Life Cycle Cost Analysis of Fuel Ethanol Produced from Cassava in Thailand

Thu Lan T. Nguyen, Shabbir H. Gheewala* and Savitri Garivait

The Joint Graduate School of Energy and Environment, King Mongkut’s University of Technology Thonburi, Bangkok, Thailand

Abstract: Life cycle cost analysis has been carried out to assess the economics of cassava-based fuel ethanol for transport in Thailand. Its relatively high cost over gasoline has put an economic barrier to commercial application. So far, there are different opinions about government support for ethanol in the forms of tax incentives and subsidies. The scope of the study includes the cassava cultivation/processing, the conversion to ethanol, the distribution of the fuel, and all transportation activities taking place within the system boundary. A distance of one kilometer driven by new passenger cars was used as the functional unit (FU) to compare ethanol (in the form of gasohol E10) with gasoline. The results of the analysis show that gasohol has the potential to be competitive with gasoline in terms of cost per FU if cassava farmers can raise their crop yield but lower chemical (fertilizer, herbicide) consumption for crop maintenance. In the industrial phase of the fuel production cycle, utilization of co-products and substitution rice husk for bunker oil as process energy tend to narrow the gap in ex-refinery price between gasohol and gasoline (52% reduction in the price gap). The remaining 38% in the price gap can be eliminated with a strong cut (about 68%) in the profit margin in ethanol conversion phase. Including other difficult-to-quantify benefits of bio-ethanol in a LCC analysis may make the results even more favorable to bio-ethanol.

Keywords: Fuel Ethanol, Transportation, Cassava, Life Cycle Cost, Thailand

1. INTRODUCTION

Thailand imports a significant amount of oil to meet domestic demand. The ratio of the country’s crude oil import to crude consumption stands at a high level (92% in 2000 [1]). Not only does oil consumption cost the country a huge amount of foreign currency via oil import bills but also contributes to environmental degradation. In that context, domestically produced ethanol has emerged as a potential substitute for conventional gasoline, most likely effective in both fossil oil savings and pollution mitigation.

In Thailand, though the promotion for ethanol to enter the energy market had started in the past 20-30 years, its popularity was first recognized in 2001. With the government’s biofuel policy, ethanol is being distributed to consumers in the form of gasohol, a mixture of ethanol and gasoline at a ratio of 9:1. Quite confident about abundant sources of raw materials for ethanol production, the Thai government has launched a project to replace gasoline with gasohol nationwide by January 2007 [2]. Ethanol can be made from a wide spectrum of agricultural commodities, of which, sugar cane, cane molasses and cassava are of importance in Thailand. At present, ethanol in the country is mainly produced from molasses. However, the main disadvantages of molasses-based ethanol lie in supply versus demand and seasonal operation. Recently, after molasses-based ethanol producers raised their product’s prices to cope with sharp increased feedstock prices, cassava-based ethanol becomes an attractive commodity for Thai oil traders.

The focus of this study is on the costs of producing ethanol from cassava, in comparison with gasoline, based on a life cycle approach. At present, it seems that without government subsidies ethanol cannot compete with gasoline in terms of price. However, improved cassava yield and co-product market development would favor ethanol’s potential to substitute for gasoline in the long term. In addition, this renewable energy source could provide a stable market for cassava farmers to sell their product as well as contribute to environmental and energy policy goals. Life cycle cost is an important tool for policy makers to assess whether an energy alternative like ethanol is feasible and practical in terms of cost. Moreover, it highlights specific areas where further technological advance and/or strategic policy could yield improvements, eliminating economic barriers.

2. METHODOLOGY

2.1 Life cycle cost analysis
2.1.1 Ethanol fuel life cycle

The scope of the study includes the cassava cultivation/processing, the conversion to ethanol, the distribution of the fuel, and all transportation activities taking place within the system boundary. Fig. 1 shows major operations included in the boundary of ethanol life cycle for conducting cost analysis. At each stage in the fuel life cycle, the expenses include materials, energy (fuel, electricity), labor, transportation, depreciation of fixed assets, maintenance, and miscellaneous costs. Farm machinery hiring and profit margin are other cost components. The final cost of cassava ethanol (CE) is the sum of all of the mentioned process costs and values.

* Cassava cultivation

Well-known for its tolerance/resistance to drought and insects/pests, cassava does not require irrigation and insecticide/pesticide application. The direct farm inputs include diesel fuel, labour, stem cuttings, herbicides, and fertilizers. As shown in Fig. 1, steps involved in this stage are land preparation, planting, crop maintenance (fertilization, weed control), and harvesting.

Land preparation in Thailand now is done by diesel tractor. In general, cassava is propagated vegetatively through stem cuttings prepared from the residual stems left after roots are harvested. Manual planting is a common practice in Thailand. For crop maintenance, commercial fertilizers and chicken manure are the two types of materials farmers use to improve soil fertility/physical conditions. Weeding is carried out by hand, small tractor and herbicides. Cassava can be harvested either manually or mechanically. In Thailand, manual harvesting is more usual. In dry season, mechanical harvesting involving the use of mechanical diggers is performed to make manual digging less arduous.

* Cassava processing

Cassava in the form of dried chip is considered suitable raw material for ethanol production [3]. In Thailand, cassava chip...
producers are mostly small entrepreneurs and chip processing is rather simple. Roots transported to processing plants are loaded into the hopper of the chopping machine by tractor. After chopping into small pieces, chips are sun-dried on a large cement floor. A tractor attached with a special implement is used to turn over the chips several times per day [4, 5]. After 2 to 3 days, dry chips are packed, ready for further processing or transportation to customers.

* Ethanol conversion

This segment includes numerous steps, e.g., milling, mixing and liquefaction, saccharification and fermentation, and distillation/dehydration (Fig. 1). Bunker oil bills and electricity bills make energy costs of ethanol plant operation. Treatment of distilled mash in anaerobic digester produces biogas. This biogas is collected and reserved for plant use, saving about 35% of bunker oil cost. Other potential by-products associated with ethanol production are CO₂ and manure. This CO₂ can be collected, purified and transformed for use in the coolant, soft drink, soda, dry ice and fire extinguisher industries. The solids contained in the digester effluent can be recovered to be used as manure in cassava farms [6].

![Flow chart of cassava based gasohol production process](image)

**Fig. 1 Flow chart of cassava based gasohol production process**

### 2.1.2 Functional unit

One kilometer driven by new passenger cars was used as functional unit to compare ethanol (in the form of gasohol) and gasoline.

### 2.2 Data collection

#### 2.2.1 Cassava farming cost

The Thai government has recently approved the construction of 6 CE plants in the north-eastern region with a total output of 1.35 million litres (ML) per day in 2007-2008 [7]. Of this output, 0.75 ML would be contributed by 2 CE plants located in Nakhon Ratchasima which is the top cassava-producing province in Thailand [8]. Cassava farming cost was collected on-site in this province. The cost is an aggregation of various cost components which can be categorized into five groups as follows.

1) Land preparation by tractor. Included in this item are cost of fuel, hiring tractor and driver.
2) Planting activity, including cost of planting materials (cassava stems)
3) Chemical (fertilizers and herbicides) and application
4) Harvesting
5) Transportation of chemicals and harvest

#### 2.2.2 Cassava processing cost

Data were obtained through personal interview with the manager of a typical cassava-drying floor in Thailand [5]. The magnitude of cassava processing cost is contributed mainly by 1) fuel use for tractor operation, and 2) manual packing.

#### 2.2.3 Ethanol conversion/distribution cost

The detailed cost breakdown for ethanol production from cassava was adapted from the 2003 cost estimate prepared by the research team in the Cassava and Starch Technology Research Unit (CSTRU), Bangkok, Thailand [9]. The estimate was done based on a production scale of 100,000 L – 200,000 L of anhydrous ethanol per day. Up to this point, the cost of ethanol (termi
ex-distillery price) is contributed by 1) raw material (feedstock), 2) utilities (energy cost), 3) chemicals, 4) repair and maintenance, 5) insurance, 6) wages and salary, 7) depreciation, and 8) profit margin. Adding transportation/distribution cost to ethanol ex-distillery price results in ethanol ex-refinery price. To estimate transport costs, assumptions were made about transport of cassava chips to ethanol factories, ethanol to oil refineries and gasohol to gas stations, as shown in Table 1.

Table 1 Assumptions about transport activities for estimating transport cost in cassava ethanol system

<table>
<thead>
<tr>
<th>Type of materials, products</th>
<th>Transport facility</th>
<th>Capacity (tonnes)</th>
<th>Average distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava chips from drying floors to CE plant</td>
<td>Diesel Truck</td>
<td>15 – 20</td>
<td>100</td>
</tr>
<tr>
<td>Ethanol from factories to oil refineries</td>
<td>Diesel Truck</td>
<td>10 – 12</td>
<td>260</td>
</tr>
<tr>
<td>Gasohol from oil refineries to gas stations</td>
<td>Diesel Truck</td>
<td>10 – 12</td>
<td>50</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSIONS

3.1 LCC analysis

3.1.1 Cassava farming

The production costs of cassava roots estimated by farmers are in the range of Bt 980 to Bt 1,140 a tonne [In 2006, 1 USD equals approximately 38 Bt]. A detailed breakdown cost structure is shown in Fig. 2.

Selling their product to processing plants, farmers get an average profit of about Bt 183 to Bt 427 a tonne depending on product market price. The market price of cassava roots in the last few months of 2006 has fluctuated from Bt 1,250 to Bt 1,500 a tonne. An unstable market is the reason why some time farmers earn nothing or even lose money after nearly one year working hard for their farm produce. If a stable ethanol market for cassava is set up, hopefully, a great number of cassava farmers in rural Thailand can be benefited. The magnitude of the income depends on the area that farmers own. A cassava farmer owning 20 rais (1 rai = 0.16 hectares) and getting an average yield of 3.4 tonnes per rai can earn Bt 12,400 – Bt 29,000 after 8-10 months, i.e., Bt1,240 – Bt 2,900 per month. Fortunately, living expenses in rural Thailand are not too high so that small cassava farmers can survive on this income.

The total production cost of cassava chips is Bt 3,300 per tonne; 95% of this cost is due to the cost of 2.5 tonnes of cassava roots [4], whereas processing cost makes just 5%. But the price of cassava chips ranges between Bt 3,700 and Bt 4,000 a tonne on the open market [10] after adding profit margin, taxes, etc. Another factor is market demand.

3.1.2 Ethanol conversion

The feedstock cost of ethanol conversion is the cost of cassava chips on the open market plus transportation cost. It amounts to Bt 3,900 to Bt 4,200 a tonne of raw material. This brings the cost of raw material to the Bt 11.71–Bt 12.61 range per litre of ethanol produced, given a conversion rate of about 333 litres of ethanol per tonne of cassava chips [9]. The cost of the ethanol product leaving the ethanol factory is termed ex-distillery price. It represents production cost (Bt 18.08) plus distillery profit margin (Bt 3.62). The detailed ex-distillery cost breakdown for ethanol production from cassava chips based on the floor price of feedstock (Bt 11.71 a litre) is presented in Fig. 3.

Before being distributed to gas stations, ethanol is transported to oil refineries for blending with gasoline. At gas stations, the retail price of ethanol in the form of gasohol is formulated as: retail price = ex-refinery price + oil fund + taxes + marketing margin + VAT [11], in which ex-refinery price is a sum of ex-distillery price and transportation/distribution cost. To encourage consumers to use gasohol, the Thai government provides fuel subsidies and tax incentives that make gasohol 1.5 baht-a-litre cheaper than 95 octane gasoline (ULG 95). Thus, a fair comparison between ethanol and gasoline should be based on their ex-refinery prices rather than retail prices or pump prices.
Transportation/distribution costs were estimated based on the assumptions presented in Table 1. Adding this cost to ethanol ex-distillery cost results in the ethanol ex-refinery price of Bt 22.2 a litre. It is Bt 3.22 more costly than gasoline. The ex-refinery price of ULG 95 posted at www.eppo.go.th/info/ in the first seven months of 2006 was Bt 18.98 a litre. Calculated per MJ energy content, these prices become Bt 1.05 and Bt 0.60, respectively. It seems that ethanol costs customers 75% higher than ULG 95.

Although ethanol has lower energy content than gasoline but its higher octane value allows higher compression ratios and more efficient thermodynamic operation in internal combustion engines. In other words, the heating value of ethanol should not be used as an indicator of its performance in a motor vehicle engine. According to the tests conducted by PTT Research and Technology Institute [12], a car (Toyota 1.6 L/2000) runs about 13.46 km per litre of gasoline whereas it runs 13.31 km per litre of gasohol E10, higher than a value of only 13.02 km estimated based on fuel energy content. Per km driven, E10 costs customers Bt 1.45 whereas ULG costs only Bt 1.41. Thus, based on fuel economy, the increment in E10 ex-refinery price over ULG95 becomes narrower than based on fuel energy content. However, though cheaper than molasses-based ethanol, the ex-refinery price of which at present (September 2006) is Bt 27.6, cassava ethanol is still more costly than ULG95. As can be seen in Fig. 4, to make gasohol competitive with gasoline at current prices, ethanol ex-refinery price has to drop below Bt 16.95.

The advantage of an LCC analysis is to provide a whole cost structure of ethanol life cycle. From such an analysis, one can identify specific areas where technological innovation or strategic policy is needed to make such an energy alternative feasible in terms of cost. As shown in Fig. 3, feedstock price is the dominant cost factor in CE production; it represents 54% of ethanol ex-distillery cost, whereas ethanol conversion contributes about 46%. A reduction in cassava price would be a possible way to reduce ethanol production cost. In the conversion phase, utilization of ethanol by-products would help offset ethanol production cost. However, an economic analysis of by-products should be done to assess this possibility. Another option is a substitution of cheaper fuels for bunker oil to power ethanol factory.

The relatively high price of ethanol is partly due to the many steps involved in the fuel production cycle. Each step brings with it various cost components, e.g., costs of materials, utilities, labour, transportation, depreciation of fixed assets, maintenance and remarkably, profit margin. Adjusting the profit margin existing in the many steps involved in ethanol production cycle also can offer a possible way to optimize ethanol price.

3.2 Possibilities of cost reduction

3.2.1 Farm cost

Tracing back to farm cost, to make ethanol ex-refinery price drop below Bt 16.95 in order to be competitive with gasoline, cassava roots should be available at a market price of no more than Bt 736 per tonne. As a result, production cost for cassava farming has to drop to Bt 553 a tonne, assuming that the profit for farmer is fixed at Bt 183 a tonne.

If farming cost remains the same, increasing cassava crop yield is one option for reducing farm cost per tonne of cassava. As shown in Fig. 5, the breakpoint of cassava yield at which the cost per tonne of cassava could drop to Bt 553 is 6.6 tonnes/rai, i.e., nearly double current yield of 3.4 tonnes/rai. In the short term, this seems neither feasible nor practical. During the past decade (1995-2004), the national average yield of cassava in Thailand has remained the same or increased slightly, about 5.5% a year [8]. Yield stagnation has resulted from soil losses due to erosion and inappropriate fertilizer application [13]. A combination of cost reduction in crop maintenance (fertilizer/herbicide application) and yield increase would be more practical. The straight line in Fig. 6...
is a series of different combinations of cassava yield and crop maintenance cost reduction resulting in a farm cost of Bt 553/tonne. For instance, a 40% reduction in chemical usage combined with an yield of 5.6 tonnes/rai would be as effective as a 94% increase in crop yield alone. This option leaves an area for cassava researchers to work on to make cassava-based ethanol economically feasible.

3.2.2 Ethanol conversion cost

a. Utilization of ethanol by-products

- CO₂: There are several ways an ethanol plant can collaborate with CO₂ customers as a supplier of untreated gas or purified CO₂ product. The more finished the CO₂ by-product leaving the ethanol factories, the larger the production cost of ethanol is offset. However, note that the processing costs as well as capital and operating costs will also increase. The simplest way is collecting and selling the CO₂ by-product directly as raw material to a nearby processor, if any. Some processors such as soda manufacturing facilities, and enhanced oil recovery projects may accept CO₂ product with lower purity requirement, than the traditional food or beverage customers. A modest selling price for “raw CO₂ product” is estimated between $4 and $15/tonne [14]. For every kg of ethanol produced, approximately one kg of CO₂ can be captured. So, per litre of ethanol, about Bt 0.31 can be salvaged from CO₂.

- Manure: One tonne of cassava chips passing ethanol conversion process can produce about 84-89 kg sludge of 10% moisture content [9]. This sludge having value of good soil conditioner can be sold to cassava farmers [6] with low price (2 baht per kg). Some heat is required for sludge dewatering. Assume that the process heat is derived from rice husk. Among various biomass-based energy resources relevant to Thailand, rice husk ranks second after bagasse regarding supply outputs [15]. After subtracting drying cost from manure selling price, one can find the contribution of manure to one litre of ethanol is Bt 0.46. If these two options are practical, ethanol ex-refinery price can drops to Bt 21.43.

b. Substituting rice husk for bunker oil

The pilot plant producing ethanol from cassava uses bunker oil as the main source of process energy. Per MJ available, it costs about Bt 0.44, whereas rice husk costs only Bt 0.05. If a nearby source of rice husk is available, its substitution for bunker oil would save Bt 2.02 per litre of ethanol produced.

Thus, combined options of utilization of ethanol by-products and substitution rice husk for bunker oil can lead to a final ethanol cost of Bt 19.41 per litre, still Bt 2.46 over the breakpoint cost.

3.2.3 Profit margin

Every step involved in ethanol production cycles brings with it some profit margin. Consistent with an estimate based on the floor price of feedstock, per litre of ethanol produced, farmers get profit of about Bt 1.37, cassava chip processors may get Bt 1.19, and ethanol factories were assumed to earn Bt 3.62. If the profit margin in ethanol conversion phase can be reduced to Bt 1.16 per litre, the cost of gasohol now becomes competitive with gasoline on fuel economy basis.

Table 2 is a summary of various possibilities of ethanol cost reduction.

<table>
<thead>
<tr>
<th>Table 2 Ethanol cost reduction opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
</tr>
<tr>
<td>Feedstock (cassava chips)</td>
</tr>
<tr>
<td>Ethanol conversion</td>
</tr>
<tr>
<td>Chemicals</td>
</tr>
<tr>
<td>Utilities (bunker oil, electricity)</td>
</tr>
<tr>
<td>Repair and maintenance</td>
</tr>
<tr>
<td>Insurance</td>
</tr>
<tr>
<td>Wage and salary</td>
</tr>
<tr>
<td>Depreciation</td>
</tr>
<tr>
<td>Total production cost</td>
</tr>
<tr>
<td>Profit margin</td>
</tr>
<tr>
<td>Ex-distillery price</td>
</tr>
<tr>
<td>Ethanol transportation/distribution</td>
</tr>
<tr>
<td>Co-product utilization</td>
</tr>
<tr>
<td>CO₂</td>
</tr>
<tr>
<td>Manure</td>
</tr>
<tr>
<td>Ex-refinery price</td>
</tr>
</tbody>
</table>
4. CONCLUSIONS AND RECOMMENDATIONS

LCC analysis provides relevant information for stakeholders since it allows to compare an energy alternative like fuel ethanol to conventional gasoline and contributes guidelines for making improvements. The case study of fuel ethanol from cassava in Thailand leads to the following conclusions:

Considering the end use of ethanol fuel, a comparison between gasohol and gasoline should be done based on fuel economy, i.e., how many kilometers per litre a car fueled with gasohol or gasoline can run, rather than energy content or volumetric basis.

More than half of ethanol production cost is contributed by feedstock price. A possible measure to make ethanol in the form of gasohol competitive to gasoline is a combination of increasing crop yield and decreasing chemical usage in crop maintenance.

Three options for ethanol conversion stage contributing to cost reduction are utilization of co-products, CO₂ and manure, substituting rice husk for bunker oil, and setting new profit margin.

One may expect that either a decrease in ethanol production cost or an increase in gasoline price would favor ethanol over gasoline. In fact, rising oil prices would make the production cost of ethanol increase accordingly, since ethanol is still a product of an oil-based economy. The gap could effectively get narrower or even eliminated with a decrease in the costs expended in producing ethanol. It is the case of a modest rate of fossil-based fuel/material inputs in CE production cycle brought about by appropriate farming practices and/or advanced ethanol conversion technologies.

Finally yet importantly, a conventional cost estimate for bio-ethanol as done above would not inform the public adequately about the various benefits which are difficult to quantify in monetary terms. Briefly, they are (1) Reducing oil imports and saving foreign currency, (2) Reducing the burdens of foreign debt and debt servicing, (3) Lessening global warming impacts and reducing some criteria air pollutant emissions, (4) Enhancing technological development, (5) Stimulating domestic agricultural production and expanding the markets for domestic agricultural commodities, (6) Stabilizing farmers’ living conditions [16]. If all these benefits are included in a comprehensive LCC analysis, the cost per km driven may already be more favorable for cassava-based gasohol.

5. ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions of 58 farmers in Nakhon Ratchasima province, the Cassava and Starch Technology Research Unit at Kasetsart University and other data providers.

6. REFERENCES


