A Study of Ethanol Production Cost for Gasoline Substitution in Thailand and Its Competitiveness

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Abstract

Dramatic increases in imported crude oil prices have led to the Thai government seeking alternative resources to reduce the imported crude oil. One of the possible solutions is to use bio-ethanol derived from agro-products such as cassava, corn, rice, sugarcane and molasses, etc., which are available abundantly in Thailand.

The Thai government aims to use the ethanol to substitute for gasoline octane 95 in the first step, by partial substitution for the gasoline octane 95, and expects to substitute more in the near future, provided that this first program is fully successful. Therefore, the competitiveness of the ethanol price with the gasoline price is the most important factor for the viability of this program.

There are four common cash crops cultivated in Thailand: cassava, corn, rice, and sugarcane. In this study, these four cash crops and molasses, one of the by-products, from sugar production, were studied to see if they can compete with gasoline 95, if they are used as feed stocks to produce anhydrous ethanol for gasohol 95, E10.

A multi-feed ethanol plant with a capacity of 150,000 liters per day of anhydrous ethanol is assumed in this study. The total capital investment of this plant is expected to be about 1,200 million baht. The averaged feed stock costs during year 2002-2005 were estimated for each type of the cash crops and molasses. It was found that the feedstock cost is the major cost burden in ethanol production. It contributes more than 50% of the total cost. On average, the ethanol cost at ex-factory was found to be in the range of 15.65-26.99 baht per liter of gasoline equivalent (excluding all taxes), depending on a type of raw materials. The average price of gasoline 95 at ex-factory price was 11.50 baht per liter during the years 2002-2005.

Thus, we conclude that the competitiveness of the ethanol is highly dependent on the feed stocks' prices. The volatility of the feed stock prices in the market significantly affects the competitiveness of the bio-ethanol as compared with the gasoline. In general, the crops, which are most likely to be able to compete with gasoline, are sugarcane and cassava because of their low average prices as feed stocks.

Key words: Feedstocks' prices, Ethanol Production, Competitiveness, Gasoline Price

1. Introduction

The present trend in depletion of global fossil fuel energy has caused an ever-increasing need to seek alternative sources of energy. Currently, the Thai government has promoted the use of ethanol from some agricultural cash crops as an alternative for fossil fuel substitution in the transportation sector.

Ethanol can be used in various methods as transportation fuel. One of the well known fuel applications of ethanol is by mixing it into gasoline. Ethanol can be mixed in gasoline up to 10 percent by volume with only minor modification or without modification for most conventional gasoline engines [1]. This blended ethanol is normally called "gasohol", and it is generally named after an amount of the percentage of ethanol (volumetric) mixer in the gasoline, For example, an amount of gasoline mixed with 10% ethanol to boost its octane number up to 95, is called gasohol 95, E 10.

In Thailand the fuel ethanol program was initiated and officially announced in 2000. Since then it has stimulated much public interest. The Ministry of Energy aims to blend 3 million liters per day of ethanol into gasoline by 2011. Presently, there are 25 ethanol companies which have been conceded permission licenses from the National Ethanol Board of Thailand to produce ethanol. It is expected that these concessionaire companies would have a total capacity of production of 4.21 million liters per day. However, in June 2006, there were only five ethanol plants constructed and operating, by producing ethanol from molasses, with a total capacity of about 0.505 million liters per day.

One major problem with ethanol production is the availability of raw materials for the production. The availability of feedstocks for ethanol can vary considerably from season to season and depend on geographic locations. The price of the raw materials is also highly volatile, which can highly affect the production costs of the ethanol. In order to make sure that a production capacity of an ethanol plant is fully utilized, it is necessary to assure that feedstocks of the raw materials are sufficient for the production throughout a year, and with a competitive price. One possible solution to this problem is to use many different types of feedstocks for the ethanol production.

The main purpose of this study is to investigate the feasibility of ethanol production of a multi- type feedstock plant, from different major agricultural cash crops, which are commonly cultivated in Thailand, and analyze the competitiveness of the ethanol price with the gasoline price. The selective agricultural cash crops in this study are cassava, corn, rice, sugarcane and molasses (a by product from sugar production).

2. The ethanol production process

Ethanol, which is also known as ethyl alcohol, is a clear, colorless, flammable, oxygenated hydrocarbon with a chemical formula C_2H_5OH. Currently, there are two commercialized ethanol production technologies deployed in businesses. The first one is based on a sugar based feedstock, and the second is based on a starch based feed stock.

For the sugar based feedstock, ethanol can be produced by microbial conversion through fermentation. The fermentation process relies on yeasts that convert sugar to ethanol. Thus, those agriculture crops which are sugar based feedstocks such as sugarcane, sugar beets, molasses, etc. can be used for ethanol production.

Another type of feedstock, which can be used for ethanol production, is starch based materials. Starch consists of long chains of glucose molecules and can also be converted to fermentable sugar by a method called "the hydrolysis technique".

Hydrolysis is a reaction of starch with water, which is normally used to break down the starch into fermentable sugar. There are two techniques for hydrolysis: enzymatic hydrolysis and acid hydrolysis.

Yeast used in the ethanol fermentation is generally bakery yeast (*saccharomyces cerevisiae*). It is adopted as a seeding for the fermentation.

The alcohol concentration from fermented sugar produced by the yeast initially is only about 5-15 % by weight [2]. The alcohol is then upgraded to a higher concentration by separating it from water and other non-fermentable materials. The concentration of the alcohol is then finally upgraded to be 95%-96 % by weight, by a distillation method. The alcohol with 95%-96% concentration is normally called "hydrous alcohol", which can fuel only specially designed vehicles such as flex fuel cars.

However, ethanol, with a purpose to be blended with gasoline, for uses in general vehicles, must be anhydrous ethanol (99.5% alcohol concentration). Thus, the residual remaining water in hydrous alcohol must be removed by a dehydration process. Currently, a molecular sieve technique is a common technique to separate the water out from the ethanol to produce anhydrous alcohol.

Normally, the ethanol production of sugar base crops yields three main by-products: stillage, fusel oil and carbon dioxide. Stillage is a residual beer remaining in the distillation waste, after the alcohol has completely been removed from the distillation columns. During the distillation process, there are two types of distillates obtained from the distillation columns: fusel oil, and alcohol. Fusel oil is a higher order of one type of alcohol with more than two carbons in its molecular structure, and it is formed during the fermentation, in conjunction with the ordinary alcohol with two carbons in its molecular structure.

CO_2 is generated during the anaerobic sugar fermentation. The CO_2 produced from the fermentation is almost equally to the amount of the ethanol produced in the fermentation process, by weight. Ethanol production from starch based crops gives one more by-product, i.e., Distiller's Dried Grain (DDG).

The steps of the ethanol production as mentioned above are summarized and shown in Figure 1.

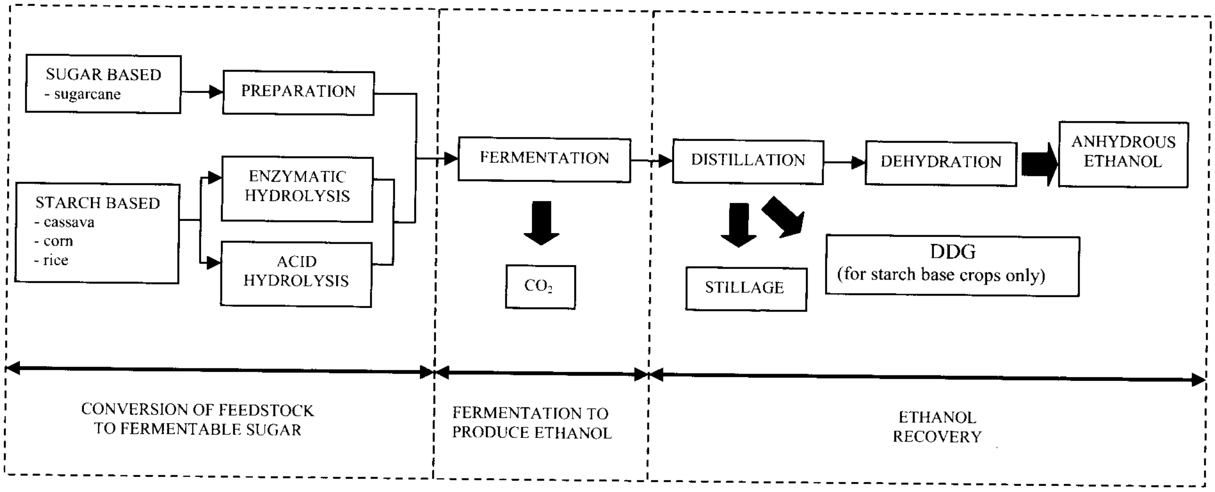

Figure 1 anhydrous ethanol production processes

3. Estimation of ethanol production costs

The processing costs of the ethanol can be categorized into four major groups: feedstocks costs, capital costs, operating & maintenance costs, and by-product gains.

- **Feedstock costs**

Feedstock prices can vary by location, seasons, local conditions of the supply-demand, and transportation. These market price variables can affect a decision in selecting a feedstock type for ethanol production

- **Operating and maintenance costs**

The operating and maintenance costs are: labor, energy, electricity, ingredients (e.g. enzymes, yeasts, etc.), repairs and maintenance, taxes, insurance cost, and administrative expenses

- **Capital costs**

Capital investment represents the first costs of all necessary equipment in production and their installations. Expenses for piping, instrumentation, insulation, foundations and site preparation are included in the capital costs. In addition, these costs also include land, buildings and waste treatment facilities.

- **By-product gains**

The fermentation process of the ethanol production also yields several byproducts, including carbon dioxide, fusel oil, yeasts and stillage. The by-products of the ethanol production can generate additional incomes. In other words, they assist to reduce the ethanol production cost, significantly, provided that they are economically recovered, effectively. The by-products are dependent on the types of feedstocks and processing methods used in the ethanol production.

The unit cost of the ethanol production can be expressed by:

$$C_{EtOH} = C_F + C_{O\&M} + C_I - C_B \qquad (1)$$

where

C_{EtOH}=Cost of ethanol production (baht per liter)

C_F = Feedstock cost (baht per liter)

$C_{O\&M}$ = Operating and maintenance cost (baht per liter)

C_I = Investment cost (baht per liter)

C_B = Byproducts gains (baht per liter)

3. Technical assumptions of the ethanol production in this study

In this study, multi feedstocks: cassava, corn, rice, sugarcane and molasses, are assumed to be processed by an ethanol plant for fuel grade ethanol production, with a capacity of 150,000 litters per day, and operating 330 days per year. The project life is assumed to be 20 years, and the interest is 6% per annum. Values in the year 2005 are chosen as the base year for cost calculations. All values in previous years before 2005 were converted to the base year, by the Consumer Price Index (CPI) of each year.

The yields of ethanol conversion from feedstock to ethanol were calculated based on the figures obtained from Thailand Institute of Scientific and Technological Research (TISTR)'s Pilot Plant. The amounts of other raw materials supply needed for processing such as enzymes, yeasts, molasses, water and chemicals were also based on the figures given by TISTR [3]. Table 1 shows the feedstocks yield and general technical assumptions used in this analysis.

4. Estimation of the feedstock costs

The costs of raw materials highly fluctuate in this study.Therefore, the prices of cassava, corn, rice, sugarcane and molasses, during years 2002 to 2005 [4], were referenced and they were adjusted to their equivalent prices in the year 2005, as the base year. The average prices during this period were found to be 1,096, 4,668, 4,728, 494 and 3,800 baht per ton, respectively. By using the conversion rates of the ethanol yields from the feedstocks, as shown in Table 1, the amounts of feedstocks required per one liter of ethanol produced could be estimated. It was found that the feedstock costs of cassava for the ethanol production varied from 5.75 to 8.56 baht per liter of ethanol. In the case of corn, rice and molasses, their feedstock costs are quite high, ranging from 11.92 to 12.80 baht per liter for corn, 10.95 to 15.19 baht per liter for rice and 12.5 to 20 baht per liter for molasses, respectively. However, for the case of sugarcane, if the ethanol is produced directly from the juice of sugarcane, its feedstock cost is much cheaper, and varied between 6.29 to 8.24 baht per liter. Table 2 shows the maximum, minimum, and average prices of each feedstock mentioned above.

The raw material cost is the most significant expense that affects the cost of the ethanol production. Unfortunately, the prices of the feedstocks are generally highly volatile as shown in Table 2. We will discuss this matter in detail again in the section of discussion and conclusion.

Table 1 Feedstocks yield and technical assumptions in this study

Feedstock	Cassava	Corn	Rice	Sugarcane	Molasses
Ethanol Yield (l/ton)	160	375	375	70	240
Plant's Feedstock Input Rates (tons/day)	940	400	400	2145	625
Plant Type	Multi-Feed and Stand Alone				
Location	Nakorn Ratchasima, Thailand				
Annual Production (million liters)	49.5				
Operation Days	330				
Project Life (years)	20				
Interest Rate	6% per annum				
Year for Cost Basis	2005				

Table. 2 The maximum, minimum and average of the feedstock costs in baht per ton and baht per liter of ethanol from 2002 to 2005

Feedstock	Maximum		Minimum		Average	
	baht/ton $_{feedstock}$	baht/l $_{EtOH}$	baht/ton $_{feedstock}$	baht/l $_{EtOH}$	baht/ton $_{feedstock}$	baht/l $_{EtOH}$
Cassava	1,370	8.56	920	5.75	1,096	6.85
Corn	4,800	12.80	4,472	11.92	4,668	12.45
Rice	5,698	15.19	4,106	10.95	4,728	12.61
Sugarcane	577	8.24	440	6.29	494	7.06
Molasses	4800	20	3000	12.5	3800	15.83

5. Estimation of the capital investment cost of the ethanol plant

The capital investment cost of an ethanol plant can be arranged into two major parts: direct costs and indirect costs. The direct costs include the costs of all machines and equipment, as well as their installation costs, land, main plant building, laboratories, offices and warehouses, instrumentation and piping works, etc. The indirect costs include engineering consulting costs and their contingency allowances.

The costs of the machines and the equipment were estimated by two methods in this study. In the first method, the equipment costs were obtained from vendor quotations directly, whenever this is possible, particularly for special processing equipment used only in this industry, such as molecular sieve etc. The second method is to obtain the equipment costs by reviewing from their historical prices and then adjust them to the present prices. This method is applied only when the first method is not available. We found that the total equipment costs were about 412.9 million baht (values in year 2005).

For the indirect costs, they were estimated in terms of certain average percentages of the total direct cost of the plant, as recommended by Garrett D.E. (1989) [5]. In this study, we found that the total capital investment is 1,208 million baht, for a project life of 20 years. Figure 3 summarizes all costs of these important components in the capital investment.

5.1 The Capital Investment Cost per Liter of Ethanol (C_I)

The contribution of the first capital investment cost per liter of the ethanol is calculated by amortization, recovered over the life time of the plant. A common approach is to annualize the capital cost by the equation [6]:

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \qquad (2)$$

where

A = annual payments (baht per year)
P = present worth of the first investment cost (baht)
i = annual interest rate in %
n = project life in years

The annualized capital investment cost is divided by the annual amounts of the ethanol production of the plant to estimate the capital cost per liter of the ethanol. It was found that the capital investment cost per liter of the ethanol in this study is 2.13 baht, if the annual interest rate is 6%, for the project life of 20 years.

6. Operating Cost ($C_{O\&M}$)

As discussed earlier, the operating expenses include water, enzymes, chemicals, operations of utilities, repair and maintenance, labor, administration, insurance, and miscellaneous expenses. In this analysis, the costs of water, enzymes, chemicals and the operations of utilities were calculated and adjusted to the prices in the base year 2005. The administration expenses were assumed as a fixed percentage of the total labor cost. For operating and maintenance, and plant's insurance cost, each of them could also be assumed as a fixed percentage of the annualized capital cost [7]. The operating cost per one liter of the ethanol can be calculated by dividing the total annual operating costs by the annual capacity of the ethanol production. The details of the calculation are shown in Table A1 in the appendix.

It should be noticed that while we use a starchy crop as raw material, the total operating cost for each type of feedstocks is not very much different. Nevertheless, when the sugarcane and the molasses are used as the raw materials, their operating costs are substantially lower than other starchy crops. By nature, sugarcane and molasses generally contain sugar which can directly be fermented by yeasts and need no any pretreatment of the feedstocks for the fermentation. The unit operating cost of the ethanol from cassava, corn, rice, sugarcane and molasses are found to be 3.67, 3.61, 3.62, 2.00 and 1.88 baht per liter, respectively, in this study (see the details in item I to item IV of Table A1 in the appendix).

7. Gains of By-products (C_B)

As discussed earlier, there are some by-products that can be available from the production processes and wastes. These by-products are considered to be of benefit to investors and they can reduce cost burdens of the production. In this study, CO_2 and fusel oil were assumed to be wastes and they have no values. DDG is a by-product of the ethanol production from corn and rice. For cassava and

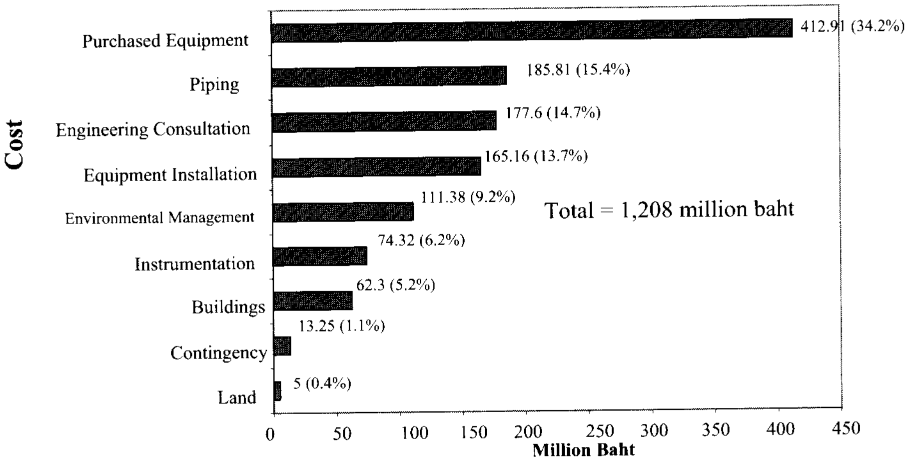

Figure 2 The investment cost of an ethanol plant, with a capacity of 150,000 liters per day

sugarcane, their by-products are cassava cake and bagasse. They can be sold for animal feeds, and for fuel burning, respectively. Similarly, the biogas from waste water treatment can be used as fuel for heating. Thus, it can also be considered as a benefit as well.

The value of the by-product gains is 1.09 baht per liter of the ethanol from cassava, 1.27 baht per liter of the ethanol from corn, 1.17 baht per liter of the ethanol from rice, 1.22 baht per liter of the ethanol from sugarcane and 0.44 baht per liter of the ethanol from molasses, respectively.

All by-products mentioned above are generally considered to be additional incomes (or gains) to ethanol producers (see the details of the calculation in item V of Table A1 in the appendix). The benefits from all by-products were subtracted from the operating costs. Finally, the net operating costs per liter of the ethanol, from cassava, corn, rice, sugarcane and molasses as feedstocks, were found to be 2.58, 2.34, 2.45, 0.78 and 1.44 baht per liter of ethanol, respectively.

8. Summary of the total cost per liter of the ethanol production

All costs of the ethanol production as mentioned in section 4 to section 7 have been summarized, as shown in Figure 4 and Table 3.

As shown in Figure 3, it is clearly obvious that the costs of raw materials are the highest proportion to the total unit cost of the ethanol production. From the statistical past records of the averaged prices of the raw materials, during year 2002-2005, it was found that the feedstock costs were 53% for cassava, 70% for rice, 72% for corn, 65%, for sugarcane and 79% for molasses, respectively, as a percentage of the total unit cost (per liter) of the ethanol production,

The net operating costs were found to be 14.1% for cassava, 13.4% for rice, 14.8% for corn, 8.2% for sugarcane, and 7.2% for molasses, as a percentage of the total unit cost (per liter) of the ethanol production, respectively.

It was found that the proportion of the investment cost contributed to be 16.5% for cassava, 17.4% for rice, 18.3% for corn, 28.8% for sugarcane and 13.7% for molasses, as a percentage of the total unit cost (per liter) of the ethanol production, respectively.

Since the unit cost structure (per liter) of the ethanol production, as shown in Figure 3, is calculated based on a volumetric basis, the ethanol's energy intensity is different from that of gasoline. The heating value of ethanol is generally less than that of gasoline for the same amount of volume. A liter of ethanol contains only 20.5 MJ, while a liter of gasoline contains 32.1 MJ. In order to compare the prices of both on the same energy content basis, the compared volume of the ethanol must be converted to be equivalent to the same value of the energy intensity per one liter of gasoline. This can be done by multiplying by a factor of 1.57 (32.1MJ divided by 20.5MJ), the cost per liter of the ethanol, for the cost comparison between the ethanol and the gasoline.

Table 3 Cost structures of the unit costs of the ethanol production for the selective crops and molasses.

Feedstock	Cassava			Corn			Rice			Sugarcane			Molasses		
	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave
Feedstock Cost (Baht/l)	8.56	5.75	6.85	12.80	11.92	12.45	15.19	10.95	12.61	8.24	6.29	7.06	20	12.5	15.83
Net Operating Cost (Baht/l)	2.58			2.34			2.45			0.78			1.44		
Investment Cost(Baht/l)	2.13			2.13			2.13			2.13			2.13		
Total Ethanol price per liter (Baht)	13.27	10.46	11.56	17.27	16.39	16.92	19.77	15.53	17.19	11.15	9.20	9.97	23.57	16.07	19.4
Ethanol prices per liter of gasoline equivalent (Baht)	20.83	16.42	18.15	27.11	25.73	26.56	31.04	24.38	26.99	17.51	14.44	15.65	37.00	25.23	30.46

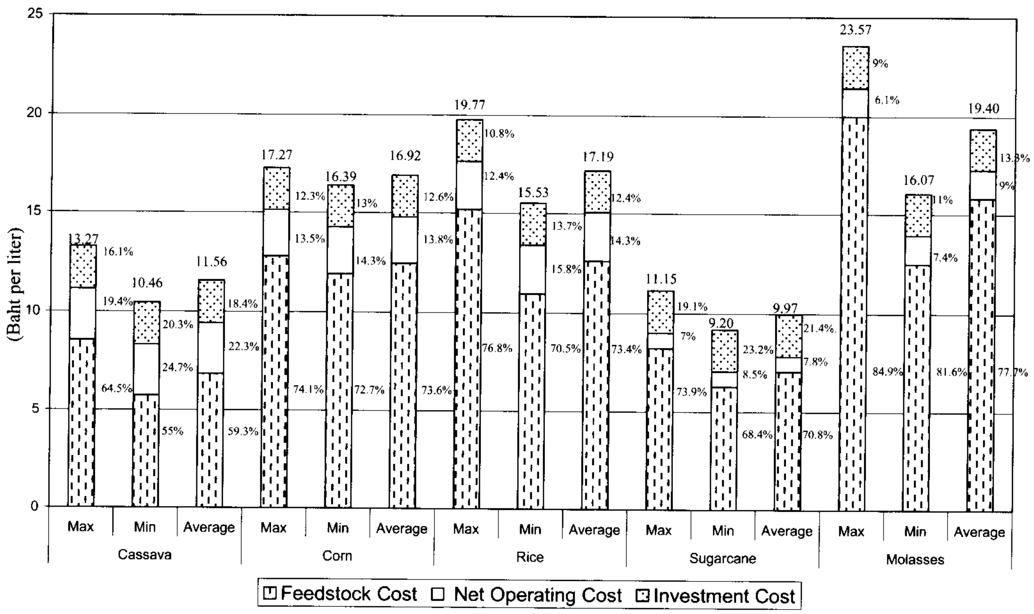

Figure 3 Cost structures of the ethanol production from the selective crops

The price comparison between gasoline octane 95 and ethanol, as per liter of gasoline's energy equivalent, for each of the selective crops are shown in Table 3 and Figure 4.

9. Discussion and conclusions

Presently, the Thai government has an intention to substitute for the imported crude oil by indigenous resources of bio-fuel. The primary purpose of the Thai government is to promote ethanol as a substitute fuel for gasoline octane 95. Hence, the price competitiveness between them is the most important factor that the government is concerned about. Ethanol can compete with gasoline, without any intervention, if its total production cost is lower than the gasoline's price.

The past statistical price records of gasoline octane 95, during the years 2002-2005 [8], were used as the reference for the comparisons in this study. The average price of gasoline octane 95

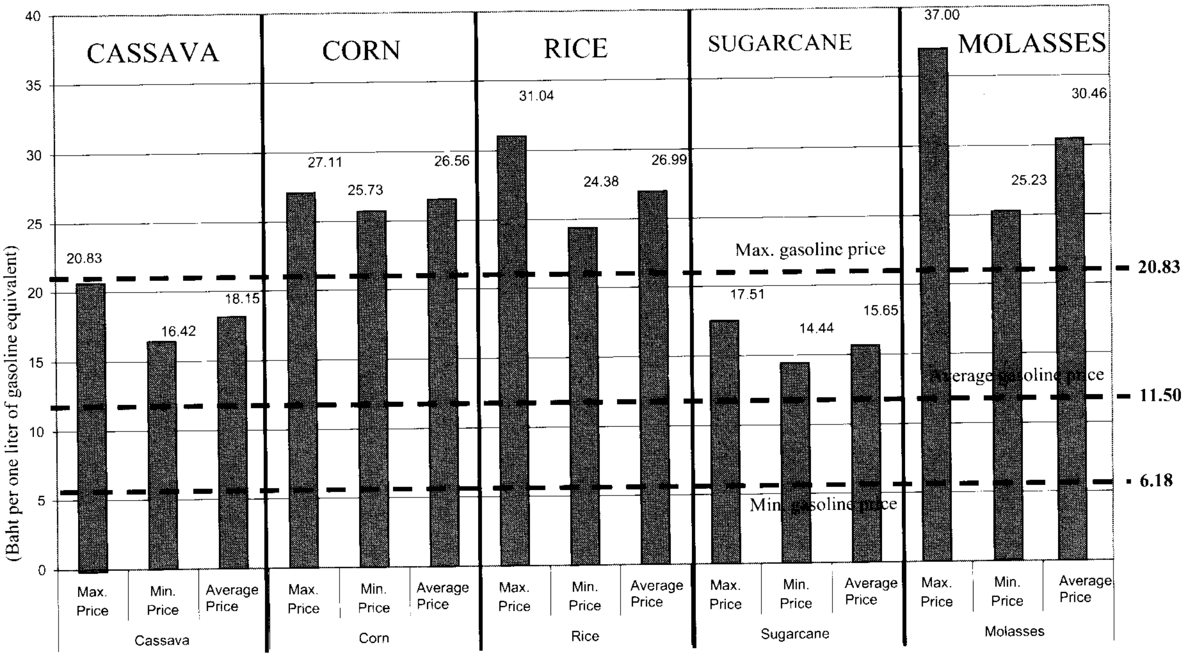

Figure 4 Comparisons between maximum, minimum and average prices of the ethanol per liter of gasoline equivalent and gasoline octane 95 prices (at ex-refinery, excluding all taxes), during years 2002-2005

(at ex-refinery plants) in the past, as well as the maximum and the minimum price of it were determined as shown in Figure 4. All prices of them did not include any taxes (the excise taxes, the oil fund and other levied tax were approximately about 8 to 10 baht per liter of gasoline).

By comparison between the ethanol's (as per liter of gasoline equivalent) and the gasoline's prices in Figure 4, we can conclude their competitiveness as follows:

(a) It is obvious that corn, rice and molasses, cannot compete with gasoline. We can see that even when their feedstocks prices are lowest, (i.e. their production cost for the ethanol are minimum) while the gasoline price is at the maximum, none of them are cheaper than the gasoline's price.

For the best competitive condition of rice, i.e. when the rice's price is at the minimum, it is able to be competitive with gasoline only when the ex-refinery price of the refined gasoline 95 should be, at least, higher than 24.38 baht per liter (crude oil price around 58 USD per barrel).

For the best competitive condition of corn and molasses, i.e. their feedstock prices are at the minimum, the ex–refinery prices of the refined gasoline 95 must be even higher than 25.73 and 26.23 baht per liter (crude oil price around 65 and 72 USD per barrel), respectively.

Molasses is the most unlikely feedstock to be competitive with gasoline among all types of feedstocks in this study. This is because the price of molasses is very high. This arises from the fact that it is also used for other purposes. The most serious competitiveness in uses of it is to produce potable alcohol drinks in Thailand, which can generally be sold at a much higher price than the fuel ethanol. As a result, under a situation when the supply of molasses is very tight, beverage producers can always afford to offer much higher prices to procure molasses than bio-ethanol fuel producers.

Hence, producers in Thailand, who solely use molasses as the feedstock and do not own any equity in sugar production plants, would be unlikely to survive in the bio-fuel business for a long time. From international experience, ethanol producers in Brazil can be highly competitive with gasoline because they integrate both of their fuel ethanol production and the sugar production processes together in order to minimize their total production costs, which is one of the key important factors to make them successful in this business [9].

(b) Sugarcane and cassava in Thailand are the only two types of feedstocks in this study, which are likely to have a high potential to be competitive with gasoline in the marketplace. However their competitiveness could be possible only when they are under special favorable conditions as follows:

It is clearly evident that, in the long term, as determined from the average fuel prices from the past historical records in this study, the average prices of ethanol produced from sugarcane and cassava were not yet able to compete with the average gasoline price during the period from 2002 to 2005. It should be remarked here that, from 2002 to 2005, the gasoline price in the world market was on an upward trend. This implies that when the gasoline price is in a slump, the ethanol produced from sugarcane and cassava are unlikely to be competitive with gasoline in the long term. From our study, they could be competitive with gasoline only when the average gasoline price was over 15.65 and 18.15 baht per liter, respectively.

The most favorable situation, i.e. when the feed stock prices of sugarcane and cassava were lowest (440 and 920 baht per ton, or 47.8 % and 55 % of the total ethanol cost, respectively). The gasoline at ex-refinery price should not be cheaper than 14.44 and 16.42 baht per liter, respectively. Otherwise, the ethanol produced from them would be unlikely to be competitive with gasoline.

From Figure 4, it is clear that the production cost of ethanol, produced directly from sugar juice, is the lowest one, as compared to all types of the feed stocks in this study. According to the past records, even when price of feedstock of the sugarcane became highest, the ethanol produced from it was still able to be competitive with gasoline, provided that the gasoline price was not lower than 17.51 baht per liter.

(c) Consequently, based on the above arguments, sugarcane and cassava are likely the most competitive cash crops, which have the highest potential feed stocks for commercialized ethanol production. At present, when the ex-refinery price of gasoline 95 is 20.86 baht per liter, while the crude oil price is about 56 USD per barrel (price on July, 16^{th}, 2006) [10], no subsidy or intervention from the government is needed for ethanol production promotion.

However, under the situation when the gasoline price is either too low or the feedstock price is too high, the bio-ethanol would not be able to compete with gasoline. If the government wants to promote a long term bio-fuel policy, then the government should help to support the competitiveness of ethanol, by using taxation or other financial instruments, such as an increase in the excise tax of the gasoline, when the gasoline price is too low, or subsidize the price of the bio-ethanol when its feedstock price is too high, in order to keep it to be competitive with gasoline all the time.

10. Policy Recommendation for the Thai Government from This Study

(a) As discussed earlier, the supply of agricultural crops are generally available seasonally. In order to ensure that the ethanol producers are able to have feed stocks that are sufficient all year-round for production, the government should promote and encourage investors to invest in ethanol production plants, by using multi-type feedstocks, rather than to promote ethanol production plants, using only a single type of raw material. This policy has more advantages, because the plants can use any type of abundant feedstock crop in any season. Thus, it would help to stabilize the production cost of ethanol.

(b) Currently, the Thai government regulates the ethanol price by attempting to relate it to the gasoline price in the world market and tries to set a policy to impose a ceiling price on the ethanol supply in the local market for fuel blending with gasohol 95, E10. Ethanol producers in Thailand generally oppose this policy because the imposed prices are frequently too low in their points of view.

In order to justify whether this policy is appropriate on not, this study analyzed the relationship between the feed stock prices of sugarcane and crude oil prices in the world market (Dubai price) during the years 1997-2006 [11]. Similarly, the price of cassava was also correlated with the crude oil prices in the world market during the same period. We found that the correlation coefficients between them are very poor, only 0.34 for sugarcane and 0.28 for cassava, respectively, as shown in Figure 5.

The results of our study are consistent with the study of the World Bank under the Energy Sector Management Assistance Programme [9]. It reported that the correlation coefficient between the sugar and the gasoline prices in the world market during year 1982 to 2005 is only -0.05. These results are strong evidence to show that the feedstock prices of feedstocks for bio-ethanol production and crude prices are hardly correlated at all.

Consequently, we conclude that the current policy of the Thai government to limit the ceiling price of the local ethanol supply to the crude oil price, would not be appropriate. Our strong argument is that the largest portion of the total ethanol production costs heavily depends on feedstock prices, which is generally highly volatile and are subject to the demand and supply of foodstuffs in the world markets, and the seasonal local supply variations. On the other hand, the variation of the gasoline prices depends on the crude oil prices in the world market, which is unrelated. Consequently, the above policy would jeopardize the promotion of bio-ethanol production for substitution of fossil fuel in the long term.

We suggest that, instead of a limit of the ceiling prices of the ethanol supply, the government should liberate ethanol prices in the market, and let them float freely, as long as the ethanol production cost is still able to compete with the gasoline price. However, in order to assure that there will be no disruption of the supply of ethanol in the long run, only under very special circumstance, such as when the feedstock prices of sugarcane and cassava are extremely low, the government should subsidize the cost of the feedstocks. This is to make sure that farmers have incentive to keep on growing the fuel crops for uses in bio-fuel production without disruption. In contrast, when the feedstock prices are too expensive, the price of ethanol from the local supply cannot be competitive with imported ethanol from aboard, then the government should intervene. The import taxes should be increased to help the local ethanol manufacturers to be competitive in the market and make sure that there would be no disruption of the ethanol supply from the local market in the long term.

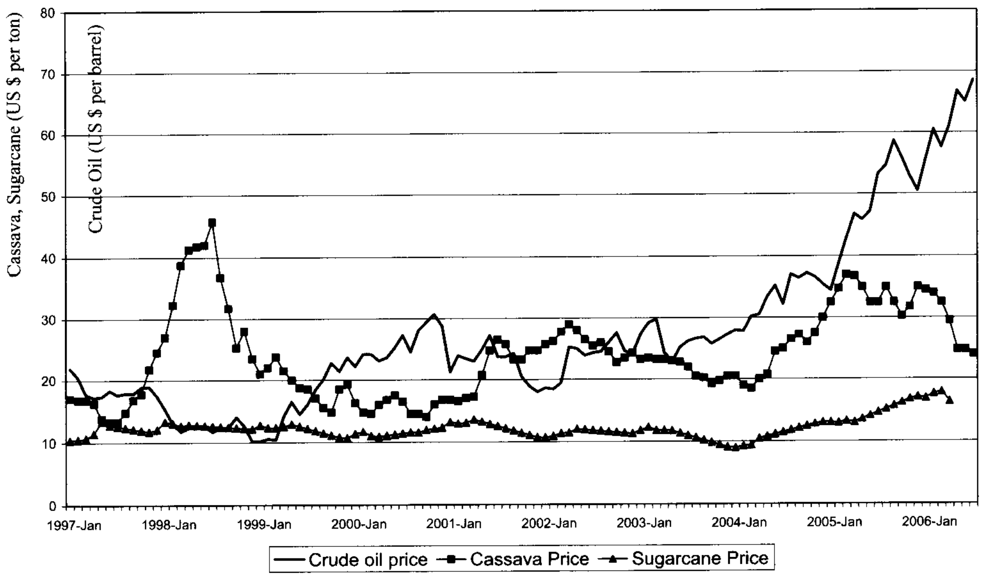

Figure 5 Comparisons of sugarcane, cassava and crude oil prices (exchange rate is 40 baht per USD)

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APPENDIX

Table A1: Net operating costs (including gains from by-products of each of the selective feedstocks)

Item	kg/day	Unit price (baht/kg)	Cassava		Corn		Rice		Sugarcane		Molasses	
			Annual expense (baht/year)	Unit Cost (baht/l)	Annual expense (baht/year)	Unit Cost (baht/l)	Annual expense (baht/year)	Unit Cost (baht/l)	Annual expense (baht/year)	Unit Cost (baht/l)	Annual expense (baht/year)	Unit Cost (baht/l)
I. Raw material preparation process												
Water	398,400	0.021	6,849,661	0.14	3,988,215	0.08	4,254,327	0.09	9,368,494	0.19	2,760,912	0.06
Ammonium Sulphate	0	25	7,194,000	0.15	7,194,000	0.15	7,194,000	0.15	0	0	0	0
Potassium Sulphate	0	90	5,167,800	0.10	5,167,800	0.10	5,167,800	0.10	0	0	0	0
Sulfuric Acid	0	35	7,830,900	0.16	7,830,900	0.16	7,830,900	0.16	0	0	0	0
Alpha-amylase	0	200	25,542,000	0.52	25,542,000	0.52	25,542,000	0.52	0	0	0	0
Gluco-amylase	0	250	31,927,500	0.65	31,927,500	0.65	31,927,500	0.65	0	0	0	0
Calcium Oxide	800	15	0	0	0	0	0	0	3,960,000	0.08	3,960,000	0.08
		Subtotal	**84,511,861**	**1.71**	**81,650,415**	**1.65**	**81,916,527**	**1.66**	**13,328,494**	**0.27**	**13,328,494**	**0.15**
II. Fermentation process												
Water	199,448	0.021	1,382,175	0.03	1,382,175	0.03	1,382,175	0.03	1,382,175	0.03	1,382,175	0.03
Antifoam	28	200	1,848,000	0.04	1,848,000	0.04	1,848,000	0.04	1,848,000	0.04	1,848,000	0.04
Molasses	56,090	1.5	27,764,550	0.56	27,764,550	0.56	27,764,550	0.56	27,764,550	0.56	27,764,550	0.56
Formalin	28	43	397,320	0.01	397,320	0.01	397,320	0.01	397,320	0.01	397,320	0.01
		Subtotal	**31,392,045**	**0.63**	**31,392,045**	**0.63**	**31,392,045**	**0.63**	**31,392,045**	**0.63**	**31,392,045**	**0.63**
III. Utilities												
Steam	360,000	0.42	59,875,200	1.21	59,875,200	1.21	59,875,200	1.21	48,708,000	0.98	48,708,000	0.98
Electricity	1125 kW	2	742,500	0.02	742,500	0.02	742,500	0.02	742,500	0.02	742,500	0.02
		Subtotal	**60,617,700**	**1.23**	**60,617,700**	**1.23**	**60,617,700**	**1.23**	**49,450,500**	**1.00**	**49,450,500**	**1.00**
IV. Labor, supplies & overhead costs of direct labor	**Daily Wage** (baht/day)	operator/shift (crews/shift)										
- Operator	200	5	990,000	0.02	990,000	0.02	990,000	0.02	990,000	0.02	990,000	0.02
- Maintenance	200	2	396,000	0.01	396,000	0.01	396,000	0.01	396,000	0.01	396,000	0.01
Administration salaries	40% of O & M Labor		554,400	0.01	554,400	0.01	554,400	0.01	554,400	0.01	554,400	0.01
Operating supplies	0.75% of Annual Capital		567,965	0.01	567,965	0.01	567,965	0.01	567,965	0.01	567,965	0.01
Maintenance supplies	1% of Annual Capital		757,287	0.02	757,287	0.02	757,287	0.02	757,287	0.02	757,287	0.02
General & administrative	60% of Total Labor		1,164,240	0.02	1,164,240	0.02	1,164,240	0.02	1,164,240	0.02	1,164,240	0.02
Insurance	0.75% of Annual Capital		567,965	0.01	567,965	0.01	567,965	0.01	567,965	0.01	567,965	0.01
		Subtotal	**4,997,857**	**0.10**	**4,997,857**	**0.10**	**4,997,857**	**0.10**	**4,997,857**	**0.10**	**4,997,857**	**0.10**
		TOTAL	**170,352,263**	**3.67**	**167,490,817**	**3.61**	**167,756,929**	**3.62**	**99,168,896**	**2.00**	**99,168,896**	**1.88**
Item	**kg/day**	**Unit price (baht/kg)**	**Annual expense (baht/year)**	**Unit Cost (baht/l)**	**Annual expense (baht/year)**	**Unit Cost (baht/l)**	**Annual expense (baht/year)**	**Unit Cost (baht/l)**	**Annual expense (baht/year)**	**Unit Cost (baht/l)**	**Annual expense (baht/year)**	**Unit Cost (baht/l)**
V. By-product credits												
CO_2	126,343	0	0	0	0	0	0	0	0	0	0	0
Refuse	0	-0.1	-32,150,580	-0.65	-40,901,520	-0.83	-36,228,720	-0.73	-38,517,600	-0.78	0	0
Net biogas profit			-21,742,380	-0.44	-21,742,380	-0.44	-21,742,380	-0.44	-21,742,380	-0.44	-21,742,380	-0.44
		TOTAL	**-53,892,960**	**-1.09**	**-62,643,900**	**-1.27**	**-57,971,100**	**-1.17**	**60,259,980**	**-1.22**	**-21,742,380**	**-0.44**
		Net Operating Cost		**2.58**		**2.34**		**2.45**		**0.78**		**1.44**