The 8th RD20 International Conference

Accelerating Clean Energy Innovation: From Africa to the World

Organizer: Council for Scientific and Industrial Research (CSIR) Co-organizers: National Institute of Advanced Industrial Science and Technology (AIST), Japan

Technical Session 2: Synthetic Fuels

Title: **'Sustainable Aviation Fuel Through Alcohol to Jet Pathway'**

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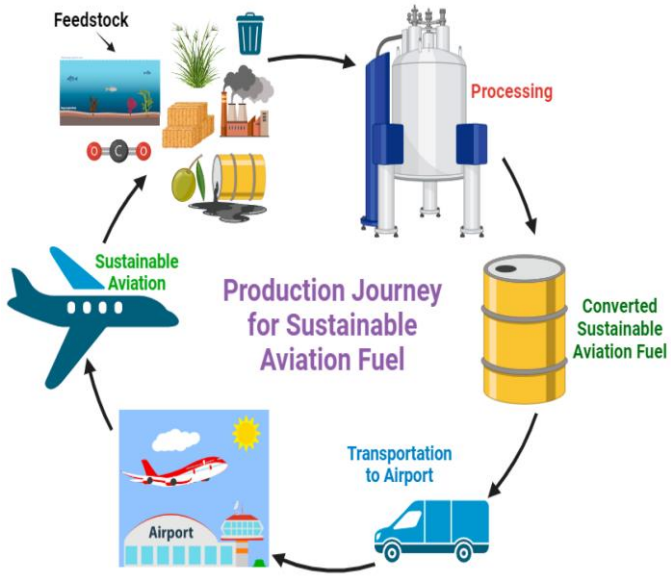
Introduction

- The global aviation sector contributes **2% of global CO_2 emissions** (920 MMT), which is projected to rise further up to 25% by 2050.
- Aviation is a hard-to-abate sector with rapid growth projections. Global passenger numbers are expected to increase from 7 billion in 2022 to nearly 10 billion by 2050.
- Sustainable Aviation Fuel (SAF) has emerged as the potential green fuel for aviation sector as it is a direct substitute for conventional fossil-based jet fuel.
- It does not require any engine modifications to existing aircraft engines or fueling infrastructure. Hence, **SAF can be used as drop-in fuel** for blending with conventional fuel (as ASTM international certified pathways).

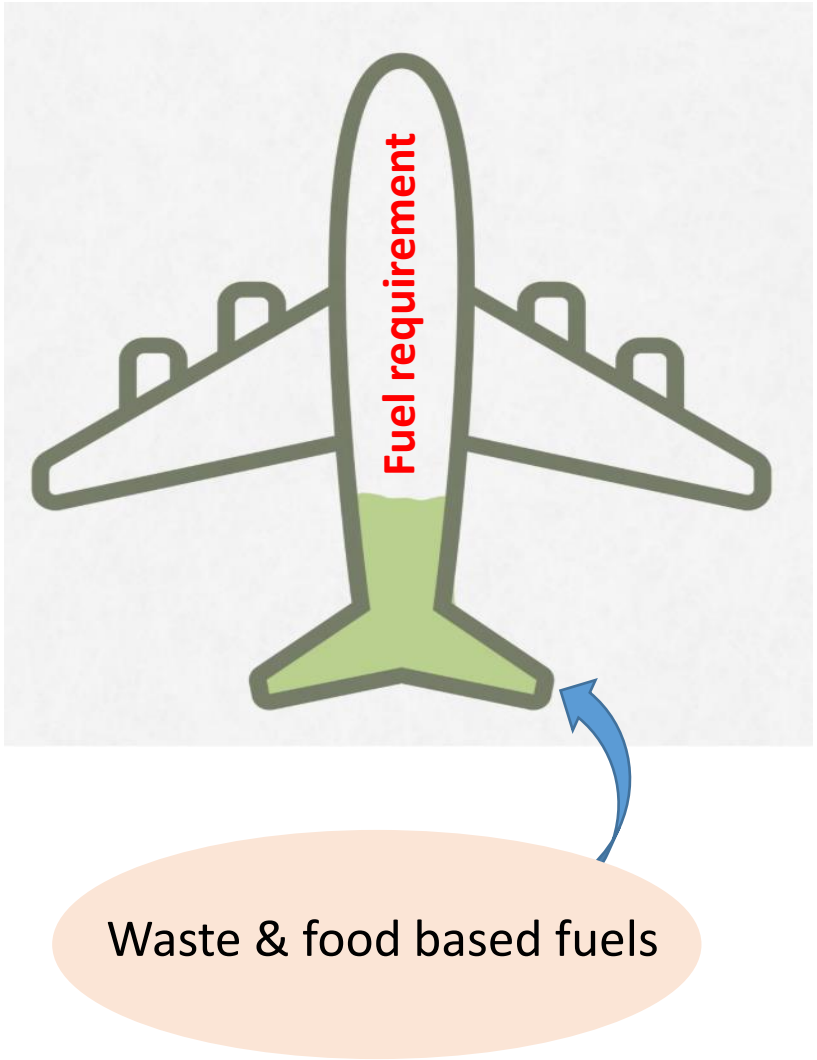


ASTM certified SAF production Pathways

SAF production pathway	Pathway description	Potential feedstock	CORSIA approved Maximum blending proportion limit	Potential GHG emission reduction	Technology Readiness Scale
HEFA	Synthesized paraffinic kerosene from hydro-processed esters and fatty acids	Vegetable oils, animal fats, used cooking oils, fish fat, technical corn oil, tall oil based raw materials	50%	70-95%	9
AtJ (Alcohol-to-Jet)	Alcohol to jet synthetic paraffinic kerosene	Ethanol, iso-butanol and isobutene from biomass (sugar, starch crops, corn, sugarcane, molasses, agricultural residues)	50%	70-95%	7-8
FT (Fischer-Tropsch)	Fischer-Tropsch hydro processed synthesized paraffinic kerosene	Biomass, Municipal Solid Waste (MSW), Agricultural/Forestry residues	50%	70-95%	7-8
Power-to-Liquids (PtL) / e-SAF	Manufacturing synthetic hydrocarbons from carbon dioxide and water via electrolysis	Captured CO_{2} (Biogenic or Industrial) and Green Hydrogen	50% (under FT-SPK pathway)	90%+	7
Co-processing in oil refinery	Co-hydro processing of esters and fatty acids in a conventional petroleum refinery	Vegetable oils, animal fats, used cooking oils from biomass processed with petroleum	5%	60-80% (incremental)	Commercial maturity
CHJ	Catalytic hydro thermolysis jet fuel	Vegetable oils, animal fats, used cooking oils	50%	80-90%	Early stage POC
SIP	Synthesized iso-paraffins from hydro-processed fermented sugars	Biomass used for sugar production	10%	65-80%	POC validation required
FT-SKA	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	Biomass	50%	70-95%	POC validation required
HC-HEFA-SPK	Synthesized paraffinic kerosene from hydrocarbon-hydro-processed esters and fatty acids	Algae	10%	80-90%	POC validation required

SAF feedstock

- SAF production is dominated by oleochemical/lipidic sources (vegetable oils like soy, palm etc.)
- These substrates will not be adequate enough to fulfill huge aviation industry demand
- Lignocellulosic biomass is cheaper and one of the crucial replacement to fossil sources for fuels and chemicals production
- SAF from biomass enables absorption of CO2 during growth through photosynthesis and liberates during combustion, building a closed carbon cycle



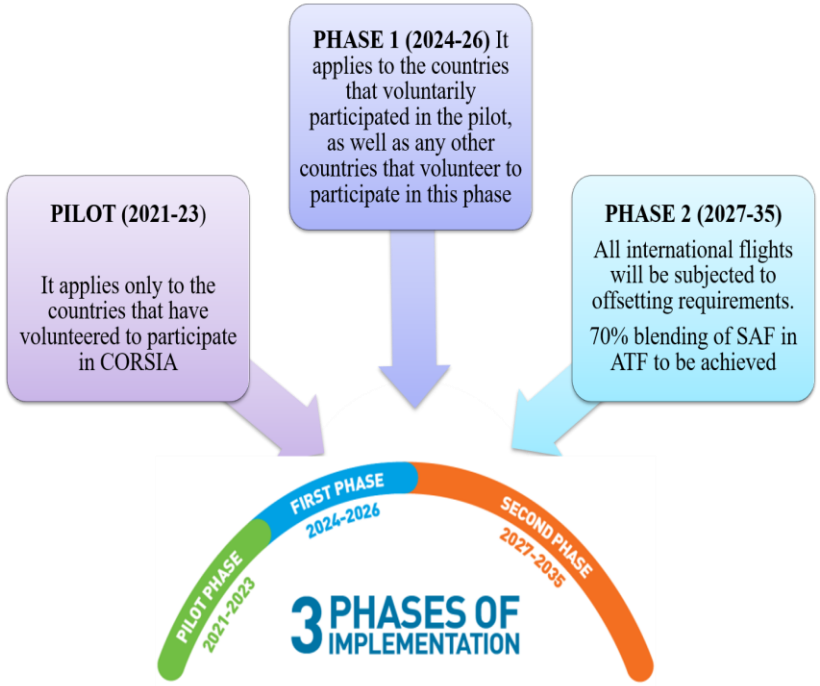
SAF production pathways: Chemistry, certification & maturity

Pathway	Feedstock → key chemistry	ASTM route	Max blend	Commercial maturity	Main constraint
HEFA-SPK	Lipids → deoxygenation + hydroisomerisation	D7566 A2	50%	Industrial	Lipid feedstock ceiling
ATJ-SPK	Ethanol / i-BuOH → dehydration + oligomerisation + H_2	D7566 A5	50%	First commercial plant	Alcohol CI + yield + H_2
FT-SPK / FT-SKA	Biomass/MSW syngas → FT synthesis + upgrading	D7566 A1/A4	50%	Limited SAF deployment	CAPEX + gas cleanup
PtL / e-SAF	Renewable H_2 + captured CO_2 → syngas/MeOH → jet	FT-based / routes evolving	50% after certification	Early commercial	Power demand + cost
SIP / CHJ / HC-HEFA	lipids → Sugars or chemical / thermochemical conversion	A3 / A6 / A7	10–50%	Niche / pre-scale	Blend cap, yield, feedstock

Scientific interpretation: ASTM approval establishes fuel safety and blendability; commercial acceptance additionally needs repeatable operation, certified lifecycle performance, feedstock security, finance and contracted offtake.

SAF Policy Landscape

- **United States**: Rolls out for SAF credit of **$1.25–$ 1.75** per gallon. The "SAF Grand Challenge" aims for 3 billion gallons/year by 2030 and 35 billion by 2050.
- **European Union**: RU's The "ReFuelEU Aviation Initiative" mandates Initial SAF blending of 2% in 2025, then subsequent rising to 70% by 2050, with specific sub-targets for PtL SAF.
- **United Kingdom**: UK Mandates for **2% SAF by 2025**, then subsequent enhancing to 22% by 2040. UK policy Includes a "buy-out" mechanism to ensure compliance.
- **Japan:** Proposed **10% SAF** mandate for international flights by 2030.
- **India:** Indicative targets of **1% blending by 2027 and 2% by 2028** for international flights.



CORSIA: what changes from 2027

International aviation enters the mandatory second phase

2024–26

First phase

2027–29

Mandatory second phase

2030–35

Broader second phase

Fuel claim

Operators may reduce offsetting requirements using CORSIA eligible fuels.

Supply-chain rule

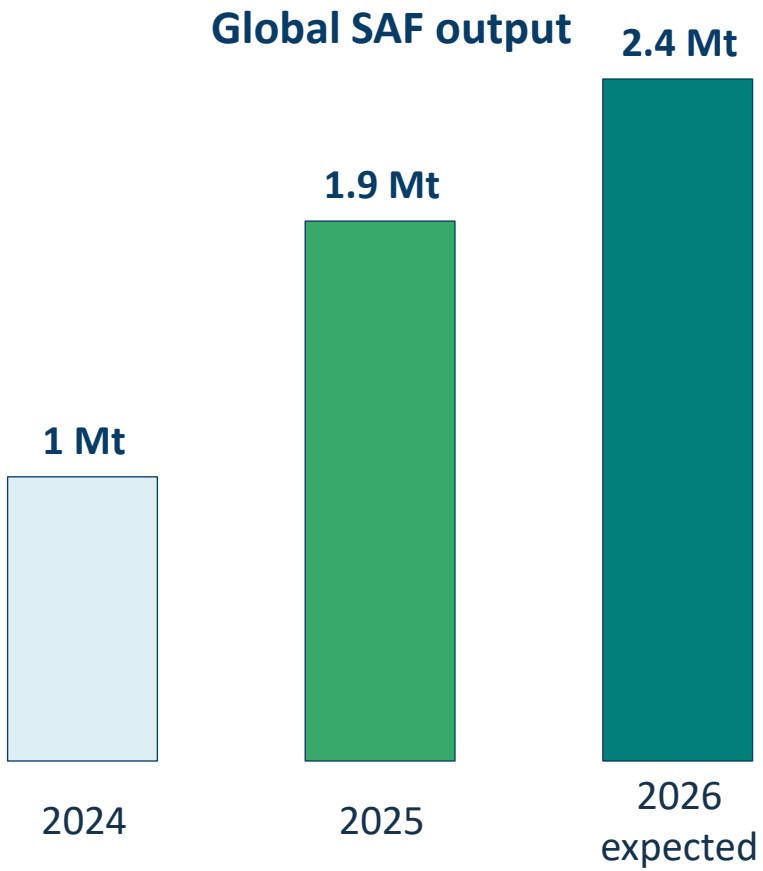
Economic operators across the chain must be certified under an ICAO-approved scheme.

Data rule

Claims require monitoring, reporting, verification and lifecycle-emissions documentation.

Global SAF production Status: Rapid growth from a very small base

Supply remains below 1% of aviation fuel use



0.8%

Estimated share of aviation fuel use in 2026.

US$4.3 bn

Estimated 2026 cost to airlines.

~400 Mt

Potential SAF production in 2050 under IATA core forecast.

~500 Mt

Estimated SAF need in 2050 for net-zero pathway.

Scale-up gap: roughly 100 Mt in 2050 under the core feedstock and technology outlook.

Alcohol to Jet Fuel Production Pathway

Why ATJ Pathway?

Availability of diverse feedstocks: *leverages the massive global bioethanol and alcohol production infrastructure, drawing from an abundant, diverse pool of carbohydrate- and waste-based resources*

Proven Chemical Processes: *The conversion process uses standard and reliable acid catalysis, such as alcohol dehydration and olefin oligomerization, compared to the complex or high-pressure hydrogen infrastructure*

Easy operations: *leverages an enormous, pre-existing global ethanol infrastructure, bypassing the structural constraints holding back other major methods*

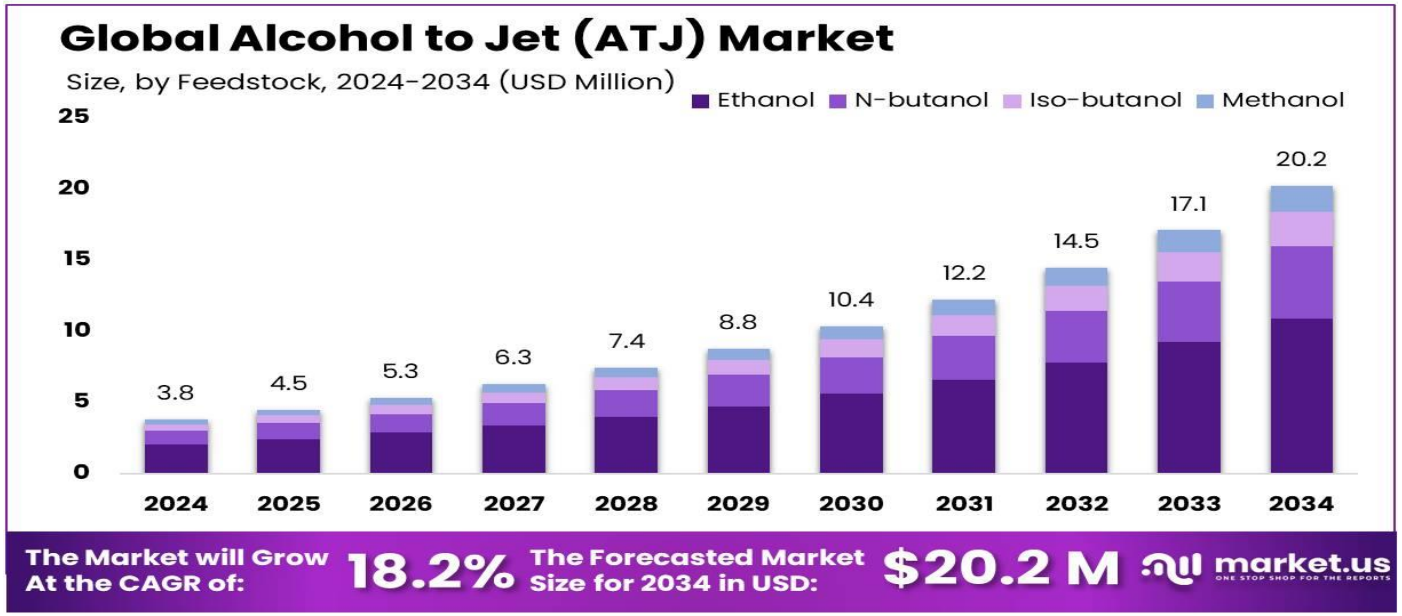
Infrastructure Compatibility: *Integrates seamlessly into existing industrial ethanol biorefineries and remains fully compatible with current fuel distribution systems*

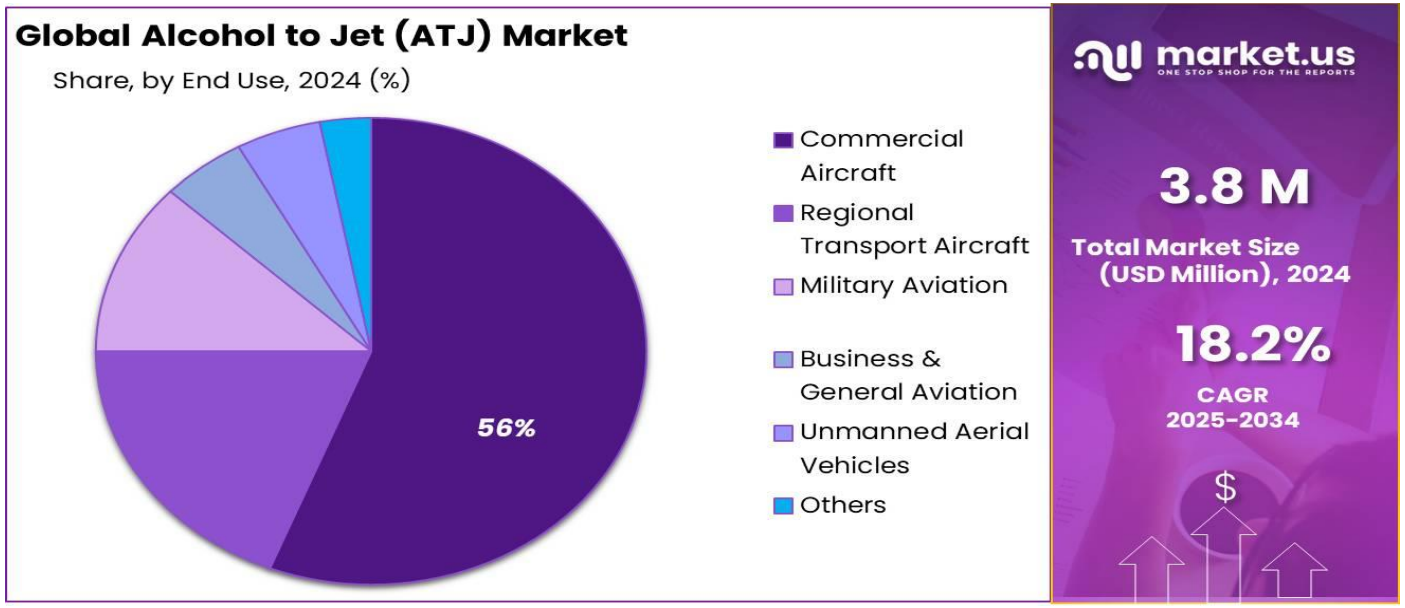
Future Flexibility: *The maturation of agricultural waste conversion and cellulosic ethanol production facilitates a seamless transition for the ATJ pathway toward non-food biomass feedstocks*

ASTM Certification: *ATJ processes are fully certified under IATA and ASTM guidelines, ensuring the final blending with fuel, meeting all strict commercial aircraft safety requirements*

Global Alcohol to Jet market

- **Global Alcohol to Jet (ATJ) Market** size is projected at **USD 20.2 Mn** by 2034,
- **Ethanol** is one of the potential feedstock for SAF owing to its commercial maturity, ease of production form diverse feed stock, availability , cost-effectiveness/ captured over a **54.60%** market share in 2024





https://market.us/report/alcohol-to-jet-atj-market/

A to J SAF – Potential opportunities for India

Ethanol-to-Jet (ETJ) Pathway

- Converts ethanol → aviation fuel
- Blending potential: up to 50% SAF with ATF (global standards)

Current Status

- India: pilot-scale & R&D stage.
- Global SAF share: <0.1% of aviation fuel demand.

Potential

- Aviation contributes ~2-3% global CO2 emissions.
- Ethanol-based SAF can reduce emissions by ~60-80%.

India Opportunity

- Large ethanol supply base.
- Strong policy push under biofuel roadmap.

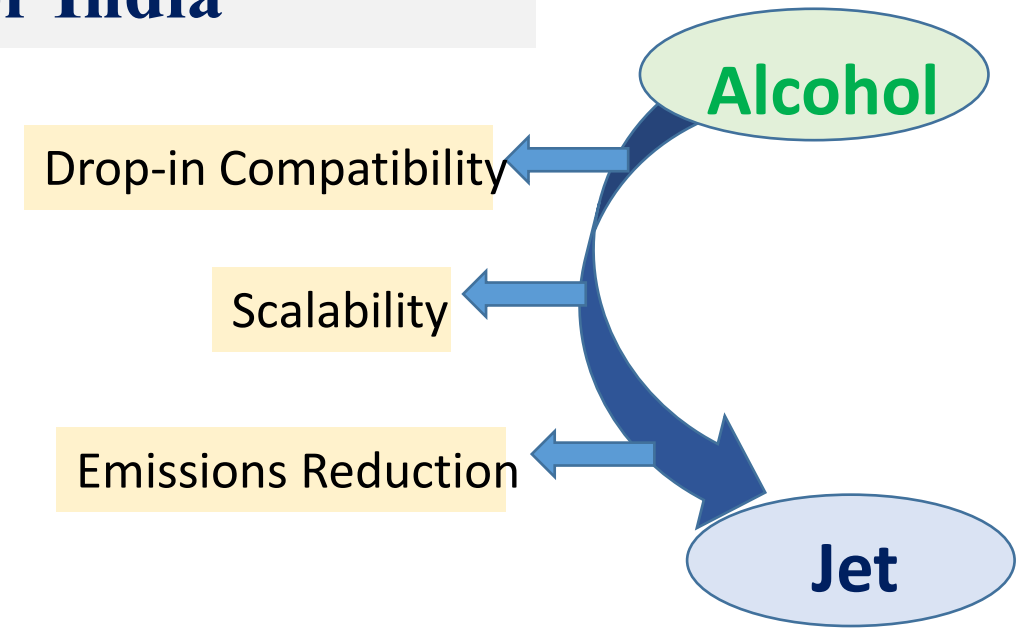
TECHNOLOGY AND RECENT INNOVATIONS

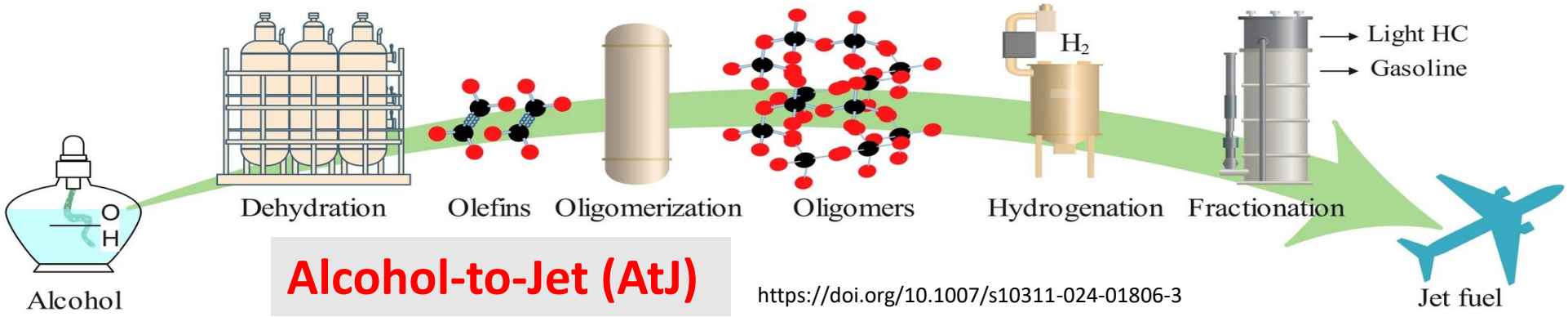
S.NO	Pathway	Feedstock	CapEx ($/L)	OpEx ($/L)	Market Price ($/L)	Conversion Efficiency	Tech Maturity
1	HEFA	Used cooking & vegetable oil	~$1.8-2.5	$1.2-1.5	$1.6-2.0	~80%	9 (Commercial)
2	ATJ	Ethanol, butanol	~$2.5-4.0	$2.2-2.6	$2.7-3.2	~45-55%	7-8 (Demo)
3	FT-SPK	Biomass, municipal solid waste	~$3.5-5.0	$2.0-2.4	$2.5-3.0	~35-40%	7-8 (Demo)

Source: https://www.downtoearth.org.in/energy/ethanol-success-can-power-indias-green-s

A to J based SAF production : Potential opportunities for India

- **Alcohol-to-Jet (AtJ)** is ASTM-approved for **ethanol, isobutanol, and mixed alcohols (C_2 – C_5)**
- India has substantial potential for SAF production through AtJ pathway, (projected capacity **4 billion liters/year** by 2028-2030)
- Leveraging existing **8x growth** in ethanol capacity, India can meet domestic mandates and export surpluses, targeting **16–19 billion liters** total SAF production by 2040

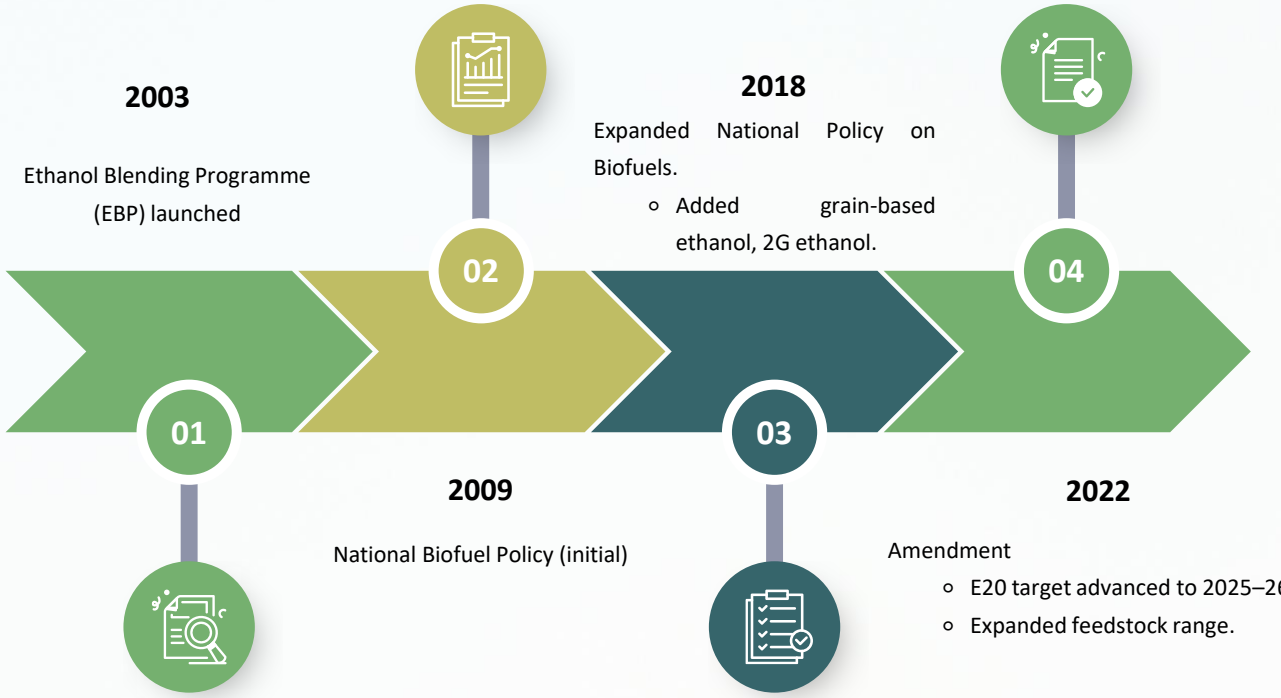




Alcohol-to-Jet (AtJ)

https://doi.org/10.1007/s10311-024-01806-3

India: National Biofuel Policy



Role in National Biofuel Policy

- Reduces crude oil import dependency.
- Enhances farmers income.
- Enables waste-to-wealth (2G ethanol).
- Supports Net Zero & emission reduction.

Ethanol Blending Programme (EBP) - Policy interventions

Ethanol Pricing (Feedstock-based)	Government sets different prices for ethanol made from molasses, grains, and sugarcane juice → ensures fair income for producers and promotes use of different raw materials.
Support for Capacity Expansion	Low-interest loans are provided to set up new distilleries → helped increase production capacity from ~400 to 1800+ crore litres.
Long-term OMC Purchase Agreements	Oil companies (OMCs) buy ethanol at fixed terms → gives assured market and stable income to producers.
Expansion of Grain-based & 2G Ethanol Plants	Use of rice, maize, and agricultural waste → reduces dependence on sugarcane and supports continuous production.

Source: https://www.greenpermits.in/11/understanding-ethanol-blending-in-india-ebp-programme-contracts-pricing-mechanism-supply-chain/
https://www.business-standard.com/article/economy-policy/govt-s-ethanol-blending-programme-faces-supply-and-pricing-problem-122101300985_1.html
https://advocategandhi.com/ethanol-blending-programme-ebp-in-india-a-comprehensive-legal-and-policy-perspective/
https://energyasia.co.in/oil-gas/cabinet-approves-revised-ethanol-procurement-prices-for-public-sector-omcs/

National Green Hydrogen Mission: India’s initiatives

Market Growth:

The India Green Hydrogen Market is projected to grow at a significant 22.50% CAGR from 2023 to 2032, driven by the country's commitment to a sustainable low-carbon future.

Policy Support:

Government incentives, subsidies, and regulatory frameworks are bolstering the green hydrogen sector, with financial support for pilot projects and encouragement for private sector participation.



Government Initiatives:

A central driver, promoting large-scale green hydrogen projects to reduce carbon emissions and combat climate change, creating opportunities for both national and international players.

Geopolitical and Global Collaboration:

India is positioning itself strategically in the global green hydrogen market, engaging in international partnerships and technology transfer agreements to strengthen its role in the global energy transition.

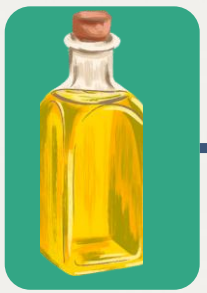
Source: National Green Hydrogen Mission, Report 2023. Government of India, Ministry of New And Renewable Energy.

India: latest rules and implementation status

1	**17 Apr 2026**	ATF Control Order amended to cover SAF-blended aviation fuel.
2	**Fuel standards**	Co-processed SAF with ATF under IS 1571; SAF conforming to IS 17081 blended with ATF and meeting IS 1571.
3	**Indicative trajectory**	International flights: 1% in 2027, 2% in 2028 and 5% in 2030.
4	**CORSIA readiness**	Fuel must also satisfy CORSIA sustainability criteria to qualify as CORSIA-eligible fuel.
5	**Next system needs**	National registry, traceability, MRV, certification capacity, airport logistics and bankable offtake.

The April 2026 amendment is the key legal enabler

HEFA (HYDROPROCESSED ESTERS AND FATTY ACIDS)



Vegetable Oil

Water

Hydrolysis

Aqueous phase remaining

Glycerol



Fatty acids

Hydro-deoxygenation

N-Alkanes

Hydroisomerization Hydrocraking

Product separation

Products & By-products

Naptha



SAF



Diesel



Some players working in HEFA pathway

INDIA

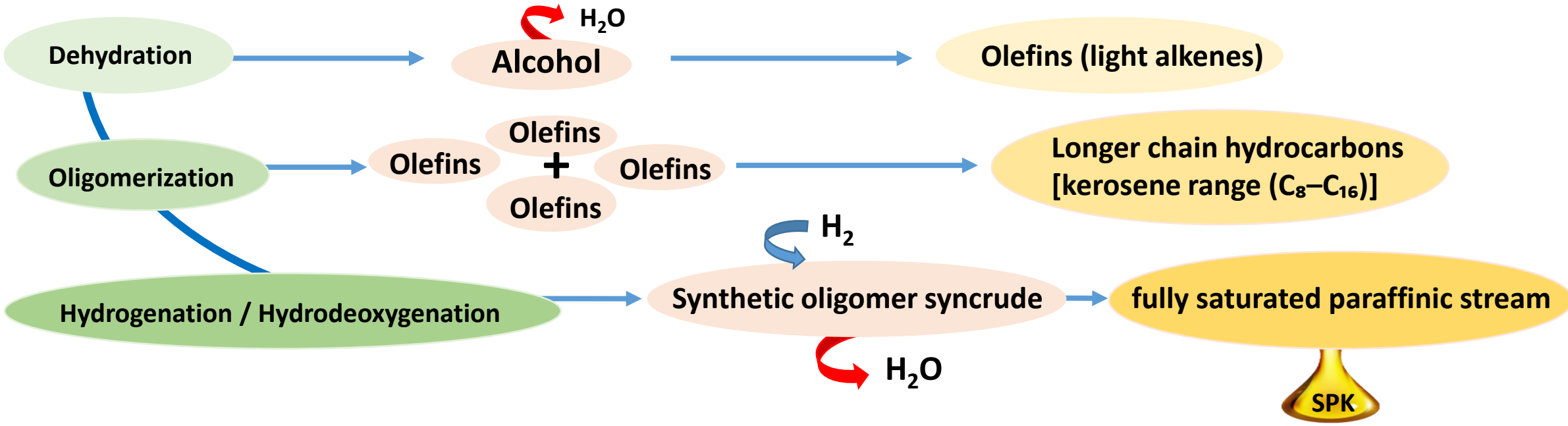
- ❑ CSIR-Indian Institute of Petroleum (CSIR-IIP).
- ❑ Airbus & CSIR-IIP Partnership.
- ❑ Xytel India.

Global

- ❑ Neste
- ❑ Honeywell UOP.
- ❑ Haldor Topsoe.

Source courtesy: https://www.hscatalysts.com/en/blog/250225-saf-2-3/
https://www.civilsdaily.com/news/airbus-and-csir-iip-collaborate-to-advance-sustainable-aviation-fuel-in-india/

Alcohol to Jet fuel conversion: Mechanism



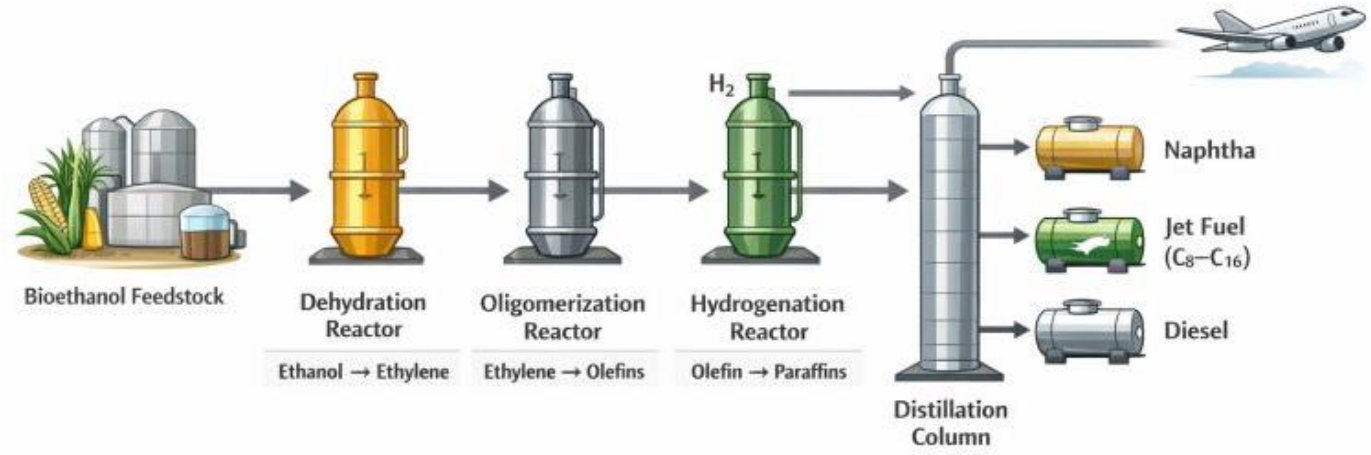
Key players

INDIA

- ❑ Praj Industries
- ❑ Indian Oil Corporation (IOCL)
- ❑ Indian Sugar & Bio-Energy Manufacturers Association (ISMA).

Global

- ❑ LanzaJet
- ❑ Honeywell UOP.
- ❑ Gevo Inc



Feedstock Availability for Alcohol to Jet fuel conversion

- India has an installed **ethanol** capacity exceeding **20 billion liters** per year, with surplus capacities estimated around **8 to 9 billion liters**, heavily supporting the **AtJ pathway**

- In April 2026, the **Ministry of Petroleum and Natural Gas** updated **Aviation Turbine Fuel** (ATF) specifications to permit blending conventional jet fuel with synthetic hydrocarbons (IS 17081), clearing the legal path for AtJ-derived SAF

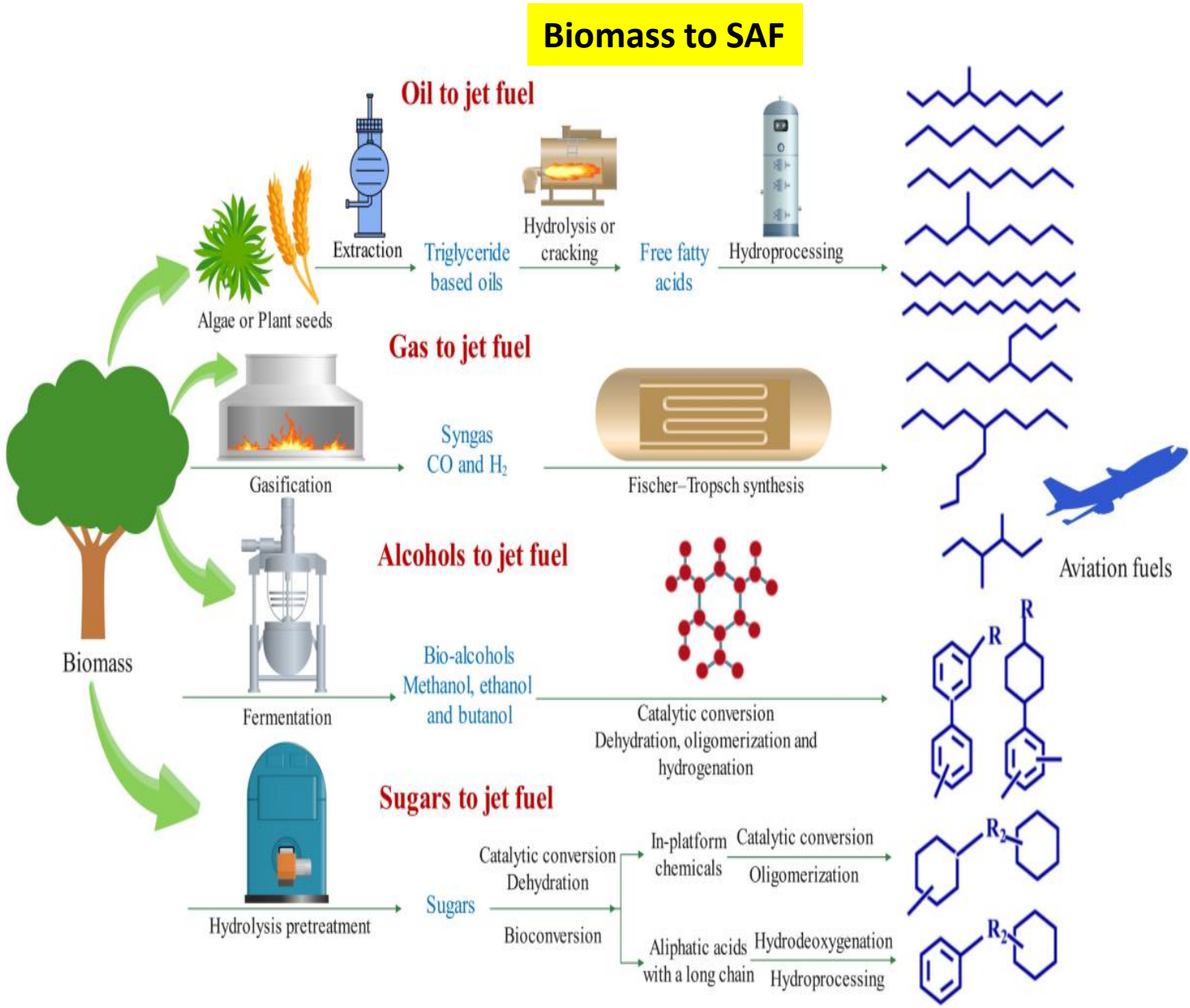
- India set indicative international flight blending mandates starting at **1%** (**53–140** million litres) in 2027, scaling to **2% (**around **290** million litres) in **2028**, and reaching **5%** (around **720** million litres) by 2030

- By 2040, the country could produce **8–10 million tonnes** of SAF per year, which would not only meet domestic demand but also allow the country to become a major exporter.



Biomass/feedstock availability in India

- The assessment of total biomass availability in India, reveals an estimated potential of over **600 million tones** (Mt) annually
- The national surplus biomass is estimated at **285 Mt/year**, that offers significant **untapped energy potential**
- India's biomass feedstock potential for **SAF** is projected as **105 Mt/year** by **2030** and **154 Mt** by **2050**

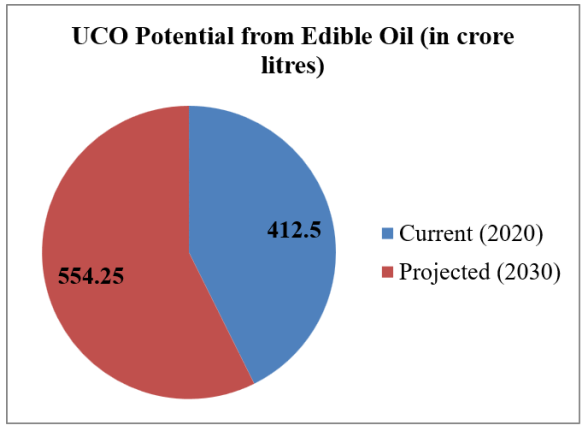


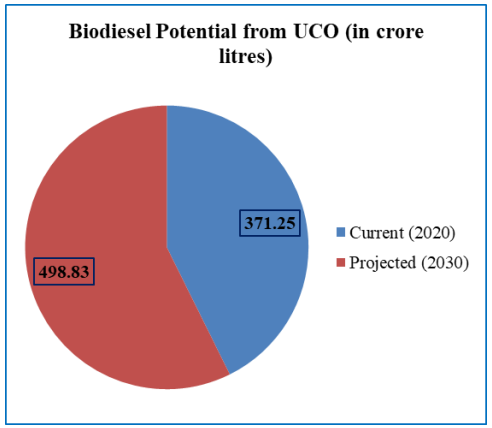
https://doi.org/10.1007/s10311-024-01806-3

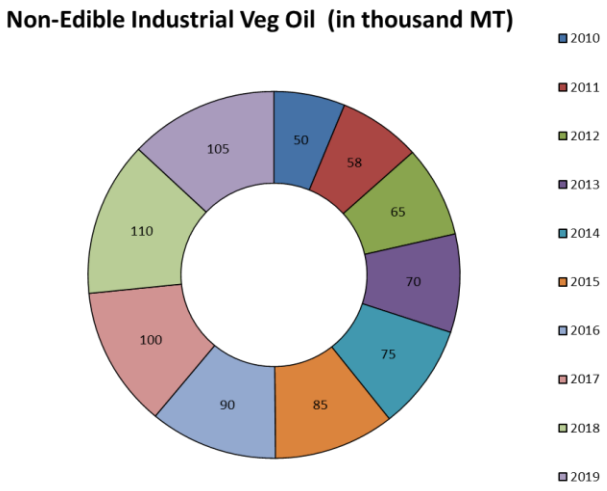
Biodiesel production and feed stock landscape

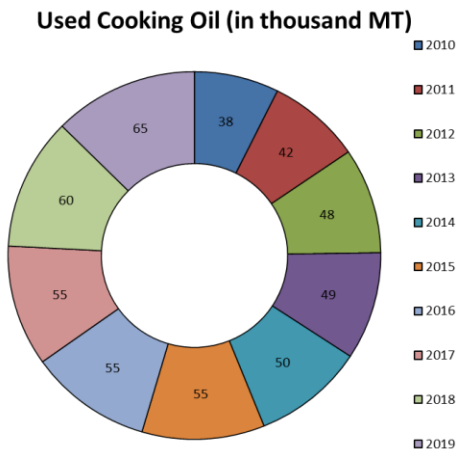
Bio-& Ren-diesel feedstock;

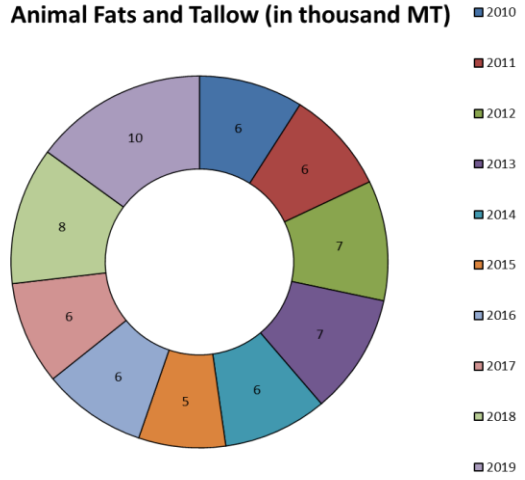
- ✓ Used Cooking Oil (UCO)
- ✓ Animal fat & tallow,
- ✓ Non-edible industrial vegetable oil
- ✓ Algae biomass
- ✓ Aquatic plant biomass











ETHANOL CONTRIBUTION FROM DIFFERENT FEEDSTOCKS

India's ethanol production has transitioned from a sugar-based system to a diversified multi-feedstock model.

01

Shift from C-heavy to B-heavy molasses.

- 100% → ~9.2% (C-heavy), while B-heavy peaked at ~60%.

02

Rapid growth of grain-based ethanol.

- Maize: 0 → ~39.6% (2023–24); DFG up to ~17.4%.

03

Diversification beyond sugar sector.

- SCJ/Syrup increased to ~25.4% (2022–23)

04

Policy-driven feedstock expansion

- Inclusion of rice (FCI), maize, DFG for supply security.

05

Transition to multi-feedstock system.

- From 100% molasses (2017–18) → diversified mix enabling E20 target.

Source: https://iced.niti.gov.in/energy/fuel-sources/others/bio-energy/bio-fuel

Challenges

Production Costs

AtJ fuel production can be expensive than conventional jet fuel or other alternative pathways due to heavy up-front capital investments and energy use

Carbon Intensity

High carbon intensity without carbon capture technology/ (Biogenic CO2 capture and utilization can address this challenge)

Infrastructure

Existing ethanol production facilities require significant new capital to build AtJ conversion units

Regulatory Complexities

Differing regional definitions of "clean fuels" (such as between the U.S. and the EU) complicate international market compliance for biomass-based fuels

Challenges: Feedstock heterogeneity

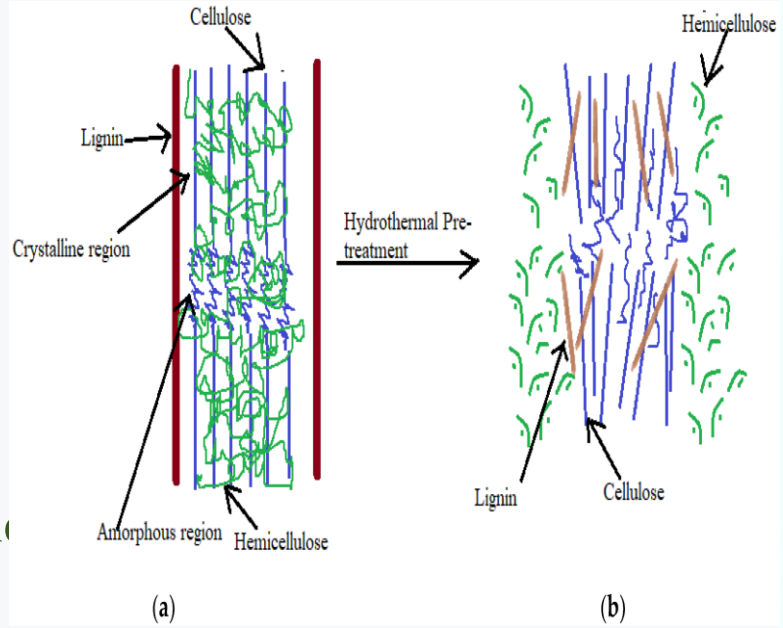
Variability, recalcitrance and mixed-sugar utilization are the upstream constraints

VARIABILITY AND LOGISTICS

- Seasonal, geographically dispersed and compositionally variable feedstock
- Low-density biomass increases transportation and handling burden and cost

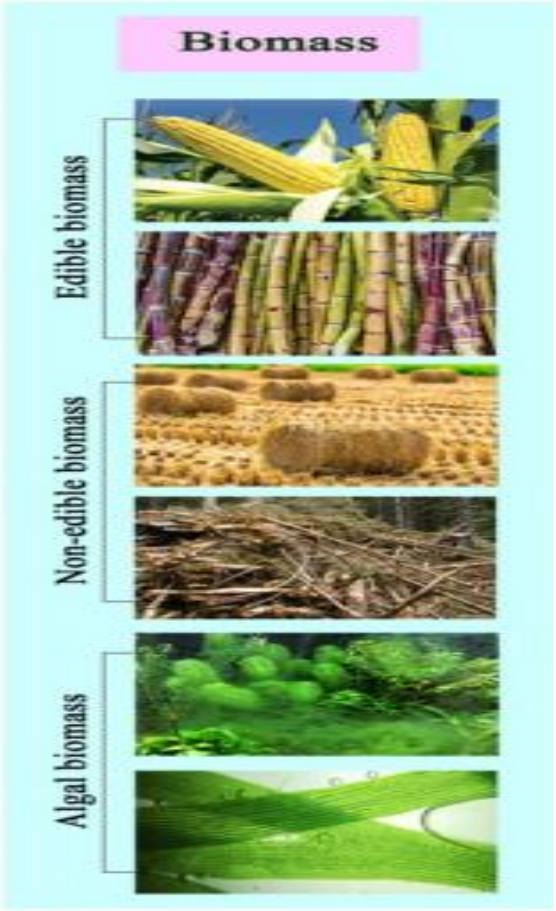
PRETREATMENT

- Lignocellulosic recalcitrance creates a need for low-cost pretreatment strategy



FERMENTATION

- Economic ATJ requires **high alcohol titre, yield an productivity**
- Microbial conversion must utilize both pentose and hexose sugars



Challenges: Downstream conversion adds energy, catalyst and hydrogen penalties



Alcohol recovery / purification	Energy- and cost-intensive
Catalytic conversion	Catalyst selection, activity and cost
Reactor severity	Process conditions can increase CAPEX
Product selectivity	Control sequential reactions toward jet-range hydrocarbons
Hydrogen upgrading	Hydrogen demand introduces a carbon-footprint burden
Overall efficiency	Multi-step biochemical + thermochemical pathway limits carbon/conversion efficiency

Challenges: Economics and meeting aviation specifications

>80% Alcohol production can represent >80% of total refinery.

34% Isobutanol shows a 34% lower catalytic conversion cost than ethanol

ASTM D7566 Pathway commercialisation also depends on meeting aviation-fuel specifications and certification requirements.



Optimized pathway as an integrated carbon-and-cost system



01 **Stabilize feedstock inputs**

Reduce variability before biochemical conversion

02 **Lower pretreatment burden**

Address recalcitrance without compromising downstream cost

03 **Increase fermentation performance**

Target titre, yield, productivity and mixed-sugar conversion

04 **Intensify recovery + catalysis**

Reduce separation energy while improving selectivity

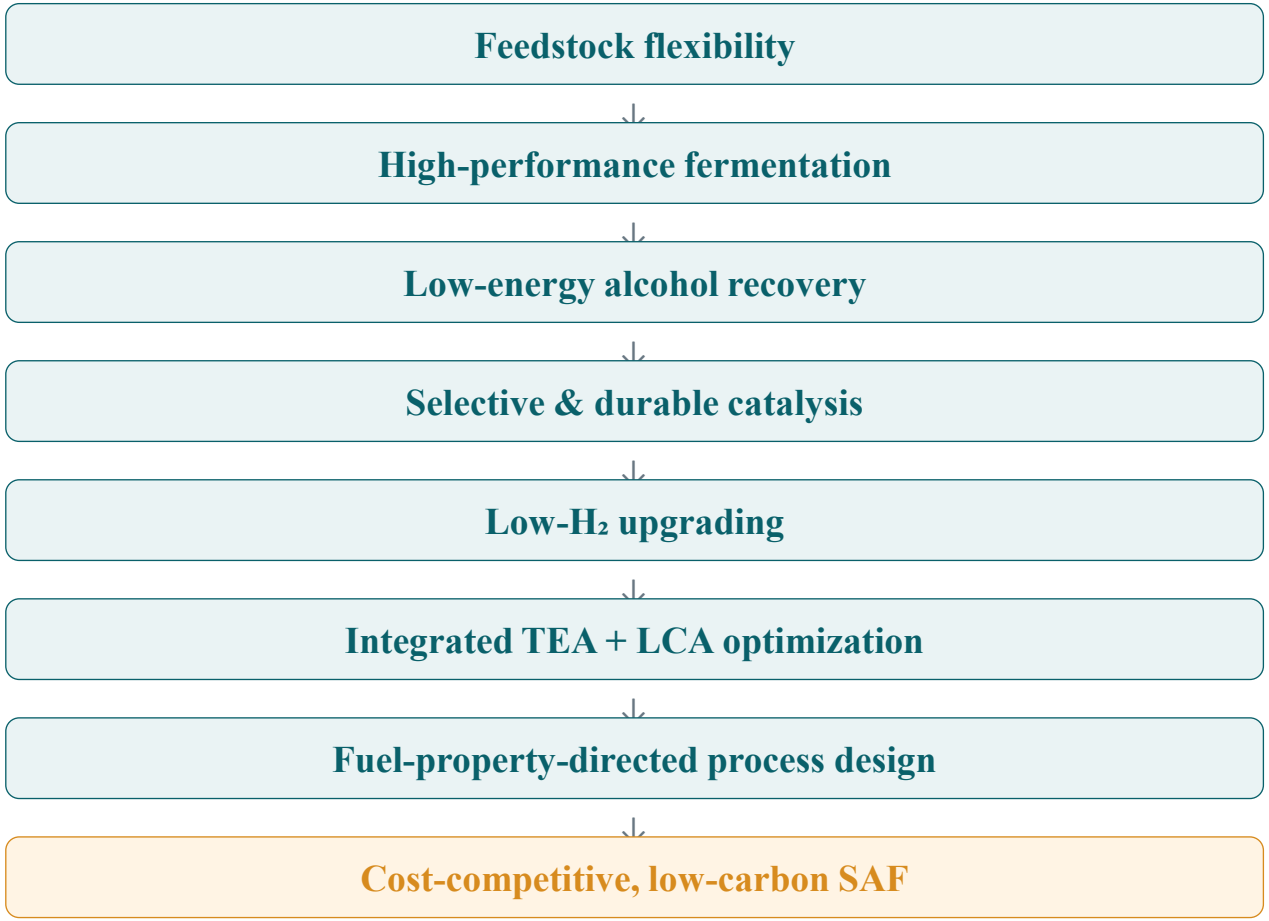
05 **Decarbonize upgrading**

Manage hydrogen demand and carbon footprint

06 **Design to fuel specifications**

Treat qualification constraints as a design requirement

ATJ Goal: Maximizing Bio alcohol yield & process efficiency



The future of Alcohol-to-Jet SAF lies not in optimizing a single conversion step, but in co-optimizing carbon efficiency, energy demand, catalyst selectivity, fuel properties and economics across the entire biomass-to-aircraft pathway.

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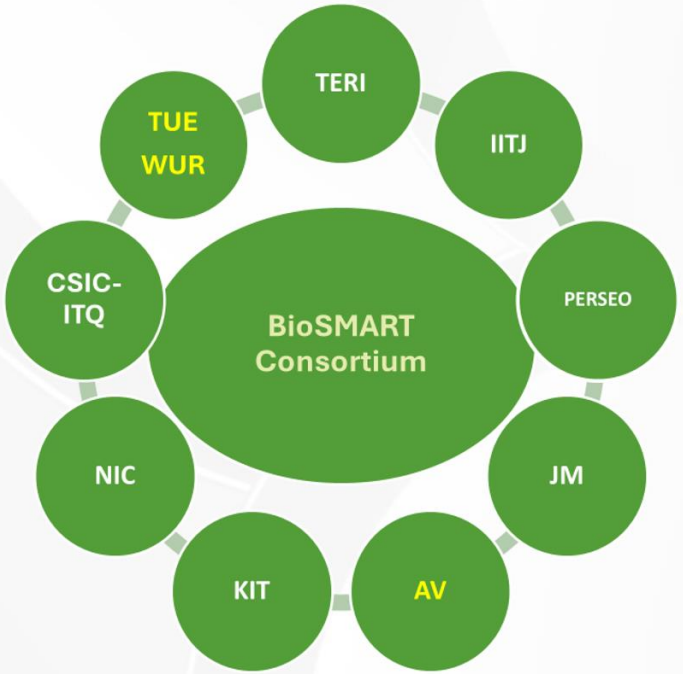
Department of Biotechnology

BioSMART: BIOBASED FUELS AND SUSTAINABLE MATERIALS FROM ADVANCED RENEWABLE TECHNOLOGIES



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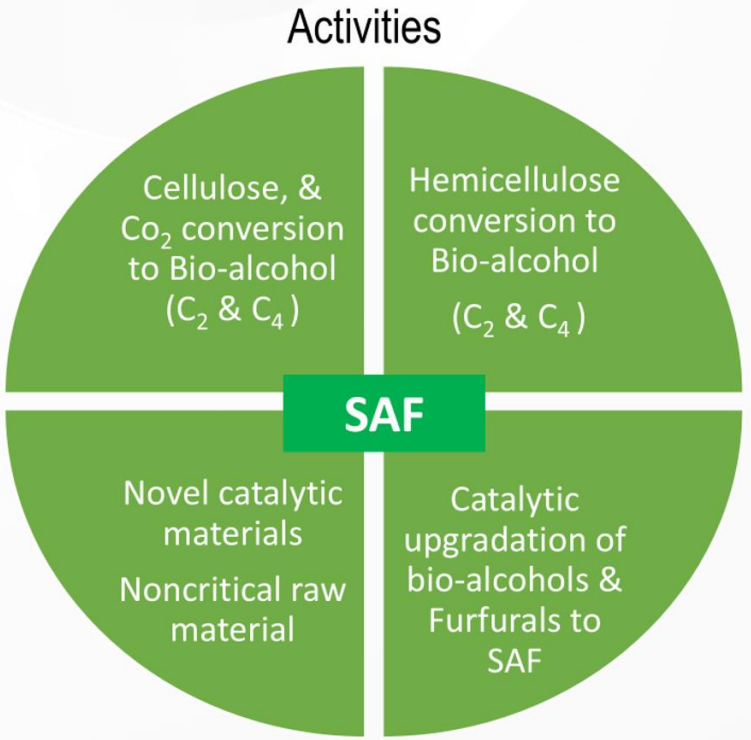
Eindhoven, Netherlands



Partner countries: Netherlands, India, Spain, UK, Germany, Slovenia

Netherlands Partners: TUE, WUR, AV

WAY FORWARD

Collaborative Research priorities need to jointly improve carbon efficiency, energy demand, selectivity, economics and fuel quality.

01 Diversify to low-carbon, non-food alcohol feedstocks

- Evaluate alternative alcohol platforms where they provide process or economic advantages.
- Develop robust supply chains for agricultural and forestry residues.
- Explore integration with existing ethanol infrastructure.

02 Improvement of lignocellulosic alcohol production

- Low-cost, less-severe pretreatment
- Higher enzymatic hydrolysis efficiency
- Efficient C5 + C6 sugar co-fermentation
- Increased alcohol titre, yield and productivity

03 Reduction of alcohol recovery energy

- Process intensification
- Improved distillation configurations
- Membrane-assisted separation
- Adsorption/pervaporation-based recovery

04 Development of next-generation ATJ catalysts

- Lower reaction temperature/pressure where feasible
- Reduced side-product formation
- Longer catalyst lifetime
- Improved resistance to water/impurities
- Regenerable and lower-cost catalysts
- Reduced hydrogen consumption

05 Reduce the carbon intensity of ATJ

- Renewable process electricity
- Low-carbon process heat
- Green/low-carbon hydrogen
- Utilization of lignin and other residues for energy
- Biogenic CO_2 management
- Water recycling
- Maximum carbon utilization from biomass to liquid fuel

06 Shifting from "meeting specification" to designing fuel properties

Target properties include:

- Density, Viscosity, Freezing point
- Volatility, Energy density
- Combustion characteristics

Research and Development 20 for Clean Energy Technologies

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Thank you very much