LECTURE-15

(BIO AVIATION TURBINE FUEL)

➢ INTRODUCTION

- Aviation fuel, a petroleum-based fuel used to power aircraft, has stricter quality requirements than fuels used in road transport.
- Jet fuel is a type of aviation fuel designed specifically to power gas-turbine engines'
- According to a report from the U.S. Energy Information Administration (EIA) (U.S. Energy Information Administration 2013), 4 gallons out of every 42-gallon barrel of crude oil are used to produce jet fuel.
- The worldwide aviation industry consumes approximately 1.5–1.7 billion barrels of conventional jet fuel per year.
- Fuel is the largest operating cost in the aviation industry, and the unstable prices of crude oil hamper long-term planning and expense budgeting.
- Renewable feedstock-derived jet fuels can reduce the dependency of the aviation industry on one single energy source, avoiding the volatility of petroleum prices, and potentially reducing greenhouse gas (GHG) emissions.
- Due to excessive greenhouse gas emissions and high dependence on traditional petroleum jet fuel, the sustainable development of the aviation industry has drawn increasing attention worldwide.
- One of the most promising strategies is to develop and industrialize alternative aviation fuels i.e. Bio Aviation Turbine Fuel (Bio ATF) or renewable bio jet fuel produced from renewable resources.
- Bio Aviation Turbine Fuel (Bio ATF) is a biofuel used for aircraft that can be prepared using animal fat, vegetable oil and agricultural waste.
- It is considered to be a source of renewable energy, unlike fossil fuels such as petroleum, coal, and natural gas.
- Bio ATF has the potential to reduce CO_2 emissions over their life cycle, which make bio-jet fuels an attractive substitution for aviation fuels.
- Jet aircraft in service today are well over **80% more** fuel efficient per seat kilometre than the first jets in the 1960s.
- Airlines' CO_2 emissions rising up to 70% faster than predicted.

- Carbon dioxide emitted by commercial flights rose by 32% from 2013 to 2018, study shows.
- Alternative fuels, particularly sustainable aviation fuels (SAF), have been identified as excellent candidates for helping achieve the industry climate targets.
- SAF derived sources such as algae, jatropha, or waste by-products have been shown to reduce the carbon footprint of aviation fuel by up to **80%** over their full lifecycle.
- Investigations have shown that hydrogenated esters and fatty acids, and Fischer-Tropsch synthesis can be the most promising technologies for bio-jet fuels production in near the coming future.
- Future works, such as searching for more suitable feedstock, improving competitiveness for alternative jet fuels, meeting emission reduction targets in large-scale production and making measures for the indirect impact are needed for further research.
- The large-scale deployment of bio-jet fuels could achieve significant potentials of both bio-jet fuels production and CO_2 emissions reduction based on future available biomass feedstock.
- On August 7, 2018 Spice Jet made its first flight landing on Delhi Airport from Chandigarh using Bio-ATF.
- The Indian Air Force has planned to expand the use of biojet fuel on its transport fleet and helicopters before coming to fighter aircraft.
- Recently the Brisbane Airport of Australia made a partnership with Virgin Australia and the US fuel company of Gevo for a 2-year supply of bio-jet fuel produced by alcohol-to-jet (ATJ) process to Virgin Australia and other Brisbane Airport-departing airlines, which approximately reached commercialization-capable level.
- For the U.S. Department of Defence (DOD) alternative fuel initiatives, the U.S. Air Force has set goals to test and certify all aircrafts and systems on a 50:50 alternative fuel blend by 2012, and to ensure that 50% of the domestic aviation fuel of the Air Force comes from an alternative fuel blend by 2025.
- The U.S. Navy’s goal was to run ships and aircraft entirely on alternative fuel blends by 2016 and to achieve 50% of the Navy’s total energy use from alternative sources by 2020.
- About 100 billion liters (5 million TOE) of bio-ethanol was produced worldwidein 2014.
- The USA consumes 14.4 billion gallons of bio-ethanol per annum, the most significant quantity in the world.
- This is also manifested in **Figure-1** where most of the bio-ethanol production is consumed in North and South America with comparatively similar amount consumed in Europe and China.
- As for bio-ethanol production, the USA and South America, especially Brazil, are well known for bio-ethanol production.
- Brazil was ranked first as a bio-ethanol exporter before 2010, but the USA surpassed Brazil as a prime exporter of bio-ethanol thereafter as depicted by **Figure-2**.
- This is attributed to significant growth in number of bio-ethanol producers.

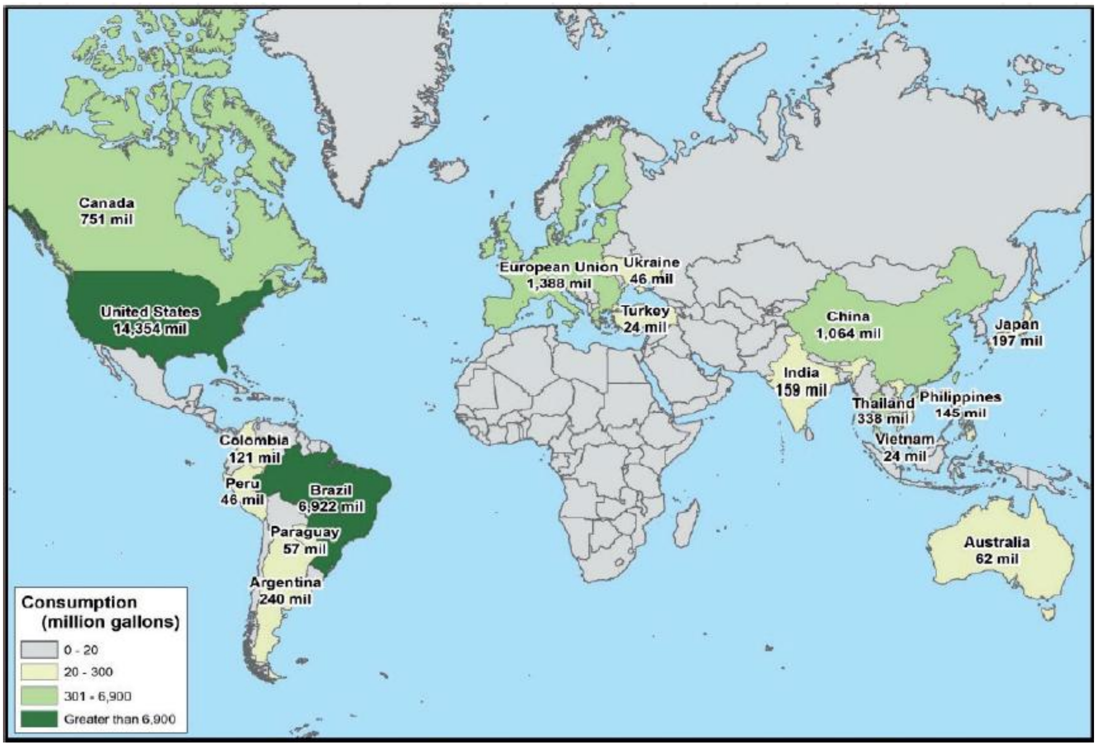


Figure-1:Global ethanol consumption for transportation fuel in 2016.

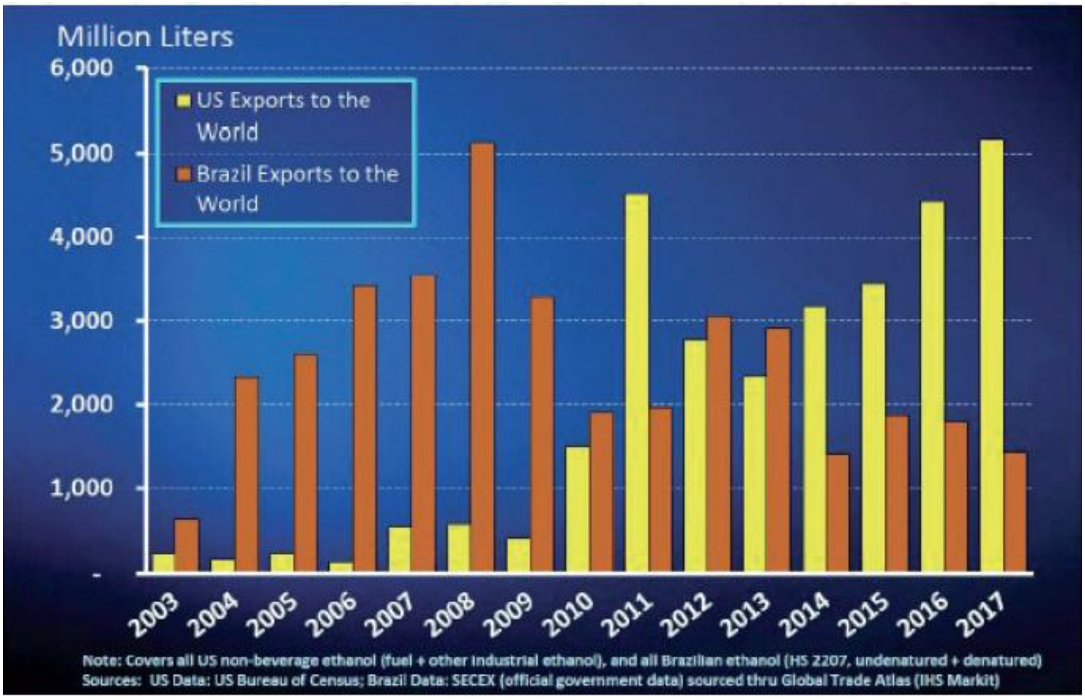
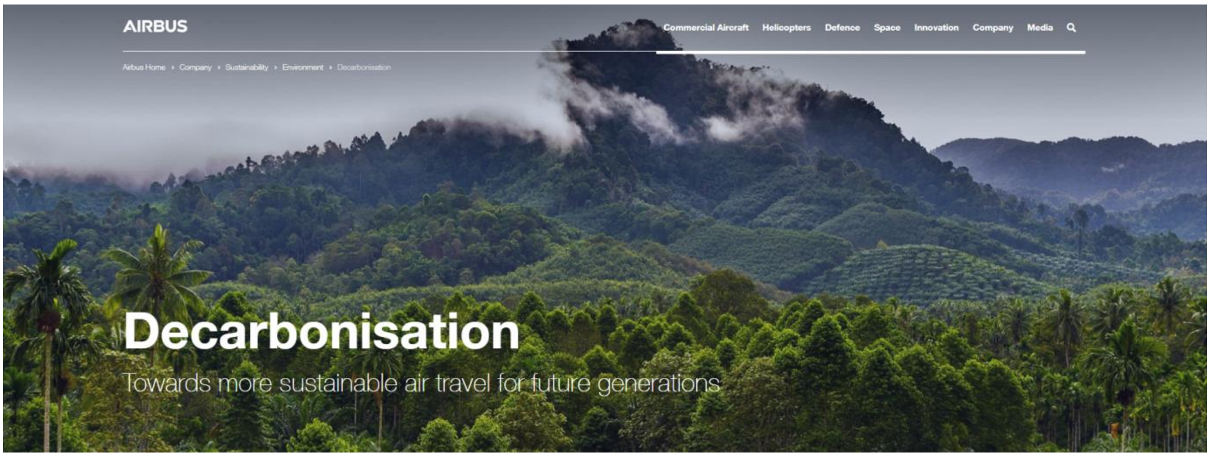


Figure-2:Yearly variation in export of US and Brazilian bio-ethanol based on nonfood-based ethanol.

➢ NECESSITY FOR BIO-JET FUEL

A C-141 Starlifter leaves a vapor trail over Antarctica.
Environmental Impact of Aviation evident from the image above

Cirrus cloud formation.



Result of decarbonization or control of CO_2 emission.

- Recent fuel consumption survey shows that 12% of transportation fuel is accounted for by aviation industry and it contributes almost 2% of greenhouse gas to environment pollution and global warming as depicted by **Figure-3**.
- CO_2 emissions in 2018 by operations and aircraft class has been shown in **Figure-4**.
- To comply with 2015 Paris Climate Change Accord, improved energy efficiency and increased low-carbon bio-energy and fuel utilization (rate) in aviation industries are expected, and such efforts are in progress in various related fields.
- As examples of such efforts, airlines and aircraft manufacturers voluntarily set goals for carbon-neutral growth, and 50% reduction of greenhouse gases by 2050 with respect to 2005 criteria and various concrete ways are implemented.
- Ordinarily, electricity, solar energy, and hydrogen fuel are mentioned as means of low-carbon energy utilization in transportation fields.
- As for aviation industries, the only technically viable means is limited to bio-jet fuel and its utilization.
- Therefore, long-term carbon reduction is only made possible by increased utilization of bio-jet fuel.
- **Figure-5** shows International Renewable Energy Agency's (IRENA's) future prospect for carbon emission by aviation industries.
- As shown in **Figure-5**, it was known that the 50 % reduction of greenhouse gas is reportedly possible by both the utilization of bio-jet fuel and the increase in the energy efficiency resulting from aircraft design improvement, optimization of airport facility, and flight paths.
- The most representative way to reduce carbon emissions is to develop the biomass-based fuels such as bio-aviation oil with low carbon emission and their production technologies.
- Also, many international airlines have launched pilot projects for their application feasibility.
- However, it is difficult to secure economic feasibility in various cost aspects in order to overcome these problems such as securing economic feasibility, developing bio-air fuels as well as setting international standards and providing incentives for the use of

bio-fuels, which can be the basis for establishing carbon emission goals and policies of international airlines.

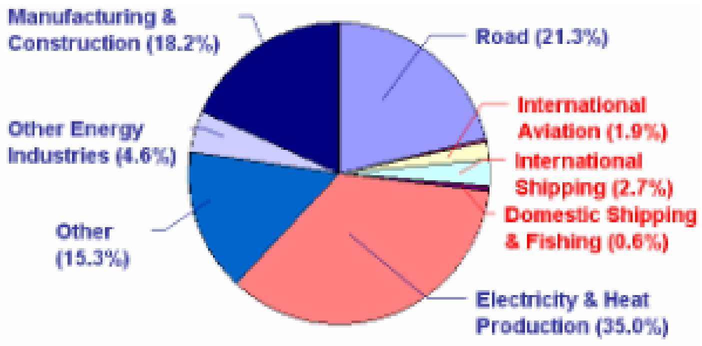


Figure-3: Sector wise contribution of CO_2 emission.

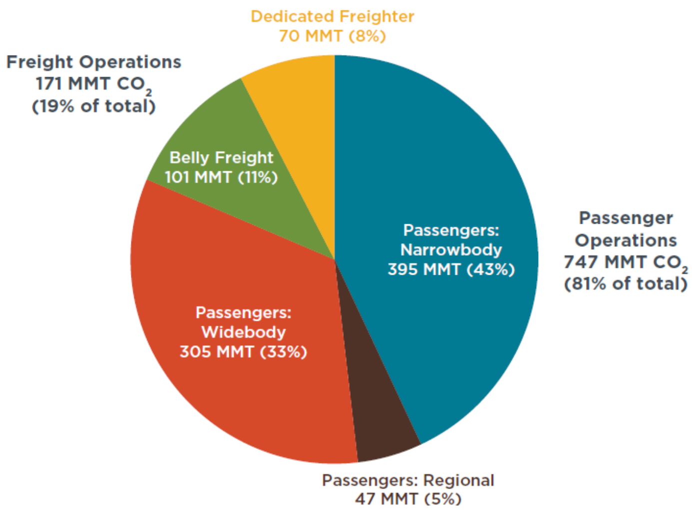


Figure-4: CO_2 emissions in 2018 by operation and aircraft class.

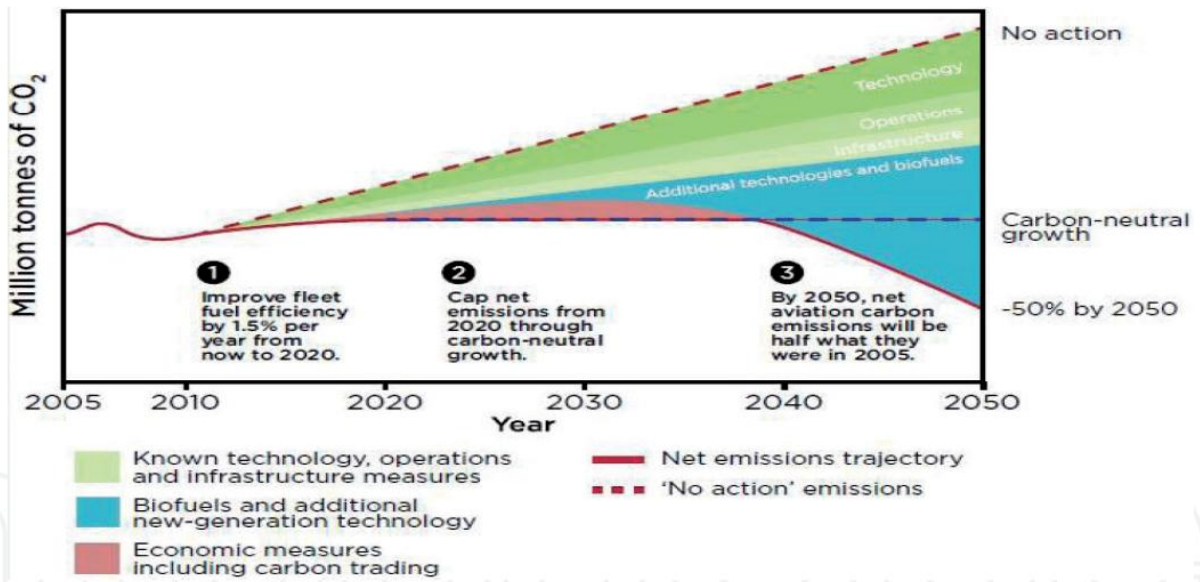


Figure-5: Future prospect for carbon emission reduction by aviation industries (unit: million tons of CO_2).

- In order to overcome such problems as securing economic feasibility, the international standards that can be the basis for establishing carbon emissions goals and policies for international airlines should be established, and the bio-jet fuel market should be activated by securing technologies for developing bio-jet fuel fuels in addition to providing incentives for the use of bio-jet fuels.
- In order to achieve this goal, the ICAO established the Commission for Aviation Environment Protection (CAEP), and efforts to reduce aviation greenhouse gas emissions have been increasing, especially for ICAO.
- Developments are emerging, and countries and international organizations are stepping up their aviation bio-fuel development policies.
- The 38th ICAO General Assembly resolution approved the importance of aviation biofuels as a medium-to-long term GHG reduction measure, established a global framework, the possibility of sustainable drop-in aviation biofuel technology, and emphasis is placed on the need to introduce policies and incentives from a perspective of accelerating wide utilization.
- The IATA announces continued use of renewable energy as the most reliable way to meet its greenhouse gas reduction targets and requires by 2020 to replace 6% of aviation fuel demand with renewables.
- The various bio-fuel support policies are being promoted by spreading awareness that bio-fuels can contribute to greenhouse gas emission reduction, energy security enhancement, rural income, and new market development.
- These support policies include tax exemptions for bio-fuels in most countries, including budgetary support (tax exemption or direct subsidies to bio-fuel producers, sellers, and users), minimum mix ratios, and import tariffs on imported bio-fuels.

➢ JET FUEL SPECIFICATIONS

- In addition to defined target compositions, jet fuel specifications and requirements are mostly defined in terms of required performance properties.
- The specifications required for jet fuels are (1) acceptable minimum energy density by mass, (2) maximum allowable freeze point temperature, (3) maximum allowable deposits in standard heating tests, (4) maximum allowable viscosity, (5) maximum allowable sulfur and aromatics content, (6) maximum allowable amount of wear in standardized test, (7) maximum acidity and mercaptan concentration, (8) minimum aromatics content, (9) minimum fuel electrical conductivity, and (10) minimum allowable flash point (U.S. Department of Defense 2011).
- There are three standards for certifying aviation fuel: ASTM D1655, International Air Transport Association Guidance Material (Kerosene Type), and the United Kingdom Ministry of Defence, Defence Standard (Def Stan) 91-91 (ONGC and Quality Control Laboratory 2008).
- ASTM Specification D7566 (Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons), which targets alternative jet fuel, lists the fuel properties and criteria required to control the production and quality of a renewable fuel for aviation safety (American Society for Testing and Materials 2013).

- **Table-1** shows the jet specifications for two typical jet fuels for commercial (Jet A) and military aircraft (JP-8).
- Jet A-1 is a civilian grade nearly identical to JP-8.
- Jet fuel requires a high flash point for the fire-hazard consideration (ExxonMobil Aviation 2005).
- Detailed specifications can be found in the documentations from ASTM.
- Major fuel properties are similar across different standards, but there are some differences.
- For instance, D7566 is an expansion of D1655 to include fuel specifications required of the synthetic paraffinic kerosene (SPK) blendstocks.
- ASTM D1655 (**Table-1**) is for conventional jet fuel from petroleum and ASTM D7566 is for jet fuel with SPK blending.
- IATA is the International Air Transport Association Guidance Material, Def Stan 91-91 is the United Kingdom Ministry of Defense, and Defense Standard.
- MIL-DTL- 83133E is military turbine fuels, for JP-8.
- The jet fuel cannot be mixed with diesel; it is kerosene-based with specified carbon chain length, and has a relatively higher flash point due to fire-hazard consideration and relatively lower freeze point to ensure good cold flow properties at high altitude.
- In addition, jet fuel needs to meet cold flow properties, such as a lower freezing point, to ensure the fuel can flow at high altitude (ASTM International 2013).

Table-1: Jet Fuel Specifications

(ExxonMobil Aviation 2005; ONGC and Quality Control Laboratory 2008; U.S. Department of Defense 2011; American Society for Testing and Materials 2013; UK Ministry of Defence 2013)

	Jet A-1				JP-8
	ASTM D1655-04a	**IATA**	**Def Stan 91-91**	**ASTM D7566**	**MIL-DTL-83133E specification**
Acidity, Total (mg KOH/g)	0.1, max	0.015, max	0.012, max	0.1, max	0.015, max
Aromatics (vol%)	25, max	25, max	25, max	25, max (8, min)	25, max
Sulphur, Total (wt%)	0.3, max	0.3, max	0.3, max	0.3, max	0.3, max
Distillation Temperature:					
10% Recovery (°C)	205, max	205, max	205, max	205, max	205, max
20% Recovery (°C)	—	—	—	—	—
50% Recovery (°C)	—	—	—	— (15, min)	—
90% Recovery (°C)	—	---	—	— (40, min)	—
Final BP (°C)	300, max	300, max	300, max	300, max	300, max
Flash Point (°C)	38, min	38, min	38, min	38, min	38, min
Freezing Point (°C), max	-47	-47	-47	–40 Jet A ; –47 Jet A-1	-47
Viscosity @ -20°C (cSt)	8, max	8, max	8, max	8, max	8, max
Net Heat of Comb. (MJ/kg)	42.8, min	42.8, min	42.8, min	42.8, min	42.8, min
Density @ 15°C (kg/m3)	775-840	775-840	775-840	775-840	775-840

(**Note:** MIL-DTL-83133E is the standard specifically for JP-8 fuel.)

➢ PRODUCTION TECHNOLOGIES FOR BIO-JET FUEL

- Representative production technologies for bio-jet fuel include alcohol-to-jet (ATJ), oil-to-jet (OTJ), gas-to-jet (GTJ), and sugar-to-jet (STJ) process.
- OTJ process produces bio-jet fuel from animal or plant tallow such as waste vegetable oil, beef tallow, and microalgae.
- More specifically, hydrotreated esters and fatty acid (HEFA) technology, a kind of OTJ process, encompasses hydrotreated renewable jet (HRJ) process among

HEFA technologies, catalytic hydro-thermolysis (CH), and rapid thermal decomposition process (HDCJ).

- STJ process involves catalytic upgrading and conversion of glucose- or starch-based raw material to hydrocarbons or biological conversion to bio-jet fuel via direct sugar to hydrocarbons (DSHC) and catalytic upgrading.
- ATJ process involves production of bio-jet fuel via hydrolysis of wooden fiber biomass or glucose into intermediate alcohols (methanol, ethanol, butanol, and fatty acid alcohols) and their dehydration and oligomerization.
- It is divided into ethanol-to-jet or butanol-to-jet technologies, depending on alcohol involved.
- GTJ process involves biogas, natural gas, or syngas from wood fiber biomass to bio-jet fuel via bio-chemical or thermos-chemical routes such as gas fermentation and Fischer-Tropsch processes.
- **Table-2** shows the production technologies for bio-jet fuel.
- **Figure-6** depicts the production process-wise raw material and technology overview for bio-jet fuel.

Table-2: Production Technologies for Bio-Jet Fuel

Technologies	Production processes
Alcohol to jet	Ethanol to jet
	N-butanol to jet
	Iso-butanol to jet
	Methanol to jet
Oil to jet	Hydro-processed renewable jet
	Catalytic hydro-thermolysis
	Hydrotreated depolymerized cellulosic jet
Gas to jet	Fischer-Tropsch synthesis
	Gas fermentation
Sugar to jet	Direct sugar to hydrocarbons
	Catalytic upgrading

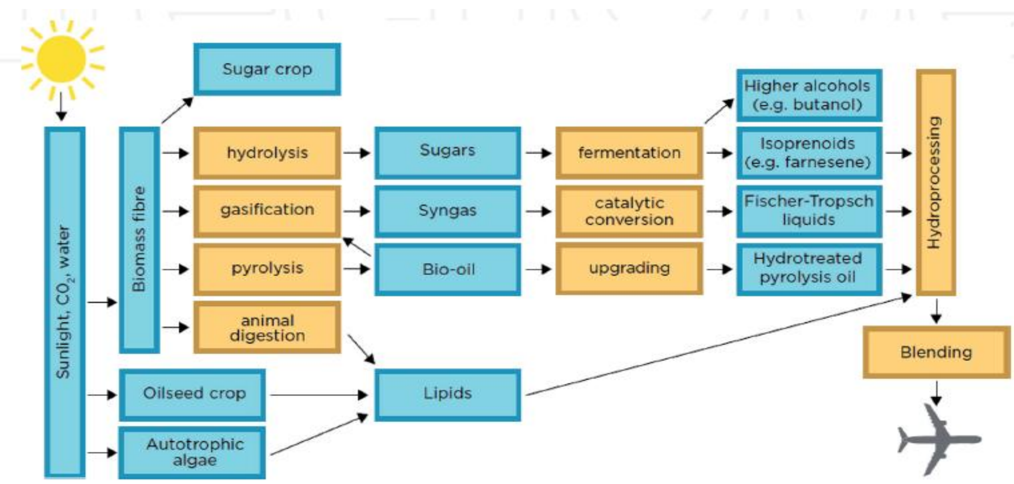


Figure-6: Production process-wise raw material and technology overview for bio-jet fuel.

- Among many classification methods, bio-jet fuel is divided via production pathways: fermentation, deoxidation, or thermal decomposition.
- As of 2016, ASTM 7566 dictates five production processes (Fischer-Tropsch Synthetic Kerosene with Aromatics (FT-SPK), HEFA, Synthesized Iso-Paraffins (SIP), ATJ as means to produce commercially viable bio-jet fuels.
- It simultaneously regulates product quality criteria as per 100% assay as well as mixing proportion in existing petroleum-based aviation fuel.
- Many other production processes are also used to produce bio-jet fuel, and the following technologies are under review by ASTM for approval.
- **Table-3** shows production process-wise classification of bio-jet fuel production process.

Table-3: Production Process-Wise Classification of Bio-Jet Fuel Production Process

Production process	Developer/manufacturer	Raw materials	Aromatic content	ASTM review stage and max. Mixing proportions
FT-SPK	Sasol, Shell, Syntroleum	Coal, natural gas, biomass	Low	(2009)-50% Approved
HEFA	Honeywell UOP, Neste Oil, Dynamic Fuels, EERC	Vegetable oil, animal fat, recycled vegetable oil	Low	(2011)-50% Approved
SIP	Amyris, Total	Sugar	Low	(2014)-10% Approved
ATJ-SPK	Gevo, Cobalt, Honeywell UOP, LanzaTech, Swedish Biofuels, Byogy	Starch, sugar, cellulose-based biomass	Low	(2016)-30% Approved
FT-SKA	Sasol	Coal, natural gas, biomass	High	Under review by committee
HDO-SK	Virent	Starch, sugar, cellulose-based biomass	Low	Investigation report submitted
HDO-SAK	Virent	Starch, sugar, cellulose-based biomass	High	Investigation report under review
HDCJ	Honeywell UOP, Licella, KiOR	Cellulose-based biomass	High	Supplement to investigation report received
CH	Chevron Lummus Global, Applied Research Associates, Blue Sun Energy	Vegetable oil, animal fat, recycled vegetable oil	Low	Investigation report under review

➢ BIO-ALCOHOL-BASED BIO-JET FUEL PRODUCTION TECHNOLOGY

- **Figure-7:** shows current worldwide production and consumption trend of bio jet fuel.
- Bio-ethanol is widely commercialized as sustainable source of energy for use intransportation with worldwide production of 104 million m^3 and 80% of its utilization as transportation fuel.
- The USA and Brazil accounted for 51.8 and 2.77 million m^3 production, respectively.
- Worldwide bio-jet fuel amounted to 30 billion m^3.
- On the other hand, Korean domestic petroleum-based aviation fuel products totalled 13% (20.66 million m^3) in 2013, which is similar to gasoline products (13.5%) and 44% of light oil products.
- Among these alcohols, bio-ethanol utilization is promising in view of its current production and consumption and worldwide use.

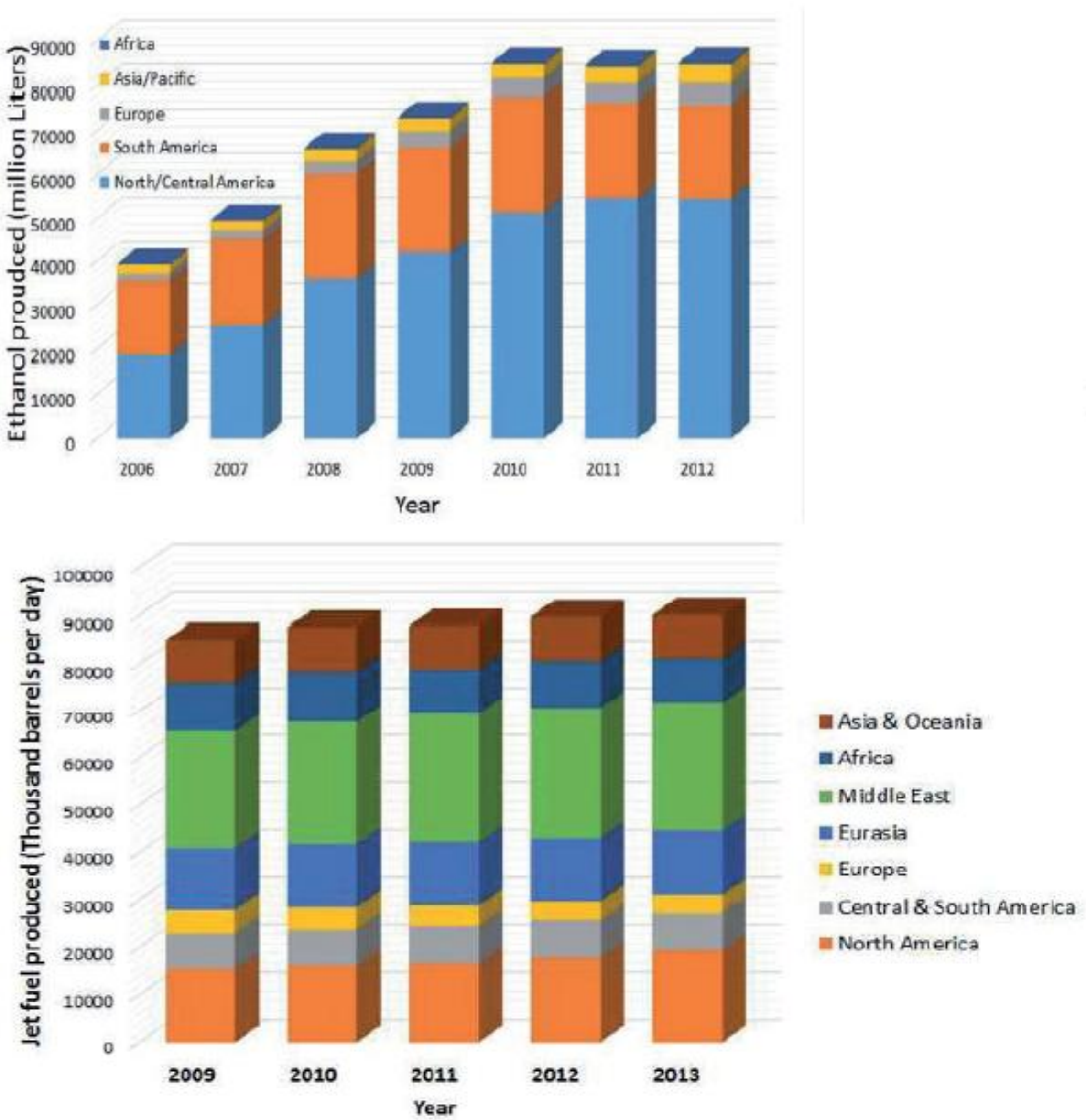


Figure-7: Worldwide bioethanol production and consumption of biojet fuel.

- Possible raw material for ATJ process includes methanol, ethanol, and butanol.
- Such alcohol-based raw material is converted to bio-jet fuel via polymerization and upgrading technology.
- At present, bio-ethanol is mixed to maximum 10~15% with gasoline.
- Although potential market of ethanol for mixing with gasoline seems limited for expansion, conversion to bio-jet fuel via bio-ethanol upgrading shows possibility of replacing existing petroleum-based aviation fuel.
- For conversion of bio-ethanol to bio-jet fuel, physicochemical properties of bio-ethanol should be compatible with petroleum-based aviation fuel.
- The USA is utilizing advanced ATJ technology to make physicochemical properties of bio-ethanol compatible with those of existing petroleum-based fuel.
- More specifically, 99.5~99.9% of anhydrous ethanol is mixed with existing fuel or converted to bio-jet fuel.
- High purity ethanol is used as raw material in the process for upgrading physicochemical properties of bio-jet fuel.
- Such ATJ process is based on bio-ethanol for production of bio-jet fuel, and oxygen contents of bio-ethanol is removed by dehydration, polymerization for access of carbon atoms from existing petroleum based aviation fuel, and hydrogenation reaction for optimization of physicochemical properties.
- **Figure-8** shows technical overview of ATJ process for production of bio-jet fuel from bio-ethanol.

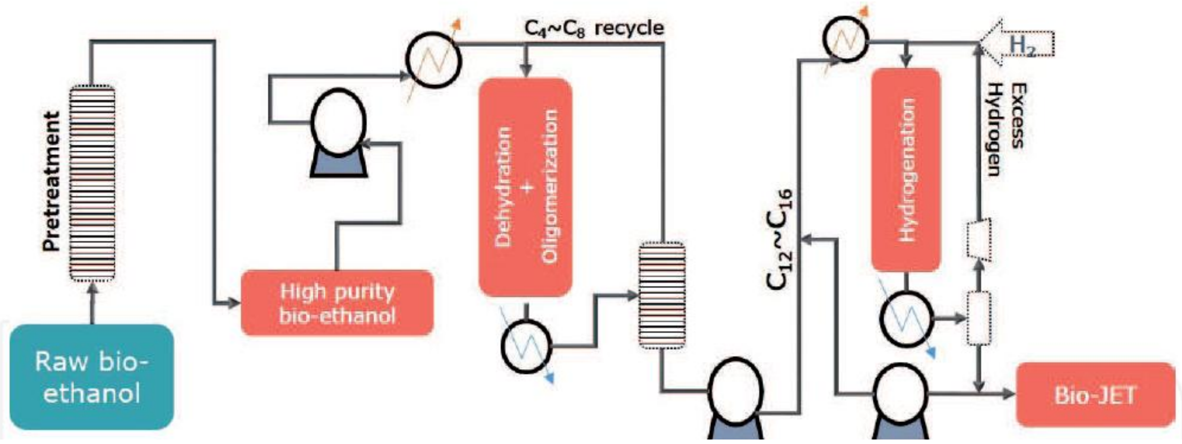


Figure-8: Technical overview of ATJ process for production of bio-jet fuel from bio-ethanol.

- To convert ordinary alcohol to fundamental aviation fuel element of hydrocarbon, oxygen contents have to be removed by dehydration via catalytic upgrading process.
- Alumina, transition metal oxides, and zeolite may be used as catalysts.
- Ethylene is obtained by removal of oxygen via dehydration.
- Ethylene is converted to another reaction intermediate of alpha-olefin by polymerization called oligomerization.
- This is approximately equivalent to existing aviation fuel compound and intended to increase distribution of carbons.
- Candidate catalysts include Ziegler-Natta-based, homogeneous chromium-diphosphine-based, and heterogeneous zeolite-based catalysts.

- During oligomerization reaction alpha-olefin with C4~C20 carbon numbers may be synthesized with 96~97% of yield.
- Commercial oligomerization reaction carried out at higher temperature and pressure where relatively wide range of carbon distribution such as 5% C4, 50% C6~C10, 30% C12~C14, and 12% C16~C18 may be obtained.
- Such wide range of carbon numbers enables separation by selective distillation to light oil and aviation fuel.
- Hydrocarbons with low carbon numbers of C4~C8 separated by selective distillation process are reintroduced into oligomerization process and further synthesized into hydrocarbons with relatively high carbon numbers.
- Existing petroleum-based aviation fuel consists of hydrocarbons with C6~C16 range of high carbon numbers which require upgrading process.
- Such upgrading process necessitates hydrogenation reaction in hydrogen atmosphere under specified conditions of temperature, pressure and flow rate.
- After separation, excess hydrogen is reused, un-hydrogenated hrdocarbons are recycled and the hydrogenated one are used as bio ATF after blending with conventional ATF as shown in the **Figure-8**.

CURRENT STATUS OF BIO-JET FUEL PRODUCTION AND UTILIZATION

Current status of bio-jet fuel production and utilization has been shown in the **Table-4**.

Table-4: Current Status of Bio-Jet Fuel Production and Utilization

Airlines	United	Cathay	FedEx/ Southwest	United	JetBlue	GE Aviation	Gulf Stream	KLM	Lufthansa
Providers	Altair	Fulcrum	Red Rock	Fulcrum	SG Preston	D' Arcinoff	World Fuel Services (Altair)	Altair	Gevo
(t/yr)Supply	17,000	100,000	10,000	270,000+	33,500	17,000	—	—	270,000+
Major raw material	Waste fat oil	Waste	Forest residue	Waste	Vegetable oil	Cellulosic biomass	Waste fatty oil	Waste vegetable oil	Wood waste
Duration	3 years	10 years	8 years	10 years	10 years	10 years	3 years	3 years	5 years
Introduced	2016	2019	2017	2019	2019	—	2016	—	—
Contract year	2013	2014	2014	2015	2016	2013	2015	2016	2016

REPRESENTATIVE TEST FLIGHT DATA FOR CIVIL AND MILITARY AIRCRAFT

The representative test flights data for civil and military aircraft have been reflected in **Table – 5.**

Airlines	Aircraft	Manufacturer/partners	Year	Raw material	Mixing proportion of bio-jet fuel
Virgin Atlantic	B747–400	Boeing, GE Aviation	2008	Coconut babassu	20%
Air New Zealand	B747–400	Boeing Rolls-Royce, UOP	2008	*Jatropha*	50%
Continental Airlines	B737–800	Boeing, GE Aviation, CFM, Honeywell UOP	2009	2.5% Algae, 47.5% *Jatropha*	50%

Continued from Table-5

JAL	B747–400	Boeing, Pratt & Whitney, Honeywell UOP, Nikki-Universal	2009	42% *Camelina*, 8% *Jatropha*, <0.5% algae	50%
KLM	B747–400	GE, Honeywell UOP	2009	*Camelina*	50%
KLM	B737–800	SkyNRG, Dynamic Fuels	2011	Waste cooking oil	50%
TAM Airlines	A-320	Airbus, CFM	2010	*Jatropha*	50%
Boeing	B747-8F		2011	*Camelina*	15%
Air France	A-321	SkyNRG	2011	Waste cooking oil	50%
Gulfstream Aerospace	Gulfstream G450	Honeywell, NBAA	2012	*Camelina*	50%
Air China	B747–400	Boeing, PetroChina	2012	*Jatropha*	50%
Alaska Airlines	B737, Bombardier Q400	Dynamic fuels, Horizon air	2011	Algae and waste cooking oil	20%
Paramus Flying Club	Cessna 182	SkyNRG	2013	Waste cooking oil	50%
LAN	A-320	Honeywell	2013	*Camelina*	30%
Thai Airways	Boeing-777	SkyNRG	2012	Waste cooking oil	50%
NRC Canada	Falcon 20, T-33	Aemetis, AFRL, Rolls-Royce, FAA-CLEEN, Agrisoma Biosciences, Applied Research Assoc., Chevron Lummus Global	2012	Carinata	100%
Military aircraft	**Aircraft**	**Manufacturer/partners**	**Year**	**Raw materials**	**Mixing proportion of bio-jet fuel**
US Navy	F/A-18	Honeywell UOP	2010	*Camelina*	50%
US Air Force	A-10c	Honeywell UOP	2010	*Camelina*, waste cooking oil	50%
US Air Force	F-22	Honeywell UOP	2011	*Camelina*	50%
US Navy	MH60S Seahawk Helicopter	Honeywell UOP, Bozeman	2010	*Camelina*	50%
US Navy	MH60S Seahawk Helicopter	Solazyme	2011	Algae	50%
Netherlands Air Force	AH-64D Apache Helicopter	Honeywell UOP	2010	Waste cooking oil and algae	50%
US Army	Sikorsky UH-60 Black Hawk helicopter	Gevo	2013	Cellulose-derived alcohol	50%
US Air Force	B-52	Syntroleum	2006	Natural gas	50%