

LCA/LCC of *Jatropha* Biodiesel Production in Thailand

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Abstract

The market price of oil has increased tremendously over the last decade. One of the major influences has been the higher demand for energy consumption in developing countries. Thailand imports a huge amount of oil each year, mainly for the industrial and transportation sectors. Statistics indicate that the selling price of diesel in Thailand increased from 0.24 Euros per liter in 2000 to 0.56 Euros/L in 2006. This problem directly and suddenly affected all sectors which rely on this fuel. In order to relieve this crisis, the government tried to promote the development of biodiesel, which has the same function as diesel fuel but is less expensive. However, there are many kinds of biodiesel fuels: such as biodiesel from used cooking oil, from plants, or from animal grease. Some of these have similar properties to petroleum-based diesel, but may require extensive improvement processes.

Jatropha shows great potential as an oil-producing plant source in Thailand. Nevertheless, from the life cycle aspect, to generate biodiesel from *Jatropha* oil, materials and energy must be consumed and emissions and wastes will be released into the environment. Therefore, it is necessary to quantify and verify the energy efficiency and the environmental impacts of *Jatropha* biodiesel production from the life cycle point of view. Thus, the objectives of this paper are to develop the life cycle inventory database of *Jatropha* biodiesel and to analyze the environmental impacts by using the concept of life cycle thinking.

It is clearly shown that the cultivation process of *Jatropha* contributes the highest environmental impacts, compared to other stages in the life cycle, due ineffective cultivation management. Suggested improvements to the *Jatropha* life cycle are introduced to maximize the benefits of using *Jatropha* biodiesel and minimize the environmental impacts, in order to help ensure future sustainable utilization.

Key Words: Life Cycle Assessment, Life Cycle Costing, *Jatropha curcas*, Biodiesel, Thailand.

1. Introduction

Jatropha curcas Linn. is a tropical plant native to America which is now naturally found throughout tropical and subtropical parts of Asia and Africa. In Thailand, *Jatropha* is called "Saboo dam." It is often found near rice fields, as the farmers plant it for use as an herb. It is a large shrub, with thick branches and numerous large leaves, and can attain a height of 3-4 m in three years.

Jatropha can be successfully cultivated both in irrigated and rain-fed conditions. The plants grow quickly, forming a thick bushy fence in a short period of time (6-9 months). Seeds resemble castor seeds in shape, but are smaller and brown. The plant is valued for its rich oil, high in fats obtained from the seeds. *Jatropha* can tolerate high temperatures, and grows very well under low fertility and moisture conditions. The leaves also yield a dye, and a latex which has many medicinal uses that are of great interest to the pharmaceutical industry. *Jatropha*'s most obvious benefit is that its oil can be used in place of kerosene or diesel. This oil has been extensively promoted as a means of making rural areas self-sufficient in fuels for cooking, lighting and automotive power. It can be converted into a methyl ester by the transesterification process. This involves the triglycerides of *Jatropha* oil reacting with methyl alcohol in the presence of a catalyst (NaOH/KOH) to produce glycerol and the fatty acid ester which is known as biodiesel. Considering its wide spectrum of utility and the prospects of it growing in wastelands without competing with other crops, *Jatropha* was selected for investigation of the feasibility of mass production of biodiesel. Life cycle assessment (LCA) and life cycle costing (LCC) aspects were used to measure the economic value.

2. Methodology

2.1 Goal definition

The first goal was to estimate the environmental impacts from *Jatropha* biodiesel production in terms of its overall life cycle. Secondly, LCC analysis was performed in order to better understand the economic value. Finally, LCA and LCC results of *Jatropha* were compared with diesel.

2.2 Functional unit

The environmental analyses require an objective basis for comparison, the so-called functional unit, which reflects the function of the fuel. According to calorific measurements, 1 L of *Jatropha* biodiesel has an energy content of 37.14 MJ, which is equivalent to 0.862 L of diesel. Therefore, the LCA of both were compared by assuming that 37.14 MJ of either *Jatropha* biodiesel or diesel would perform the same amount of work (i.e. an automobile will travel the same distance) under similar conditions.

2.3 Scope definition

The scope of this LCA study is as broad as the data available. It starts from seeding acquisition and extends through the use phase, focusing on the extraction of raw materials, energy consumption, and the emissions during life cycle processes, as shown in Fig. 1.

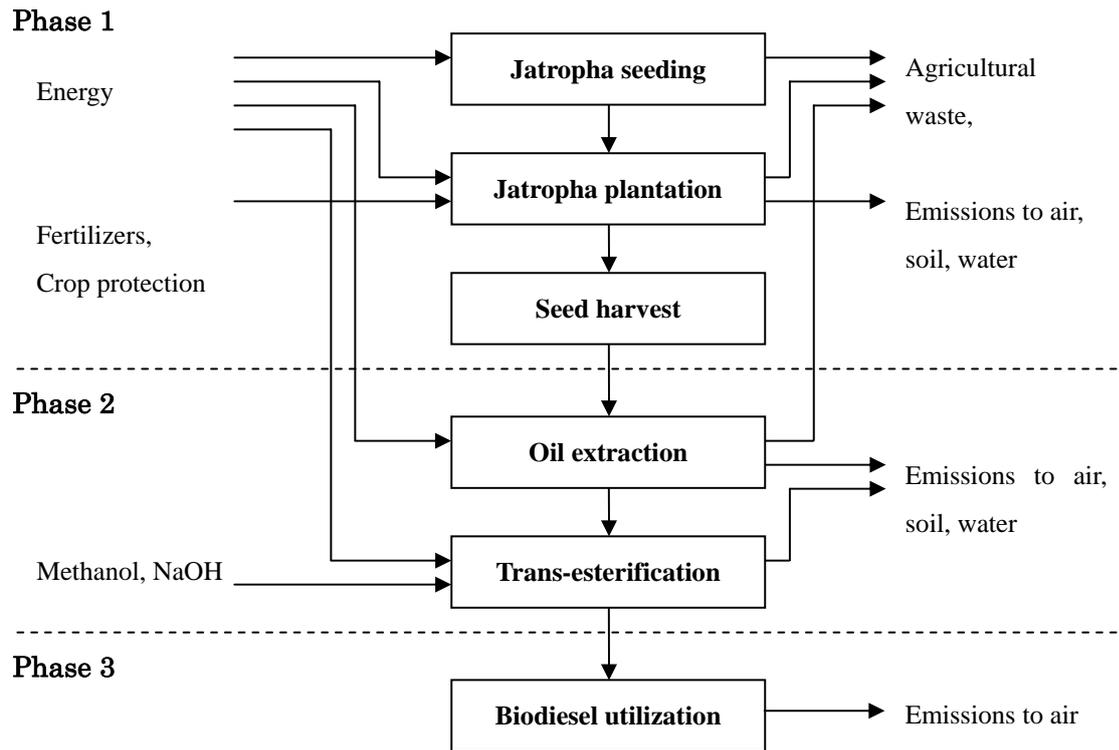


Fig 1. The three phases of the *Jatropha curcas* biodiesel production life cycle.

3. Life Cycle Costing

To properly account for all the expenses in a *Jatropha curcas* biodiesel production system that operates over many years, overall LCC analysis costs are grouped into six main categories and converted into present value [2], as shown in Equation 1:

$$LCC = C_{pw} + O_{pw} + M_{pw} + F_{pw} + R_{pw} - S_{pw} \quad (1)$$

where:	<i>C</i>	=	Capital cost
	<i>O</i>	=	Operation cost
	<i>M</i>	=	Maintenance cost
	<i>F</i>	=	Fuel cost
	<i>R</i>	=	Replacement cost
	<i>S</i>	=	Salvage value
	pw	=	Present worth

As in Eq. (1), capital cost includes the cost of every component of the production system, including production machinery, buildings, equipment and other assets related to the overall biodiesel production life cycle. Operation cost is recurring and varies by how much biodiesel is produced (e.g. the cost of methanol, sodium hydroxide, or labor cost). Maintenance cost (system maintenance) is another recurring cost. This category includes equipment maintenance, site maintenance, system

supervision, etc. The biodiesel production reactor must be cleaned up approximately every 4-5 batch productions. Fuel cost is the total energy consumption cost for the system, equipment and transportation – mainly from electricity and diesel consumption. Replacement cost or spare part consumption is the total cost of spare parts and consumables over the design life of the system, and includes the equipment necessary to complete the predicted work load for all maintenance actions (i.e. preventive maintenance, corrective maintenance and servicing). Salvage value is a kind of system income that occurs at the end of the “useful life” of a machine or other equipment in the system, and is deducted from the final total cost.

Finally, while adding up costs over time is better than simply comparing initial capital costs, a mathematical method called “net present value” (NPV) analysis takes into account the fact that the value of money changes over time [3]. Using six cost categories, this method seeks to calculate the final costs in each category based on the present worth of the currency. The NPV that is part of the LCC of *Jatropha curcas* biodiesel production analysis can be expressed as a series of annual costs in constant currency, taking into account the changing value of money as well as cost escalations due to inflation.

Economic factors used in the present worth analysis of the life cycle period are the discount rate and cost escalation. The length of the analysis period is chosen to be the optimum service life of the longest-lasting component. In this case the useful life module is in the range of 20 years, which is the average productive life span of *Jatropha curcas* plants. The discount rate is the factor that describes the changing value of money over time. It is basically equivalent to the amount of money that could be made with the capital if it were invested in a bank or other investment vehicle rather than in a power system. A typical discount rate value of 7.5% is used in this analysis. Cost escalation, also called inflation, is used to account for the fact that components and services traditionally get more expensive over time. The electricity and fuel escalation rates are 3.13% and 1.6% respectively, while the maintenance costs escalation rate is 3.0%.

4. Results

In the life cycle inventory analysis, we collected the available and actual data in the agricultural process at a *Jatropha* plantation site, and data in the production process at a small-scale *Jatropha* biodiesel factory. However, data in the using stage was obtained from a report by a petroleum company in Thailand. It is obviously seen from Table 1 that input materials such as fertilizers, herbicides and energy are taken into account. Fertilizer in the form of mixed nitrogen, phosphorus and potassium in a 15:15:15 ratio is applied at a rate of 6,250 kg per hectare per year. Watering and herbicide require 800 cubic meters and 1.86 kg per hectare per year, respectively. It is assumed that this amount of fertilizer must be applied to maintain a steady-state nutrient balance in the soil for *Jatropha curcas* farming. Although *Jatropha curcas* can be grown in non-fertile areas, to obtain a higher yield fertilizers are added. Much consideration is given to how much fertilizer remains in the soil and how much leaches into water sources. In some research reports, it is recommended that *Jatropha curcas* be grouped in with perennial plants, as their root systems are better than annual plants

at fertilizer uptake. Since Thailand is located in a tropical area, many kinds of microorganisms are at work in the soil and water to digest excess fertilizer, so this aspect is not as much of a problem as in a colder climate where there is a high amount of fertilizer consumption [4]. In the case of water pumping, most of the energy consumption, as shown in Table 1, is used for the irrigation system during the summer to increase yield as fertilizer is added.

Table 1 *Jatropha curcas* biodiesel production inputs.

Process Input	Quantity	Unit
Agricultural process		
Fertilizer (15:15:15)	6,250.00	kg/hectare/yr
Herbicides	1.86	kg/hectare/yr
Energy (electricity)	10,268.75	MJ/hectare/yr
Water	800.00	m ³ /hectare/yr
Biodiesel production		
Methanol	20.00	kg/100 L
NaOH	0.92	kg/100 L
Electricity	147.00	MJ/100 L
H ₂ O	100.00	Liter/100 L
Use phase		
<i>Jatropha curcas</i> biodiesel	1.00	Liter

In the biodiesel production stage, there are two methods available in Thailand. The first is biodiesel production from cold-pressed processing, in which the biodiesel can be used directly by agricultural machinery – but the properties do not fit well with diesel engines. The second method of biodiesel production uses chemical processing, so-called transesterification, to generate biodiesel that has properties similar to diesel. Energy and chemical reagents such as methanol and NaOH are used, as shown in Table 1.

In the using stage, biodiesel from transesterification processing is tested in diesel engines to compare the amount of combustion gases that emanate from the exhaust versus those from conventional diesel.

Analysis of the environmental impacts, as shown in Fig. 2, indicate that the agricultural process contributes to the highest environmental impact: 44.66% of the total. The environmental impacts of biodiesel production and utilization are 27.82% and 30.34%, respectively. The major impacts are eco-toxicity of water (acute), eco-toxicity of water (chronic), and acidification, as shown in Fig. 3. These significant impacts take place due to the use of fertilizers which contain chemical substances that have a harmful effect on the ecology, particularly water. Acid gases can also

accumulate in the atmosphere and contribute to acidification. In the biodiesel utilization phase, the environmental impacts take place because of emissions into the air during combustion.

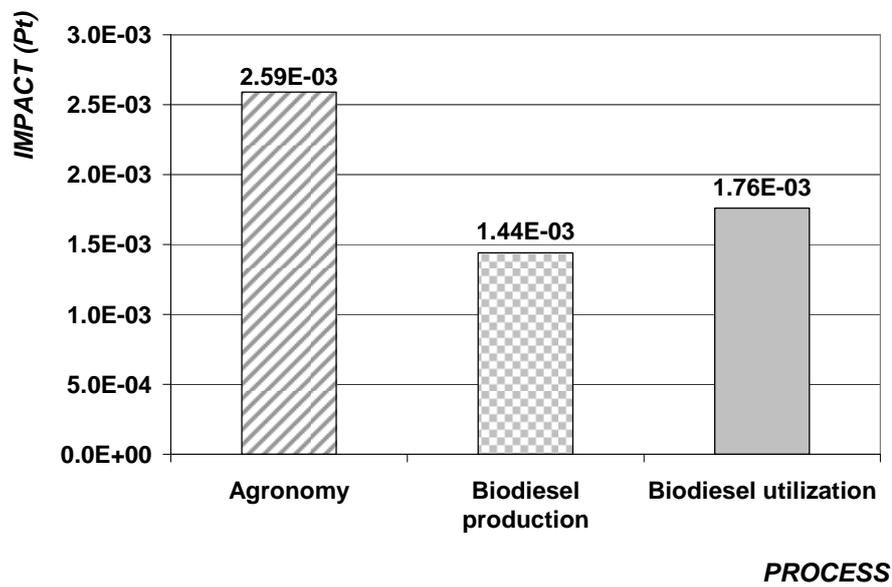


Fig 2. Life cycle assessment (LCA) results of *Jatropha* biodiesel.

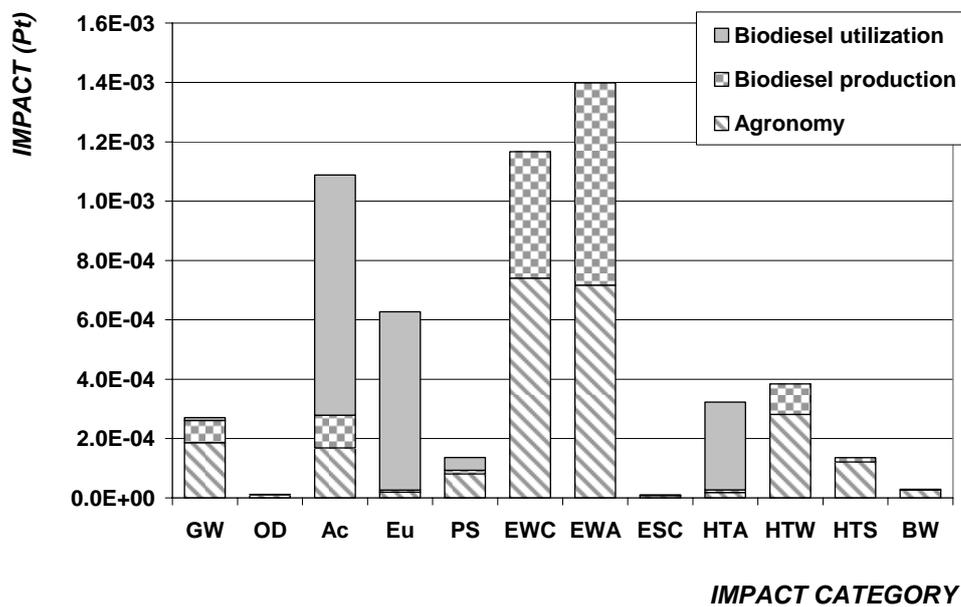


Fig 3. Environmental impact categories.

*Remarks: Global Warming (GW), Ozone Depletion (OD), Acidification (Ac), Eutrophication (Eu), Photochemical Smog (PS); Ecotoxicity to Water, Chronic (EWC), Ecotoxicity to Water, Acute (EWA), Ecotoxicity to Soil, Chronic (ESC); Human Toxicity to Air (HTA), Human Toxicity to Water (HTW), Human Toxicity to Soil (HTS), Bulk Waste (BW)

4.1 Life cycle impacts comparisons

According to life cycle inventory data analysis and the results of life cycle impact assessment using SimaPro LCA software, it could be inferred that the total environmental impacts from biodiesel are greater than from conventional diesel. However, it is obviously seen that the environmental impact at the use phase is better. This means that good agricultural management and improvement in production efficiency could enhance production yields while simultaneously reducing environmental problems.

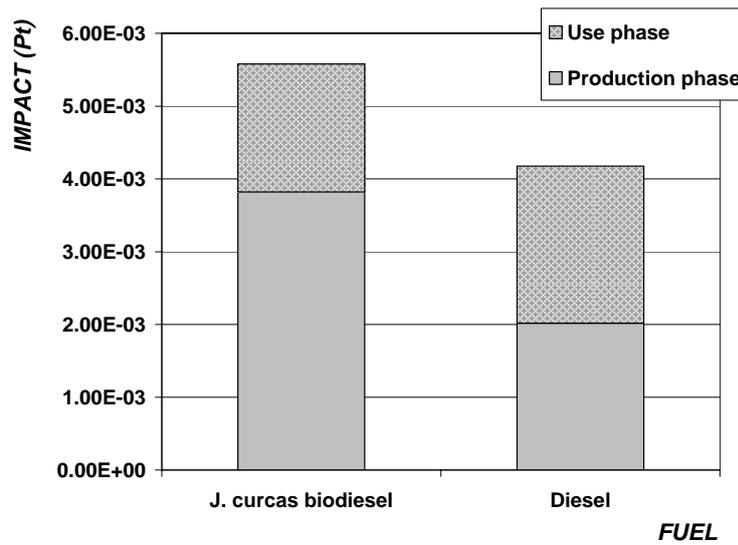


Fig 4. LCA comparisons between *Jatropha* biodiesel and conventional diesel.

The environmental impact categories shown in Fig. 5 indicate that biodiesel had less impact in 5 categories out of 12. Among these are ozone depletion, human toxicity to soil, and global warming problems. In the case of global warming, the advantage of biodiesel was primary attributable to the fact that *Jatropha curcas* assimilates CO₂ as it grows. However, the eco-toxicity to water (acute), eco-toxicity to water (chronic), and human toxicity to water of the biodiesel life cycle are higher.

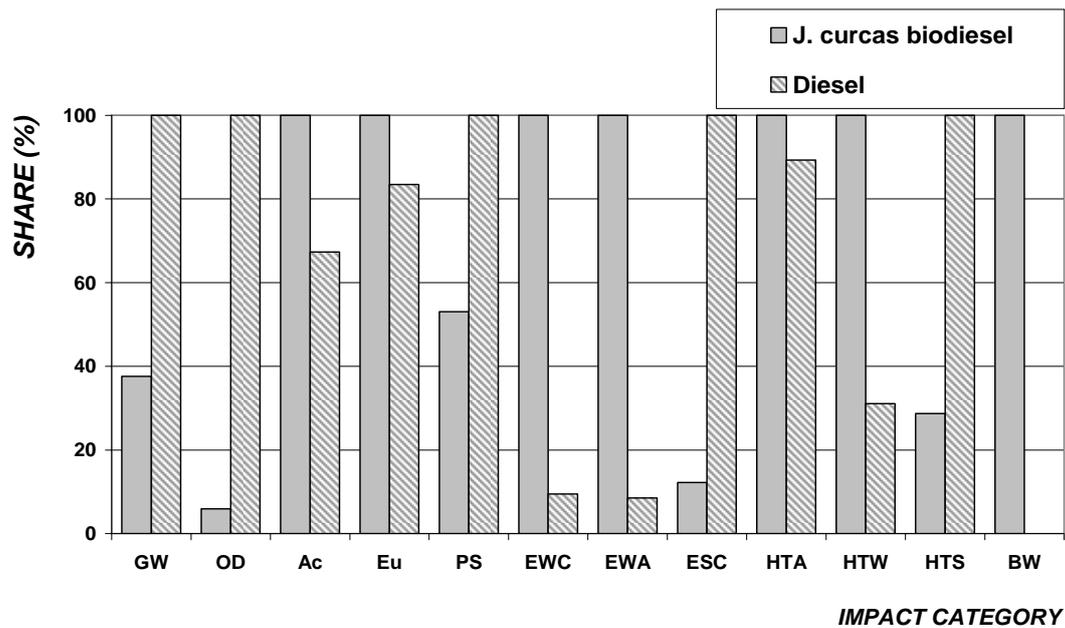


Fig 5. Impact category comparison between *Jatropha* biodiesel and conventional diesel.

*Remarks: Global Warming (GW), Ozone Depletion (OD), Acidification (Ac), Eutrophication (Eu), Photochemical Smog (PS), Ecotoxicity to Water, Chronic (EWC), Ecotoxicity to Water, Acute (EWA), Ecotoxicity to Soil, Chronic (ESC), Human Toxicity to Air (HTA), Human Toxicity to Water (HTW), Human Toxicity to Soil (HTS), Bulk Waste (BW)

4.2 Life cycle improvement

The cultivation process can be improved by better irrigation systems, because *Jatropha* needs a large amount of water for growth. It is known that conventional water pumping systems consume a lot of electricity. Modern irrigation systems should be introduced on large *Jatropha* plantations. The biodiesel production process of transesterification not only uses a great deal of chemicals and electricity, but also generates chemical waste which leaches into the soil and water. Batch-type biodiesel processing machines might not be ideally designed, as they require a lot of electricity for operation, and may not be energy-efficient. New technologies for biodiesel production are now within reach, and should provide better efficiency and increase the production rate. In transesterification, methanol and NaOH are needed to change *J. curcas* oil into *J. curcas* biodiesel. After both chemicals are mixed and separated from the biodiesel, the excess is released (including glycerin, a secondary reaction product) as waste that contaminates the water and soil. Because they are not recovered and reused, this leads to one of the adverse environmental impacts. The optimal chemicals used should be found through transesterification waste management.

4.3 Life cycle costing

Fig. 6 shows that the agricultural process accounts for 62.62% of biodiesel costing. The most expensive are operational costs such as fertilizers, insecticides, and electricity for water pumping systems, especially during the dry season. The percentage cost of the biodiesel production process is about 25.27%, while the external cost or environmental cost at the use phase is approximately 12.12%. Thus the total cost of *Jatropha* biodiesel without externalities is about 0.6 Euro per liter; the total cost including the environmental cost is 0.7 Euro/L.

This makes the production cost of *Jatropha* biodiesel higher than the retail selling price of diesel in the present market, which is about 0.5 Euro/L (although this price does not include the environmental cost).

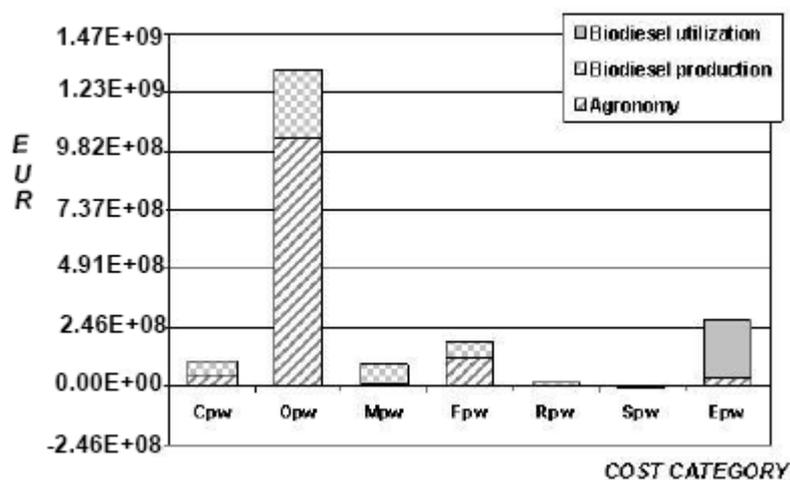


Fig 6. LCC results of *Jatropha* biodiesel.

5. Conclusion

From a life cycle aspect it could be concluded that *Jatropha* biodiesel production in Thailand needs more improvement, based on its greater environmental impacts and total cost than conventional diesel fuel. The production methods of *Jatropha* should be developed to increase the yield per hectare per year. Also, proper cultivation technologies, such as improved irrigation systems, should be applied to maximize the efficiency of *Jatropha* production. Although the emissions at the use phase of *Jatropha* biodiesel seem not to be a very serious problem, the quality of biodiesel must be controlled in order to enhance engine performance in the long term.

According to this study, biodiesel from *Jatropha* oil is still not suitable for use as an alternative fuel at this time, as the cost and the environmental impacts are too high. But in the future, more advanced technologies could be used to enhance the advantages of this plant. *Jatropha* can not only be used as an herb, for biomass and for biodiesel, but also can help reduce the global warming problem. Therefore, the life cycle improvements of *Jatropha* biodiesel should be applied immediately in both ecological and economic ways so it can become a sustainable alternative fuel in the future.

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