# Could agriculture be a sustainable source of alternative energy for human beings?

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**Mitigation of carbon dioxide emission is difficult because of the high rate of consumption of petroleum. Therefore, there is an urgent need for the introduction of alternative energy resources into biomass conversion systems. Biofuels are the only renewable carbon dioxide-free sources of energy. Biomass not only plays a role of control for microclimate on the crop land and natural vegetation but it also keeps the biological diversity. However, the conflict between food and biofuel production has become a major problem. Hence, non-food biomass such as wood and grass has to be used as an energy resource. Second-generation BTL and GTL technology will support biofuel production by the development of catalysts.**

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## Introduction

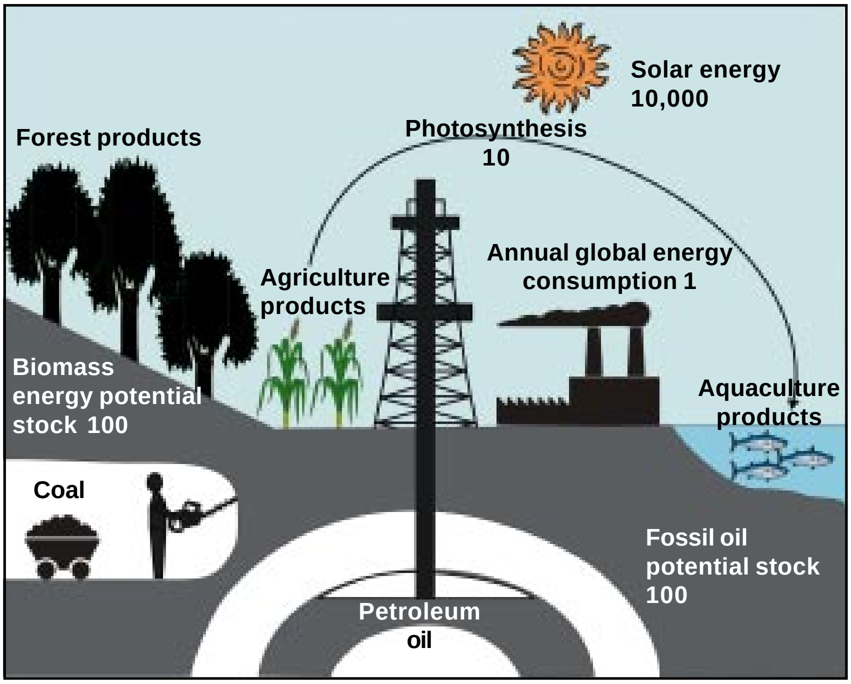
The energy value of the total stock of biomass on the earth equals that of petroleum crude oil: both stand at 100 times the current global consumption of energy. The energy value of photosynthesis products is currently estimated to be 10 times the global energy consumption. As shown in Figure 1, with regard to the stock and flow of energy, the production of photosynthesis substances runs agriculture, aquaculture and forestry. The energy efficiency of photosynthesis is estimated to be roughly 0.1 per cent of the solar energy incident on the earth (Japanese National Bureau of Energy, 1988).

## Characteristics of biomass

The low efficiency of energy conversion from biomass shows that the energy density is not very high, and that the energy is distributed over a much broader area of the earth than petroleum crude oil.

Biomass has another good characteristic – the potential existence of biomass is to create a mild climate depending on water resources. Figure 2 shows the heat transfer between the atmosphere and soil at the surface. The net radiation (Rn) from the sun in day time can be mainly divided into (1) heat transferred to the atmosphere (sensible heat flux, Ha), (2) latent heat

**Figure 1: Biomass is a renewable energy resource**




for the evaporation of water from the soil to the surrounding microclimate and plants (latent heat flux, Hl), (3) energy required by plants for photosynthesis (Pe), and (4) energy conducted into the soil (ground heat flux, G). However, meteorological observations have shown that G is nearly equal to zero throughout the year. The heat transfer balance is thus:

$$Rn - G = Ha + Hl + Pe \qquad (1)$$

The Bowen ratio, shown below, is used to describe regional microclimate characteristics (Irmak, 2008):

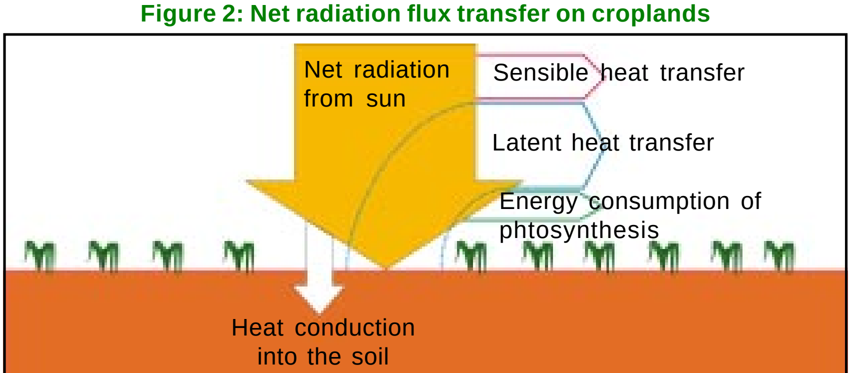
$$\text{Bowen ratio} = Ha/Hl \qquad (2)$$

Table 1 shows the Bowen ratios for different regions. Generally, the smaller the ratio, the milder the climate. One can see that biomass production is related to this ratio. Further, these microclimate characteristics depend on the availability and supply of water because Hl is associated with evapotranspiration on croplands and natural vegetation.

**Table 1: Bowen ratio**

| Land | Bowen Ratio |
|---|---|
| Forest and lake side | 0.2-0.3 |
| Paddy field | 0.23 |
| Croplands (non-irrigated areas) | 0.85 |
| Savanna and sandy areas | 1-3 |
| Desert | 7-10 |

**Figure 2: Net radiation flux transfer on croplands**




Biomass plays an important role in microclimate control in the region. We also realize that we should store ground water for maintaining croplands and natural vegetation.

## Non-food biomass as an energy resource

The conflict between food and biofuel production has become a serious issue. Thus, we should instead look to non-food biomass such as wood and grass for sustainable alternative energy. This implies that we should shift from the use of edible resources to cellulosic substances for biomass conversion. Further, we must attempt to use waste that originates from foodstuff. It is very important to develop food recycling techniques for converting feedstuff or bio-energy. Food recycling involves the use of phosphorous as a fertilizer in the agricultural and food production system.

The current concern with biofuel production from palm, coconut and jatropha oil is that the required increase in plantation area will infringe on the land available for food production (Ignaciuka and others, 2006). In Southeast Asia, there are a number of traditional and non-traditional biomass resources that remain underutilized for bioenergy production. FFTC (2008) estimates that the biofuel industry could have a major impact on agriculture, particularly in many of the rural areas in the Asian region.They suggest that with the establishment of energy providers and processing facilities in rural areas, the utilization of agricultural wastes and traditional and non-traditional crops can form a significant source of income for the farmers. The authors are nevertheless apprehensive of the competition with food production in regions where land is limited, as is the case in the Asian region.

Tilman and others (2006) reported that a reliable, efficient and sustainable supply of some foods, biofuels and ecosystem services can be established by enhancing biodiversity. They conducted a long-term experimental field test of the diversity – the stability hypothesis. The results obtained show that the monoculture, that is, the plantation for the production of biofuel such as palm, coconut and jatropha so on, will decrease biomass productivity.

## Biomass-Nippon strategy

Following the Russian government's ratification of the Kyoto Protocol on 5 November 2005, the effectuation of the Kyoto Protocol has been started on 1 April 2008. The current carbon dioxide ($CO_2$) emission levels are 8 per cent above the 1990 levels. Furthermore, according to the principles of the Protocol, it is necessary to reduce $CO_2$ emissions by 6 per cent of the 1990 levels. Therefore, Japan needs to reduce its emissions by a total of 14 per cent. Japanese industry has focused on the manufacture of energy-saving industrial equipment and vehicles following the oil shock of the 1970s, and the $CO_2$ curtailment beyond this has resulted in a very difficult situation. We need to focus on energy saving in the public welfare sector. On the other hand, Clean Development Mechanism (CDM) – with its system that is expected to contribute to $CO_2$ reduction in developing countries, which carries out equivalent conversion – and Joint Implementation (JI) – in which this $CO_2$ reduction is carried out as a joint enterprise – must attract the attention of Japan's business community. Further, as the host country for the G8 summit 2008, Japan must demonstrate its initiatives to combat global warming.

### Aims of Biomass Nippon strategy

- Control of global warming;
- Creation of a recycling-oriented society;
- Fostering new strategic industries with a competitive edge;
- Revitalization of agriculture, forestry and fisheries; and
- Globalization.

### Current status of biomass utilization in Japan

There are various factors associated with biomass utilization in Japan, as shown in Table 2.

**Table 2: Utilization of biomass discharged from industries**

| Biomass | Volume of production (app. 10 t/a) | Condition of utilization (approximate) |
|---|---|---|
| Livestock waste | 9.10 | Compost (approx. 80 per cent) |
| Food waste | 1.90 | Food & feed (10 per cent), unused (90 per cent) |
| Waste paper | 1.40 | No recovery of waste paper; half of it is incinerated |
| Black liquid from pulp industry | 1.40 | Energy of almost all (direct incineration) |
| Sludge from sewage plant (based on concentrated sludge) | 7.60 | Material for construction and compost (60 per cent), landfill (40 per cent) |
| Woody plant (factory) | 0.61 | Energy and compost (90 per cent) |
| Forest waste | 0.39 | Unused (almost 100 per cent) |
| Woody waste from construction materials | 0.48 | Materials for craft paper, materials for board paper, bedding material for livestock, etc. (40 per cent) |
| Edible parts of crops, such as straw and chaff | 1.30 | Compost, feed, bedding material for livestock (30 per cent) |

### Acceleration of progress of the policy

The Ministry of Agriculture, Forestry and Fisheries is implementing 'Biomass town master plan', which will create 300 new sites as models for practical local implementation. This plan calls for means to combine unused biomass, resource crops and energy crops, including organic waste. This project will continue until fiscal year 2010 and will cover the whole of Japan.

Thus far, 157 plans have been approved by the national government. The Japanese government has been planning to extend this concept to the Southeast Asian nations. It has a specific budget to extend support to other Asian nations, which would like to attempt a biomass town master plan of their own.

## Overview of biomass conversion technology

Biomass utilization can be roughly divided into material cycle utilization, such as in the production of compost and livestock bedding, and thermal cycle utilization, such as by direct combustion and gasification. The conversion system varies according to the moisture content of the biomass. Biochemical conversion is desirable for livestock and food wastes that have a moisture content of 80 per cent-90 per cent (w.b.), whereas wastes from lumber mills, wood waste from building construction, discarded paper, etc., are more suitable for physico-chemical conversion. Since the moisture content of woody forest waste is 40 per cent-60 per cent (w.b.), neither biochemical conversion nor physico-chemical conversion is feasible on account of low energy efficiency. The typical relationship between moisture content and calorific value is shown in Figure 3.

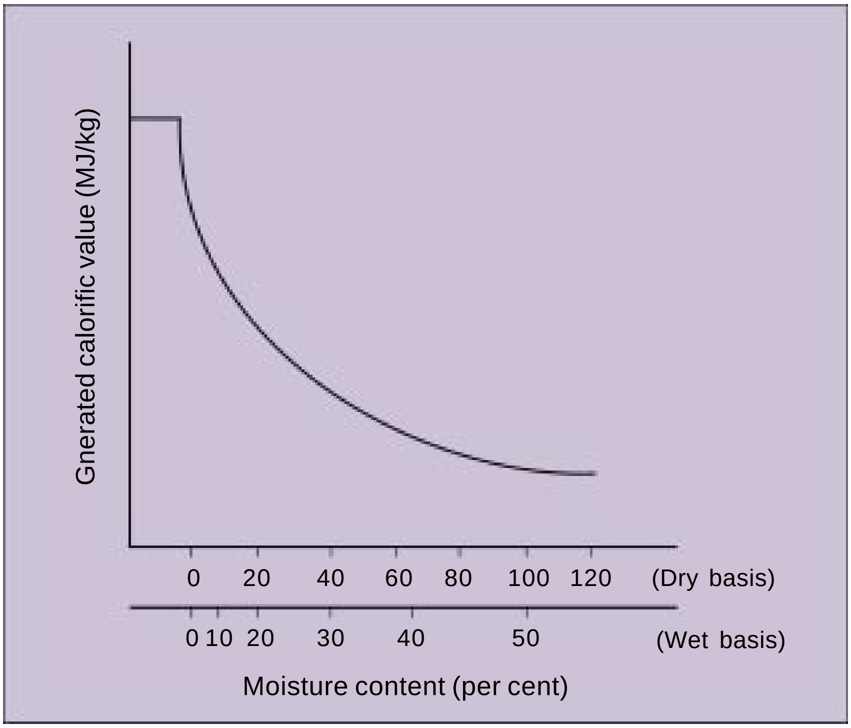
### Factors limiting biomass conversion

There are some other limiting factors, as shown in the Figure 3. We should take into account the characteristics of biomass in the development of biomass conversion technology:

- Low density of energy, which is related to the distance from the conversion plant to biomass collection areas;
- Cost restriction for biomass collection, transportation, conversion, harvest, stock yard compared with petroleum oil cost; and
- Environmental friendliness and sustainability.

These factors affect the cost to the end user of biofuels. In this report, we focus on the biomass conversion

**Figure 3: Generated heat vs moisture content of biomass**




technology. The following sections describe the three types of conversion methods.

## Direct use of biomass

This is currently popular in Europe and Japan, where wood pellets are produced and directly burned in stoves and boiler furnaces. As the wood pellets have long carbon fixation cycle – around 20 years compared with one year for grass and rice-straws – we recommend, instead, the use of grass and rice straw pellets, called agro-pellets or green pellets, which can also be easily used as livestock feed. These green pellets have the advantage of improved carbon fixation, given the short duration of the carbon fixation cycle involved.

## Biochemical conversion

Direct combustion cannot be performed on materials with high moisture content, because of the high latent heat of evaporation during combustion. Since livestock and food waste have high moisture content, thermo-chemical processes are not feasible. Therefore, biochemical conversion using microbes has to be performed, that is, fermentation. Figure 4 shows the decomposition processes driven by anaerobic bacteria and the process by which facultative microbes convert raw materials to short-chain fatty acids that are organic acids. These organic acids are fermented by obligate microbes such as methane microbes into methane and $CO_2$. There are two methods for methane fermentation. One involves a system comprising two fermenting reactors that are connected in series. This is known as 'two-phase methane fermentation system' (Maekawa, 1998). The other method involves a single fermenting reactor, as depicted in Figure 5.

The former is an effective fermentation method for kitchen garbage, starch and cellulose. Starch and cellulose can be fermented not only by methane fermentation but also by lactic acid and ethanol fermentation.

Small amounts of petrol are added to ethanol – a biofuel – and lactic acid is used for manufacturing the biodegradable plastics, polylactic acid. In addition, there are developments that proceed for cascade-utilization, such as feeding biomass to livestock and then using livestock waste for biogas production. A fully integrated system in Idaho, the United States, uses a combination of both ethanol fermentation and methane fermentation. It produces fuel-ethanol from potatoes rejected by a potato chip manufacturer. The broth discharged from the ethanol fermentor is fed to the methane fermentor. The biogas produced provides the energy necessary to distill the ethanol produced to 97 per cent purity. The digested effluent is used as fertilizer in potato fields, while the water is used for irrigation. This biomass fuel production system is a recycling system that is successful in local production, like the one shown in Figure 5.

An improved process employing FAME technology has been introduced recently. It uses heterogeneous catalysts for trans-esterification and esterification of vegetable oils (Plantenga and others, 2007).

## Physico-chemical conversion

### Gasification and fermentation

With regard to woody biomass with a low moisture content, gasification by partial combustion is required for

**Figure 4: Representation of anaerobic decomposition**

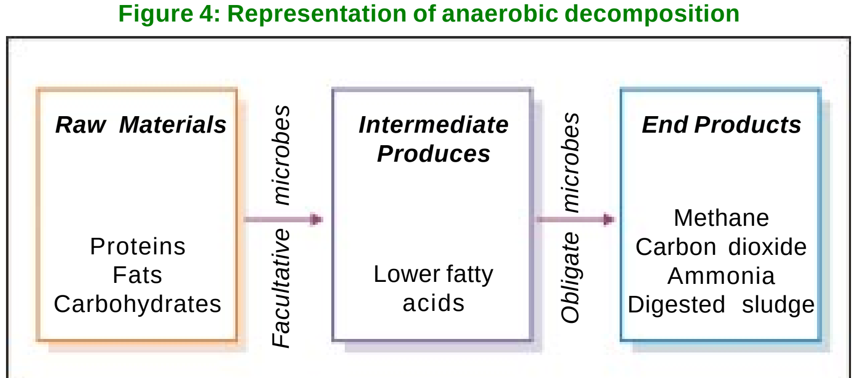


**Figure 5: Flow of organic waste, which is used for methane fermentation (Nantan City, Kyoto, Japan)**

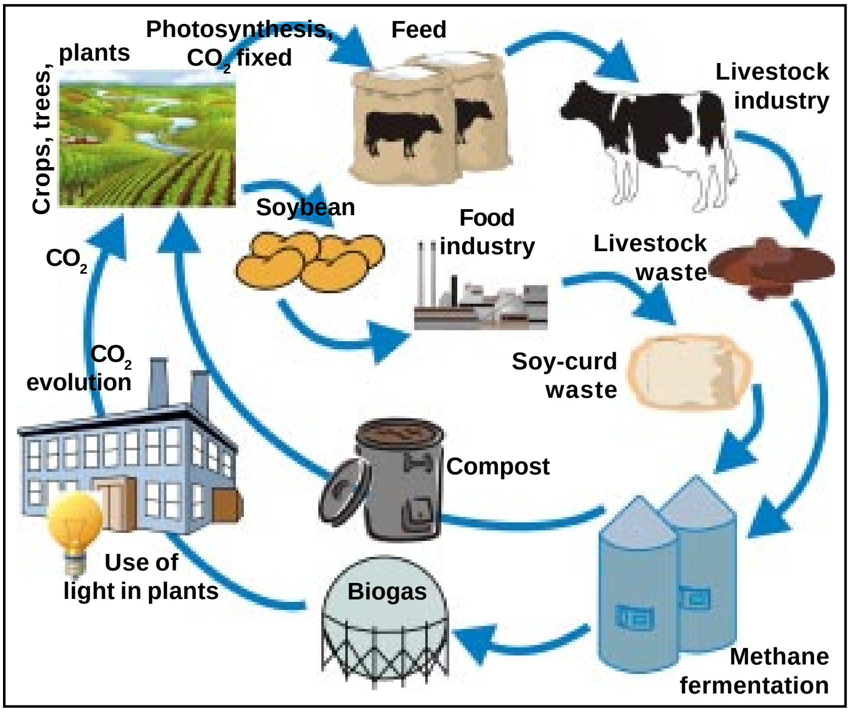



**Table 3: Input-output of the methane fermentation system in Nantan City, Kyoto, Japan**

| Biomass: livestock and food waste | | Reuse | Utilization |
|---|---|---|---|
| Resource name | Produced volume (average t/d) | | |
| Swine waste | 4.50 | Electricity | 3600 kWh (sale 800 kWh/d) |
| Dairy cow waste | 5.25 | | |
| Soy-curd waste | 3.25 | | |
| Beef cattle waste | 4.20 | Steam | 1800 MJ/d |
| Sludge cakes from sewage plant | 13.00 | | |
| | | Liquid fertilizer | On sale |

alternative energy technology. Gasification technology must be overcome the treatment of tar and char; the tar can clog the piping system. Despite these disadvantages, gasification is an easy method of producing hydrogen, which can be supplied on a small scale to fuel cells, micro gas turbines and gas engines.

Woody biomass is also used to produce ethanol in Japan, Europe and the United States. This too includes a physico-chemical technology for producing sugar from ligno-cellulose using strong acids and high temperature and pressure. Sugar produced by thermal and physico-chemical processes can be fermented by yeast to ethanol, a biochemical process. Many researchers are seeking microbes that can metabolize pentose for conversion from biodegradable, ligno-cellulosic substances treated by a physico-chemical process.

Sakai (2005) reported a pilot-scale high-performance gasification system that uses superheated steam. The composition of the gas produced is similar to that of syngas. Several researchers have attempted to achieve complete gasification under supercritical conditions at pressures greater than 30 MPa (Yu and others, 2002).

### Biomass-to-liquid process (BTL)

BTL technology at the commercial level is not very popular around the world. Dynamotive Energy Systems in Canada operates two pilot-scale and two commercial-scale plants that produce biodiesel from rice straw, corn, sugar-cane, wood chips and rice hulls. The conversion efficiency (yield) is 55-73 per cent of biodiesel and 15-75 per cent of char.

Ensyn Corporation in the United States has demonstrated the use of a rapid thermal processing technology developed in the 1980s. In this process, biomass is rapidly heated to 500-600ºC in a few minutes and then rapidly cooled in a few seconds. The biomass gets converted into a liquid-like heavy oil and only a limited amount of gas is generated. Ensyn operates seven commercial facilities and produces chemicals, fuel and carbon products from wood wastes.

Neste Oil, Finland, has developed the NExBTL process, which uses a Ni-Mo sulphide catalyst to hydrocrack vegetable oil into alkanes, alkylcycloalkanes and alkylbenzenes, which, as fuels, are superior to diesel oil extracted from petroleum crude oil. The Porvoo plant in Finland uses this process to produce 170,000 t of diesel oil annually. The company has plans to build a 300,000 t/a plant to produce diesel oil in Singapore in 2010; further, it plans to build an 800,000 t/a plant in Rotterdam, the Netherlands, to produce diesel oil.

### Gas-to-liquid process (GTL)

This technology requires gasification as the first step, which is followed by the conversion of the produced syngas to biodiesel or bioethanol via the Fischer-Tropsch process. Choren of Germany produces about 14.8 million litres of diesel oil annually from forest residues and waste wood. The conversion efficiency is 80 per cent of diesel oil. Range Fuels, the United States, produces bioethanol from gasified wood by the Fischer-Tropsch process. It has planned to build a 151-million litres/annum plant to produce bioethanol in Georgia. The conversion efficiency is estimated to be up to 75 per cent.

### Local use of biomass

Since the energy density of biomass is low, this method must be implemented over a wide area. However, all the biomass collection areas must be within a maximum radius of approximately 50 km from the conversion facility itself. Thus, the installation of a small-scale biomass conversion system, including the logistics, provides a good opportunity to build an industrial network in a particular region. The standard cost of establishing conversion equipment that can generate 1 kW of power is approximately US$ 2,000-5,000. Facility costs will henceforth become an important issue in technical development towards the proliferation of such infrastructure.

## Algae production system

A significant volume of biodiesel and bio-ethanol could be supplied from biomass. Biodiesel production is estimated to rapidly grow to about 40 Mt by 2010. This increase will be useful for the production of vegetable oil.

We are hopeful that other crops can be used for conversion to diesel oil. We expect algae, which contains about 40 per cent oil, to be useful for the production of diesel oil at a higher yield and quality. Maekawa (2008) considered the feasibility of algae production for its use as a supporting alternative biomass source for biodiesel production. Green algae and photosynthetic microbes are thought to be the best for high-speed fixation of $CO_2$ as compared with higher plants such as trees, crops and grass. For the development of technology for the rapid $CO_2$ fixation on algae cultivation, we set the following solution:

- Screening of species and strains having a low hydrocarbon content in the photosynthetic microbes and green algae;
- Development of novel bioreactors for the rapid fixation of $CO_2$;
- Cost-effective process for obtaining diesel oil from photosynthetic products in the microbes as well as green algae; and
- Development of cost-effective integrated system.

One of the business ventures of a company in the United States was almost successful in forming a photobioreactor on bench scale. The company is now pilot testing the reactors. The results have been very encouraging. In terms of cost effectiveness, it requires more than 20 g dm/l yield, as determined by the results of our experiments (Fujita and Maekawa, 1994) and economic analysis.

From an engineering perspective, the challenge requires the following solutions:

- Selection of optical wavelength and appropriate quantum emitted to the algae;
- Stirring strength of the photobioreactor such as the Goertler eddy that is associated with the shape of the photobioreactor;
- Seeking a cost-effective and appropriate mixing system for the reactor for the rapid mixing of $CO_2$;
- Establishment of a technology for supplying nutrients and rare metal elements for the growth of algae; and
- Cost-effective processing for ensuring that the algae produces oil and feed.

If fast-growing algae and high dry matter concentration, about ten times the yield as compared with crops, are available, using the novel photobioreactor mentioned above will bring the cost of oil produced from algae to below US$0.40/litre. It can be used by anybody, anywhere and any time, and it makes possible the elimination of dependency on petroleum imports.

## Conclusion

Biofuel production in the second stage should be shifted from food resources to non-food resources. The technology used for biomass conversion includes the application of a cost-effective catalysis in the process. As the worldwide market share of biofuel rapidly increases in the coming year, we must seek non-food resources in order to avoid the food vs fuel conflicts in the agricultural sectors. The second generation technology is expected to support biofuel production by developing suitable catalysts. As this technology has the appropriate process, we need alternative crops in the agriculture industry. With regard to $CO_2$ fixation rate and the good quality of the oil produced, we hope that the algae production, as an agro-industry, would be able to meet the high demand for biofuel.

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