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Evolution and Application of Biofuels

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Abstract Biofuel is a renewable fuel. Due to global warming, oil crisis and other factors, biofuel is receiving increasing attention. Biofuel is the fuel extracted from biomass, which has the advantages of diversity, materiality, recyclability and environmental protection. It is mainly used for road transportation. According to the evolution of biofuel, its production process has gone through four iterations, so far the research of biofuel is still in constant exploration. This review summarizes the common biofuel, among which bioethanol and biodiesel are well known and widely used. We should have a correct understanding and view of biofuel, and scientifically face the difficulties and challenges that will be encountered.
Keywords Biofuel; Renewable fuel; Bioethanol; Biodiesel

The concept of biofuel is relative to fossil fuel. As we all know, fossil fuel, also known as mineral fuel, which is naturally produced through long physical, chemical or biochemical processes in nature, such as oil, coal, natural gas, etc. While biofuel, such as biogas, bioethanol and biodiesel, are produced in a relatively short time cycle through artificial conversion or refining. Humans have long learned to use biomass as a direct fuel, such as wood or straw burning directly for heating or cooking, so some people will mix biomass and biofuel. With the development of modern biotechnology, people can extract biofuel from agricultural, industrial waste, domestic waste, such as crop straw, livestock manure, kitchen waste, factory production waste, etc.

Since the 1970s, the price of traditional energy has been rising, the pressure on the earth's environmental protection has gradually been increasing, and the impact of global climate change has become more and more serious, so it is urgent to seek new energy sources. At this time, biofuel came into view and was concerned by countries all over the world. More and more attention was paid to the research and development of biofuel. After the initial exploration, remarkable results were achieved. Biofuel is a renewable energy source that can be stored and transported. It has a wide distribution and is less limited by natural conditions. During its use, it emits relatively little waste (SO_2, NO_X), reducing greenhouse gas emissions to a certain extent and posing less harm to nature. It is recyclable and environmentally friendly.

At present, the most widely used types of biofuel is bioethanol and biodiesel. In 2020, the global production of biodiesel reached 42.9 million tons. The European Union is the world's largest producer of biodiesel, accounting for 38% of the world's total. In 2020, the global production of bioethanol reached 120 million tons, and the United States and Brazil together account for 84% of the global bioethanol production.

In 2019, biofuel accounted for only 3% of the global road transport fuel consumption, and their use in aviation biofuels was also very limited. But demand for biofuels is growing, the demand for biofuels will increase by 56% between 2022 and 2027, reaching 79 million tons. Take biodiesel in the European Union as an example, from 2012 to 2019, the consumption of biodiesel in the European Union increased from 14.556 billion liters to 18.815 billion liters. At the same time, the European Union proposed in the RED II (Renewable Energy Directive) revised in 2021 that the consumption share of renewable energy will increase from 32% to 40% by 2030, and the

proportion in the transport sector should reach to 26%.

The International Energy Agency (IEA) also wants biofuel to meet more than a quarter of global transport fuel demand by 2050, in an effort to reduce reliance on fossil fuel (Jeremy Moorhouse, 2021, Transport biofuels, IEA, Nov. 2021). At present, there is still a significant gap between meeting the requirements of the IEA's sustainable development goals. To achieve the IEA's goals, global biofuel production must increase by 10% annually from 2020 to 2030, and the biofuel market will usher in new development opportunities.

Every coin has two sides. Although biofuel can relieve the pressure brought by fossil fuel and reduce the harm to the environment caused by greenhouse gases, there are great constraints on production capacity, such as high production cost and a shortage of raw materials. We should have an objective, comprehensive and correct understanding of biofuel, not to be partial, and promote the development of biofuel industry in a healthy and scientific way.

1 The Proposal of Biofuel

Humans have a very long history of utilizing biomass. From the primitive society, humans first learned to use fire, and the fire used in the early days was found and preserved from the nature. As time went on, humans learned to create fire, and drilled biomass, namely logs, to make fire, and used the fire to meet people's daily needs, such as heating, cooking, driving away wild animals and so on. Logs were the earliest biofuel used by humans.

Later, humans discovered electricity. As early as 585 BC, electricity was discovered and people had a preliminary understanding of it. However, the study of electricity began in the mid-19th century, and people began to study electricity from that time on. In 1879, the world's first thermal generator was successfully built, since then electricity has been applied to industrial production, and thermal power generation is the main form of electricity generation. During this period, it would have been a good time for biofuel to be emphasized and applied in large numbers, but the unexpected discovery of fossil fuels prevented the further development of biofuel.

Until the 20th century to the mid-21st century, humans realized the crisis of energy shortage of fossil fuels and turned to other alternative energy sources. Biofuel is once again entering everyone's vision. As early as the oil crisis in the 1970s, some countries began to study biofuel as a substitute for fossil fuel.

2 The Development and Evolution of Biofuel

Although biofuel is the best alternative to fossil fuel, the development has gone through many iterations. The raw materials of production gradually developed from the original food crops to agricultural by-products and algae, and the conversion pathway of biofuel has also developed in the opposite direction from a single biochemical conversion to physical and thermochemical conversion, making the utilization rate of biofuel has been greatly improved, and the conversion technology of biomass energy has also had a qualitative development.

2.1 The first generation of biofuel based on food crops

The first biofuel is made from food crops grown on arable land. Through transesterification or yeast fermentation, sugar, starch or oil components in food crops can be converted into biodiesel or ethanol. Common food crops used to make biofuel includes corn, sugar cane, soybeans, cassava and other crops (Figure 1).

In the United States, the production of bioethanol occupies more than 40% of the corn (Food vs fuel: Ukraine war sharpens debate on use of crops for energy, Financial Times, 12th Jun. 2022), leading to a fail of corn supply, soaring prices, a significant reduction in exports, and even a food crisis in United States. Globally, 10 percent of food crops are used for biofuel production (Guest view: Global hunger fight means no biofuel, Reuters, 6th Jun. 2022).

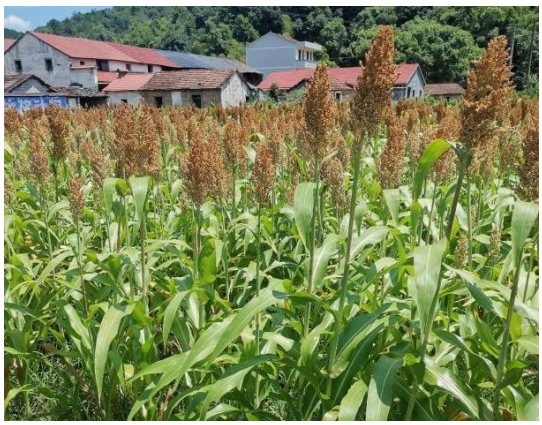

Figure 1 Planting of fuel crops (Photo taken at Cuixi Farm)

2.2 Second generation fuel by using agricultural by-products

The second-generation biofuel is produced by using lignocellulose or lignocellulosic biomass, or agricultural residues/wastes, and it has broken away from the production mode of food crops as raw materials. Common raw materials include agricultural and forestry waste such as wheat straw, rice straw, perennial forage, and sugarcane bagasse. Things like waste vegetable oil and municipal solid waste can also be used to produce biofuels. This ensures the recycling of agricultural waste.

The open utilization of second-generation biofuel is generally considered to be superior to that of first-generation biofuel. First, the second-generation feedstock uses agricultural and forestry waste rather than food crops, which improves crop utilization and does not cause food crises. Secondly, according to American research, second-generation biofuel is more effective in reducing greenhouse gas emissions.

2.3 Third generations of biofuel based on algae

Third generation of biofuel is made from algae as raw material (Figure 2). In the past, humans have focused on land plants, which has created a conflict between food and biofuel. While algae from marine sources have a big advantage over land plants. It is known that algae can produce more biomass than the equivalent amount of land plants, and algae can grow not only on land and in seawater, but also in various municipal wastewater (Greenwell et al., 2010).

Figure 2 Biofuel -- Seaweed Research (Photo from Baidu)

But algae fuel production is a big investment, and needs more investment in the early stage of production. In the early stage of algae culture, the cultivation conditions are strict, and the conversion and production technology has certain limitations. Compared with other biofuels, the produced fuel degrades faster and is easy to solidify at low temperatures. Although algal fuel is an excellent alternative raw material for biofuel preparation, its limitation is still relatively large, and further open research and utilization is needed.

2.4 The fourth generation of new biofuels

The fourth generation biofuel includes electric fuel and solar fuel. Electric fuel is prepared by using chemical bonds in liquid and gas compounds. Commonly used compounds are butanol, biodiesel, and hydrogen, but there are other alcohols and carbon-containing gases, such as methane and butane. Solar fuel is a synthetic chemical fuel that uses solar energy to convert light energy into chemical energy. Common examples include reducing protons to hydrogen, or turning carbon dioxide into organic compounds.

3 Common Biofuels and Their Applications

The well-known biofuels all can be produced by using the first, second, third and fourth generation biofuel production processes described above. Most of the biofuel can be obtained by using two or three different production processes.

3.1 Biogas and biomethane

Biomethane is a pure compound left after biogas removes excess carbon dioxide and impurities. It is a kind of common biofuel. Biogas is a kind of gas mixture produced by the anaerobic digestion (fermentation) of organic matter (usually refers to agricultural waste) by anaerobic organisms, the main component of which is methane.

Biogas can be produced either from biodegradable agricultural waste or by digesting energy crops in anaerobic digesters to increase biogas production. The leftovers from production can be used as biofertilizers. Today, the production technology of biomethane is very mature and widely used. Farmers abroad often use anaerobic digesters to digest cow waste to produce biogas and biomethane (Figure 3).

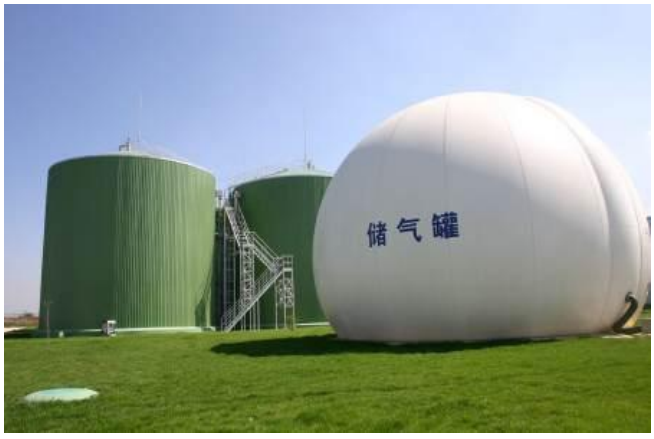

Figure 3 Cow dung biogas power generation facilities (Photo from Baidu)

3.2 Syngas (mixture of carbon monoxide and hydrogen)

Syngas is a mixture of CO, H_2 and other hydrocarbons. It is produced when biomass is not burned sufficiently. The biomass will first be dried and then pyrolyzed. If sufficient O_2 is not provided during biomass combustion, the biomass cannot be completely converted into CO_2 and H_2O. At this time, the mixture of CO and H_2 will be produced. The combustion effect of synthetic gas (mixed gas) can obtain more energy compared to direct complete combustion of biomass.

Syngas can be used in internal combustion engines, turbines or high-temperature fuel cells. Syngas can also be used to make methanol, dimethyl ether and hydrogen. It can also be converted into a diesel substitute through the Fischer-Tropsch process (F-T synthesis), or it can be mixed with alcohol and then used with gasoline.

3.3 Bioethanol

An organic compound, alcohol, can be obtained by fermenting sugars (such as starch and cellulose) through microorganisms or enzymes. The most common is ethanol, propyl alcohol and butanol are rare.

Bioethanol is the most common biofuel in the world, especially in the United States and Brazil. Corn ethanol is common in the United States and sugarcane ethanol in Brazil. Bioethanol is mainly produced by fermenting wheat,

corn, sugar beet, sugarcane and molasses. Bioethanol can also be obtained from fermented potatoes and fruit waste that can be made into alcoholic drinks.

Bioethanol is a common alternative to gasoline, which can be used on its own or mixed proportionally with gasoline for use in car engines. Most current car engines can run on bioethanol or a mixture of gasoline (up to 15% of which is bioethanol) (Figure 4). The advantage of bioethanol is that it has a relatively high octane number, which can improve the explosion-proof performance of gasoline. At the same time, it has high oxygen content, which can make gasoline burn more fully and improve the conversion rate of gasoline. Some high-altitude cities even require the use of a mixture of gasoline and bioethanol to reduce air pollution.

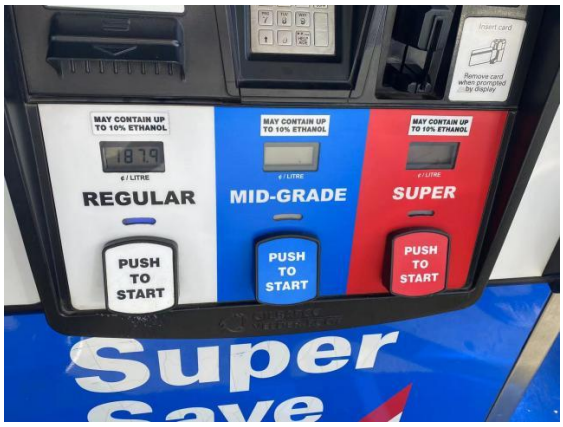

Figure 4 Gas station in Canada (Photo taken by Dr. Fang)

3.4 Biodiesel

Biodiesel, the most common biofuel in Europe, is a typical green energy. It is formed from fats (vegetable oil, animal oil, waste oil) and methanol or ethanol by ester conversion, its chemical composition is fatty acid methyl ester (or ethyl ester). The raw materials for biodiesel production include animal fat, vegetable oil, soybeans, rapeseed, jatropha, mahua, mustard, flax, sunflower, palm oil, hemp, wild pepper, papaya, and algae.

The fuel performance of biodiesel is very similar to and superior to that of fossil diesel. Therefore, biodiesel and fossil diesel can be completely mixed. The mixed diesel can also be directly used in diesel engines (which do not need any changes or adjustments due to the design of engine fuel track) and its modification equipment, and can also be used in diesel engines in the form of pure biodiesel (B100) (Figure 5).

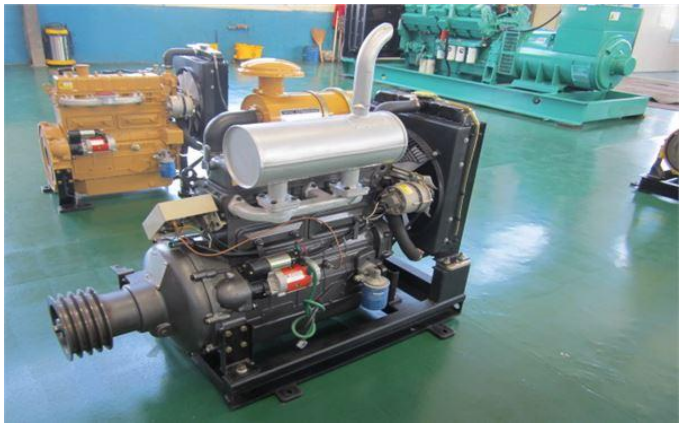

Figure 5 Diesel engine (Photo from Baidu)

Compared with fossil diesel, biodiesel has lower carbon content, better hydrogen and oxygen content, so it burns more fully, effectively reducing the emission of combustion particles. Biodiesel is also a solvent that can remove residues deposited by fossil diesel and effectively clean up carbon deposits in engine combustion chambers, and can be used as a fuel additive.

In addition, because biodiesel is non-toxic and biodegradable, with a ignition point of up to 300°F (148°C), while mineral diesel has a ignition point of only 125°F (52°C), thus, the handling and transportation of biodiesel is also very safe.

4 Prospect

Forced by the crisis of global warming and the increasing scarcity of fossil energy resources, how to deal with these crises has to arouse the attention of the world. The development of renewable energy dominated by biofuels has been a general trend, such as corn ethanol in the United States, sugarcane ethanol in Brazil, biomass power generation in northern Europe, biogas in Germany, etc. All countries in the world are looking forward to finding suitable renewable energy to gradually replace fossil energy.

But looking at the development of biofuels, it has to be said that there is a long way to go, and there are many difficulties and controversies. In this case, we need to correctly understand and view the development of biofuel, and biofuel research and development should be based on science and handled carefully. It cannot be achieved at the cost of ecological destruction, and long-term intentions and plans must be made to achieve true sustainability and development.

Authors' contributions

ZJ was responsible for thesis conception, literature collection, thesis writing, revision and finalization; WZR was responsible for the translation of the paper, and HYP and DDY were responsible for the proofreading of the paper. All authors read and approved the final manuscript.

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