Izmir Institute of Technology

Department of Energy Systems Engineering

ESE 101 Introduction to Energy Systems Engineering

Production of Aviation Grade Biofuels

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Abstract

Biofuels have been used for ages. The trend is shifting towards the renewable biofuels also in the aviation sector, as in other sectors. Over the next few decades, aviation fuel demand is predicted to rise, and jet engines will continue to rely primarily on kerosene fuel. It is critical to boost research and development so that biokerosene production becomes viable, in order to reduce environmental effect and generate alternative energy sources for energy security. According to these goals companies that exist in the aviation sector developing environmentally friendly, more efficient technologies. This report mainly reviews the technologies of production processes and their challenges and opportunities.

Table of Contents

1.0. Introduction

Since the discovery of fire, solid biofuels have been in use. Wood was the earliest biofuel, and it was utilized for heating and cooking by peoples. Liquid biofuel has been used in the car industry. In the World War II the high demand of biofuels was due to the increased use as an alternative for imported fuel. The commercial and geopolitical interest in biofuel has waned as availability has expanded. People began to pay attention to the usage of biofuels in the twentieth century. The excessive cost of oil and the emission of greenhouse gases were two of the key causes for people changing their focus to biofuel. (*History of Biofuels - BioFuel Information*, n.d.).

1. Aviation Grade Biofuels

1.1. Definition of Biofuels

Any fuel made from biomass is referred to as a biofuel (biological material). The term biomass simply refers to the biological raw material used to make the fuel. Biomass has the potential to be utilized directly as a fuel. The biological raw material utilized to generate the fuel is referred to as biomass. Biomass has the ability to be used as a fuel directly. Agricultural and industrial wastes, as well as crops and plants, can be used to make biofuel. By offering an alternative to fossil fuels, biofuels can reduce greenhouse gas emissions and boost energy security. (*What Are Biofuels? | Biofuels*, n.d)

1.2. The Utilization of Aviation Biofuels

Aeroplanes and helicopters are the two most common types of aircraft, however we can also include unmanned aircraft, such as drones, in this category. People often confuse the terms "aviation industry" and "airline industry," yet they refer to two distinct industries. An airline is a firm that provides air transportation for passengers and cargo. Aviation encompasses companies that design, manufacture, and operate drones, as well as aircraft manufacturers, researchers, air safety specialists, and others interested in military aviation. The two major types of flight in the aviation sector are civil and military aviation. We can simply differentiate them as:

All aviation that is not related to the military is referred to as civil aviation. This applies to both private and commercial flights, whether they are transporting goods or passengers. On the contrary, the use of aircraft within military domains is referred to as military aviation. (Revfine.com, 2021). We can divide biofuels into generations according to the production procedures as follows:

Sugar, starch, and edible fat are used to make first-generation biofuels. Fermentation of sugars, starches, or cellulose produces them. Although first-generation biofuel techniques are beneficial, they are incapable of producing enough biofuel without endangering biodiversity and food supply. A number of them produce only limited gas emission savings. (Dahman et al., 2019).

Complex biofuels are the second generation of biofuels. The feedstock used to make second generation biofuels is often not food crops, which distinguishes them from first generation biofuels. As biomass is defined as any source of organic carbon, these biofuels can be made from a variety of sources. Because first-generation biofuel production has significant limits, second-generation biofuel technologies are being developed. (Biofuels - Second Generation Biofuels, n.d.; Singh et al., 2015).

Biofuels derived from algal biomass are known as third generation biofuels. Algal fuels have high yields, are often growth with minimal impact on water resources. Production requires large amounts of energy and fertilizer, the produced fuel degrades faster than the opposite fuels. Due to the economic considerations, this manufacturing process is abondend or changed to other application options. (Lee & Lavoie, 2013).

Solar fuels and electro fuels are examples of fourth generation biofuels. Solar fuel is a chemical fuel that is synthesized by turning solar energy into chemical energy. (Aro, 2015).

The main goal of using biofuel is to provide energy security and profit to native communities. There are some reasons why we have a tendency to use biofuels:

• Reduced emissions of greenhouse gases, primarily CO2, based on the initial biomass and thus the route taken.

• Reduction of particulate pollution, such as SOx, NOx, and CO. Biofuels are usually more cost-effective and environmentally friendly to burn than crude oil products.

• Greater energy security. Energy source quality ensures market stability and decreases the risk of scarcity.

• Growth of the bioenergy industry, resulting in new job opportunities and capital opportunities.

• Oil dependence has waned, and oil is a finite resource. (Baumi et al., 2020)

ASTM (American Society for Testing and Materials)

Sustainable aviation fuel must be approved as safe and acceptable for commercial usage as a result of to the high standards needed within the aviation sector. The aviation sector collaborates extensively with international fuel specification bodies, similar to ASTM International, to form standards and certificates. All biojet fuels must be able to be used as a drop-in replacement for typical jet fuel. However, before biojet can be introduced into current jet fuel supply chains, new fuels must demonstrate that they meet ASTM criteria and complete an extensive testing program to receive ASTM certification. (Hammel, 2013).

2. The Technologies for the Process of Production of Aviation Grade Biofuels

An aviation biofuel is a biofuel used to power aircraft that is also sustainable, such as Synthetic Paraffinic Kerosene (SPK). It has been hailed by the aviation industry as a method of curbing carbon emissions from aircraft. It is one of the essential aspects in reducing the carbon footprint (a measure of the damage caused by human activities to the environment in terms of the number of greenhouse gases produced) within the environmental effect of aviation, according to the International Air Transportation Association. Looking on which kind of biomass is employed, biofuels could lower dioxide emissions compared to standard jet fuel.

2.1. Hydroprocessed Esters and Fatty Acids (HEFA) Technology

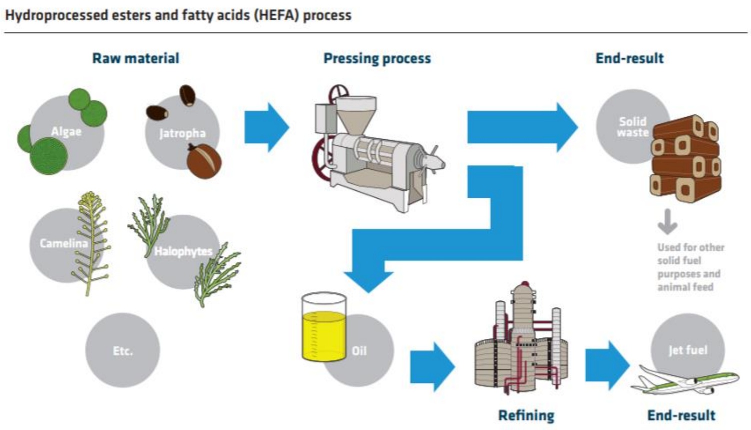

Figure 1, Production process of HEFA technology (Anon, 2011, p.17)

The HEFA technique (also called hydrotreated renewable jet, or HRJ) involves pressing biomass to obtain the fats inside Camelina, algea or jatropha, which are then processed into an aviation fuel within the same means as crude fossil fuel is refined. Another results of the pressing method is that the meal, which may be a leftover substance. This meal will be employed in a range of situations. Solid wastes generated during the jatropha processing. Camelina meal can be used as animal feed, whereas the meal from protoctist oil production will be utilised for fertilizer, animal feed, and alternative uses. For the HEFA pathway, feedstock prices are significantly above the price of fossil-derived jet fuel. (Bauen et al., 2020; Kandaramath Hari et al., 2015; Ray, 2021b).

HEFA Challenges

- There aren't really any technical challenges but challenges of HEFA lie in feedstock cost, availability, sustainability and quality.
- Historically, HEFA-bio-jet has been more expensive than fossil-derived jet fuels, and suitable feedstocks for HEFA-bio-jet alone are frequently more expensive than regular jet fuel.
- In many cases, crop feedstocks are completely avoided due to potential sustainability issues
- There are many newly developed feedstocks such as camelina, carinata, Salicornia. These are still immature feedstock supply chains and are currently at low availability. (Bauen et al., 2020; Kandaramath Hari et al., 2015; Ray, 2021b).

HEFA Opportunities

- Oil and fat conversion efficiency into HEFA-SPK (and other byproducts) is over %76, making it the most efficient bio-jet fuel pathway.
- High feedstock density enables major facilities and cost-cutting by large corporations that are not achievable with other technologies.
- HEFA facilities can readily generate SAF at a rate of 15%, and quantities are rapidly increasing.
- Through additional funding, at an exceedingly high rate sustainable aviation fuel might be obtained.
- Green hydrogen, which emits very little carbon, is being used to improve sustainability features. (Kandaramath Hari et al., 2015; Ray, 2021b).

2.2. Gasification / Fischer – Tropsch (Biomass to Liquid) Technology

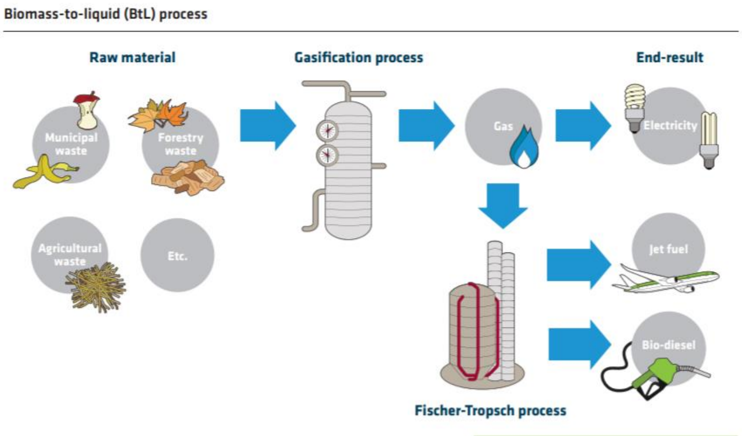

Figure 2, Production process of gasification and fischer-tropsch process (Anon, 2011, p.17)

Gasification, a method in which biomass is heated to high temperatures, generating gas, is used in the "Biomass to Liquid" process to break down the feedstock. The Fischer-Tropsch method is then used to turn this gas into liquid jet fuel. In this trend two main feedstocks are targeted; municipal wastes and residues. Significant emission reductions can be achieved as a result of it. (Ray, 2021b, 2021a).

Gasification / FT Challenges

- The vital investment value that may be fully fledged once developing these facilities is that the significant obstacle of gasification-based biojet production.
- Bio-jet biomass through gasification has slow commercialization since ASTM certification in 2009.
- The need for cleanup of the raw syngas before Fischer-Tropsch synthesis is another costly component. Cleanup usually entails a number of stages to remove various contaminants, with feedstock diversity and varying amounts of contaminants adding to the complexity and cost.
- This technology has a very high capital cost. (Kandaramath Hari et al., 2015; Ray, 2021b, 2021a).

Gasification / FT Opportunities

- Producing FT waxes that could subsequently be co-processed in oil refineries could be a possible option for this strategy.
- This is one among the technologies that can manufacture SAF with a very low carbon intensity.
- Another area for advancement is the improvement of bifunctional catalysts capable of producing a higher jet percentage of up to 70%.
- The main advantages of this technology include the high abundance, availability, low procurement cost.
- Waste feedstocks in considerable quantities, such as municipal solid waste, forest and agricultural wastes, are used.

2.3. Hydrothermal Liquefaction (HTL) Trends

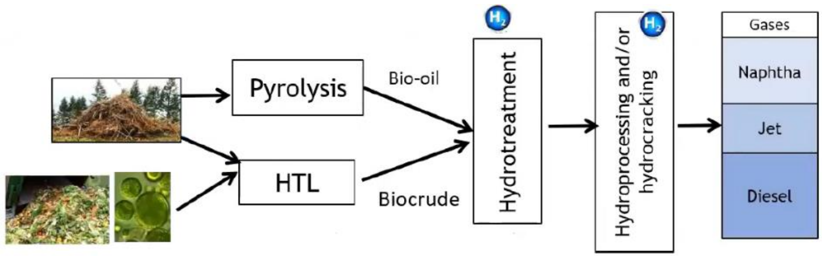

Figure 3, Hydrothermal liquefaction to jet graph (SusanvanDyk via ieabioenergy, 2021)

Hydrothermal liquefaction (HTL) is a new biofuel process that can create transportation fuels from a wide range of biowaste and biomass. Thermal-catalytic conversion converts wet (lignocellulosic) biomass to a bio-crude with a low oxygen concentration. As a result, hydrogen is used to upgrade the bio-crude. The bio-crude is consequently upgraded using hydrogen. This technique is still in the early phases of development, and work on converting bio-oils/biocrude into finished fuels is ongoing. HTL can utilize a diversity of feedstocks, including wet wastes and also sewage sludge. There are very promising developments of HTL for sustainable aviation fuel such as the HyFlexFuel Project. (Bauen et al., 2020; Kandaramath Hari et al., 2015; Ray, 2021b)

HTL Challenges

- The high pressure and caustic conditions during which the method happens are challenges for this method. In these conditions upgrading and technical challenges may occur.
- Certain feedstocks such as algae have a high N contain which is also removed through hydrotreatment and increased hydrogen.
- These pathways do not have ASTM certification, and even if they did, they are estimated to take several years to complete due to the complexity and variety of feedstock and technologies.
- One of the issues has been limited volume availability for testing. (Bauen et al., 2020; Kandaramath Hari et al., 2015; Ray, 2021b).

HTL Opportunities

- The high pressure and caustic conditions during which the method happens are challenges for this method. In these conditions upgrading and technical challenges may occur.
- One of the benefits of the HTL process is that it only requires 10%–15% of the energy in the feedstock, resulting in an energy efficiency of 85–90%.
- HTL can use different wet feedstocks. HTL is specifically very flexible in terms of using wet feedstocks as well as other feedstocks.
- HTL can make use of a low-cost, long-lasting feedstock.
- Hydrothermal Liquefaction can produce bio-oil intermediate with an oxygen level of less than 10%. It would be simpler to upgrade to produce alternative fuels, such as bio-jet. (Bauen et al., 2020; Kandaramath Hari et al., 2015; Ray, 2021b).

2.3.1. HyFlexFuel Project

The HyFlexFuel project aims to establish an entire process chain for producing sustainable liquid fuels from a variety of biomass feedstocks using hydrothermal liquefaction. HTL is becoming more popular as a technology and has the potential to produce drop-in biofuels at a massive scale in a truly sustainable and cost-effective manner. HyFlexFuel's strength comes from the fact that it covers more than just hydrothermal liquefaction; it also incorporates biocrude upgrading to fuel products. Furthermore, the supply and exploitation of a wide range of feedstocks is thoroughly investigated. As a result, the project will create technology solutions and insights that will serve as a solid foundation for future developments in HTL-based industrial fuel generation. (Rais, 2021).

2.4. Alcohol to Jet (ATJ) Technology

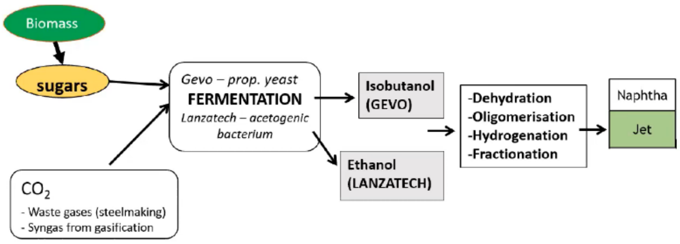

Figure 4, Production of alcohol to jet process (SusanvanDyk via ieabioenergy, 2021)

The fermentation of cellulose and carbohydrates is used in the alcohol-to-jet process. Agricultural waste materials (stover, grasses, forestry slash, crop straws) are processed using a variety of microorganisms, yeasts, and bacteria, and then transformed either directly to jet fuel or via a series of alcohol conversion processes. The feedstocks are simple to get by and cheap, this might be a more cost-effective method. It is also a cost-effective and energy-efficient procedure.

The jet production step from alcohol to jet is fully commercial. Two of the main producers are “GEVO” and “LANZATECH”. “GEVO” generates isobutanol, which is then enhanced to jet, while “LANZATECH” can convert ethanol into a jet fraction (different ratios of sustainable aviation fuel). One of the significant advantages of this technology is that it can produce up to %70 of a jet fraction. (*Beginner’s Guide to Aviation Biofuels*, 2011; Ray, 2021b)

ATJ Challenges

- The first step is a really biochemical step where there is fermentation. The yields of alcohol can be low compared to Saccharomyces cerevisiae which is used for normal ethanol production.
- Butanol is toxic to the fermentation organism which will also limit its volume production.
- Because of the difficult process, production costs are projected to be higher than for other routes.
- There are freestanding facilities for cellulosic ethanol production that has had limited success and difficulty in commercialization although very strong policies. The production of ATJ from biomass is projected to be highly unfeasible. (Bauen et al., 2020; Kandaramath Hari et al., 2015; Ray, 2021b).

ATJ Opportunities

- AtJ techniques are attractive due to the fact they are able to convert many sorts of alcohols which include ethanol, methanol, and isobutanol into jet gas and different hydrocarbons from a variety of sources.
- Infrastructure expense can be decreased.
- AtJ technology can achieve high jet fraction (%70)
- ASTM certification was granted to both the isobutanol-to-jet and ethanol-to-jet methods, continued improvements specifically reducing the number of steps for ethanol to jet is a research target allowing for immediate market access.
- Low feedstock costs, high alcohol yields, high conversion yields, and high sustainability are all likely to help ATJ technology succeed. (Bauen et al., 2020; Kandaramath Hari et al., 2015; Ray, 2021b).

2.5. Pyrolysis Technology

Pyrolysis of biomass is a process that involves heating biomass (from industrial, agricultural, municipal, or forestry waste) to make an oily material that can later be processed into jet fuel. This technology is highly efficient while also being environmentally friendly.

A wide range of biomass feedstocks can be employed in the pyrolysis process, allowing for the conversion of agricultural residues, wood wastes, and municipal solid waste into clean energy. The development of pyrolysis, like other technologies, has technical obstacles, the most prominent of which is heat transport to the reactor. (Ray, 2021b, 2021a; Zafar, 2021).

2.6. Direct-Sugar to Hydrocarbon (DSHC) Technology

In the DSHC process, the sugar molecules are converted to biokerosene by a biological mechanism. Biochemical fermentation or catalytic conversion can be used in the biochemical process. (Kandaramath Hari et al., 2015) This process includes the production of synthesised iso-paraffinic fuel (SIP) from sugar fermentation and upgrading. The directsugars-to-hydrocarbon pathway was previously known as SIP (farnesane). One of the most significant disadvantages of this process is that has a high cost of technology. (Ray, 2021b, 2021a).

3. Conclusion

This report provides an overview of the aviation-grade biofuels and the technologies which have a goal to develop the production process of sustainable aviation biofuels. HEFA is now commercially available and will be the primary technology via HyFlexFuel Project for at least the decades. When compared to biojet created from waste products, biofuels made from conventional agricultural products or those displacing present agricultural land may have considerable impacts on land use. Obtaining sustainable biomass feedstocks continues to be a source of contention, and this will certainly apply to aviation.

Although there are numerous potential biojet fuel manufacturing options, cost factors may restrict the economic sustainability of some of them. Costs of development and demanding certification procedures continue to be major roadblocks to the timely introduction of new fuels to the market. All technologies should be commercialized since they can use a variety of feedstocks and take advantage of geographical variances. Technical obstacles continue in the technology development process, but the significant price differential between conventional aviation fuel remains the largest roadblock.

Policies are critical, and great progress is being made in this area in the United State and Europe, which will have a huge effect on sustainable aviation fuel development. Besides they should be connected to the emission of greenhouse gases. The progression of SAF advancement is accelerating hence this is giving the industry reason to be hopeful.

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