An Introduction to Biofuels

By: Alexandre Cardoso and Kara Kalmbach

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An Abbreviated History of Biofuels

1,000,000 B.C. Humans discover fire

30,000 B.C. First man-made biofuel, charcoal, is created

4,000 B.C. First use of a liquid biofuel -- vegetable oil to light pottery lamps

4,000 B.C. Fermentation technology used to make alcohol for drinks but not used as a biofuel

1630 Jan Baptist van Helmont witnessed a flammable gas escaping decomposing vegetable matter

1720 Whale oil lights street lamps -- it becomes the first globally traded liquid fuel

1808 English chemist Sir Humphry Davy determines that flammable gas in manure is methane

This paper is the first in a white paper series that will provide a detailed outlook into the variety of Biofuels, their respective processes and the hazards associated with their production and use. This paper provides a review of the history of biofuels and bioreactors and discusses present and future developments for biofuels, as well as some of the hazards that are associated with the production and use of biofuels.

Biofuels: A Brief History

Biofuels are fuels that can be derived from biomass feedstocks such as plants, algae, food waste, or animal waste. These feedstocks create a vast opportunity for future energy production, as it is estimated that the energy stored annually in terrestrial plants is 3-4 times greater than the current global energy demand [1]. Since these feedstocks can be replenished, biofuels are also a renewable energy source. In recent years there has been a push towards renewable energy sources such as biofuels because of concerns about climate change.

Bioenergy is the energy stored within different biological sources. Since humans first discovered fire, this energy has been used for cooking, heating and lighting. Wood was the first feedstock used to produce bioenergy, but further research has produced more complex energy sources such as Sustainable Aviation Fuel (SAF), biodiesel, biogas, and other biofuels. Prior to the discovery of fossil fuels, biofuels were the primary source of energy.

Within the last 30 years, there has been a push toward an increased use of renewable energy and reduction of greenhouse gas emissions, resulting in a renewed interest in biofuels with a projected growth to produce 30% of the world's demanded energy by 2050 [1].

Categorization of Biofuels

Biofuels are an indirect way of harnessing solar energy through the use of photosynthesis. Plants and algae use energy from the sun combined with carbon dioxide and water to form carbohydrates, which can be used as an energy source by the plant and animals that eat the plant.

1826 Ethanol used as a fuel by American Inventor Samuel Morey to run an internal combustion engine in a boat

1859 First recorded anaerobic digestion plant construction in Bombay, India

1861 Louis Pasteur first discovers butanol from fermentation

1895 First biogas extraction from a sewage treatment facility built in Exeter, England

1937 Belgian Scientist George Chavanne patents the procedure for the transformation of vegetables oils for use as fuels

1972 Flash pyrolysis technology developed to convert organic solid waste into a liquid fuel

1976 Rudolf Wilhelm Gunnerman files U.S. patent for extruded, self-bonding wood pellets

1977 Brazilian scientist Expedito Parente developed the first industrial process for biodiesel production

These plants can also be burned to harness this energy or put through more complex production processes to produce advanced biofuels. The use of carbon dioxide in photosynthesis produces a unique advantage of biofuels to have net zero emissions or negative net emissions when paired with carbon sequestration [4].

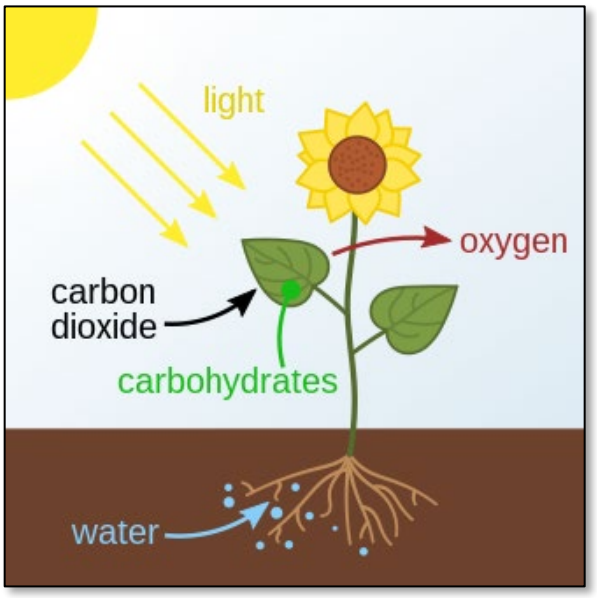

Figure 1: Illustration of Photosynthesis [6]

Biofuels describe a large and varying group of fuels of varying production processes. Biofuels can be produced from farmland, bioreactors, distillation processes, lakes, ponds, etc. They are used in solid, liquid, and gaseous forms and are categorized as first, second, third, or fourth-generation, based on the production process. Each generation has different advantages and disadvantages associated with it. Biofuels of the second and third generations are considered advanced biofuels [2]. The fourth generation of biofuels is still in the research phase [7] and thus those fuels are currently not widely used. A diagram outlining the generations of biofuels can be seen in Figure 2 below.

1979 First pilot bioethanol plant with a distillation column established at South Dakota University

1989 First industrial scale biodiesel plant was operated in Asperhofen, Austria

1996 Commercial Operation starts to produce biodiesel from waste grease

2001 Process for Bioenergy Carbon Sequestration (BECS) developed

2008 First test flight with SAF

2021 First commercial flight with SAF

2023 Projected completion for first ATJ commercial plant

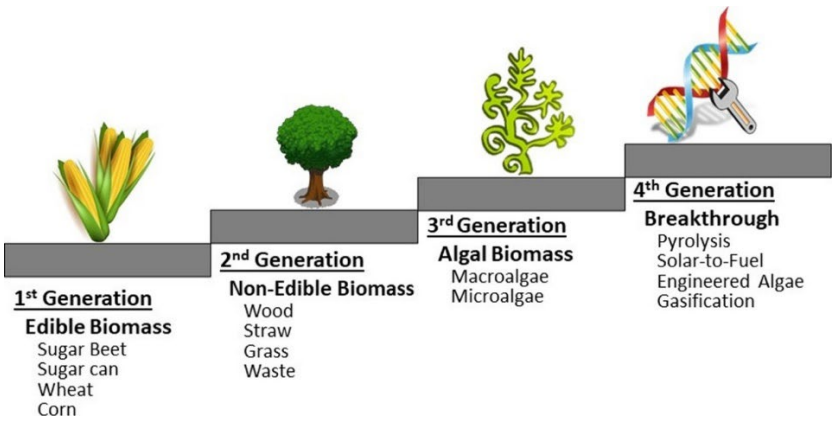

Figure 2: Generations of Biofuels[3]

First-generation biofuels are generated from edible biomass such as corn, sugar cane, oils, and animal fats. These feedstocks are then used to produce bioethanol or biodiesel via fermentation or transesterification, respectively. The first-generation biofuels are currently the most widely produced, in the form of bioethanol from corn and sugarcane. The most significant concern in using edible biomass as a feed stock is that this can potentially put stress on the food supply [8]. There is a push to produce a larger proportion of second- and third-generation biofuels versus first-generation biofuels, due to first generation fuels using food crops as feedstock.

Second-generation biofuels are generated from cellulosic biomass such as perennial grasses, wood chips, and crop residues such as sugarcane bagasse [5]. These feedstocks can be cultivated on low quality land or can be extracted from waste plant material from plant processing. Such crops do not take up valuable farmland that is used for food crops and do not consume a lot of water or fertilizers. The feedstocks are high in cellulose, producing cellulosic ethanol. This conversion process is more difficult than processing with common food crops, but the conversion does not take away from food production.

Third-generation biofuels use algal biomass to produce biofuels. The algal or cyanobacteria is grown in a photobioreactor to produce oils that can then be used to produce biodiesel [9]. These feedstocks could also be grown in ponds or lakes. The dried residue from the algae can also be used to produce ethanol. Using these feedstocks produces a high yield of biofuel and does not decrease food production nor does it require farmland.

Fourth-generation biofuels include solar-to-fuel and advanced biofuels made from genetically engineered algae. The fourth generation is similar to the third generation in how the feedstock is grown and the types of fuel it can produce. Genetic engineering is used to increase the desired traits of organisms. This can help increase yields and efficiencies as compared to third-generation biofuels.

Biofuels: Future Push towards Renewables

Currently, fossil fuels are the dominant energy source to meet global energy demand, but these sources are nonrenewable and contribute heavily to carbon emissions. At the current consumption rates the supply of petroleum, natural gas, and coal are estimated to last only another 45, 60, and 120 years respectively[1]. The combination of limited supply, CO_2 production and rising prices of fossil fuels has pushed the search for renewable alternatives.

Biofuels potentially have a large environmental benefit in that they use CO_2 in their production through the growth of plants. However, fossil fuels are consumed during the production of first-generation biofuels in farming equipment, fertilizer manufacturing, transportation, and ethanol distillation [5]. The energy consumed in the production of second- and third-generation biofuels is less, as they require no fertilizer, and less water, and third generation biofuels do not require arable land. Biofuels are regarded as mostly carbon neutral, as the CO_2 produced during production is offset by the CO_2 used for machinery, etc. during the growth stage of the plant. When combined with carbon sequestration, biofuels are considered to have net negative emissions, as the CO_2 produced during the production will have been captured and stored.

For first- and second-generation biofuels, land use could become a large concern in the production of biofuels. To meet energy demand from these early generation biofuels, large amounts of land area would be required with a low biodiversity of plants resulting in deforestation and the reduction of biodiversity of wildlife areas. In the coming years, it is anticipated that most biofuels will be of the second- and third-generation to ensure that land meant for food production is not being diverted to fuel production. Third- and fourth-generation biofuels do not use farmland and thus could be used in place of first- and second-generation biofuels to reduce the impact to forests and wildlife areas.

Biofuels: Associated Hazards

With the rise in production and use of biofuels, the associated hazards with the feedstocks, production processes and products must be assessed. Biofuels are a result of diverse feedstocks and production processes, but throughout the biofuel industry there is potential for fire, explosions and/or toxic-related hazards. It is important to understand the properties of the feedstock material, the respective process, and the properties of the product so the process can be designed to ensure a safe operation. Specific hazards associated with uses of bioreactors, feedstocks and products and how to mitigate these hazards will be discussed in future issues of this white paper series.

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(Note all online references were accessed in October 2023)

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