Biofuels Research and Development at Mae Fah Luang University

Pongmanee Thongbai1,*, Anthony G. O’Donnell1,2, David Wood1 and John K. Syers1
1 Centre for Biofuels Study, School of Science, Mae Fah Luang University, Chiang Rai, Thailand
2 Institute for Research on Environment and Sustainability, University of Newcastle upon Tyne, United Kingdom

Abstract: The increasing global demand for energy and recognition of the limited available crude oil supply have resulted in a large increase in crude oil prices, highlighting the urgent need to develop alternative energy. In the next ten years, biofuel is the only renewable energy source that can be conveniently replace petroleum-based diesel in the transportation sector which accounts for 70% of global crude oil consumption. With environmentally-friendly advantages, biodiesel has comparable fuel properties to petroleum diesel. Growing demand for biodiesel in Europe causes the expansion of rapeseed production in the whole region, and it is clear that biodiesel will have to be imported, most likely from Asian and Southeast Asian countries where are more suited to producing vegetable oils in order to meet future EU targets for renewable energy. Jatropha (Jatropha curcas) has recently been identified as an additional, sustainable source of biodiesel. Jatropha may be a more suitable crop than oil palm for sub-tropical countries, due to its wider adaptation and lower water requirement, making it a useful crop on poor agricultural land, providing a major, positive impact on rural communities. With the qualities of Jatropha oil are similar to those of other vegetable oils, jatropha oil price is more stable as it is not related to alternative uses for food or as cooking oil. However, certain agronomic and biological issues currently limit the widespread use of Jatropha seed oil as a biofuel, and with limited R&D has been done on Jatropha, made it not ready for commercial production. These issues are the main driving forces for Mae Fah Luang University (MFLU) to develop the Centre for Biofuels Study (CBS), in collaboration with the University of Newcastle upon Tyne, UK (UNCL The approach/philosophy of the center to biofuels R&D is to be ‘demand driven’, reversing the ‘supply driven’ pattern of most alternative energy research institutions. Expertise from the two partners, and strong support for community and industrial sectors ensure the advancement of research in this aspect.

Keywords: Biofuel Plant, Jatropha curcas, Varietal Improvement, Carcinogenic, Genetic Engineering

1. INTRODUCTION

The increasing global demand for energy and recognition of limitations in the availability of the crude oil supply have resulted in a large increase in crude oil prices in the past three years, and will continue to do so. The International Energy Agency forecasts that the world will require 50 percent more energy over present consumption levels by 2020 [1]. This highlights the need to develop alternative energy sources which are sustainable and environmentally friendly (less carbon dioxide emissions). Alternative transportation technologies, such as fuel cells and solar panels, are being explored but commercial implementation is expected to take one to two decades. In many countries, transportation fuel accounts for a considerable amount of their energy requirements (about 40% in Thailand) and diesel is the main transportation fuel. In the next ten years, it seems that biofuel is the only renewable energy source that can be used conveniently in the transportation sector, which takes up about 60% of the global crude oil consumption [1, 2].

There is a growing interest in biodiesel (methyl esters of vegetable oils), which may be used to partially replace petroleum-based diesel as a transportation fuel. Biodiesel has mainly straight chain structures and shorter carbon chain profiles and a narrower boiling point range than petroleum diesel. These properties, combined with the presence of oxygen in biodiesel, result in higher engine combustion temperatures and a “cleaner burn”, compared to petroleum diesel. [3] Biodiesel has successfully been introduced in Germany (based on rape seed oil) and the USA (based on soybean oil and spent cooking oil), and plans have been announced for Malaysia (based on palm oil). The rapid increase in demand for biodiesel is being driven by the following main factors [2, 4]:

(1) Biodiesel is a renewable source of transportation fuel which diversifies and increases the security of energy supply. Many countries and regions have set targets for the use of renewable energy sources. The European Union targets are 5.8% renewable energy by 2010 and 20% by 2020. Thailand has a target of 8% renewable energy by 2011, including a target of 10% biodiesel in the diesel pool by 2012.

(2) Biodiesel has comparable fuel properties to petroleum diesel and may be used as 100% biodiesel (B100) or as a blend with petroleum diesel (typically B5 or B20 which are bends of 5% and 20% of biodiesel with petroleum diesel) without any modification to existing vehicles.

(3) Biodiesel has a much better lubricity than petroleum diesel even when used as a blend (B5 or B20). It improves the lubrication in fuel pumps and injector units, which decreases engine wear and tear.

(4) Biodiesel has a higher ‘Cetane Number’† (about 60 to 65 depending on the vegetable oil) than petroleum diesel (53) and is a beneficial Cetane Number Improver when used as a blend with petroleum diesel.

(5) Biodiesel has a higher flash point (above 120 ºC) than petroleum diesel (EU specification is minimum 55 ºC) which makes biodiesel safe for handling, distribution, and storage.

(6) The cleaner combustion of biodiesel not only produces 78% less carbon dioxide emissions than petroleum diesel but also reduces particulate matter emission by 70% and carbon monoxide emission by 50%. In addition, biodiesel is virtually sulphur free and does not contribute to acid rain. This helps to meet Kyoto Treaty targets for the reduction of greenhouse gases.

(7) Biodiesel reduces crude oil import requirements and saves foreign currency. For example, Thailand currently imports more than 90% of its crude oil requirements at a cost of some US$ 20 billion/year which is about 10% of GDP; these figures could be reduced significantly by using biodiesel.

* Corresponding author: pongmanee@mfu.ac.th
† A measure of a fuel’s readiness to auto-ignite.
A disadvantage of biodiesel is its 10% lower heat of combustion, which is partly alleviated by its cleaner combustion (this effect is negligible with B20) and slightly higher nitrogen oxides (NOX) emissions with some vegetable oils but this may be countered by exhaust modification. However, the use of a lower quality biodiesel (possibly even straight vegetable oil) in marine engines, farm vehicles/equipment, and diesel generators should be evaluated. Jatropha (see below) may be suitable for these end-uses.

Biodiesel has been introduced successfully in Germany (based on rapeseed oil) and the USA (based on soybean oil), and plans have been announced for Malaysia (based on palm oil). In Europe, the growing demand for biodiesel causes the expansion of rapeseed production in the whole region, and it is clear that biodiesel will have to be imported. Asian and Southeast Asian countries are more suited to producing vegetable oils in order to meet future EU targets for renewable energy, with palm oil being extensively produced in Malaysia and Indonesia. In order to develop a successful international biodiesel industry, the producing countries will have to meet established diesel fuel quality standards. It has already been demonstrated in Germany and the USA that biodiesel can meet these standards. The future demand for biofuels is unlikely to be met using biomass waste alone as a feedstock but will require cultivation of dedicated bioenergy crops. The availability of sufficient land and efficient crop production systems are the most critical factors in developing a biofuels industry. Exploitation of biomass in a non-sustainable way, such as the clearing of forests or the red uction of soil carbon stock could, however, causes major net releases of carbon to the atmosphere with its consequent negative impact on climate change. The application of genetic manipulation to produce higher-yielding crops with controlled chemical properties, coupled with advances in conversion technology, could alter the dynamics of the biofuels industry.

2. INCENTIVE FOR AND ISSUES RELATING TO JATROPHA

Jatropha (Jatropha curcas) (Box.1) has recently been identified as an additional, sustainable source of biodiesel. It has recently been identified as an additional, sustainable source of biodiesel and it is being investigated in India, South Africa, and The Philippines. Jatropha may be a more suitable crop than oil palm for sub-tropical countries (such as the semi-arid regions in Thailand) as it can grow on low-fertility soils and is highly tolerant to drought (typically 300 mm rainfall per year). In Thailand, oil of palm production in 2001 was about 1.5 million rai with yield of 2800 t/rai and total production of 4 million tones (MOAC). Limitation of oil palm production in Thailand are i) high production cost; ii) not improve & reliable varieties, and iii) limit of suitable planting area. While oil palm oil needs 7 to 8 years to reach maturity, Jatropha might be more advantage as it reaches maturity in only 3 to 4 years. Jatropha may be a more suitable crop than oil palm for sub-tropical countries, especially in Thailand, due to its wider adaptation and lower water requirement, making it a useful crop on poor agricultural land, providing a major, positive impact on rural communities. The methyl ester qualities of Jatropha oil are up to EDIN51606 standards (Table 1), but the price of Jatropha oil is likely to be more stable as it is not related to alternative uses for food or as cooking oil. Moreover, pure Jatropha oil could be used either directly or blends with diesel in a direct-injection single-cylinder diesel engine. Forson et al, (2004) found that, besides providing similar performance to petroleum-based diesel, blending Jatropha oil into diesel fuel appears to be effective in reducing the exhaust gas temperatures, improving ignition, and has substantial prospects as a long-term substitute for diesel fuels [5].

Box 1. General Information of Jatropha (Jatropha curcas L) (Hiller, 1966; Becker & Francis, 2003)

Taxonomy and nomenclature

Family: Euphorbiaceae

Vernacular/common names: physic nut, purging nut (English); Pourghiere, pignon d’Inde (French); Purgier-nub, Brechnub(German); piniconillo (Mexico); coquillo, tempate(Costa Rica); tartagon(Puerto Rico); mundubisi (Brazil); pinol(Peru); pinon(Guatemala); kannanaeranda, parvata-randa(Sanskrit); baggherenda, jangliarandi, sadarandan(Hondi); ikadam(Nepal); sabudan(Thailand); tubang-bakod (the Philippines); jarak budeg (Indonesian); bagani (Cote d’Ivoire); kpoiti (Togo); tabanani(Senegal); mupuluka(Angola); butuje(Nigeria); makaen(Tanzania); purgerboonjiet(South Africa); dand barri, habel meluk(Arab); yu-lu-tzu(Chinese); purge-eroot(Dutch); tagiola d’India(Italian); purgueira(Portuguese)

Distribution and habitat

It is still uncertain where the centre of origin is, but it is believed to be Mexico and Central America. It has been introduced to Africa and Asia. This highly drought-resistant species is adapted to arid and semi-arid conditions. The current distribution shows that introduction has been most successful in the drier regions of the tropics with annual rainfall of 300-1000 mm. It occurs mainly at lower altitudes (0-500 m) in areas with average annual temperatures well above 20 °C but can grow at higher altitudes and tolerates slight frost. It grows on well-drained soils with good aeration and is well adapted to marginal soils with low nutrient content.

Botanical description

Small tree or large shrub, up to 8 m tall and with diameter up to 20 cm. Trunk is straight, branching low above the ground; bark is thin and yellowish. Leaves are 6x15 cm and lobed. Flowers are small and greenish, and can be either unisexual with male and female flowers on the same tree, or bisexual flowers but pollens and stigmas receptive at different time.

Flowering and fruiting habit

The trees are deciduous, shedding the leaves in the dry season. Flowering occurs during the wet season and two flowering peaks are often seen. In permanently humid regions, flowering occurs throughout the year. The seeds mature about 3 months after flowering. Early growth is fast and with good rainfall conditions, nursery plants may bear fruits after the first rainy season; direct sown plants after the second rainy season. Flowers are pollinated by insects, especially honey bees.

Fruit and seed description

Fruit: a grey-brown capsule, up to 4 cm long; it is normally divided into 3 cells, each containing one seed.

Seed: seeds are black, about 2 cm long and one cm thick. There are 2000-2400 seeds per kg.
Harvest
When the fruits begin to open, the seeds inside are mature. Collection is best done by picking fruits from the tree or hitting and shaking the branches until the fruits break off. Seeds collected from live fences can normally be reached by hand. For taller trees it is possible to collect the fruits in a small bag that is attached to a stick. In Costa Rica it is estimated that a tree produces about 30 kg fruits per year or about 12 kg seed. The yield per hectare is about 4800 kg seed.

Processing and handling
After collection the fruits are transported in open bags to the processing site. Here they are dried until all the fruits have opened. It has been reported that direct sun has a negative effect on seed viability and that seeds should be dried in the shade. When the seeds are dry they are separated from the fruits and cleaned.

Storage and viability
The seeds are orthodox and should be dried to low moisture content (5-7%) and stored in air-tight containers. At room temperature the seeds can retain high viability for at least one year. However, because of the high oil content the seeds cannot be stored for as long as most orthodox species.

Dormancy and pretreatment
Freshly harvested seeds show dormancy after ripening and pre-treatment is necessary before the seeds can germinate. Dry seed will normally germinate readily without pre-treatment. If this is the case, it is not recommended to remove the seedcoat before sowing. Although it speeds up germination there is a risk of getting abnormal seedlings.

Sowing and germination
Germination is fast, under good conditions it is complete in 10 days. Germination is epigean (cotyledons emerge above ground). Soon after the first leaves have formed the cotyledons wither and fall off. In the nursery, seeds can be sown in germination beds or in containers. Although the seedling grows very fast they should stay in the nursery for 3 months until they are 30-40 cm tall. By then the plants have developed their repellent smell and will not be browsed by animals.

Table 1 Some important parameters of raw and transesterified jatropha oil from India. (From Francis and Becker, 2001[4])

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Raw Jatropha Oil</th>
<th>Jatropha Oil Transesterified</th>
<th>EDIN 51606 standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g cm(^{-3}) at 20°C)</td>
<td>0.920</td>
<td>0.879</td>
<td>0.875 - 0.890</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>236</td>
<td>191</td>
<td>&gt; 110</td>
</tr>
<tr>
<td>Cetane no. (ISO 5165)</td>
<td>23-41</td>
<td>51</td>
<td>&gt; 49</td>
</tr>
<tr>
<td>Viscosity (mm(^2)/s at 30°C)</td>
<td>52</td>
<td>4.84</td>
<td>3.5 - 5 (40°C)</td>
</tr>
<tr>
<td>Neutralisation no. (mg KOH/g)</td>
<td>0.92</td>
<td>0.24</td>
<td>&lt; 0.50</td>
</tr>
<tr>
<td>Total glycerine (%)</td>
<td>-</td>
<td>0.088</td>
<td>&lt; 0.250</td>
</tr>
<tr>
<td>Free glycerine (%)</td>
<td>-</td>
<td>0.015</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td>Phosphorus (ppm)</td>
<td>290 (17 in de-gummed oil)</td>
<td>17.5*</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Sulphated ash (%)</td>
<td>-</td>
<td>0.014</td>
<td>&lt; 0.03</td>
</tr>
<tr>
<td>Methanol (%)</td>
<td>-</td>
<td>0.06</td>
<td>&lt; 0.3</td>
</tr>
</tbody>
</table>

* negligible when de-gummed oil is used

Regardless of technical possibilities mentioned above, there are certain agronomic and biological issues which could currently limit the widespread use of Jatropha seed oil as a biofuel. These include [4, 6]:

1. **Unstable and variation in seed and oil yield, carcinogen conten, lack of germplasm centers and very limited breeding programs**
   Jatropha seed and oil yield varies widely (seed 0.5 - 12 tonnes per hectare per year, oil 12-30%), depending on variety and growing conditions. Elite lines established for commercial cultivation with wider adaptability to diverse environments are needed to reduce such variation and ensure a secure supply of oil. Secondly, being a wild shrub, most varieties of Jatropha grow to a significant height (in excess of six meters), which is inconvenient to harvest the oil-bearing nuts. Therefore, developing ‘dwarf’ varieties, possibly by introducing a gene for ‘dwarfing’ is required. Moreover, recent work has indicated that Jatropha contains carcinogens in the form of taxalbumin curcin, jatrophine, saponine, and phorbolesters. This could seriously limit the widespread development of Jatropha, especially in using Jatropha seed cake as an animal feed (the by-product from oil extraction) [1, 7, 8, 9, 10]. Breeding varieties with low toxin levels could bring higher prices for the by-product and assist in meeting ‘economies of scale criteria,’ allowing Jatropha to compete even more favorably with biofuels. However, little information about work on genetic modification of all these issues is available, as well as a reliable and productive database.

2. **Limited understanding of the genetic and biochemical pathways for oil production and storage in seeds**
   The increasing popularity of Jatropha has more to do with its potential to supply biofuel than any other of its uses, However, the
developmental pattern of seed oil synthesis and accumulation, the underlying genetic and biochemical pathways and factors affecting seed storage and oil and nutrient composition are poorly understood.

3. Lack of understanding of optimal agronomic management practices

Very little is known about the mid- to long-term effects of intensive, commercial cropping of Jatropha on soil physical and hydrological conditions; this is particularly important in fragile, semi-arid environments (such as northeastern Thailand). Also, converting a wild shrub growing on marginal land into a commercial cash crop could invite a range of ‘monoculture problems,’ which agriculturalists know all too well.

4. Compatibility of alternative biodiesel fuels and fossil diesel fuel

Previous work in India and Africa indicates that the methyl ester formed from Jatropha seed oil is a suitable replacement for fossil diesel fuel and does not require any modification of commercial diesel engines used in cars and trucks [4, 5]. However, this has not been confirmed by engine tests by major car manufacturers. Such tests with Jatropha-based biodiesel are required to gain market acceptance by transport fuel producers/distributors, car manufacturers, and consumers. It is possible that some genetic modification of the Jatropha seed oil composition will be required to ensure that Jatropha-based biodiesel meets critical fuel properties, pointing to the importance of linking the biotechnology program in with industry at a very early stage.

3. ESTABLISHING BIOFUELS RESEARCH IN MAE FAH LUANG UNIVERSITY

The main incentives to develop a Jatropha research program at Mae Fah Luang University are:

1. The production of a useful crop on poor agricultural land or wasteland would create jobs, generate farming income and have a major, positive impact on rural communities in Thailand. Local communities in Chiang Rai already showed strong interest in growing Jatropha for biofuel. Few farmers have been growing Jatropha for more than 20 years. At the present, with support from Chiang Rai Provincial Administrative Organization, Community in Chiang Rai Community co-operation, has been formed from around 300 farmers from all over Chiang Rai for pilot Jatropha plantation aiming for crude oil to run two stroke farm engines. In addition, a private company who is supported by the Office of Innovation Promotion (Min. of Industry) and is establishing a pilot plant for oil and biodiesel production in Nang Lae. They stated their need for technical support and future research for plant production systems, oil processing and biodiesel production.

2. Much R&D has been carried out on biodiesel from rapeseed, soybean and oil palm, and this has resulted in their commercial introduction. However, limited R&D has been done on Jatropha and it is certainly not yet commercial.

3. The expertise requirements for Jatropha R&D (plant sciences, crop agronomy, and oil-industry applications) fit in well with MFLU capabilities. Complementary expertise on plant genetic engineering and oil chemistry from the University of Newcastle upon Tyne, (UK), assures a substantial contribution for advancement in this research area.

As the resolution Mae Fah Luang University (MFLU) is strongly determined to fulfil the intention of Her Royal Highness the Princess Mother of ‘Afforestation and Human-Resources Development’ and His Majesty the King on ‘Attaining Sustainable Livelihoods’, developing an Centre for Biofuels Study in March 3, 2006, is aligned with the MFUL mission to preserve and restore the environment as well as improving people’s well-beings and maintaining sustainable livelihoods through quality education, innovative research, development, and knowledge dissemination to strengthen the community through academic services.

3.1 Research Objectives

i) To implement integrated and multi-disciplinary R&D for ‘energy from the land’ using biofuel plants (with initial emphasis on Jatropha) for feasible industrial-scale production;

ii) To establish and strengthen a network for research, development, and small/Community-scale production of biofuels;

iii) To build the capacity of MFLU and the biofuels network through joint teaching, staff and postgraduate student exchange, collaborative research, and national and international workshops.

3.2. Research Conceptual Framework and Methodology

As shown in Fig. 1, the approach/philosophy of the project is to be ‘demand driven’ or ‘what products are required by the different user groups’, reversing the ‘supply driven’ pattern of most alternative energy research institutions.
3.3. Scope of activities include
i) establishing/developing a research team and a network of individuals from the organizations involved in biofuel/biodiesel industry through field visits, communication and national and international meetings/workshops;

ii) development and implementation of a model to check the technical feasibility of Jatropha as a suitable raw material for commercial biodiesel;

iii) undertaking and facilitating integrated, basic, and commercially-relevant R&D, initially focused on Jatropha. Areas of research will include i) participatory research with community for economic/commercial feasibility study of Jatropha and Jatropha-based biodiesel production in the community scale; ii) plant genetic resources preservation and DNA fingerprints; iii) varietal improvement for seed and oil yield and quality, short-cut genetic engineering techniques such as Markers Assisted Selection (MAS) and gene silencing and related physiological studies; and iv) improving transterification processes for Jatropha. Subsequently, issues such as agronomic and cultural practices, oil processing & quality, and value-added products will be explored.

iii) developing information on databases for genetic resources, edaphic factors, research management, and communication for educational, extension, and industrial use;

iv) training, consultation, and extension on biofuel, sustainable/renewable energy for interested farmers and the public to increase production efficiency and identify end-users;

v) capacity building through joint research and teaching, staff and postgraduate student exchange, collaborative research, and national and international workshops.

3.4 Organization Structure & Partners
CBS-MFU will be an affiliate unit of School of Science, Mae Fah Luang University. It will operate under the guidance of an Advisory Committee, to be established by MFLU and NCLU, in collaboration with other research organizations, energy policy bodies, industrial and local community. The CBS-MFU and its program are characterized by complementarities of expertise and activity between the two lead partners. The University of Newcastle has strengths in biotechnology, including gene manipulation (which includes gene silencing/suppression) and in oil quality analysis, in particular. It can provide training in these and other areas for Mae Fah Luang University students and staff, both in Thailand and in the United Kingdom. Mae Fah Luang University has expertise in plant sciences, crop agronomy, and oil-industry applications. Importantly, it has the land and most of the laboratory facilities required to undertake the work needed to progress work on biofuels. The complementarities of expertise and activity of the two partners provide exciting opportunities for effective collaboration, which the CBS intends to capitalize on.

4. CONCLUSION
This research will be directly benefit to the farmers producing Jatropha who will replace diesel with Jatropha oil for their farm machinery, biofuel industries at communities, national and international scales as well as national and international research and development organizations. The expertise required for Jatropha R&D (plant sciences, crop agronomy, organic chemistry, and oil-industry applications) fits in well with MFLU capabilities, and complementary expertise on plant genetic engineering and oil chemistry from the University of Newcastle upon Tyne, assuring substantial contribution to the CBS for advancement of research in this area, and fulfilling its mission to a) reduce national petroleum-based fuel import, b) introduce diversified energy supply sources and increase security of energy supply, c) conserve environment by reducing carbon dioxide and other transport fuel pollutants such as carbon monoxide, sulphur dioxide, particulates, etc., and d) establish Thailand as a leader in Jatropha improvement.

5. ACKNOWLEDGMENTS
The authors gratefully acknowledge the support from Ass. Prof. Dr. Vanchai Sirichana (President of MFLU), Prof. Dr. Sujin Jinahyon (Advisor to the President of MFLU), Chiang Rai Provincial Administrative Organization and Mr. Seangthong Mamobsuk (Executive Manager, Sengthong Subudam Co. Ltd.).
6. REFERENCES