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Recent Developments and Future Prospects on Biofuels R&D

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ABSTRACT The transport biofuel is emerging a promising option to realize the sustainable growth of our society. Two biofuels, bioethanol and biodiesel, are currently used in the transport sector. As the production of biofuels is getting activated, the stable supply of the feedstocks is becoming a critical issue. Active works have been carried out to secure the stable supply of the raw materials for the production of biofuels. One approach is the breeding of the energy crops to get higher productivity and / or the desirable fuel properties. The other approach is finding new energy crops which may not be used for edible purpose. First current aspects and challenging issues for the implementation of biofuels have been introduced. Finally the recent works and future prospects on the development of the energy crops are summarized.

Introduction

As concerns over the global warming and the shortcomings of fossil fuels are increased, active works have been carried out to resolve the problems and to realize the sustainable growth of our society (Chien and Hu 2007, Lidula et al. 2007, Lund H 2007). The major problems, which we are facing with, may be summarized as follows; shortage of the fossil fuels, the global warming and revitalization of rural society. With regard to shortage of the fossil fuels, oil is the most critical one because the oil supply is expected to be constrained before 2025 (Greene et al. 2006). The introduction of the alternative fuels is necessary to solve the oil crisis.

To mitigate the global warming, the real aspects for the emissions of carbon dioxide should be understood. According to the European analysis, 90% of total increment of carbon dioxide emitted from 1990 to 2010 will be from the transport (EC 2006). So the report concluded that the expansion of renewable energies and the alternative fuels in the transport sector should be done to meet the reduction target of carbon dioxide specified in Kyoto protocol. Introduction of the alternative fuels in the transport sector has become an important project to minimize the problems associated with oil crisis and global warming.

Biofuels have their own advantages over the alternative fuels; First biofuels can be directly used under the current infra for the transport. Second biofuels have no problem for the shortage of the resources because it is produced from the renewable biomass. Finally the production cost of raw material steadily decreases due to the higher productivity resulted from the improvements of the cultivation technology and breeds of the crops (Lee 2005). Because of those advantages, biofuels are emerging as the promising alternative fuels to cope with the oil crisis. Biofuels are also effective to mitigate the global warming because the biomass used for the production of biofuels grows to absorb carbon dioxide by photosynthesis.

Because of the issues mentioned above, the implementation of the biofuels is more remarkable than heat and power. European Union sets a target to increase the share of biofuels by 18 times from 2003 to 2010 while the

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increasing rates of heat and power will be only 1.7 and 2.5 times respectively (Commission of EC 2005). European Union prepared an action plan to increase the share of the biofuels to 5.75% from 2% in 2005 (Commission of EC 2005). According to USA action plan, the increasing rate of biofuels is expected to be much higher than that of power until 2030. In Korea, an increasing rate of carbon dioxide emitted in the transport is going to be predicted to be about 3.5% / year until 2020, the higher increasing rate compared to those from the other sectors like industrial and residential sector (Lee 2005).

The development of biofuel production is expected to offer new opportunities to diversify income and employment in rural areas. In European Union, 10% of total arable area was forced to be a set-aside land to reduce the surplus grains. However, energy crops are allowed to cultivate in the set-aside land. In EU, about 90% of total set-aside land is currently utilized to cultivate rapeseed, sun flower and sugar beet which are used for the production of biofuels like biodiesel and bioethanol (Enguidanos 2002). By producing biofuels from the domestically available biomass resources, EU could reduce the dependence on imported oil and help the rural society to create a new market for the agricultural products. In USA, surplus corn grain is currently used for bioethanol production that may help to stabilize the corn price in the market.

Because of those advantages of the biofuels, many countries, either developed or developing, are now enforcing a law to support the implementation of biofuels. Encouraged by policy measures, global production of biofuels is now estimated to be over 35 billion liters.

In this paper, current status, challenging issues and the future prospects on biofuels R&D will be reviewed.

Conversion Technologies of Biofuels

Bioethanol

The transport biofuels currently used are bioethanol, the alternative fuel for gasoline and biodiesel, the alternative fuel for diesel. Bioethanol may be produced from sugar based biomass by biological conversion process (Figure 1). Currently all commercial bioethanol are made from sugar and starch materials like sugarcane, maize and cereals (Table 1). Because of this, there should be competitiveness with food production for agricultural land. So it is desirable to utilize the lignocellulosic biomass like crop and forest residues which may not be used for food. However lignocellulosic conversion is currently a relative expensive process. The development of a cheap and efficient hydrolysis process is the bottle neck for the commercialization of bioethanol production from lignocellulosics. To resolve the problem, both acid treatment and enzymatic hydrolysis processes have been studied (Lee et al. 2000, Hamelinck et al. 2005, Ohgren et al. 2007).

Biodiesel

Biodiesel is normally produced from plant oils by chemical conversion technology (Figure 1). A base catalyst such as sodium hydroxide is generally used for the reaction because of its high reactivity. However, an acid catalyst, mainly sulfuric acid, is often used for biodiesel production from the feedstocks having high acid values. Among various alcohols, methanol, the cheapest alcohol, is commonly used as a reactant. After the reaction, the glycerol may be easily separated because of its low solubility in biodiesel and higher density. Over 95% of raw materials used for biodiesel production are edible plant oils like rapeseed, sun flower and soybean oils (Table 1). The others are animal fats and used cooking oil. As major portion of biodiesel are made from edible oils like

Fermentation
Sugars ---------------→ Bioethanol

Catalyst
Triglycerides + alcohol -------------→ Biodiesel + glycerir
(Plant oils, fats)

Figure 1. Reaction paths for the biofuels.

Table 1. Raw materials for the production of biofuels

Biofuels	Feedstocks
Bioethanol	Sugars from Sugar cane or Sugar beet Starches from Corn, Wheat, Sweet potato, Cassava, and lignocellulose from various energy crops
Biodiesel	Rapeseed, Sun flower, Soybean

in bioethanol, active works to identify a new raw material which can not used for food.

One of the promising feedstocks is jatropha oil which is toxic to humans.

Current Status on the Utilization of Biofuels in Major Countries

Both biofuels can be distributed with the established infra and used in existing vehicles. The biofuels are normally blended with petro - fuels and used as a fuel in the vehicles (Table 2). Ethanol accounts for about 90% of total biofuel production. World production of ethanol and biodiesel has been increased by two and four times respectively between 2000 and 2005 (Figure 2). In 2005, bioethanol and biodiesel takes 2% and 0.2% of gasoline and diesel market respectively in the world. The leading producers of bioethanol are Brazil, the United States and China. Brazil supplied 44% (17 million kL) of total motor fuel consumed in land with bioethanol from sugarcane. In the USA, 15million kL of bioethanol was produced from subsidized maize crops in 2005. China, the third largest producer of fuel bioethanol, supplies 0.5 million kL using maize as a main feedstock. Most vehicles using gasoline as a fuel are suitable for running on gas blended up to 10% with bioethanol. More recently the flex fuel vehicles (FFV) running on much higher blends (up to 85% bioethanol)

Table 2 Typical use of biofuels for transportation (IEA 2004)

Biofuels	Typical use
Bioethanol	- 10%, 20% blends, converted to ETBE - 85%blends and hydrous ethanol for exclusive vehicles
Biodiesel	- 5%, 20% blends - 100% for the exclusive vehicles

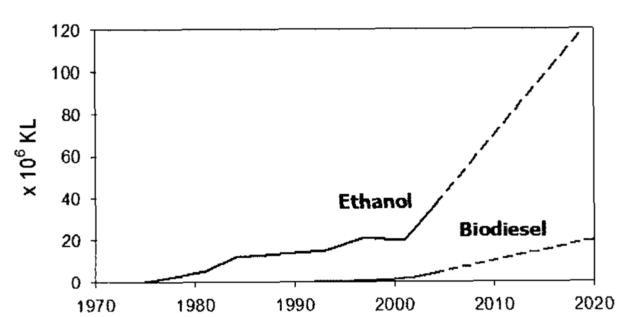

Figure 2. Biofuels production, projection to 2020.

have been developed and supplied in Brazil, the USA and Sweden.

With regard to biodiesel, Germany is the leading producer and takes about 40% of world's biodiesel production. Most diesel engines with run satisfactorily on 10% biodiesel blends and many use up to 100%. To make use of pure biodiesel as a motor fuel, the vehicles need to get some minor modifications. In the USA, 20% biodiesel blends are the most common motor fuel.

As all crude oil consumed in Korea is imported from abroad, Korea had strong interests for the introduction of biofuels in the transport sector. As a result, the demonstration supply of 20% biodiesel blended diesel oil has been started in Korea from 2002 to reduce the air pollution in Seoul metropolitan and the dependence on the imported oil. After four year demonstration supply of BD20, Korea started a new biodiesel implementation program from the July 2006 that supplies the BD5 and BD20 over nationwide (Figure 3). With the strong support of Korean Government on biodiesel implementation, biodiesel business is getting active. Now the total biodiesel production capacity is over 200,000 tons / year and will expand to be over 400,000 tons / year by 2008. Since over 90% of raw materials used for biodiesel production are imported vegetable oils, securing the stable supply of the raw material is becoming critical issue. Several options have been actively reviewed not only by Korean Government but biodiesel companies. The promising candidates are the rapeseed plantation domestically and oil crop plantation in South East Asian countries. Korean R&D on the development of rapeseed for the plantation is going to be described later.

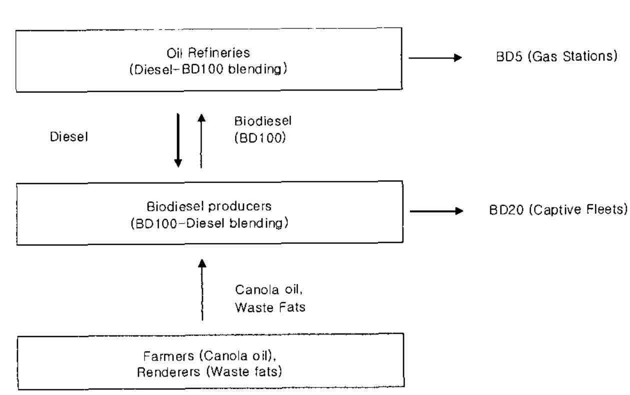

Figure 3. Biodiesel distribution infra in Korea.

Challenging Issues

As the supply of biofuels is increased rapidly, stable supply of raw materials is becoming a critical issue for the biofuels production. For example, about 5 and 8% of total arable land is required to displace only 5% of gasoline consumption in EU and USA respectively. It is even worse for biodiesel. 13% and 15% of total crop land are needed respectively to supply enough biodiesel to displace 5% diesel in USA and EU (IEA 2004). So the expansion of biofuels supply in the transport sector should bring the shortage in the food sector. To mitigate the problem, R&D works for the improvements of biomass productivity per unit land area are very important.

In addition to the productivity, the properties of biomass are also important. As biodiesel is used as a motor fuel, it should meet the fuel specification for the vehicles. Among the many fuel specifications, the cold weather performance and the storage stability of biodiesel are the most important. For the use of biodiesel as a motor fuel, it is desirable to have high oxidative stability and good cold flow properties. However, these two properties have the inverse relationship. The saturated fatty acids, palmitic and stearic acids as illustrated by the melting point of the fatty acid methylester (Table 3), are the major components limiting the cold flow property of biodiesel. In the meanwhile, the polyunsaturated fatty acids having multiple double bonds, linoleic and linolenic acids, improve cold flow properties but are most susceptible to oxidation. So oleic acid is the component which may give the most desirable fuel property. Since every plant oils contain five major compounds and have different compositions, the biodiesel made from the plant oils should have different fuel properties (Table 4). Another limitation associated with the use of biodiesel as a motor fuel is the increase of nitrogen oxide (NOx) in the emission gases. If the content of the polyunsaturated fats in the plant oils is lowered, the problem can be alleviated (Bringe 2004). In fact, the performance of biodiesel is reported to be enhanced by modifying the soybean oil (Kinney 2005).

Table 3 Melting points of various fatty acid methylesters (Mittelbach 2004)

components	Melting point, °C
Palmitic acid methylester (C16:0)	30.5
Stearic acid methylester (C18:0)	39.1
Oleic acid methyester (C18:1)	-20
Linoleic acid methylester (C18:2)	-35
Linolenic acid methylester (C18:3)	-55

As the production of biofuels is increased rapidly, securing the stable supply of raw materials emerges as an important issue. Active R&D works are under way to improve the productivity and the fuel properties of the currently available energy crops and to utilize the new feedstocks for the production of biofuels.

R&D on Energy Crops

Active works have been performed for two different feedstocks, the sugar based biomass for bioethanol and the oil crops for biodiesel, to increase the biomass yields. The tool used for achieving the goal is plant biotechnology. The major works taken for the development of good energy crops are summarized.

Maize is mainly used for bioethanol production in USA and China. Maize has several advantages over other crops because a higher portion of biomass, starch (seed) and cellulosic material (stover), may be used for bioethanol production. And maize is one of the major crops currently cultivated in the world. Compared to other lignocellulosic biomass, it may be easily collected. Two different approaches

Table 4 Compositions and fuel properties of major biodiesels

	Composition, %					Fuel property	
	C16:0	C18:0	C18:1	C18:2	C18:3	CFPP, °C	Oxidation stability, hr
Rapeseed biodiesel	3-5	1-2	55-65	20-26	88-10	-20	7
Soybean biodiesel	11-12	3-5	23-25	52-56	6-8	-3	4
Palm biodiesel	40-48	4-5	37-46	9-11		10	1

have been carried out to increase the productivity of maize through genetic engineering (Torney et al. 2007). The first target is to increase the yield of maize. The productivity of maize in US has been increased steadily over last four decades (McLaren 2005). The major portion of the traditional yield increase is mainly due to the improved genetics via traditional gene recombination (McLaren 2005). If we consider that almost 50% of the total bioethanol produced in USA is equivalent to recent increased yield of maize grains, plant biotechnology surely should take the important role to contribute the stable supply of raw materials for bioethanol. The second target is changing the compositions of biomass. This approach is quite important for the utilization of lignocellulosic biomass. As the shortage of edible crops used for bioethanol is expected to happen soon, active works are being carried out to utilize the lignocellulosic materials. However, recalcitrance of the substrate and its high lignin content are the main barriers for the commercialization. Therefore, several biotech R&D projects are underway to decrease the lignin content in the lignocellulosic biomass by knocking out gene responsible for the lignin formation (Minorsky 2002). Low lignin will be helpful not only to increase the potential yield of bioethanol but to reduce the operating costs for conversion because of the requirement of lower enzyme loading.

Some projects have been initiated to improve the properties of rapeseed and soybean which are the currently available feedstocks for biodiesel. For the improvements of rapeseed, R&D works have been focused to increase the seed productivity and the oil content of the seeds. According to the R&D plan proposed by UFOP in Germany, the productivity of rapeseed oil will be increased by 120% in a few years (Table 5). In Korea, an improved breed of rapeseed having high oil productivity was developed by Jang. The breed will be taken in the project for demonstration of rapeseed during winter.

Different approaches have been carried out to get the improved variety of soybean. As shown in the Table 6, soy bean oil has high linoleic acid and palmitic acids. The high oxidative reactivity of soybean oil is mainly due to the high contents of polyunsaturated fatty acids. Fuel oxidation is usually manifested as the formation of gums and sediment in the fuel which may clog the fuel filter. Therefore reducing the relative abundance of linoleic and linolenic acids has a remarkable impact on the oxidative reactivity of the biodiesel.

Some works have been performed to modify the fatty acid composition of soybean oil to improve the usefulness of soybeans for fuel application (Bubeck 1989, Kinney 1997, Rebetzke 1998). USDA supported a project to develop a new breed of soybean having the more desirable fatty acid profile. In the project, two different approaches have been employed to modify the fatty acid profile of soybean oil. First method is the application of the metabolic engineering to block the pathway from oleic acid into polyunsaturated acids. The technology was found to be quite effective to reduce the polyunsaturated acids and a concomitant enhancement in oleic acid in the soybean embryos (Kinney AJ 1998). Different methods to block the pathway also have been performed to develop a high oleic acid transgenic soybean line (Kinney AJ 1996; Kinney AJ 1997). From the works, they developed three breeds having oleic acid content ranging from 84 - 88% across multiple environmental conditions (Kinney AJ 1997). The yields of the new breeds were reported to be comparable to that of control.

Mutational breeding approaches were found to be quite effective to increase the oleic acid content of soybean oil by

Table 5 The target for the development of rapeseed in Germany (Austrian Biofuels Institute 2002)

	Current	Target
Seed productivity, ton / ha	3.5 - 4.0	6 - 7
Oil content, %	40	50
Oil productivity, ton/ha	1.3 - 1.6	3.0 - 3.5

Table 6 Fatty acid composition of several breeds of soybean (Bringe 2004)

	Control	USDA line	Target
Oleic acid	21.8	31.5	71.3
Linoleic acid	53.1	52.7	21.4
Linolenic acid	8.0	4.5	2.2
Palmitic acid	11.8	5.2	2.1
Stearic acid	4.6	4.1	1.0
Other	0.7	2.0	2.0
Cold filter plugging point, °C	-2	-10	-21

Figure 4. Photos of a newly developed rapeseed (left) and the control (right).

reducing the saturated acid content in the oil (Bubeck 1989, Rebetzke 1998). These observations led to the design of soybean transformation experiments targeting dual regulation of polyunsaturated fatty and saturated fatty acids. From the works, the oleic acid content of the newly developed soybean transformants was up to 91% and the palmitic acid content was as low as 2.2% (Buhr 2002).

By doing the work, new soy biodiesel having much improved cold flow properties may be made (Table 6).

With regard to the former option, Korean Ministry of agricultural is planning to conduct the demonstration project to evaluate the feasibility for the cultivation of rapeseed at the paddy field during winter. Newly developed breed of rapeseed having high oil productivity, named to be Sunmang, will be employed in the project (Figure 4, Jang 2002). If the project goes on successfully, about 50,000 - 100,000 tons of rapeseed oil may be produced domestically.

Conclusion

As the implementation of biofuels are considered as a promising option for the sustainable growth of our society, the demand for the biofuels is expected to increase steadily for the time being. The supply of biofuels with current available feedstocks may not meet the increasing demand within a decade, active works should be carried out to secure the stable supply of the raw materials. Among various options, first the improvements in the productivity of biomass should be pursued. With the progress of plant biotechnology, the objective can be attained in near future. Second new feedstocks should be identified and the utilization technology for biofuels production should be developed to meet the increasing demand for biofuels in the future. Since not much work has been done on the energy crops yet, big progress may be possible if an appropriate R&D is carried out. Plant biotechnology is expected to play a key role to achieve the progress.

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