Bio-jet Fuel

Dilip Kumar Adhikari

Abstract The crude oils are processed in a refinery to make a host of useful products; including gasoline, diesel, jet fuel, petrochemicals, and asphalt components. Kerosene is produced as a straight run product but is also produced through hydroprocesses, especially from heavier crude oil feedstocks. Kerosene jet fuel is a hydrocarbon fuel composed almost entirely of hydrogen and carbon elements. The hydrocarbon composition consists mainly of paraffins (iso and normal), cycloparaffins (naphthenes), and aromatics. Aviation jet fuel produced from different feeds and processes will have different ratios of these hydrocarbon components. Combustion of Aviation Turbine fuel or jet fuel (Jet-A1) for aviation purpose has contributed to "global warming" leading to a proposed blending of "Biojet" to reduce the carbon footprint. In 2009 a new ASTM specification (D7566-09, *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*) was developed for aviation turbine fuels. The specification allows for a maximum of a 50% blend of Biojet with conventional jet fuel. While Bioethanol and Biobutanol, a proven biofuel for the automobiles, were found unsuitable biofuel for aviation purpose due to a mismatch in ASTM D7566-09 specifications. Several technological options have emerged on intensive R&D efforts globally. Such technologies used plant seed oil, waste cooking oil, animal fat, agricultural residues, and MSW as feedstock to produce renewable hydrocarbon fraction as drop-in fuel known as "Biojet". Basic advantage of using plant or agricultural waste based feedstock instead if crude oil is the minimization of carbon footprint in the aviation fuel. However, several challenges have emerged to meet the stringent specifications of aviation fuel and challenges being addressed to ascertain Biojet as sustainable, cost-effective, and green aviation fuel.

Keywords Aviation Turbine Fuel (ATF) · Jatropha oil · HEFA
DSHC · ASTM · Bio-Jet

D. K. Adhikari (✉)
CSIR-Indian Institute of Petroleum, Dehradun, India
e-mail: dilipiip52@gmail.com

S. Kumar and R. K. Sani (eds.), *Biorefining of Biomass to Biofuels*, Biofuel and Biorefinery Technologies 4,
https://doi.org/10.1007/978-3-319-67678-4_8

1 Introduction

Air travel has changed our world for the better quality of life, enabling better relationship of communities, fuelling commerce, facilitating the exchange of goods that could not have existed for previous generations. While air travel makes our world a smaller and better place, there are significant costs associated with the energy needed for flight. The passenger, cargo, and military air transportation place significant demands around on very specialized jet fuel (Jet-A-1) derived from crude oil. Increase in air traffic globally at 5% per annum has set high demand 200 million tons per annum of jet fuel in the aviation industry (Davidson et al. 2014). Thus, combustion of traditional fossil fuel (Jet-A) in large quantity by air carriers poses a global threat to high altitude propagation making 2% of total greenhouse gases emission by total transportation sector. As a measure to curb the "Global Warming" some countries have proposed to impose "carbon-tax" on the airlines using fossil fuel based aviation fuel such as Jet A-1. The members of the International Air Transport Association (IATA) have pledged the following goals:

- To improve fuel efficiency by 1.5%/year over the decade to 2020
- To make all aviation industry growth carbon neutral by 2020
- To reduce net CO_2-e emissions by 50% by 2050, against 2005 levels.

1.1 Growth of Aviation Industry

Indian aviation industry is the fastest growing sector with CAGR of 18% by 2020. India has the highest fuel costs and taxes in the world and if not it is among the top two or three which hits the profitability of smaller airlines.

Domestic and international air traffic in Indian civil aviation sector has also been increased around 20% in last five years (Fig. 1).

The main greenhouse gas (GHG) emissions generated by air transport during flight are carbon dioxide (CO_2), nitrogen oxides (NO_X), water vapor (H_2O), and particulate matter (PM) and hence causes global air pollution.

Essentially an urgent need for green fuel, alternate to fossil fuel based jet A-1 fuel for aviation sector is of high demand. Second generation Biofuels could be potential alternative and can be mixed with fossil fuel based Jet A-1 which would lead to minimizing the net carbon dioxide (CO_2), nitrogen oxides (NO_X), water vapor (H_2O), and particulate matter (PM) footprint in the environment simultaneously could meet up demand of aviation fuel partially. These fuels can be partially mixed with aviation fuel using existing refueling infrastructure providing the easy supply chain system globally. Each kilogram of fuel saved reduces carbon dioxide (CO_2) emissions by 3.16 kg. However, there are several challenges exists in application of Biofuels in the aviation purpose as compared to other transportation mode such as automobiles. One of the major challenges of application of Biofuels

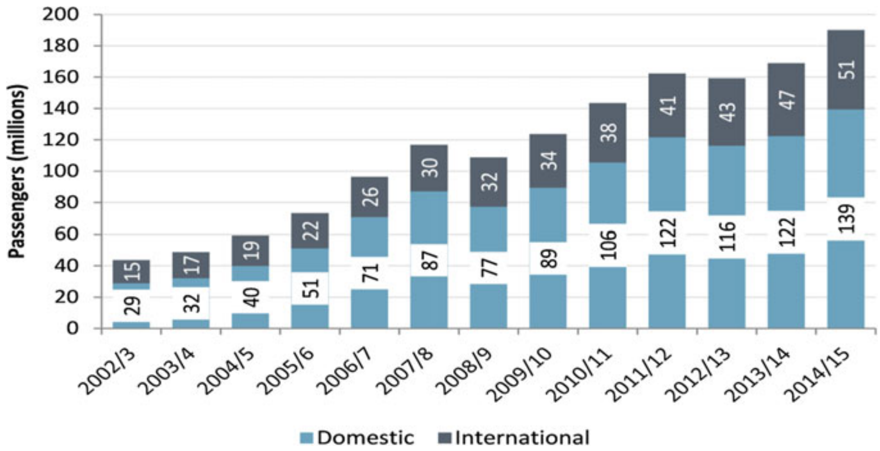

Fig. 1 Indian domestic and international passenger traffic. *Source* www.steerdaviesgleave.com/news-and-insight/Indian-airport-passenger-trafic-continues-to-grow

for aviation purpose is the meeting of stringer fuel specifications as compared to that of automobiles.

Main requirements for sustainable alternative jet fuels:

- Can be mixed with conventional jet fuel,
- Can use the same supply infrastructure and do not require adaptation of aircraft or engines (drop-in fuel),
- Meet the same specifications as conventional jet fuel, in particular, resistance to cold (Jet A: −40 °C, Jet A-1: −47 °C),
- High energy content (min 42.8 MJ/kg)
- Meet sustainability criteria such as lifecycle carbon reductions, limited fresh water requirements, no competition with food production, and no deforestation.

The stringent specifications of aviation fuel as required by present aircraft industry certainly need to comply with any alternate fuel (Table 1).

1.2 Sustainable Aviation Biofuels

Bioethanol and Biodiesel are most sustainable Biofuels propagated now for the automobiles used as surface transport. Bioethanol is mixed with gasoline at 5–10% (E5–E10) and used in the traditional cars in India, EU, and the USA whereas a mixture of 85% bioethanol in gasoline (E85) is used in Flexi cars in Brazil. Diesel vehicles run successfully with 20% biodiesel in petro-diesel (B20) globally. Lignocellulosic biomass and nonedible oils extracted from plant seeds are most sustainable feedstocks used for large-scale production of Bioethanol and Biodiesel

Table 1 Aviation fuel specification compliance (Jet A-1)

Cold flow properties, pour point °C	<44
Energy density	44 MJ/kg
Fuel composition	Proper ratio of *n*-alkanes, iso-alkanes, Cyclo-alkanes and aromatics (25 vol.%) Selective hydrocarbons *n*-dodecane (C_{12}) 43% Iso-cetane 27% Methylcyclohexane 15% 1-methylnaphthalene 15%
Density at 15 °C	0.779–0.840
Viscosity at −20 °C Cst max	8.0
Kinematic viscosity at 40 °C	1.2
Smoke pt. mm min	19
Thermal stability JFTOT ΔP (mm Hg) max	25.0
Existent gum (mg/100 mL) max	5.0–7.0
Ignition, extinction, and flammability	Within limits
Compatibility issues	Materials in jet engine and additives

Table 2 Limitation of specification of bioethanol and biodiesel as aviation fuel

	Bioethanol	Biodiesel
Energy density MJ/kg	26.4	37.27
Kinematic viscosity cSt at 40 °C	0.80	1.9–6.0
Pour pt °C	Within limit	13–16
Flash point		130 °C higher
Compatibility	Corrosive with moisture	Non compatible
Impurities		Glycerol, acids

respectively. Technologies for large-scale production of these two Biofuels have been licensed to several commercial farms in USA and Brazil. The Life Cycle Analysis (LCA) of these two Biofuels showed that both have a significant low carbon footprint as compared to gasoline and diesel. Thus, Bioethanol and Biodiesel have emerged as most sustainable biofuel for automobiles. However, Bioethanol and Biodiesel have some limitations to use as aviation Biofuels as mentioned in Table 2.

The inherent properties of bioethanol and biodiesel have restricted its use as sustainable aviation fuel although they are quite successfully being used in road transport vehicles. An alternative fuel, preferably from renewable sources, and meets all the required fuel specifications, is the preferred option. Therefore, essential criteria for aviation biofuel or Biojet is targeted toward synthetic fuel either hydrocarbon or non-hydrocarbon types meeting essential specifications of fossil-based Jet-A or Aviation Turbine Fuel (ATF) with “DROP-IN” characteristics. Such biofuels are carbon neutral and they require less investment in terms of refining operation and supply chain infrastructure management. In 2005–2006 the Defence Advanced Research Projects Agency, or DARPA, sponsored projects in the quest for bringing green jet fuel to the U.S. military.[1] They focused on the development of a process that efficiently produces an alternate for petroleum-based military jet fuel (Jet Propellant 8; JP-8) from oil-rich crops produced by either agriculture or aquaculture, and which ultimately can be an affordable alternative to petroleum-derived JP-8 (Roberts 2008).[2] Alternative fuels in aircraft is subject to very specific constraints (safety, logistics, temperature, etc.). Over the short and medium terms, we can only consider drop in solutions, fuels with similar properties to those of kerosene, which do not require drastic changes to be made to equipment architecture and infrastructures, given the degree of investment in air transport (Roberts 2008).

1.3 Renewable Feedstocks

Nevertheless, development of sustainable bio-jet fuel requires sustainable, quantitative, and qualitative supply of renewable feedstocks. Such feedstocks should be available in all the continents of the globe, as it would facilitate smooth supply of fuels to the international airlines. At present, several production options exist—biomass, plant seed oils, and algae being more commonly known feedstocks that are available in South East Asia, EU countries, North and South American countries. Bio-jet fuels produced from plant seed oils have already powered commercial flights in small proportions—amongst them United, Lufthansa, JAL, and several others, all of whom have operated flights with one engine powered by a mix of Jet A and biofuel derived from Jatropha, a nonedible evergreen shrub. British Airways and Solena have partnered to produce a synthetic kerosene product from agricultural and municipal waste that is planned to begin production in 2015. In June 2011, a Gulfstream G450 became the first business jet to cross the Atlantic Ocean using a blend of 50/50 biofuel developed by Honeywell derived from camelina and petroleum-based jet fuel.

The potential feedstocks for production of carbon neutral and cost competitive Bio-jet fuel are classified under three categories:

(a) Lipids—Oil from seeds of camelina, jatropha, rapeseed, karanjia, maize (corn), as well as palm oil, and used cooking oil. Some processes also targeted to utilize animal fats and algal lipids. Lipids from microalgae, oil from seeds of halophytes (salt-tolerant plants), Jojoba wax, Microbial oil produced by yeasts and bacteria.

---

[1]http://www.greentechmedia.com/articles/read/darpa-gives-logos-196m-for-bio-jet-fuel-6023.

[2]http://www.defenseindustrydaily.com/darpa-solicitation-can-you-replace-jp8-jet-fuelwith-abiofuel-02428/.

(b) Lignocellulosic biomass includes wood, agricultural residues, forest residues. Energy crops including fast-growing trees and grasses such as bamboo, miscanthus, and giant reed.
(c) Sugars.

Most oil plants originate from tropical and subtropical climates. A large share of the world plant oil production comes from countries like Indonesia, Malaysia, China, India, the USA, Argentina, and Brazil with palm, rapeseed, Jatropha, and soybean as the major feedstock oils. Some edible and nonedible oil production with high productivity in the world is given in Table 3.

In spite of sustainable availability potential of plant oils around the globe supply of some of them, particularly edible oils, are scarce in some countries such as India. Other alternate sources are aquatic algae that could be cultivated in offshore or marine water. Microbial lipids such as yeast lipids are also being considered as potential non-plant source of feedstocks.

However, the future of biojet production from oils and fats is about achieving sustainability with volumes and at relatively low cost. To achieve these three major issues the only obvious options are to produce non-food grade oil feedstocks from high yielding sources in places where the very large areas of production space is available, where competition with (or displacement of) existing food production is not an issue, and where adequate water and other inputs are also available. Nevertheless type of fatty acid composition in the oil feedstock play a major role in quality of Bio-jet fuel (Table 4).

In the Indian context, Bio-Jet fuel consumption is around 4.5 Million Tons per annum. Availability of waste land in India is 3 million hector, which can be utilized for Jatropha or pongamia plantation yielding around 9 Million tons per annum of oil for biojet production. In 2012 global biomass energy supply was 10% of total energy supply. Biomass supplies more than 80% of the Biomass energy supply in Nigeria in comparison to 7.5 and 24% in China and India respectively. Situating in tropical region Asia and Africa produce 70% of total biomass supply in the world (Table 5).

Table 3 Oil production per unit area (ha) of different oil plants

Plant	Latin name	Productivity (l/ha/year)
Palm	*Elaeis guineensis*	5698
Coconut	*Cocos nucifera*	2578
Jatropha	*Jatropha curcas*	1812
Castor bean	*Ricinus communis*	1354
Karanja	*Pongamia pinnata*	1250
Rapeseed	*Brassica napus*	1140
Camelina	*Camelina sativa*	500
Cotton	*Gossypium hirsutum*	308
Corn	*Zea mays*	168

http://www.environmentalleader.com/2007/07/06/honeywells-uop-developing-bio-jetfuel-formilitary

Table 4 Role of fatty acid structure on fuel properties

Properties	Short chain	Long chain	Saturated	Unsaturated
Viscosity	Favorable	Unfavorable	Unfavorable	Favorable
Freezing point	Favorable	Unfavorable	Unfavorable	Favorable
Flash point	Desirable	Undesirable	Undesirable	Favorable
Energy content	Low	High	High	Low
Oxidation stability	Acceptable	Acceptable	Better	Unfavorable
Combustion	Unfavorable	Favorable	Better	Unfavorable
NO_X	Increase	Reduced	Reduced	Increase

Table 5 Global primary biomass energy supply in EJ

Year	World	Africa	America	Asia	Europe	Oceania
2000	43.1	10.5	7.33	21.6	3.36	0.26
2005	47.2	12.0	8.19	22.5	4.20	0.27
2010	53.9	13.7	9.64	24.3	5.97	0.22
2012	56.2	14.7	9.73	25.0	6.46	0.26

IEA 2015
EJ Ekta Jule

2 Bio-jet Fuel Process Technologies

2.1 Hydroprocessed Ester and Fatty Acids (HEFA)

The renewable jet fuel process, developed by UOP LLC Company is a good example of novel technological methods that may be implemented in aviation biofuels production. The process can convert a variety of refined natural oils and fats including edible and nonedible natural oils, tallow, and algal oils. The renewable jet process uses a selective cracking step which reduces the natural oil C_{16}–C_{18} carbon chain lengths to carbon chain lengths in the C_{10}–C_{14} range for jet fuel. The renewable jet process is based on UOP's Ecofining™ process,[3] which is commercially available for the production of green diesel produced from vegetable oils. While the Ecofining unit can produce up to 15% of Bio-SPK jet fuel, as a coproduct with diesel, this new process is designed to maximize the yield of Bio-SPK (Bio-kerosene) to 50–70%.[4] This is achieved by optimizing the catalytic processes of deoxygenation, isomerization, and selective cracking of the hydrocarbons present in natural oils and fats to yield a high quality, ultralow sulfur jet fuel that meets Jet A-1 specifications, including freeze point of −47 °C and flash point of 38 °C (Fig. 2). Coproducts from this new process are diesel and naphtha

[3]http://www.uop.com/hydroprocessing-ecofining/.
[4]See Footnote 1.

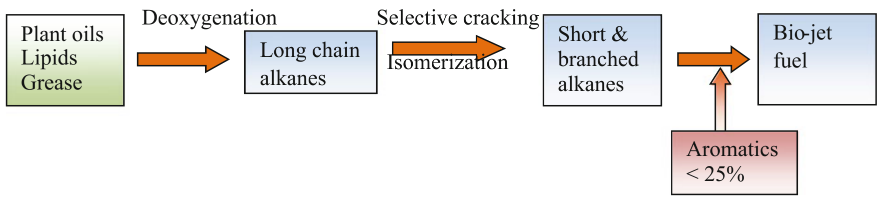

Fig. 2 Ecofining^{TM} process scheme

range fuels. The process can be adjusted to produce a specific freeze point of the Bio-SPK or can alternately be operated in a diesel mode.

Another novel catalytic process was developed by CSIR-Indian Institute of Petroleum Dehradun to convert nonedible vegetable oil such as Jatropha seed oil to biofuels by hydroprocessing for aviation and transportation sectors. A highly selective catalyst was developed and process temperature (400–420 °C) and pressure (60–80 bar) were optimized for hydrotreating, hydrocracking, and hydroisomerization of vegetable oil to Biojet fuel either in a single step or two steps process. The process was successfully demonstrated in a pilot plant processing Jatropha oil 100 kg per day with 99% conversion and 33–40% yield of Biojet fuel and rest liquid products as diesel and gaseous fuel. Better conversion (99%) and maximum yield (40%) of Biojet could be achieved by designing selective catalysts such as mesoporous alumina, silica–alumina, and hierarchical mesoporous zeolites for hydroconversion of seed oil, waste cooking oil, and algal oil (Sinha et al. 2012).

The process has the advantage of using oil with varying FFA content. The process scheme is shown in Fig. 3 and Table 6.

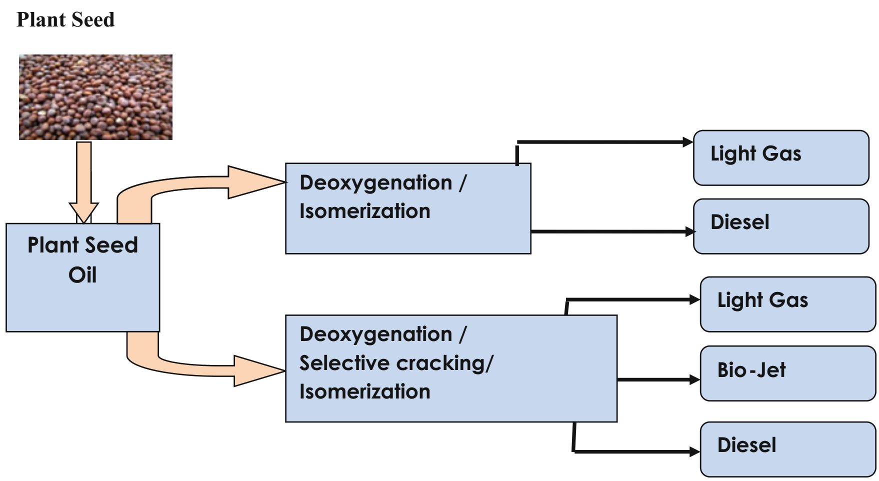

Fig. 3 CSIR-IIP process scheme for aviation and transportation fuel

Table 6 Comparison of properties of biojet produced by CSIR-IIP

Property	Units	Limit	Jet A-1	IIP biojet
Freezing pt.	°C	Max. −47	−52.2	−63
Viscosity (−20 °C)	mm^2/S	8.00	3.72	3.45
Flash pt.	°C	38.0	43	49
Density	kg/m^3	775.84	793	780
Total aromatics	%v/v	Max. 26.5	23	13
Sulfur	%m/m	0.3%	0.2	0.009
Smoke pt.	mm	25.0	26	34
Specific energy	MJ/kg	42.8	42.9	43.5

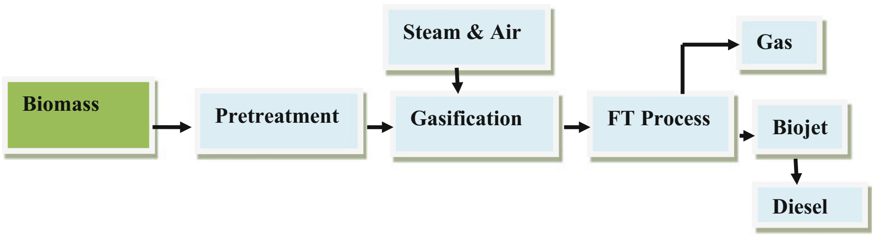

Fig. 4 Synthetic bio-kerosene process scheme

Properties signify that CSIR-IIP process could achieve better aviation fuel specification without any additional aromatics supply as compared to petroleum-based Jet A-1 or Ecofining TM process by tuning of catalyst surface, operating conditions, and pretreatment of feed oil to remove some metal and non-metal inhibitors.

2.2 *Synthetic Bio-kerosene Process*

The process is basically developed on the concept of Biomass to Liquid (BtL) conversion using feedstocks like lignocellulosic biomass, wood residue, cereal straw, and forest residues to synthetic fuels such as biodiesel, biojet fuel Fig. 4. It is a five-step process consists of (a) pretreatment of biomass (b) gasification or pyrolysis (c) Syn-gas purification (d) Fischer-Tropsch (FT) synthesis (e) Hydroisomerization of FT-wax to Biojet, Biodiesel, and naphtha depending on needs. The kerosene fraction obtained using the BtL process is of very good quality, free from sulfur and other impurities.

2.3 Alcohol Oligomerization Process

Many companies have reported development of processes to produce jet fuel from alcohols, but its economics depend upon the source from which alcohols are produced. Gevo, an American renewable chemicals and biofuels company, has claimed to have successfully produced isobutanol from fermentable sugars derived from cellulosic biomass, and converted this into isobutylene and paraffinic kerosene (jet fuel). Another company, Lanzatech, is also claimed to produce alcohol from industrial waste gases containing "clean" carbon monoxide and converting this alcohol into jet fuel by oligomerization and hydrogenation (Fig. 5).

2.4 Direct Sugar to Hydrocarbons (DSHC)

The Direct Sugar to Hydrocarbons (DSHC) process converts sugar to a pure paraffin molecule that can be blended with conventional jet fuel. The process utilizes an advanced fermentation process to accomplish the conversion. This biological conversion is carried out under aerobic conditions, unlike "traditional" fermentation of sugars to ethanol.

The process in this pathway involves a yeast fermentation process fed by sugarcane (or any other plant sugars including from sugar beet, sweet sorghum, or cellulosic sugars) to produce the unsaturated fermentation product farnesene. This then undergoes another conversion process that results in the hydrogenated and saturated hydrocarbon fernesane. This approved pathway is developed by a collaboration between French petroleum refining and distribution company Total and California-based industrial bioscience company Amyris. However, for its use in commercial aviation this new biojet product is presently only to be used in blends of up to 10% with conventional jet kerosene.

Farnesene is a terpenoid olefin (1,6,10-Dodecatrienes, $C_{15}H_{24}$) biochemically synthesized through mevalonate or isoprenoid pathway present in most of the eukaryotes and higher bacteria. It is insoluble in water and soluble in alcohols. Its Pour point −76 °C and b.p 250 °C, density 0.83 (15 °C). The physic-chemical

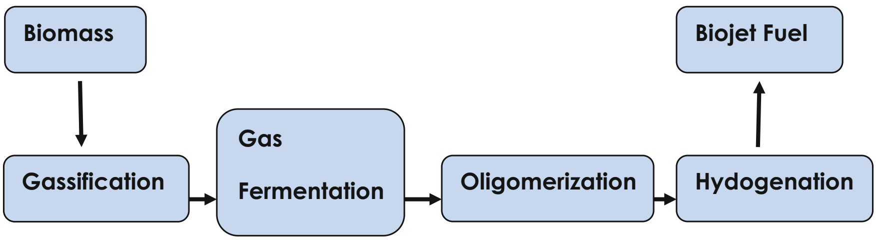

Fig. 5 Alcohol oligomerization to jet fuel (AJT) process scheme

properties of farnesene or its isomers have an advantage over ethanol and butanol as Biofuels since it is non-hygroscopic, very low pour point and density, flash point meets aviation fuel specifications.

2.4.1 Mevalonate Pathway

Actyl-CoA + Acetoacetyl-CoA → 3-Hydroxy-3-methylglutaryl CoA (HMG-CoA) → Mavelonate → Isopentyl-PP → Geranyl-PP → Farnasyl-PP → Farnesene

The major enzymes associated with the terpenoid biosynthetic pathway are (a) acetyl-CoA acetyltransferase, (b) 3-hydroxy-3-methylglutarylcoenzyme A synthase, (c) HMG-CoA reductase, (d) mevalonate kinase, (e) phosphomevalonate kinase, (f) mevalonate pyrophosphate decarboxylase, (g) isopentenyldiphosphate (IPP) isomerase, (h) isoprene synthase, (i) farnesyl pyrophosphate (FPP) synthase, (j) α-farnesene synthase.

The pathway needs 2 mol of NADPH and 3 mol of ATP which are generally available through glycolysis and other pathways in aerobic and anaerobic microorganisms. Recent developments in metabolic engineering and synthetic biology have allowed overproduction of terpenoids based on microbial fermentation rather than plant-based production, resulting in several remarkable breakthroughs, not only in the production of complex natural products, such as precursors of taxol and artemisinin, but also in the production of bulk chemicals and biofuels (Martin et al. 2003; Özaydın et al. 2013, Zhu et al. 2014) (Fig. 6).

2.5 *Bio-oil Hydroprocessing to Biojet Fuel*

The process is based on hydrotreatment of Bio-Oil produced by Catalytic Fast Pyrolysis of lignocellulosic and wood biomass. Bio-oil can also be coprocessed with Heavy Vacuum Gas oil (HVGO) in hydrotreatment unit of an Oil refinery to

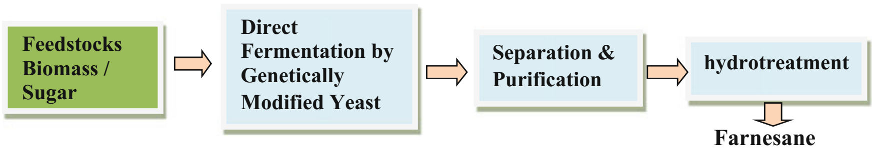

Fig. 6 Direct sugar to biojet (farnesene) process scheme

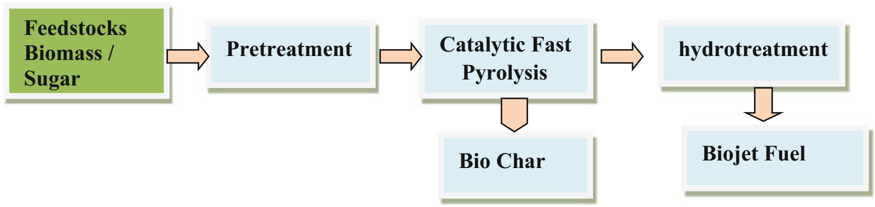

Fig. 7 Hydrotreatment of bio-oil to bio-jet fuel

Table 7 Biojet fuel process development status

Biojet fuel process	Certification	Feedstock type	Feedstock cost	Potential investment
Fischer-Tropsch (FT)	ASTM 2009 max. 50% blend with Jet-A1	Woody and lignocellulosic biomass	low	Very large
Hydroprocessed plant seed oil	ASTM 2011 max. 50% blend with Jet-A1	Plant oils, waste oils from food industry, animal fats, algal oil	High for edible oils but medium with nonedible oil supply	Medium
Alcohol oligomerization to jet fuel (ATJ)	Under process of ASTM certification	Sugars, starches	Medium but restricted in some countries on Food vs. Fuel	Medium
Direct sugar to hydrocarbons (DSHC)	ASTM 2014 max. 10% blend with fossil jet	Sugars, cellulosic materials	medium	Large
Hydrotreated pyrolysis oil	Under process of ASTM certification	Woody and lignocellulosic biomass	medium	Very large

produce Jet-A1 fuel. The process is under developmental stage promoted by few giant companies such UOP, Ensene & BTG to demonstrate the process in a demo plant (Fig. 7).

It has been demonstrated that use of various renewable feedstock such as plant oilseeds, biomass, and sugars could be converted to Bio-jet fuel through different chemical/ catalytic and biocatalytic processes. However, application of such "Biojet Fuel" in commercial flights requires ASTM certification and techno-economic feasibility. Current status of such feasibilities for commercial application is summarized in Table 7.

3 Issues Limiting the Deployment of Biojet Fuels on a Global Scale

The options to deploy cost-effective biojet fuels on a global scale are limited by several issues such as technical constraints, high production costs, price and competing uses for feedstock, production capacity, lack of policy incentives, and the real potential of waste and residues.

3.1 High Cost of Production

Biojet fuel is currently costlier than petro Jet-A1 fuel due to uncertain and poor supply chain of feedstock such Jatropha oil, camellia oil, or Pongamia oil etc. in the international market. Basically cost of biojet fuel is dependent on (a) input cost and composition of feedstock, (b) process technologies, (c) conversion efficiency and product yield, (d) value-added coproducts, (e) process energy efficiency. Biojet fuel produced by HEFA process was projected around US$4.5–5.4/gal which is almost double the current price of petroleum Jet A fuel (NREL Technical Report 2016). It was found that Feedstock and hydrogen represent almost 50–70% of the Biojet fuel price. Therefore, sustainable supply of potential feedstock is the key factor for cost reduction.

3.2 Technology and Plant Capacity

Many processes developed for Biojet fuel are in the pilot or Demo scale. Some of them still require technical maturation. Application of waste/ residues as feedstock more benefit on net greenhouse gas reduction comparing other potential feedstock; however, their availability and supply chain strategy has not yet established globally. High capacity stand-alone production plants need high capital and operating cost. Feasibility of use of Biojet fuel in aviation sector is possible as drop-in fuels in near future. Therefore, such plants should build in the vicinity of petroleum refinery or other biofuel plants.

3.3 Lack of Policy Incentive

Government of several countries has announced incentives on blending of Biodiesel and Bioethanol with petrol or diesel respectively to make parity with the fossil fuels. However, no such action has been initiated for use of Biojet fuel in the aviation sector. This situation may potentially create global differences in price and availability of feedstock and biojet fuel.

4 Conclusion

Road map for development and application of Biojet fuel as drop-in fuel in the aviation purpose has been laid down. Biojet is considered an important part of the aviation industry's GHG emission reduction strategy. Using it to reach a GHG emissions goal of 2050 emissions at one-half of the 2005 level would involve significant development of standards and regulatory approvals, feedstocks, conversion facilities, transportation infrastructure, and logistics. Initial use of biojet has proceeded in commercial and military applications. The most suitable option for biojet production for petroleum importing countries like India are:

(a) Conversion of low-cost nonedible plant seed oil to biojet by UOP developed Ecofining process or CSIR-IIP developed hydroprocess.
(b) Production of Bio-oil from MSW or biomass by catalytic pyrolysis and hydrotreatment of bio-oil to biojet.
(c) Production of ethanol from sugar cane and convert it to biojet using the ATJ pathway.
(d) Production of sugars from biomass and direct conversion of sugars to hydrocarbons (DSHC) pathway as it has been demonstrated by Amyris in Brazil, producing an aromatic hydrocarbon from sugar that can be blended at up to 10% with jet fuel.

However, there are certain roadblocks in terms of cost, supply chain management of feedstock, establishing techno-economic feasibility, and governmental policy.

References

Davidson C, Newes E, Schwab A, Vimmerstedt L (2014) An overview of aviation fuel markets for biofuels stakeholders. Technical Report NREL/TP-6A20-60254

Martin VJJ, Pitera DJ, Withers ST, Newman JD, Keasling JD (2003) Engineering a mevalonate pathway in *Escherichia coli* for production of terpenoid. Nat Biotechnol 21(7):796–802

Özaydın B, Burd H, Lee TS, Keasling JD (2013) Carotenoid-based phenotypic screen of the yeast deletion collection reveals new genes with roles in isoprenoid production. Metabol Eng 15:174–183

Roberts WL (2008) Bio jet fuels. In: The 5th international biofuels conference, North Carolina State University USA

Sinha AK, Anand M, Rana BS et al (2012) Development of hydroprocessing route to transportation fuels from non-edible plant-oils. Catal Surv Asia. doi:10.1007/s10563-012-9148-x

Technical Report NREL/TP-5100-66291 July 2016 (www.nrel.gov/publication)

Zhu F, Zhong X, Hu M, Lu L, Deng Z, Liu T (2014) In vitro reconstitution of mevalonate pathway and targeted engineering of farnesene overproduction in *Escherichia coli*. Biotechnol Bioeng 111(7):1396–1405