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2nd Generation Biofuels: Technical Challenge and R&D Opportunity in Thailand

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Abstract: The use of biofuels is a promising approach to reduce fossil fuel use and alleviate the global warming. But the use of food resources as feedstock for biofuels inevitably causes serious problem in the near future. The production and use of 2nd-generation biofuels, which utilised lignocellulosic biomass as the feedstock, is a rational solution to this issue. As a result a lot of hope has been placed on 2nd-generation biofuels. Even at high oil prices, 2nd-generation biofuels will probably not become fully commercial nor enter the market for several years to come without significant additional government support. To produce those biofuels, however, there are several technologies barriers, and further research and development is necessary to overcome them. The objective of this paper is to overview the biofuel production and intended to mark at the technical challenges facing 2nd-generation biofuels. Finally, to disseminate the production and the use of 2nd-generation biofuels, considerably more investment in research, development, demonstration and deployment (RDD&D) is needed to ensure that future production of the various biomass feedstocks can be undertaken sustainably and that the preferred conversion technologies, including those more advanced but only at the R&D stage, are identified and proven to be viable.

1. Background

Recently, much attention has been paid to liquid biofuels such as biodiesel fuel (BDF) and fuel ethanol. The current oil price hike is a definite reason for it, but the uses of biofuels are also effective to alleviate the global warming, since they do not increase the carbon dioxide when burnt.

In Thailand, the most dominant and nationally used is fuel originated from fossil fuel whether for domestic or industry and transportation. One of the governmental policies is to withdraw or reducing the use of liquid petroleum fuels in transportation, substituted with gasohol (gasoline blended with fuel ethanol, biodiesel, and LPG. In the same direction, the government also promoting to the diversify energy need by exploring the other alternative energy such as biofuels. The development of biofuels is not only due to the reduction of national dependency on fossil fuel with a risk of regular growing up price, but also keeping the permanent supply of national energy. The use of biofuels is considered to be an immediate countermeasure to reduce GHG in transportation.

Since the liquid fuel properties required are totally different between Diesel and Otto-cycle engines, there is need to provide different biofuels for each type of engines. Biodiesel is used as a fuel for Diesel engines, while ethanol is used for Otto-cycle engines as an alternative to gasoline. The present major feedstock for biodiesel fuel is vegetable oils, and sucrose from sugarcane or starch from corn etc, are used for fuel ethanol. The production of biofuels from these materials is not very difficult. Biodiesel production can be achieved by a simple chemical reaction, trans-esterfication. The ethanol production technologies from sugar or starch are basically the same as those for producing alcoholic beverages. Those biofuels are called 1st-generation biofuels and their production in increasing rapidly worldwide.

Since many countries, for example Thailand, are rich in agricultural resources, the biofuel production from those materials is also beneficial for their agricultural sector. However, there should be problems in the near future. Since the present feedstock is also used for foods, some conflicts for resources will be probable between food and fuel use. Considering the increase of population, we have already confronted the food price rises worldwide, which are partially attributed to biofuel production.

Therefore, new technologies to produce biofuels from non-food feedstock, such as agricultural residues or wood wastes, are anticipated. Those materials are also called lignocellulosic biomass, because they are composed of cellulose, hemicelluloses, and lignin. The biofuels produced from lignocellulosic biomass are called 2nd-generation biofuels. To produce those biofuels, however, there are several technologies barriers, and further research and development is necessary to overcome them. This paper includes a short overview of biofuel production and looks at the technical challenges facing 2nd-generation biofuels.

2. What are 2nd-generation biofuels?

According to UN report on biofuels, "2nd-generation biofuels are made from lignocellulosic biomass feedstock using advanced technical processes". Lignocellulosic sources include "woody", "carboneous" materials that do not compete with food production, such as leaves, tree bark, straw or woodchips. However, in the longer term, many envisage biofuels being made from materials that are not even dependent on arable land, such as algae materials growing in water.

3. Advantages of 2nd-generation biofuels

There is believed that 2nd-generation biofuels are more promising than their 1st-generation counterparts because:

- They have a more favourable GHG balance. Cellulose ethanol could produce 75% less CO_2 than normal gasoline, whereas corn, cassava or sugarcane ethanol reduces CO_2 levels by just 60%. As for diesel, Biomass-to-Liquid (BTL) technology could slash CO_2 emissions by 90%, compared with 75% for currently-available biodiesel;
- They are able to use a wider range of biomass feedstocks, and do not compete with food production;
- They could use less land. For example, a new genetically modified variety of sugarcane is able to produce higher biofuels. In this case, plant science could increase production volumes per area of land;
- They could be produced at cost-competitive prices, especially if low-cost biomass is used, and;
- They offer a better quality of fuel than 1st-generation biofuels.

4. Conversion routes

The production of biofuels from lignocellulosic feedstocks can be achieved through two very different processing routes. They are:

- Biochemical - in which enzymes and other microorganisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol;
- Thermochemical - where pyrolysis/gasification technologies produce a synthesis gas ($CO+H_2$) from which a wide range of long carbon chain biofuels, such as synthetic diesel or aviation fuel, can be reformed.

5. Preferred technology route

There is currently no clear commercial or technical advantage between the biochemical and thermochemical pathways, even after many years of RD&D and the development of near-commercial demonstrations. Both sets of technologies remain unproven at the fully commercial scale, are under continual development and evaluation, and have significant technical and environmental barriers yet to be overcome.

For the biochemical route, much remains to be done in terms of improving feedstock characteristics; reducing the costs by perfecting pretreatment; improving the efficacity of enzymes and lowering their production costs; and improving overall process integration. The potential advantage of the biochemical route is that cost reductions have proved reasonably successful to date, so it could possibly provide cheaper biofuels than via the thermochemical route.

Conversely, as a broad generalisation, there are less technical hurdles to the thermochemical route since much of the technology is already proven. One problem concerns securing a large enough quantity of feedstock for a reasonable delivered cost at the plant gate in order to meet the large commercial-scale required to become economic. Also perfecting the gasification of biomass reliably and at reasonable cost has yet to be achieved, although good progress is being made. An additional drawback is that there is perhaps less opportunity for cost reductions.

One key difference between the biochemical and thermochemical routes is that the lignin component is a residue of the enzymatic hydrolysis process and hence can be used for heat and power generation. In the Biomass-to-Liquid (BTL) process it is converted into synthesis gas along with the cellulose and hemicellulose biomass components. Both processes can potentially convert 1 dry tonne of biomass (~20GJ/t) to around 6.5 GJ/t of energy carrier in the form of biofuels giving an overall biomass to biofuel conversion efficiency of around 35%. Although this efficiency appears relatively low, overall efficiencies of the process can be improved when surplus heat, power and co-product generation are included in the total system. Improving efficiency is vital to the extent that it reduces the final product cost and improves environmental performance, but it should not be a goal in itself.

Although both routes have similar potential yields in energy terms, different yields, in terms of litres per tonne of feedstock, occur in practice. Major variations between the various processes under development, together with variations between biofuel yields from different feedstocks, gives a complex picture with wide ranges quoted in the literature. Typically enzyme hydrolysis could be expected to produce up to 300 *l* ethanol/dry tonne of biomass whereas the BTL route could yield up to 200 *l* of synthetic diesel per tonne. The similar overall yield in energy terms (around 6.5 GJ/t biofuels at the top of the range), is because synthetic diesel has a higher energy density by volume than ethanol.

A second major difference is that biochemical routes produce ethanol whereas the thermochemical routes can also be used to produce a range of longer-chain hydrocarbons from the synthesis gas. These include biofuels better suited for aviation and marine purposes. Only time will tell which conversion route will be preferred, but whereas there may be alternative drives becoming available for light vehicles in future (including hybrids, electric plug-ins and fuel cells), such alternatives for aeroplanes, boats and heavy trucks are less likely and liquid fuels will continue to dominate.

6. Challenges to implement 2nd-generation biofuels

Promotion of 2nd-generation biofuels can help provide solutions to multiple issues including energy security and diversification, rural economic development, GHG mitigation and help reduce other environmental impacts (at least relative to those from the use of other transport fuels). But there are activities that must be carefully concerned before implementation.

- **Cost:** Relatively high production costs (currently higher than those for both mineral oil-based petrol and conventional bio-ethanol) mean that 2nd-generation biofuels cannot yet be produced economically on a large scale.
- **Technological breakthroughs:** Key developments are needed on enzymes, pre-treatment and fermentation in order to make processes more cost- and energy-efficient. Biotechnology could offer a solution by offering the opportunity to change the characteristics of feed materials for fuels.
- **Infrastructure needs:** The commercialisation of 2nd-generation biofuels will also necessitate the development of a whole new infrastructure for harvesting, transporting, storing and refining biomass.

7. Technological breakthroughs needed

The processes for developing 2nd-generation biofuels are much more complex than those used for 1st-generation fuels and both the technologies and the logistics are still at a very early stage. While with 1st-generation biofuels, natural oils are extracted from the plants to produce fuel, 2nd-generation processes, working with waste and 'woody' materials require complex catalysis and chemical alteration procedures to create the oils in the first place. So far, only certain small experimental or demonstration plants exist, and production is yet nowhere near to being started on a commercial level.

Below are some explanations as to the various processes currently being developed and needed to produce 2nd generation biofuels.

7.1 The biochemical pathway

7.1.1 Saccharification of lignocellulosic biomass for ethanol production

The major components of lignocellulosic biomass are cellulose, hemicelluloses, and lignin. The cellulose molecules are systematically arranged, while the hemicelluloses and lignin fill in gaps between the cellulose molecules. Among those components, cellulose and hemicelluloses have molecules composed of sugars and can be converted into ethanol by sacchaification and fermentation. However, cellulose is crystalline substance and very difficult to hydrolyse. Therefore, the most important research item is how to saccharify cellulose efficiently with low costs.

In the conventional procedure, the hydrolysis with sulphuric acid has been the mainstream for saccharification. Although the saccharification is achieved in short time in this process, it is difficult to control the reaction due to high reaction temperatures. This feature leads to several problems, such as the generation of fermentation inhibitors, and the decrease of sugar yield due to the decomposition of sugars. Furthermore, the costs for recycling or treating the acid used are expensive. On the other hand, much attention has been paid to the enzymatic saccharification process, which does not use deleterious chemicals and can give higher sugar yields. However, appropriate pretreatment which make enzymes more accessible to cellulose is essential for enzymatic saccharification and it also helps to reduce the enzyme loading and costs. Hence, efficient pretreatment technology is required.

7.1.2 Research for efficient cellulase production

Another problem in practical enzymatic saccharification is that the enzyme which hydrolyse cellulose into glucose, i.e. cellulase, is much more expensive than other hydrolases such as amylase. Since ethanol is an alternative to gasoline, very low production costs are required. Under these circumstances, it is the common idea now that ethanol producers should also produce cellulase by themselves, rather than purchasing them from enzyme companies. But in this case, ethanol producers need to have their own cellulase-producing microorganism.

7.1.3 Other issues for ethanol production

Lignocelllosic biomass has hemicellolose fraction other than cellulose. To enhance ethanol yields, sugars from hemicelluloses should be also utilised as fermentation substrates. The problem is, hemicellulose contains pentose sugars such as xylose and arabinose, and those pentose sugars cannot be fermented by the conventional yeast. This problem is especially important when feedstock is hardwood, grasses, or oil palm, because xylose is the major sugar in hemicelluloses in those materials. To overcome this problem, many genetically engineered microorganisms have been developed worldwide, but they still seem to have some problems for practical production.

Ethanol to be blended into gasoline should be completely dehydrated. But the distillation generally consume much energy and disadvantageous in term of life-cycle assessment. Less energy-consuming technology like a dehydration membrane is required.

Finally, ethanol fermentation accompanies large amounts of wastewater and residues. The technology for their treatment or utilisation is also important.

7.2 The thermochemical pathway (New generation biodiesel fuels)

7.2.1 The Biomass-to-Liquid (BTL)

Diesel fuel from lignocellulosic biomass can be produced by Fischer-Tropsch (FT) synthesis via gasification of biomass. The fuel produced by this process is called Biomass-to-Liquid (BTL) fuel. Nonetheless, the implementing researches for gasification, gas purification, FT synthesis catalysts, and upgrading of generated wax, for the efficient BTL production, are required such as followed.

▪ Transformation of biomass resources into a homogeneous material that can be injected into a gasifier. This can be done either via pyrolisis (using temperatures of 500°C for a few seconds in order to produce liquid bio-oils from solid biomass, such as coal or wood) or via torrefaction (using temperatures around 300°C for about an hour, to make materials like wood easier to grind into a finely-divided solid).

▪ The feed is then gasified to obtain synthetic gas, known as syngas, which mostly contains hydrogen (H_2) and carbon monoxide (CO). This process generates large quantities of CO_2 that are not converted into synthesis liquid fuel, lowering the end-fuel's “well-to-wheel” carbon footprint. Furthermore, gasification generally requires large-sized facilities and big capital investments, which makes progress in this area slower than in others. So far, no specific biomass gasification technologies have reached the industrial stage. However, solutions derived from technologies for natural gas, coal or petroleum is being put to use. Also, future biomass gasification units could be integrated into existing refineries, thereby helping to reduce capital and operating costs.

▪ Conversion of the syngas into liquid hydrocarbons via a catalysed chemical reaction. This procedure is known as Fischer-Tropsch synthesis and can yield gasoline, diesel or kerosene, according to the type of catalyst used. So far, only a handful of companies have commercialised Fischer-Tropsch technology and these projects still use natural gas (Gas-to-Liquid or GTL) and coal (Coal-to-Liquid or CTL), rather than biomass.

7.2.2 Hydrogenation and cracking

Research is also underway that seeks to convert bio-oils and fats directly into motor fuels, without gasification. Hydrogenation can be used to make diesel fuel while cracking can yield gasoline. These processes could also use algae oil as a feed.

Much attention has been paid to hydrogen treatment for vegetable oil or animal fat recently. With this treatment, oxygen atoms in triaclyglycerol are eliminated and double bonds of fatty acids are saturated. As a result, fuels more similar to petroleum origin diesel fuel and has better quality than conventional biodiesel fuel are obtained. R&D for this new procedure is underway by several oil companies. Some people term this fuel 2nd-generation biodiesel fuel, but it still requires oil or fat which also can be used as food.

8. Conclusions

The use of biofuels is a promising approach to reduce fossil fuel use and alleviate the global warming. But the use of food resources as feedstock for biofuels inevitably causes serious problem in the near future. The production and use of 2nd-generation biofuels, which utilised lignocellulosic biomass as the feedstock, is a rational solution to this issue. As a result a lot of hope has been placed on 2nd-generation biofuels.

However full commercialisation of either biochemical or thermochemical conversion routes for producing 2nd-generation biofuels appear to remain some years away. There is no clear candidate for “best technology pathway” between the competing biochemical and thermochemical routes. This is in spite of several decades of research and development, and more recent investment in several pilot-scale and demonstration plants. The development and monitoring of several large-scale demonstration projects is essential to provide accurate comparative data.

Even at high oil prices, 2nd-generation biofuels will probably not become fully commercial nor enter the market for several years to come without significant additional government support. And to realise its dissemination, considerably more investment in research, development, demonstration and deployment (RDD&D) is needed to ensure that future production of the various biomass feedstocks can be undertaken sustainably and that the preferred conversion technologies, including those more advanced but only at the R&D stage, are identified and proven to be viable.

Once proven, there will be a steady transition from 1st- to 2nd-generation biofuels (with the exception of sugarcane ethanol that will continue to be produced sustainably in several countries).

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