stations supplying biodiesel. According to the Department of Energy Business, the sales of biodiesel B5 in the whole month of April 2007 were 32.22 million liters, which is equivalent to 1.07 million liters/day.

1. The PTT group plans to produce 1.0-1.5 million liters per day once biodiesel use becomes mandatory. The PTT has begun building a biodiesel plant, called Thai Oleo Chemical Co., Ltd. (TOL), which is scheduled to complete and operate by the end of 2007, with a production capacity of 600,000 liters/day. A biodiesel plant under the joint venture between PTT and Bio Energy Plus Company has been completed with the current capacity of 10,000 liters/day. The plant may be extended to 200,000 liters/day in the near future. PTT also has a joint venture with Southern Palm Company to build a biodiesel plants in Surat Thani Province in 2008 with production capacity of 300,000 liters/day.
2. Bangchak Petroleum Public Company Limited (BCP) also successfully develops its own biodiesel B100 production unit from used oil with total capacity of 50,000 liters/day. BCP recently reported its plan to open new production facilities in 2008, which will add another 400,000 liters/day to its current production capacity.

- **Biomass for heat and power**

The Energy Conservation Promotion Program (ENCON), as the government's renewable energy strategy, was established under the Energy Conservation Promotion Act of 1992. It was the first major initiative by the Thai Government to promote renewable energy and energy conservation. A renewable Small Power Producer (SPP) program which provided subsidy of up to 1 US cent/kWh was launched in 1995 and 16 biomass power projects were approved for about 200 MWe. The present installation is estimated at 2,000 MW. The ENCON Program also provided financial subsidy (for system construction) of pig farm biogas projects amounting to nearly 28.6 million USD during 1995-2004.

As a result of recent oil price hike, the Thai government in August 2003 launched an Energy Strategy for Competitiveness, which set the following goals for renewables:

- Increasing the contribution of commercial renewable energy from 0.5 % in 2002 to 8 % of the final energy consumption in 2011.

- Impose 5 % RPS (renewable portfolio standard) for the power sector until 2011.
- Furthermore, targets for the use of biofuels in the transport sector have also been set: 3 ml/d of ethanol as E10 gasohol and 4 ml/d of biodiesel for B5 in 2011.

Because of the immense importance of biomass as an alternative, clean energy source in the context of Thailand, several policy initiatives to promote increased use of bioenergy have been introduced since the promulgation of the Energy Conservation Promotion Act in 1992. Prominent among them are the Very Small Power Producer (VSPP) and Small Power Producer (SPP) regulations, which paved the way for state electric utilities to make power purchase agreements (PPA) with renewable power producers on either "firm" or "non-firm" basis. Under these regulations, subsidies (drawn from the Energy Conservation Promotion Fund) are provided to the lowest bidders of VSPPs and SPPs in each round of call for tender. This measure has been successful in attracting investors to a certain extend. However, because of the rapid rise in the cost of biomass residues, particularly rice husk, and technical and financial barriers in grid connection, the regulations have recently been revised to render them more attractive. In particular, a special electricity buy back rate in the form of an "adder" on top of the normal retail or wholesale rate – depending on the size of the power plant -- has been introduced as an incentive for various types of renewable energy technologies. The adder for electricity generated by using biomass as fuel is 0.9 US cents per kWh and the offer is valid for seven years for each contract, while the retail and wholesale rates are approximately 7 and 9 US cents per kWh, respectively. The size range of VSPP has also been expanded from 6 to 10 MW. Analysis shows that this incentive scheme is attractive for the case of co-generation but not sufficient for the case where electricity is generated as the sole product using condensing turbines. Therefore, it is recommended that more attractive feed-in-tariffs be introduced in such a way that it reflects the external costs of electricity generation.

To promote power generation using renewable energy, the government also considers introducing more incentive measures besides the existing "Adder" measure in order to induce investment in power generation using all potential types of renewable energy, including biomass.

Promotion will also be made on the development of prototype energy villages, emphasizing the application of traditional cultures and way of living of the villagers as the basis for energy management within individual villages so that they could become self-reliant.

2.2 National policies and strategies addressing the implementation of improved energy crops and agroforestry systems

Because of the important role of fuels for transport in Thailand, the promotion of biofuels became a national agenda following the recent hike in world oil prices. Targets have been set for their use for 2011: 3 ml/d of ethanol or 10% of total projected gasoline consumption (E10) and 4 ml/d of biodiesel or 5% of projected biodiesel consumption (B5). Key policy measures that have been introduced to promote the use of ethanol include the pricing of E10/95 gasohol (premium or octane

95 gasoline mixed 10% of ethanol) at 7 US cents cheaper than the premium gasoline by the waiver of excise tax and contribution to the Oil Fund on the part of ethanol. To ensure investor confidence, it has also been planned that the sale of premium gasoline would be completely phased out from the market and be substituted by E10 when the problems associated with the use of gasohol in some engine types is resolved. However, the policy that set the selling price of ethanol with the Brazilian export price as reference plus transportation cost is deemed not attractive for investors. Therefore, a suitable pricing mechanism that takes into account the external benefits of ethanol has to be established.

The key policy issues of biodiesel are inadequate supply of palm oil and the high production cost. Thus it is essential to increase the palm oil feedstock by plantation expansion, promoting better agricultural practice, and enhance palm oil yield through the use of biotechnology. The issue of biodiesel pricing has been recently dealt with by the government. A subsidy of about 35 US cents per liter has been provided for refineries to purchase biodiesel so that the entire high speed diesel market will be substituted by B2 by the end of 2007.
Because of the complexity of the biofuel industry and trade, it is recommended that a high level, multi-stakeholder committee be set up to coordinate and resolve all issues associated with the entire supply chain, be they of a legal, regulatory, market, financial or technical nature, in a holistic fashion.

2.2.1 Cassava production and utilization in Thailand

Three main raw materials are used for ethanol production in Thailand: sugarcane, molasses, and cassava. The current capacities of raw materials for ethanol production are shown in Table 1. Due to the limited availability of sugar cane, and the increased cost of molasses, cassava appears have great potential.

Table 1: Raw material capacity for ethanol production

Raw material	Amount of raw material for ethanol production (million ton/year)			
	2008	2009	2010	2011
Sugar cane	0.00	18.0	30.0	43.0
Molasses	1.58	1.01	0.78	0.54
cassava	1.83	1.25	1.61	2.56

Cassava is a crop that can grow in poor soil under harsh conditions, with little maintenance. Cassava is largely grown in the eastern, northeastern and central parts of Thailand. The average yield per hectare for all farmers in Thailand is 16.5 tonnes, which is higher than the world average. Approximately 22 million tonnes of cassava fresh root were produced in 2004, with the following breakdown: chips (30%), pellets (26%) and starch (44%). Of this production, Thailand exported 79 % of the chips, 59 % of starch, and 100% of the pellets. Although exports of pellets and chips have gone down since 1990 due to the decreased demand from EU, exports have been increased, due to strong demand from China. Almost one million tonnes were used in Thailand in 2003, mainly for production of monosodium glutamate, sweeteners, and other food-related products. Due to the decreasing trend in the price of starch and hard pellets, the utilization of cassava for ethanol production was promoted. This not only helped to stabilize the price of starch and hard pellets, but it also supported the government's renewable energy program. The utilisation of cassava fresh root is expected to continue to increase, and to reach 4.7 million tonnes in the year 2007/2008.

As shown in Table 2, the production of cassava has steadily increased during the 1970s and 80s through expansion of the planted area, but has decreased again since early 1990s. Despite the total planted area remained unchangeable, the production of cassava has increased by improving the national average yield to approximately 20 t/ha, while the global average efficiency for cassava production was approximately 11 tonnes/hectare in 2004. The current market price is about THB 1.3 to 1.5 per kg. By increasing the market price, the productivity figure could be boosted to 32 tonnes/hectare. The higher price would stimulate use of fertilizer and improved crop management methods. The Thai government is heavily promoting conversion to gasohol. Major production problems are declining soil productivity, soil erosion and long drought period.

Table 2: Cassava production in Thailand

Year	Plantation Area (1,000 ha)	Production (1,000 tons)	Productivity (ton/ha)
1995	1,294.88	16,217	12.52
1996	1,261.60	17,388	13.78
1997	1,265.12	18,084	14.29
1998	1,071.04	15,591	14.56
1999	1,152.00	16,507	14.33
2000	1,184.96	19,064	16.09
2001	1,106.88	18,396	16.62
2002	995.84	16,868	16.94
2003	1,029.60	19,718	19.15
2004	1,081.12	21,440	19.83
2005	1,043.84	16,938	16.23
2006	1,109.28	22,584	20.36
2007	1,196.64	26,411	22.07
2008*	1,168.27	27,618	23.64

Source: Office of Agricultural Economics: http://oae.go.th
*Estimated data

Research and development in Thailand has focused on a breeding program for increasing root yield and starch content; adaptation for unfavorable conditions; and resistance to plant diseases. Information on cassava, including the 12 cassava cultivars developed by the Rayong field crops centre and Kasetsart University, has been widely disseminated to farmers. A special effort has been made to raise awareness about the importance of soil conservation.

With the vision of enhancing the value of cassava products, a number of development strategies are proposed to increase cassava production:

1. Use the entire fresh root yield to produce approximately equal shares of chips and pellets (50 %) and starch (50 %);
2. Establish a research cluster for Thai cassava;
3. Take government actions to support a high price (i.e. THB 1.50/kg) for fresh root cassava;
4. Continue the income-oriented policy for farmers;

5. Switch to use high-yield varieties;
6. Set a short term target yield at 18.75 tonnes/hectare, and a medium-term target at 31 tonnes/hectare;
7. Continue to expand starch exports world wide, especially in Asia markets; and
8. Promote ethanol production for domestic use.

Research and development in ethanol production technologies includes

- Cassava starch processing: the process includes cassava collection, transportation, chopping, washing, rasping, starch extraction and separation and ultimately starch hydrolysis.
- Cassava chip processing: the process includes cassava collection, transportation, chopping, sun drying, and finally starch hydrolysis.
- Starch hydrolysis steps: three processes can be distinguished into conventional, current and future process.

The "conventional process" includes milling and mixing, liquefaction, saccharification, fermentation, and finally distillation for recovery of ethanol. In the "current process", the saccharification and fermentation processes are conducted simultaneously, prior to distillation for ethanol recovery; this allows for energy savings and reduces time in the production process by 24 hours, compared to the conventional process. In the process to be developed in the future, there will be no cooking step, so that liquefaction, saccharification and fermentation will take place in a single step -- following the milling and mixing step, and prior to the distillation step leading to ethanol recovery. This novel process will contribute to further optimization of ethanol production with regard to time and energy savings.

Numerous by-products are produced as a result of ethanol production from cassava, with various end uses. Distilled Dried Soluble (DSS) are sold as animal feed. Fuel oil and acetaldehyde resulting from the distillation process can be sold commercially, and part of the waste resulting from the fermentation step can be used as bio-fertilizer.

2.2.2 Opportunities to increase contribution of bioenergy

Opportunities still exist to increase the contribution of bioenergy in three main categories as follows:

(1) Biomass residues from agriculture and forestry
(2) Energy crops on current agricultural land
(3) Biomass on marginal land

However, such an undertaking is a complicated process as there are several barriers to be overcome.

- Biomass residues from agriculture and forestry – Production of agricultural residues can be increased through the following means:
  (1) Increasing the production of selected crops, e.g. sugarcane and oil palm through reducing planted areas of other crops.
  (2) Increasing the production of biomass residues of existing crop plantation areas through developing now crop varieties with high biomass yields.

- Energy crop from agricultural land – Since it is not feasible to increase agricultural land, an increase in energy crop production could be achieved through the following means:
  (1) Reducing land for food production – As Thailand has been producing surpluses of food and has been a major food exporting country; it is possible to increase the production of energy crops by reducing the land areas for producing food. However, this approach requires efficient management of land uses, taking into account the trade-offs between economic benefits of food and fuel productions.
  (2) Increasing crop yields through genetic improvement – It is possible improve the crop yields through genetic improvement. For this approach, it is necessary to initiate R&D in genetic engineering with the purpose of improving yields of the main crops.

- Production of biomass on marginal lands – In Thailand degraded forest accounts for more than 15% or 7.5 million hectares. In principle, degraded forest can be used for biomass production for energy purpose. However, several obstacles have to be removed. The main problems to be addressed include:
  (1) Institutional and legal barriers in gaining access to use the degraded forest.
  (2) A large part of degraded forest is occupied illegally by the rural population.
  (3) The know-how on producing biomass on degraded land is still lacking.

2.2.3 Research and development promotion

Both policy and technology development types of research are needed to promote the bioenergy industry in Thailand.

For technological issues, some of the most pressing issues for biofuels are the improvement of feedstock production yield, particularly palm oil, cassava and sugar, and the improvement of their conversion efficiency so as to reduce the fuel production cost. Of secondary importance are investigations on the effects of biofuels on engine parts and their solution. For biomass to heat and power, the central question is the logistics of collecting and transporting agricultural residues of greatest potential, namely rice straw and sugarcane leaves and trash, the key challenge being the small scale and non-mechanized nature of Thai agriculture and the traditional believes and practices of the farmers. Another issue is the upgrading of heat and power generating technologies to more efficient ones, particularly high efficiency steam turbines, at an affordable cost.

International research collaboration is also a tool to accelerate the development of bioenergy. Thailand has research collaboration with the New Energy Development Organization (NEDO), Japan, to initiate some bioenergy projects, including

1. Development for the efficient disposal of co-fermented methane from chicken litter and agriculture waste composed oil/fat
2. Bioethanol engine applicable test for heat pump use
3. Gasification of cassava waste for combined heat and power generation
4. Ethanol production from molasses and bagasse in the sugar factory

For policy issues, the key policy questions concerned with are the issue of appropriate pricing structure of biofuels and the level of subsidy, and the appropriate feed-in-tariffs for electricity generated by biomass. A long-term issue associated with large scale bioenergy production is sustainability, as most of the biomass resources used for energy purposes in Thailand are concurrently important sources of food and fodder. Thus such practices would not only affect food security, but also alter land use patterns and biodiversity. Therefore in-depth analyses and reliable data that would support decision making and planning are highly essential.

3. Best practices in agricultural sector in Thailand

3.1 Water management

3.1.1 Water resources and situations

Water is essential for life and all economic activities. Statistics of the annual average rainfall from the year 1995 to 2004 shows continuous decreasing rainfall since 1999. However, in 2005 Thailand was hit by several depressions causing floods in the north and northern regions. Due to 25 watersheds development and management, the water impoundment capacity can reach up to the total volume of 73,700 million cubic meters. For underground water resources, it was estimated from the 12 basins with underground water of 15,877 million cubic meters/year that could be potentially developed at about 3,175 million cubic meters/year, where the upper and lower Chao Phraya Basin have high yield potential.

Drought situation in Thailand tends to be increasingly serious. It is found that water demand for all activities in 2001 is around 67,052 million cubic meters. In 2005, Thailand faced severe drought due to 2 months delaying of the previous year seasonal rainfall, causing water shortage in many reservoirs. The situation was worse by increasing water demand from various sectors.

Water shortage in the eastern seaboard during mid 2005 was very severe, especially in Chonburi and Rayong provinces where conflicts regarding water usage took place among communities, agricultural and industrial sectors. Ministry of Natural Resources and Environment by Department of Underground Water Resources has developed underground water to increase water resources within the areas.

Heavy flood problems also took place in 2005 in several areas of the country, such as the areas of Yom, Chee, Khong, Ping, the east coast, and the lower Chao Phraya river basins. Regarding water quality, there were 4 out of 49 rivers and 9 fresh water resources under survey that water quality are classified as very low. Those are the lower Chao Phraya, lower Tha Chin, lower Lam Takong, and Song Khla Lake.

To solve water resource problems efficiently, cooperation and coordination from all concerned sectors is needed, especially all various government sectors need to work in harmony. Major activities included in the action plan are the rehabilitation of natural water resources, the repairing of pipe water systems, the flushing of underground wells, repairing tap water systems, cleaning shallow bodies, construct new deep wells as well as repair and construct new dams and weirs at upstream areas to retard water flow.

3.1.2 The royal project for improving water management: The Monkey Cheeks (Kaem Ling) Project

On the 14th of November, during the heavy floods throughout the country, His Majesty advised those concerned in solving the problem that the "Monkey Cheeks Project" provides the solution to the flooding problem in the Bangkok Metropolis. The Monkey Cheeks project is a water organization system for the flooding season to prevent as well as reduce flooding in the lower Chao Phraya river by draining the water ways such as ditches and canals (or klongs) into small reservoirs. This is similar to the monkey holding the banana bits in its cheeks. Water is drained into the sea when the sea water level reduces. The Monkey Cheeks project is one that relies on nature to solve problem in the flood prone areas.

3.2 Soil improvement

3.2.1 Land resources and land use

Thailand has total area of 320.7 million Rais which consists of agricultural land of 131 million Rais or about 40% of the country area. The country has been facing problems of deteriorated soil and improper land use for decades. Improper land use management and deforestation have resulted in severe erosion in many areas of the country. In some areas of the non-utilized land, it is found that the serious soil loss was greater than 20 tons/rai/year. In addition, saline soils and acid soils in several areas also need special treatment. Department of Agricultural Economics reported about land use and type of agricultural holding area that there are somewhat change in type of agricultural holding area during 1998-2001. In 2001, there were about 65 million rais of paddy field and 28 million rais of field crop areas. Concerned organization has continuously carried out plans and activities for soil rehabilitation and conservation. Those activities include growing Vetiver grass to prevent erosion, promotion of organic farming, remediation of saline soil and other special problem – soils, and revision of laws related to land use.

Land use surveys showed that soil resource problems involved a total of 210 million rai in 2002. Soil resource problems are classified into two types: (a) degradation of soil quality, such as saline soil, eroded soil, and sandy soil, and (b) inappropriate land use. Agricultural land holding has declined from 26 rai per household in 1992 to 23 rai per household in 2001. Another problem is poor distribution of land ownership.

To solve or reduce these problems, measures have been implemented, including

- Enhance and promote the local governmental organizations to oversee the use of water resources in sustainable manner by encouraging public participation.
- Announce mud slide risk areas, and establish mud slide monitoring network and warning system.
- Introduce appropriate land use planning based on the land's carrying capacity by relocating people from the land area where slope is higher than 35 degree, restoring the land for reforestation, promoting public education in agriculture to slow down water velocity and prevent land slides, constructing check dams, investigating land rights and land reform within national reserved forest areas, clear zoning of land use, reallocating land for agriculture, rehabilitating the

ecosystem through reforestation, and so on. To accomplish these, a clear direction must be set and communicated to all concerned.

3.2.2 The royal project for soil improvement: The Aggrevating the Soil (Klaeng Din) Project

“Aggrevating the Soil” A Royal Theory During the royal visit to the people in Narathiwat Province in 1981, His Majesty the King observed that after the swamp lands had been drained to expand agriculturally productive areas and to reduce flooding problem, the soil had grown strongly acidic and that crops planted by the farmers had failed. His Majesty then called on all government agencies to search together for ways in which to improve these swamp lands of perennially stagnating water for maximum use in agriculture, bearing firmly in mind the impacts of such improvements on the ecology. The strong acidity was due to the fact that the swamp soil was composed of a 1-2 meter layer of organic matter or decomposed plant residue underlain by bluish grey mud with high content of pyrite (FeS_2). When the soil dries, pyrite releases sulfuric acid as it oxidizes.

The Pikun Thong Royal Development Study Centre was put in charge of the Project which His Majesty named Klaeng Din. The Project studied the naturally-occurring process of acidification of the sulfur-bearing peat soil. The activities consisted of the alternate drying and flooding of the soil to accelerate the reaction of pyrite, to the point where the soil becomes extremely acidic and crops cannot be grown productively. The next step was to search for counter-measures. The methods of solving the strongly acidic soil problem based on His Majesty's idea are as follows:

1. Solution by controlling the ground-water level – To prevent the release of sulfuric acid by the soil, the ground water must be kept above the layer of mud to prevent the pyrite from oxidizing.
2. Soil improvement according to His Majesty's “Klaeng Din” Idea – There are 3 methods to be chosen according to the conditions of the soil:
    a. Using water to remove soil acidity: Besides reducing acidity and increasing the soil pH, flooding the soil also dilutes the toxic iron and aluminum solutions. Additional applications of nitrogenous and phosphatic fertilizers will make the crops productive.
    b. De-acidifying soil by using lime mixed with topsoil such as marl and lime dust. The amount of lime used depends on the degree of soil acidity.
    c. Using lime in combination with soil flooding and control of ground-water level. This comprehensive method yields the best results for very strongly acidic soil that has lain idle for a long time.
3. Adjusting the soil surface by
    a. Making it slope sufficiently for the area to be drained
    b. Reshaping or rearranging the paddy field or its boundary ridges and bunds in such a way that water can be stored and/or drained at will.
4. Cultivating crops on raised beds – This method can be used for cultivating field crops, vegetables, fruit or other tree crops that generate a high cash return. However, to be sure of obtaining a good return on crops grown on raised beds, irrigation water is needed for filling and refilling the ditches with fresh water to reduce acidity. Cultivating crops on raised beds should take into consideration the flooding in the area. If the danger of flooding is too great,

planting tree crops should not be risked on raised beds or the height of the beds should be reduced and the tree crops replaced by annual or vegetable crops, grown in rotation with rice.

The suitable procedure for improving strongly acid soil for agricultural use depends on the types of crop cultivated and cultivated areas. For example,

- Rice cultivation in irrigated areas, e.g. for soil with pH under 4.0, apply 1.5 tons of lime per rai; while for soil with pH from 4.0 to 4.5, apply 1 ton of lime per rai. Rice cultivation in rain fed areas, e.g. for soil with pH under 4.0, apply 2.5 tons of lime per rai; while for soil with pH from 4.0 to 4.5, apply 1.5 ton of lime per rai. After applying lime, turn the soil over and then cover with water for 10 days. Drain water to remove toxic substances and re-flood prior to transplanting.
- Cultivation of Annual Crops

  - Vegetables:

    1) Raise beds, 6-7 meters across, with 1.5 meter-wide drainage ditches that are 50 centimeters deep.
    2) Turn the soil over and leave to dry for 3-5 days.
    3) Make ridges, each 1-2 meters wide and 25-30 centimeters high, on the raised beds to facilitate drainage and prevent the beds from being slushy when watering or raining.
    4) Apply liming material to reduce soil acidity. Use 2-3 tons of lime dust or marl per rai. Mix with the soil and let stand for 15 days.
    5) Apply 5 tons of compost or organic fertilizer per rai, one day before sowing. This makes the soil more friable and improves its structure.

  - Selected Field Crops: These can be grown in two ways: i) Growing field crops on raised beds involves one single cropping and preparation of the land according to the method discussed above for vegetables; ii) Growing field crops as a second crop after the rice-growing season follows much the same method as used for field crops in general. However, it may be necessary to raise the beds about 10-20 centimeters higher than those on higher ground in order to prevent any unseasonal rain water being retained in the area. If lime has already been applied, probably no more needs to be added.
- Cultivation of Fruit Trees

  1) Build a big earthen embankment around the entire area to be cultivated to prevent rainy season flooding and install a pump to provide drainage when needed.
  2) Raise beds for cultivation as described earlier for strongly acidic soil.
  3) As the water in the drainage ditches will be acidic, pump in fresh water when acidity becomes strong, approximately every 3-4 months.
  4) Keep the water in the drainage ditches above the level of the pyrite-bearing mud and thus prevent the oxidation process from increasing acidity in the soil.
  5) Scatter 1-2 tons per rai of lime, either calcium oxide, marl or lime dust, over the entire area to be cultivated.
  6) Use the spacing appropriate for the crop to be cultivated.
  7) Dig holes 50-100 centimeters deep and 50-100 centimeters wide where each tree will be planted. Keep the excavated topsoil and subsoil separated, and expose them to sunlight for 1-2 months to kill germs in the soil. Mix the topsoil with compost or manure and also with some subsoil, and re-fill the hole with the mixture. For this purpose, use 1 kilogram of compost per ton of soil, mixing it well with 15 kilograms of lime per hole.

8) Control weeds, diseases, insect pests, and water the plants in the usual manner. Fertilizer use depends on the requirements and type of tree grown.

3.3 Development of Plant Species for Improved Yield and Quality

Production of ethanol comes from sugarcane/molasses and cassava; while the production of biodiesel mainly comes from oil palm. It is necessary to increase the productivity by enhancing efficiency of production or productivity per area. Due to the high productivity per area in case of Brazil and Australia, their production cost of ethanol is lower than in Thailand. Especially for Brazil, their production cost of ethanol is lowest in the world.

Currently, the average productivities of sugarcane, cassava and oil palm are 11.8, 3.5 and 2.8 ton/rai respectively, when their maximum potential could give 45, 13 and 15 ton/rai respectively. Genetically improved sugarcane and cassava test planted under appropriate conditions have already shown to give a higher productivity than the average productivity. For example, cassava series KU 50, Rayong 9 and Rayong 7 can yield 6 ton/rai. Multi-location tests of sugarcane plantation in the country also showed that many plant series yield more than 20 ton/rai. Genetic improvement, selection of good series and plantation management (i.e. irrigation and fertilizer) can largely improve productivity per area of energy crops in Thailand. In long term, biotechnology will assist the species improvement to provide theory productivity of each energy crop.

From the data of plantation area and genetic potential of energy crop, it is estimated that Thailand has great potential to increase the productivity per area and less or no need to increase plantation area in case of sugarcane and cassava. However, expansion of plantation area for oil palm is still necessary.

The development of improved energy crops has to focus on 2 different issues. The first is to genetically modify the plant species to have high resistance to insects and diseases, for example, palm with high resistance to insects, sugarcane with high resistance to worm and cassava with high resistance to viruses. Development of plants that can be grown in unsuitable plantation conditions, for example, sugarcane that can grow in draught areas. The rate and efficiency of photosynthesis are increased so that plants are faster growing and hence high productivity. The plant internal structures of sugarcane can also be modified to be more appropriate for the fermentation process to yield high sugar rate. The second issue deals with the development of microorganisms that help improve genetic modification, for example, the development of enzymes to convert sugar and cellulosic materials into more fermentable sugar. Nevertheless, application of genetic engineering raises concerns in biological, environmental and food safety and this therefore needs to be assured before commercializing and recommending to agriculturists.

The government and private sectors worldwide have intensively invested in biotechnology research for biofuel applications. In Thailand, DNA technology is used for plant improvement, e.g. the jasmine rice series 105 that can survive in sudden flood for 15-21 days and fast recover to its normal condition.

4. Challenges in the Development and Deployment of Bioenergy in Thailand

The economic potential of biomass as an energy source is much lower than the technical potential. To exploit its full potential, several barriers will have to be overcome. Barriers to bioenergy development and deployment are outlined. Policy measures, including R&D, that are necessary for promoting bioenergy are highlighted.

4.1 Policy Barriers

Although the Thai Government has been fairly proactive in energy policy and implementation during the past 20 years, the energy policies have not been very effective. The problems of energy policies in Thailand include the following.

- Frequent policy changes – There have been frequent changes in energy policy due to frequent changes of Government and minister in charge. These changes have discouraged investments in renewable projects and have slowed down the implementation of policy measures for promoting renewable energy.
- Inefficient policy implementation – Implementation of government energy policies have not been effective due mainly to inefficiencies in the bureaucratic system and policy changes as discussed.

4.2 Problems related to biomass feedstocks

- General problems
  It is difficult to collect large quantities of biomass wastes due to their disperse nature. Most types of biomass are too bulky and costly to transport. The availability of some types of biomass is seasonal and annual production fluctuates from year to year depending on climatic conditions. The costs of biomass wastes also fluctuate widely, depending on production output and economic conditions.
- Competing uses
  Apart from energy, biomass and biomass wastes are widely used for other purposes:
  - Wood wastes and bagasse are used to make particle boards and paper.
  - Rice husk is used as fuel in brick production and other rural industries.
  - Palm oil is used in food and cosmetic industries.
  - Cassava is used to make modified starch and animal feeds.
- Difficulty in increasing biomass feedstocks
  As discussed earlier, increasing biomass for energy purposes from the current agricultural land and marginal land is a complicated undertaking. Policy, institutional, technical and social issues will have to be seriously addressed.

4.3 Institutional barriers

Institutional barriers include the following:

- Lack of a neutral national regulatory body.
- Conflicting policies of different ministries.

- Poor coordination among several government agencies involved in renewable energy promotion and development.
- Lack of cooperation and understanding from power utilities.
- Complication in the implementation of the operation plan for increasing biomass feedstocks.

4.4 Ineffective promotional mechanisms

Several incentive schemes for promoting bioenergy have been initiated by the governments since 1990. However, these mechanisms have not been very effective. Some suggestions for improvement include the following:

- Implementation of more efficient financial and tax incentive schemes.
- The level of financial incentives (feed-in tariffs or adders) needs to be regularly adjusted.
- A neutral body should be set up to oversee and arbitrate issues concerning the production and sale of electricity from biomass.

4.5 Weak energy science, technology and innovation (STI) system

- The STI System

  In principle the strength of the STI system of a country depends on the followings:
    - R&D capability in the public sector and universities
    - Technology development and manufacturing capability of the private sector
    - Government strategies
    - Effectiveness of the HRD system
- Energy research and development

  One of the key issues is the lack of a national energy R&D roadmap that would serve the goals of the national energy strategies. The funding support for energy R&D is inadequate. Most energy R&D activities are undertaken by the public sector and not all of them are responsive to national needs. The involvement of the private sector in energy R&D is lacking. The national R&D capability needs to be strengthened urgently.
- Capability of the private sector

  The habit of relying on imported, turn-key solutions for most renewable energy projects is a major barrier for private companies to get involved in energy technology development and manufacturing. The role of the government in promoting technical capability in the private sector has also been limited. Although incentive programs covering tax reductions and soft loans for R&D activities in the private sector have been initiated, they have not proved to be very effective. Technology support programs run by different agencies are not well funded, nor are they well coordinated. A well integrated national program for strengthening the energy STI system through financial and taxation incentives, technology procurement policy, technology market development and technology transfer through trade and investment, is desirable.

- Human resources development
  Several public institutions have been established to develop energy human resources specializing in energy technology, energy management and energy R&D. However education programs of these institutions do not fully address the national needs for energy manpower. In addition funding support to these institutions is not adequate to educate highly qualified personnel in sufficient number.

4.6 Lack of reliable information

Although a non-profit organization called "Biomass One-stop Clearing House" has been set up recently to provide technical and financial information on bioenergy systems to interested public, there is still a large information gap on the availability and advantages of bioenergy technologies. It is envisaged that building confidence in bioenergy technologies through demonstration of successful cases are essential.

In addition basic technical information including the current production of agricultural products, current yields of biofuels per unit area that can be produced from various crops and requirements on standards of biofuels should be widely disseminated. Otherwise, it may lead to wrong decisions by energy planners and farmers, as happened in the recent past.

4.7 Public misconception on the safety of power plants

Low confidence in coal and hydro power plants have led to opposition even to biomass fueled plants, as a large section of the population do not differentiate between coal based and biomass based plants.

The advantages of bioenergy, especially its clean burning characteristics and the fact that it is CO_2 neutral, should be continually highlighted.

4.8 Technical Barriers

Several bioenergy technologies (e.g. small-scale biomass gasification and technologies for converting municipal wastes to energy) are not fully nature. Technical problems still exist, which have discouraged users from adopting these technologies. Most imported advanced bioenergy technologies are still too expensive and therefore not feasible economically. In addition most imported technologies have to be adapted so that they could be operated satisfactorily on local fuels that have different properties from those for which they were designed.

5. Failure and lesson learnt

5.1 Resource potential and logistics for biomass power plants

The government promotion of renewable energy utilisation has attracted power plant investors. A number of biomass power plants, especially rice husk due to its suitable properties for thermal conversion, have been largely increased. Most of rice husk power plants are located in the central part of Thailand, where rice is widely grown and the husk is produced in the local mills.

However, without consideration of power plant zoning and logistics of rice husk, the heavily increased demand of rice husk feedstocks has become the major non-technical barrier to operate the power plants. The rice husk power plants as well as other users of rice husk as co-processed fuels or for other purposes have been competing to get the rice husk and therefore the price has gone up more than 5 times in many areas. So far, there are a number of rice husk power plants that are not being in operation due to the lack of feedstocks.

5.2 Resource potential for biofuel production

Surging global demand for energy crops for production of alternative fuels has sparked a series of efforts within the Agriculture Ministry to lift the country's output of such crops, particularly palm and tapioca, from a limited plantation area. This year, the Energy Ministry also plans to raise the amount of biodiesel progressively, from 2 % mixed into the B2 fuel that all retailers will be selling next month to 5 %, 50 % and eventually 100 %, or pure biodiesel. The plantation areas have to be further expanded and therefore seedlings to suit each area need to be prepared and new technologies with which to raise crop yields need to be researched.

Last year, Thailand produced 7.27 million tonnes of palm kernels, which produced 1.24 million tonnes of palm oil. Of this, 850,000 tonnes were used domestically and the rest exported. Palm-oil production is expected to climb to 1.47 million tonnes this year, but domestic demand is forecast to rise to 920,000 tonnes, due mainly to the hunger of biodiesel plants. It is expected that this domestic demand will grow to 980,000 tonnes next year and 1.2 million tonnes in 2012.

To ensure the smooth conversion of additional palm oil into biodiesel, the Industry Ministry would need to entice manufacturers to set up plants around new plantation areas. Palm kernels must arrive at factories within 24 hours of being harvested, so these facilities must be located within a 200-kilometre radius of plantations. Although there is no guaranteed price for palm kernels, the higher demand will keep the price above 3.50 baht (11 US cents) per kilogram. Farmers are able to break even at 2.50 baht (8 cents) per kilogram, and the current price is 5 baht (16 cents).

With prices continuously escalating, it is foreseen that controlling consumer prices will be difficulty. To ease speculation-driven shortages, the ministry recently allowed imports of palm oil despite the possibility of hurting domestic prices, with a new crop of palm kernels expected to reach the market next month.

Aside from palm oil, the Commerce Ministry is also expected to suffer a sugar-driven headache. Due to ongoing disputes with sugar mills, farmers who suffered from low prices last year may turn to other crops. This will hurt the country's 11 ethanol plants, which need sugar molasses as a raw material. These plants will need 1.87 million tonnes of molasses this year, but output will be only 1.48 million tonnes. However, it is hopeful that once sugar prices go up, farmers will once again plant sugar cane. But the yields need to be increased. Also, farmers might be more enthusiastic about planting sugar cane if there were a benefit-sharing scheme between sugar mills and farmers for revenue from molasses. At present, farmers make money only from sugar cane.

It would also be a plus if domestic sugar prices were allowed to move in line with world market rates, because this would encourage sugar mills to sell syrup for ethanol production rather than turning it all into sugar for export. Thailand's sugar production this year is expected to be about 7 million tonnes. Of this, 5 million tonnes will be exported.

The tapioca prices are now attractive, i.e. at 1.90 baht (6 cents) per kilogram against a farmer break-even point of 1.20 baht (4 cents). Still, with higher demand for ethanol production from limited plantation areas, the Agriculture Department faces the need to raise tapioca yields from 3.2 tonnes per rai to 3.5 tonnes. Because corn is more expensive, China and Europe need more tapioca for animal feed and energy production. This will raise prices further and could lead to farmers switching land from sugar cane to tapioca. Last year, 7.3 million rai was planted with tapioca, producing 26.72 million tonnes of cassava root. The area is expected to increase marginally to 7.4 million rai this year, for an output of 27.97 million tonnes. At present, domestic consumption demands 6 million tonnes. The rest is exported.

As more farmers turn to higher-priced crops, this will inevitably lead to smaller areas of food crops, and food prices will rise as a consequence. As supply and demand pressures intensify between the need for energy and for food, agricultural zoning is not working. In this situation, consumers will have to bear higher food prices. Therefore, cooperation between the Agriculture, Energy, Industry and Commerce ministries was essential in setting a national agenda.

The Agriculture Ministry will also have to investigate whether farmers are really benefiting from higher prices for farm goods or simply being forced to bear higher costs of living like everyone else.

5.3 Effect of single crop plantation on soil condition

Single crop plantation has a number of negative effects on soil condition as well as other environmental problems.

- **Degradation of soil quality**

Conventional agriculture always uses model of mono cropping (Agricultural pests are often specific to the host - a particular crop and will multiply as long as the crop is there). So it also always intensifies water, chemical fertilizer (e.g. global mean fertilizer use more than doubled from 34 kg/ha of cropland in 1964-1966 to 86 kg/ha in 1983-1985, and expansion of irrigation from 13 to 15 % of the world's arable land between 1974-1976 and 1984-1986) and pesticides to exploit soil's productive capacity to obtain high yield. These caused erosion of soil (mono-cropping cannot prevent from erosion of soil) and degradation of soil quality (existence of heavy metal in soil from pesticide) over years. Beside intensified crop, in order to increase production, conventional agriculture also uses expansion of cultivated area to solve this. In some situations, flood, drought can appear, areas of arable soil can be transformed into desert and they impact on environment by climate changes. These are negative impacts, not only on agricultural soil and environment nowadays but also on future generations.

On the other hand, the use of fertilizers can affect on soil quality by making acidified soil and it is difficult to grow crops on it with a high yield. When using these chemicals, they are also destructive to the environment. It occurs very often when these chemicals run-off the farmland during and after rainfall and drain into nearby rivers and streams. This influx of chemicals can result in the extinction of species, and thus adversely affects the local biodiversity. Additionally, most of these pesticides have a wide spectrum of activity and as they are broadcast in sprays, they are applied against ecosystems, rather than directly to pests.

- **Pollution of soil, water and food with pesticides and nitrates**

Chemical fertilizers and pesticides used in conventional agriculture unarguably benefit the increased crop yield. However, their residues can at the same time be leached into soil and water, which seriously affect beneficial soil organism systems and acidifying soil or make soil no longer suitable for plant growing. Others parts of residues can evaporate in form of gases such as N_2O, NO_2. Gases from these or other activities (e.g. tilling of soils which permits oxidation of organic matter, producing CO_2, emission of large amounts of N_2O from cultivated soils, or application of fertilizers increases N_2O release by plants) will also contribute to greenhouse gas - global warming.

Problem of water pollution is largely known. Chemical fertilizers and pesticides leached into soil and contaminating sources of water, even in lower levels, can affect the growth of crops, such as lower the crop yield, and if in heavy level, crops can die. If these chemical fertilizers leached into soil and run into river or sea by ground water, they will become nutrients for algae or seaweed. These plants will grow rapidly and use up oxygen in the water. Other plants then cannot live anymore.

- **Reduction of ecological diversity and human society**

Conventional agriculture causes the reduction of ecological diversity, which also leads to reduced sustainability. When using pesticide to control pests, beneficial organisms or living animals having weak resistance to pesticide (e.g. bees, and earthworms) may die.

Beside impacts on environment, conventional agriculture also affects strongly on human society.

- Excessive application of fertilizers and pesticides are not only unhealthy for the consumers, but also unsafe for the farmers who must be exposed to them.
- When products of over-nitrate-used crops are harvested, they are very difficult to preserve. That is due to the high content of water and damages by pests. The lifetime will then become very short and therefore lower the economic value of product. This in turn will induce more use of pesticide to control pests to maintain yield.
- During agricultural burning; dust from tillage, traffic and harvest, pesticides drift and nitrous oxide emissions from the use of nitrogen fertilizer cause air pollution.

From above, it can be clearly seen that conventional agriculture can gives high crop yield, but also has many negative impacts on environment and human society. In order to solve and restrict these negative impacts, new solutions to agriculture production needs to be applied. The use of compost, manure, or other organic matters is an option to replace chemical fertilizers; while application of integrated pest management, biological pesticides, insect trapping by the use of lures such as pheromones, biological control methods can replace the use of chemical pesticides. However, application of organic agriculture is relatively new and to implement widely dissemination to farmers for good understanding and efficient practices (e.g. timing for plantation or best rotation combinations of crops) is necessary.

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