Sustainable Aviation Fuels

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SAF In India- CSIR-IIP-HEFA-SKA-Technical Milestones

TRL 01-02

TRL 02-03

LAB-SCALE
Start of bio-jet project concept

BENCH-SCALE
Indo-Canada consortium -DST
600 Liters of biojet- PWC

2008-2009

2010-2011

2011-2012

2013-2014

2015-2016

PILOT-SCALE-I

2017-2018

2019-2020

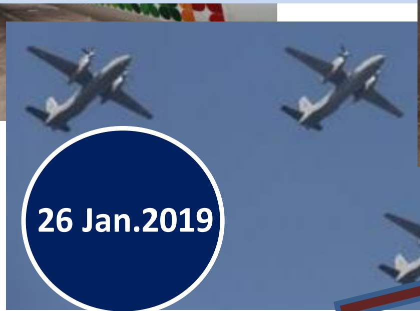
2021-2022

PILOT-SCALE-II

First test flight by Spice-jet (Dehradun to Delhi)- Bio-jet (25%)

27 Aug.2018

Republic day Flypast- Bio-je



26 Jan.2019

CSIR-IIP SAF APPROVED FOR USE IN IAF AIRCRAFT (10%)

25 Nov.. 2021

CSIR-IIP SAF recognized by BIS (1st January 2019)`

IAF'S AN-32 lands at Leh- Bio-jet (10% in both engines)

31 Jan. 2020

TRL 7

2022
- ✓ **Tier1 and 2 stage of D4054**
- ✓ **Collaboration area created for CSIR-IIP HEFA technology**

First SAF Flight Demonstrations In India- CSIR-IIP-HEFA-SKA

Civilian Flight

Bombardier Q400 Operated by SpiceJet

Dehradun-Delhi, 27 August 2018

210 km / 130 miles / 110 nautical miles

23 on-board observers + 5 crew

25:75 Biofuel/Jet A-1 in one engine

All engine parameters satisfactory

Military Flights

Indian Air Force (IAF)

Antonov AN-32 Transport

Republic Day Parade (26 Jan 2019)

*Many subsequent flights (**65 h**) including high-altitude take off and landing*

IAF-HAL, Dornier: 25 h

Printed from
THE TIMES OF INDIA

In a first, IAF uses blended bio-jet fuel to fly aircraft

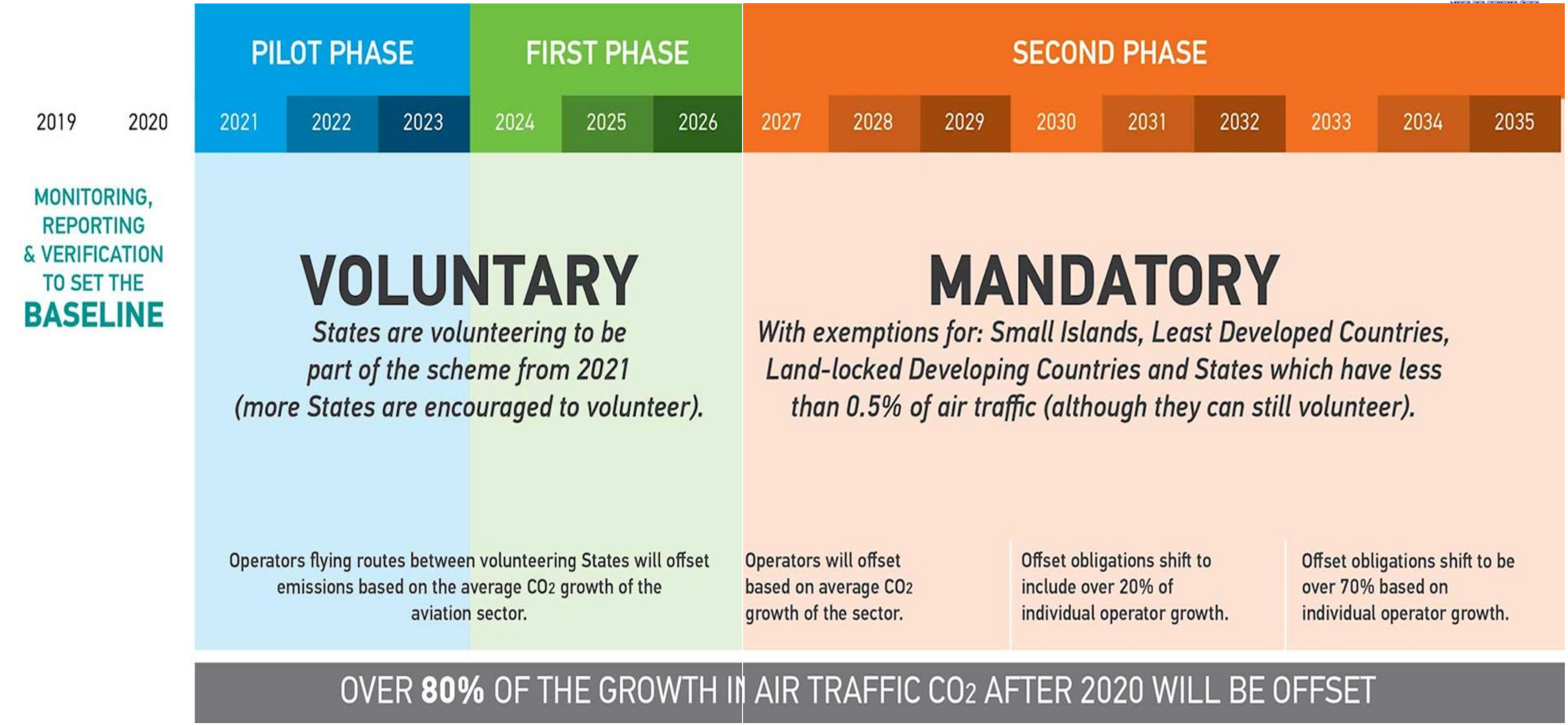
TNN | Dec 17, 2018, 08:15 PM IST

NEW DELHI: The IAF flew a military aircraft with blended bio-jet fuel for the very first time in India on Monday morning. A Russian-origin AN-32 transport plane was flight-tested, with the 10 per cent bio-jet blended ATF (aviation turbine fuel) made from Jatropha oil, in a sortie flown from the Chandigarh airbase.

"The project to flight-test the bio-jet fuel, with experimental test pilots and engineers from IAF's premier testing establishment ASTE, is a combined effort of IAF, DRDO, directorate general aeronautical quality assurance (DGAQA) and CSIR-Indian institute of petroleum," said IAF spokesperson Wing Commander Anupam Banerjee.

Demand assurance by IAF and Private Airlines; Refinery identified – MRPL-ONGC; Supply sources identified; Engineering partner - EIL

ICAO’s Carbon Offset and Reduction Scheme for International Aviation (CORSIA)



		PILOT PHASE			FIRST PHASE			SECOND PHASE								
2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035

MONITORING, REPORTING & VERIFICATION TO SET THE **BASELINE**

VOLUNTARY

States are volunteering to be part of the scheme from 2021 (more States are encouraged to volunteer).

Operators flying routes between volunteering States will offset emissions based on the average CO_2 growth of the aviation sector.

MANDATORY

With exemptions for: Small Islands, Least Developed Countries, Land-locked Developing Countries and States which have less than 0.5% of air traffic (although they can still volunteer).

Operators will offset based on average CO_2 growth of the sector.

Offset obligations shift to include over 20% of individual operator growth.

Offset obligations shift to be over 70% based on individual operator growth.

OVER **80%** OF THE GROWTH IN AIR TRAFFIC CO_2 AFTER 2020 WILL BE OFFSET

https://aviationbenefits.org/environmental-efficiency/climate-action/offsetting-emissions-corsia/corsia/corsia-explained/

105
airports distributing SAF

34
policies adopted or under development

46.3
Billion liters of SAF under offtake agreements

11
approved conversion processes (+5 under evaluation)

42
feedstocks recognized under ICAO CORSIA

SAF Facilities

211
Announced Facilities

73
Billion liters/year total capacity

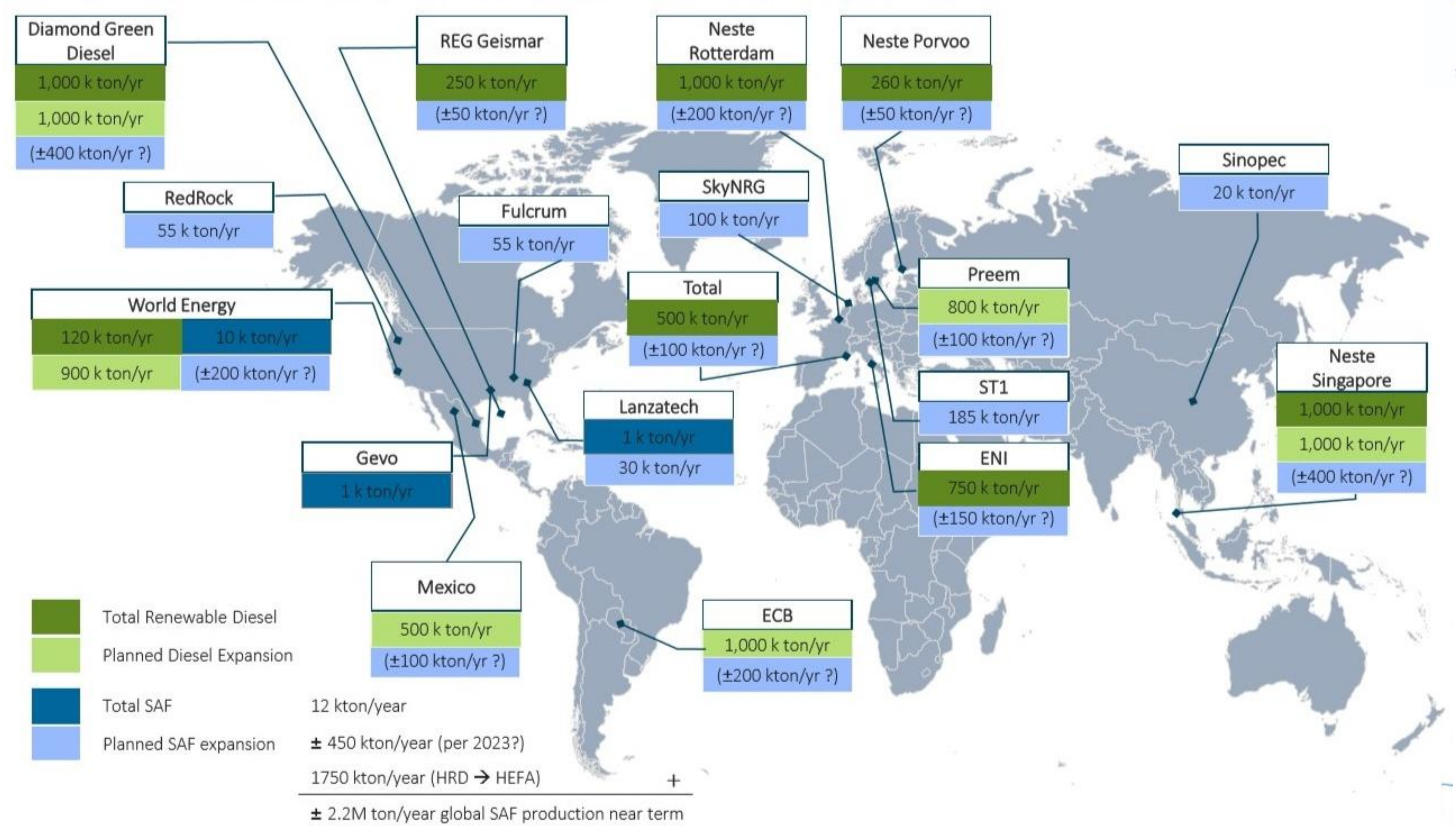
ACT SAF

HELPING COUNTRIES TAKE ACTION ON THE DEVELOPMENT AND DEPLOYMENT OF SUSTAINABLE AVIATION FUELS

Feasibility studies 51

https://www.icao.int/environmental-protection/Pages/SAF.aspx

Existing and Announced SAF production capacity



Diamond Green Diesel
1,000 k ton/yr
1,000 k ton/yr
(±400 kton/yr ?)

REG Geismar
250 k ton/yr
(±50 kton/yr ?)

Neste Rotterdam
1,000 k ton/yr
(±200 kton/yr ?)

Neste Porvoo
260 k ton/yr
(±50 kton/yr ?)

RedRock
55 k ton/yr

Fulcrum
55 k ton/yr

SkyNRG
100 k ton/yr

Sinopec
20 k ton/yr

World Energy
120 k ton/yr | 10 k ton/yr
900 k ton/yr | (±200 kton/yr ?)

Total
500 k ton/yr
(±100 kton/yr ?)

Preem
800 k ton/yr
(±100 kton/yr ?)

Neste Singapore
1,000 k ton/yr
1,000 k ton/yr
(±400 kton/yr ?)

ST1
185 k ton/yr

Lanzatech
1 k ton/yr
30 k ton/yr

ENI
750 k ton/yr
(±150 kton/yr ?)

Gevo
1 k ton/yr

Mexico
500 k ton/yr
(±100 kton/yr ?)

ECB
1,000 k ton/yr
(±200 kton/yr ?)

🟩 Total Renewable Diesel
🟩 Planned Diesel Expansion
🟦 Total SAF — 12 kton/year
🟦 Planned SAF expansion — ± 450 kton/year (per 2023?)
1750 kton/year (HRD → HEFA) +

± 2.2M ton/year global SAF production near term

https://www.adsgroup.org.uk/sustainability/sustainable-aviation-fuels/

PRODUCER	LOCATION	START UP	ANNUAL CAPACITY		FEEDSTOCK	TECHNOLOGY
Operational - Diesel & Jet						
World Energy Paramount	Paramount, CA, USA				Tallow, vegetable oils and lipids	Honeywell UOP / Eni Ecofining
Phase 1		2015	114 ML	0.09 Mt		
Phase 2		2016	151 ML	0.12 Mt		
Operational - Diesel						
Diamond Green Diesel	Norco, LA, USA				Tallow, vegetable oils and lipids	Honeywell UOP / Eni Ecofining
Phase 1		2013	606 ML	0.47 Mt		
Phase 2		2018	1.1 BL	0.86 Mt		
(Phase 3)		*(2021)*	*(2.1 BL)*			
Eni S.P.A.	Venice, Italy				Palm oil transitioning to lipids and algal oil	Honeywell UOP / Eni Ecofining
Phase 1		2014	513 ML	0.40 Mt		
Phase 2		2016	718 ML	0.56 Mt		
Neste	Singapore				Tallow	Neste NExBTL
Phase 1		2010	1.28 BL	1 Mt		
(Phase 2)		*(2022)*	*(1.7 BL)*			
Neste	Rotterdam, Netherlands	2011	1.28 BL	1 Mt	Palm oil transitioning to lipids and other oil seeds	Neste NExBTL
Neste	Porvoo, Finland				Palm oil transitioning to lipids and other oil seeds	Neste NExBTL
Phase 1		2007	128 ML	0.1 Mt		
Phase 2		2009	128 ML	0.1 Mt		
Renewable Energy Group (FKA Dynamic Fuels)	Geismar, Louisiana, USA	2010	284 ML	0.22 Mt	Tallow	Syntroleum Biosynfining
UPM Group	Lappeenranta, Finland	2015	120 ML	0.94 Mt	Tall oil from pulp and paper industry	Haldor Topsoe Hydroflex
Total Operational Annual Capacity (2018)			**6.4 BL**			

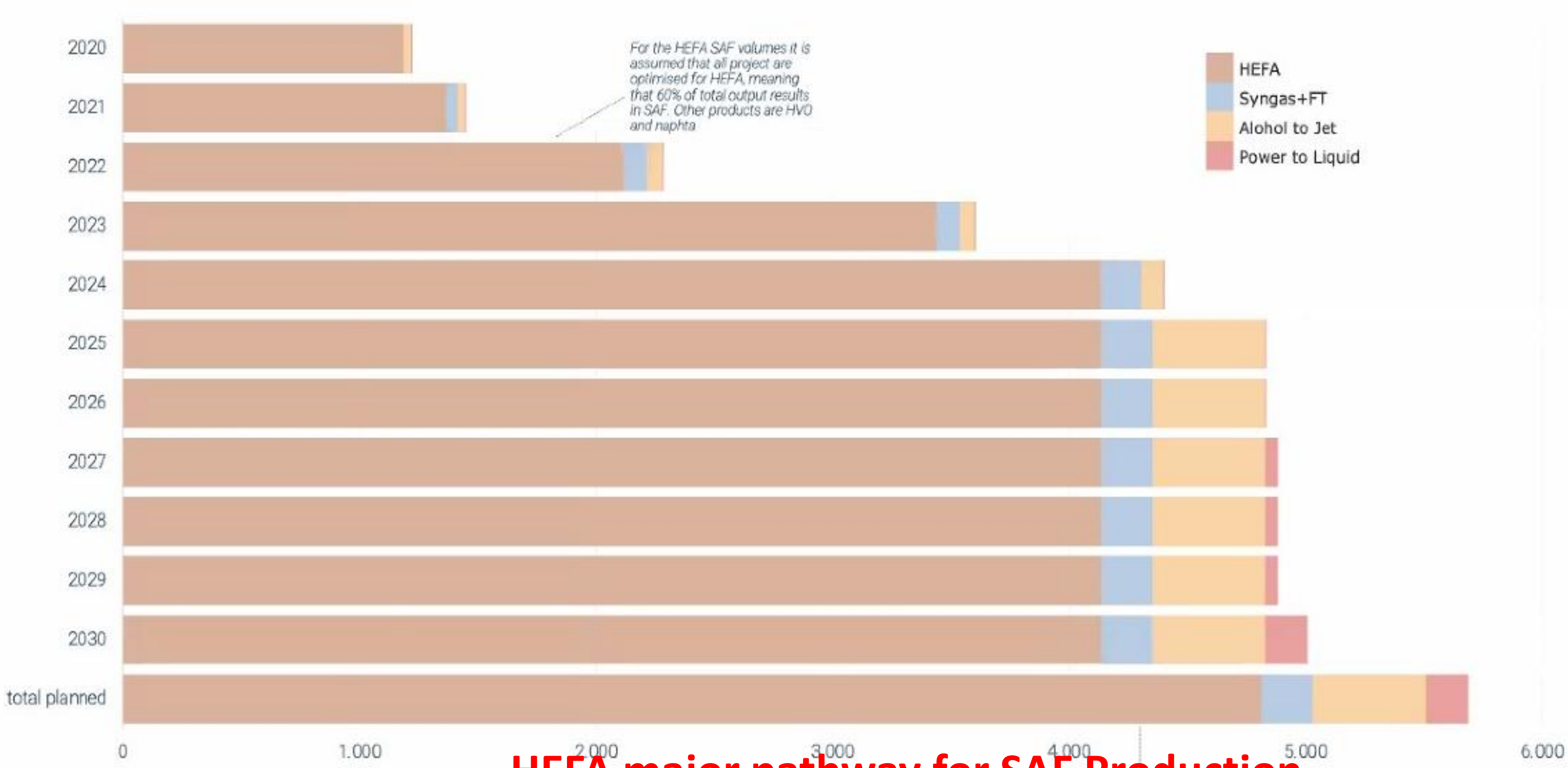
The present status of different approved technological pathways

Technology Pathway	Technology Provider	STATUS	PRODUCER	COMMENTS
Hydroprocessed Ester of Fatty Acids - Synthetic Paraffinic Kerosene (HEFA-SPK)	CSIR-IIP	Pilot Scale	CSIR-IIP (India)	Successful Flight trials – SpiceJet, Bombardier (Q400) and Indian Airforce (AN-32), 2018-2021
	Honeywell UOP	Commercial	Altair (USA)	Lipid feed, 2016, United Airlines, USAF
	Axens	commercial	Total (France)	Lipid feed, 2021
	Neste	Commercial	Neste (Singapore, Finland, Netherlands)	Lipid feed, SAF distilled from green diesel cut
Synthesized Iso-Paraffins (SIP) from Hydroprocessed Fermented Sugars	Amyris	Demo	Total (France)	Sugar feed, flight, proven

The present status of different approved technological pathways

Alcohols-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK)	**LanzaTech**	**Pre-commercial Demo**	**Freedom Pines Fuels (USA)**	**Lignocellulosic feed, gas feed, ATJ Process, Flight proven**
	GEVO	Demo	Gevo (USA)	Flight proven
	Byogy/ Swedish Biofuels/	Pilot	Swedish Biofuels (Sweden)	Not approved by ASTM
Hydrothermal Liquefaction (ARA-CLG)	Applied Research Associates (ARA) and Chevron Lummus Global (CLG)	Demo	ReadiJet (USA)	Fats, oils, greases feed
Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)	Sasol, Shell, Syntroleum,	Commercial/ Demo	SASOL,	Mature technology Economics at a huge scale, fossil feedstock (coal and natural gas)
	Velocys BP others	Demo	Velocys Red Rock Fulcrum	Fulcrum will make FT liquids for co-processing with petroleum (little if any jet fuel is made)

Expected development of global production capacity

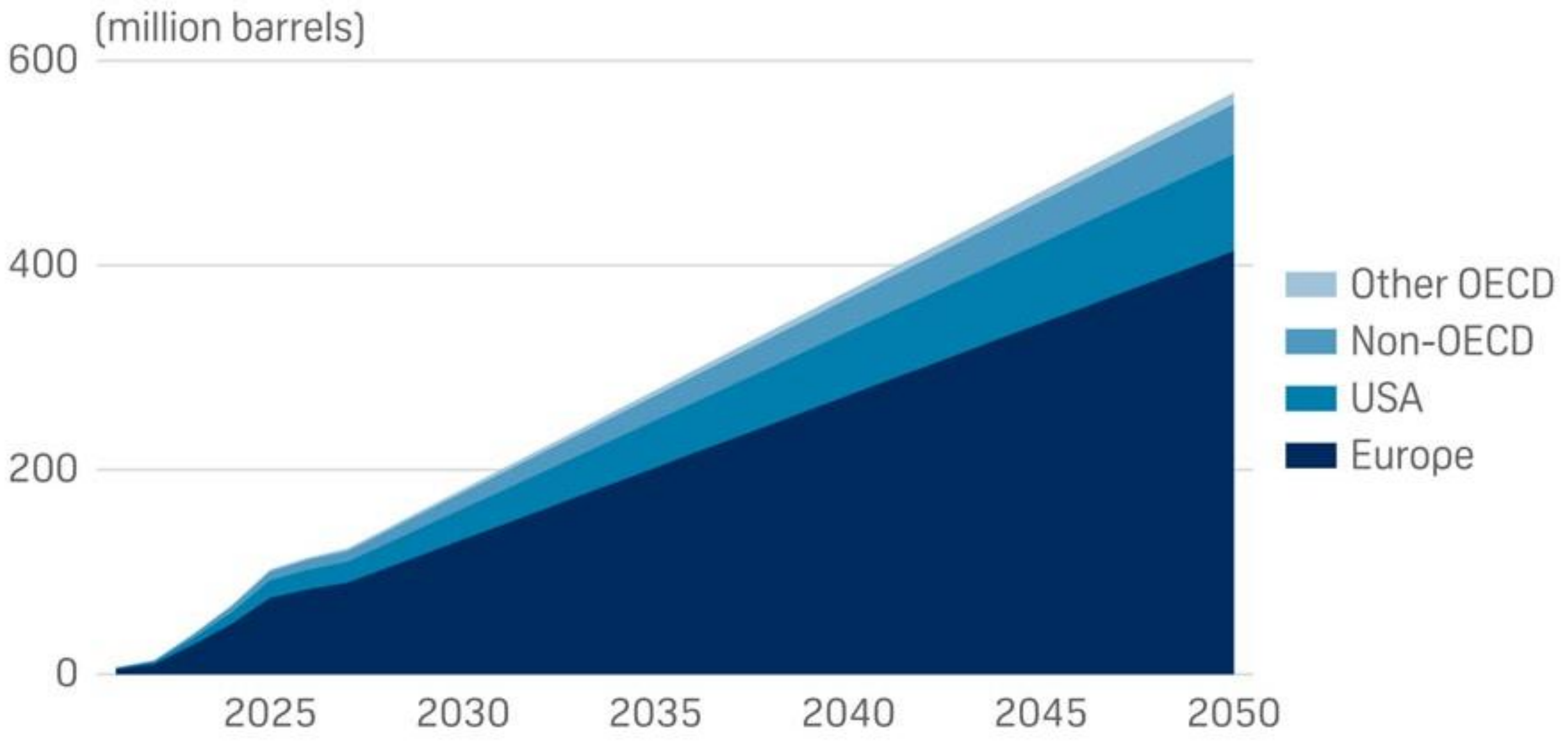


For the HEFA SAF volumes it is assumed that all project are optimised for HEFA, meaning that 60% of total output results in SAF. Other products are HVO and naphta

Source: database studio Gear Up, situation as of April 2021

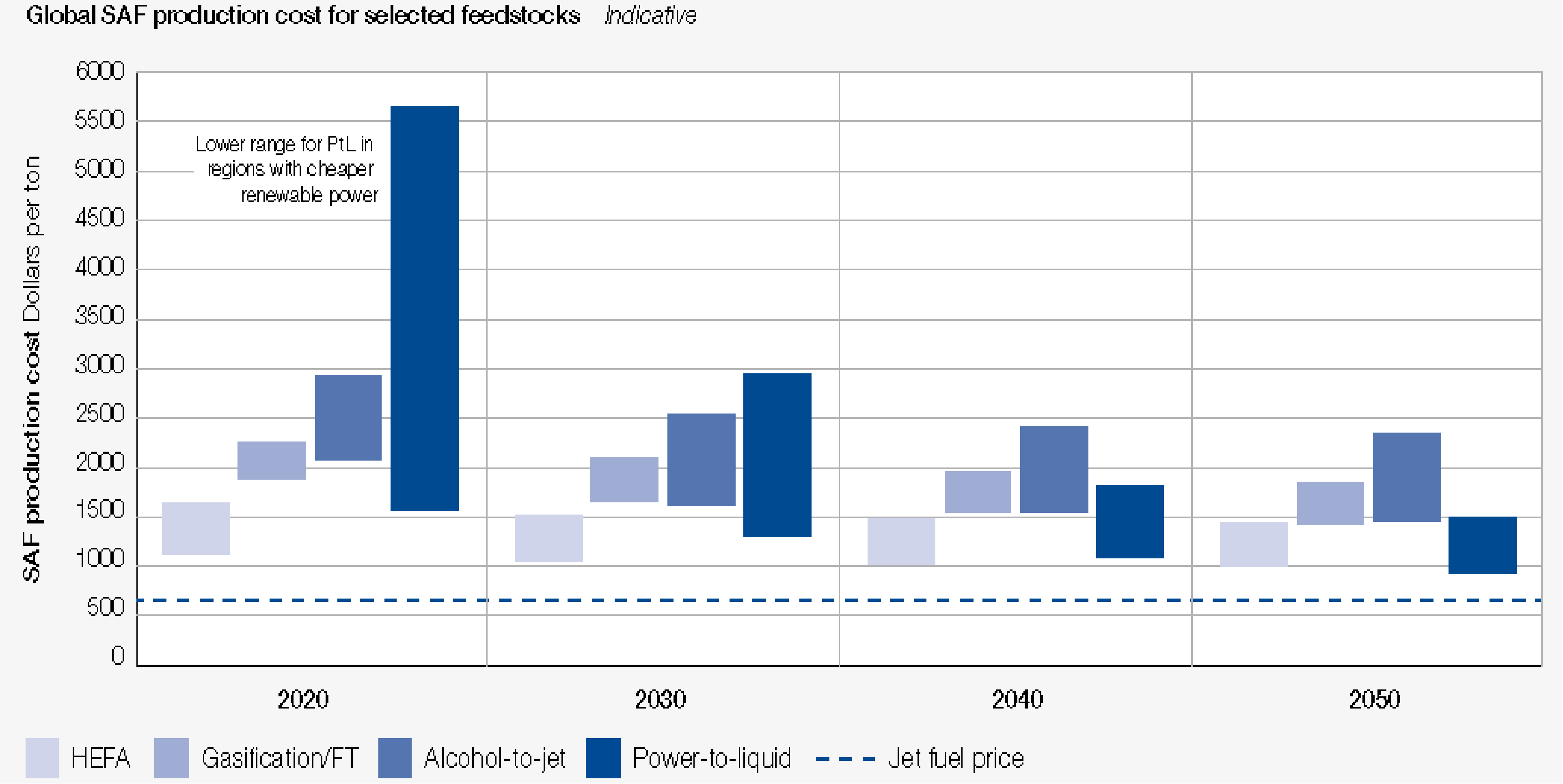
HEFA major pathway for SAF Production

Long Term SAF Demand



Note: Assumes 2% blending achieved by 2050 in countries without national blending mandates
Source: S&P Global Commodity Insights

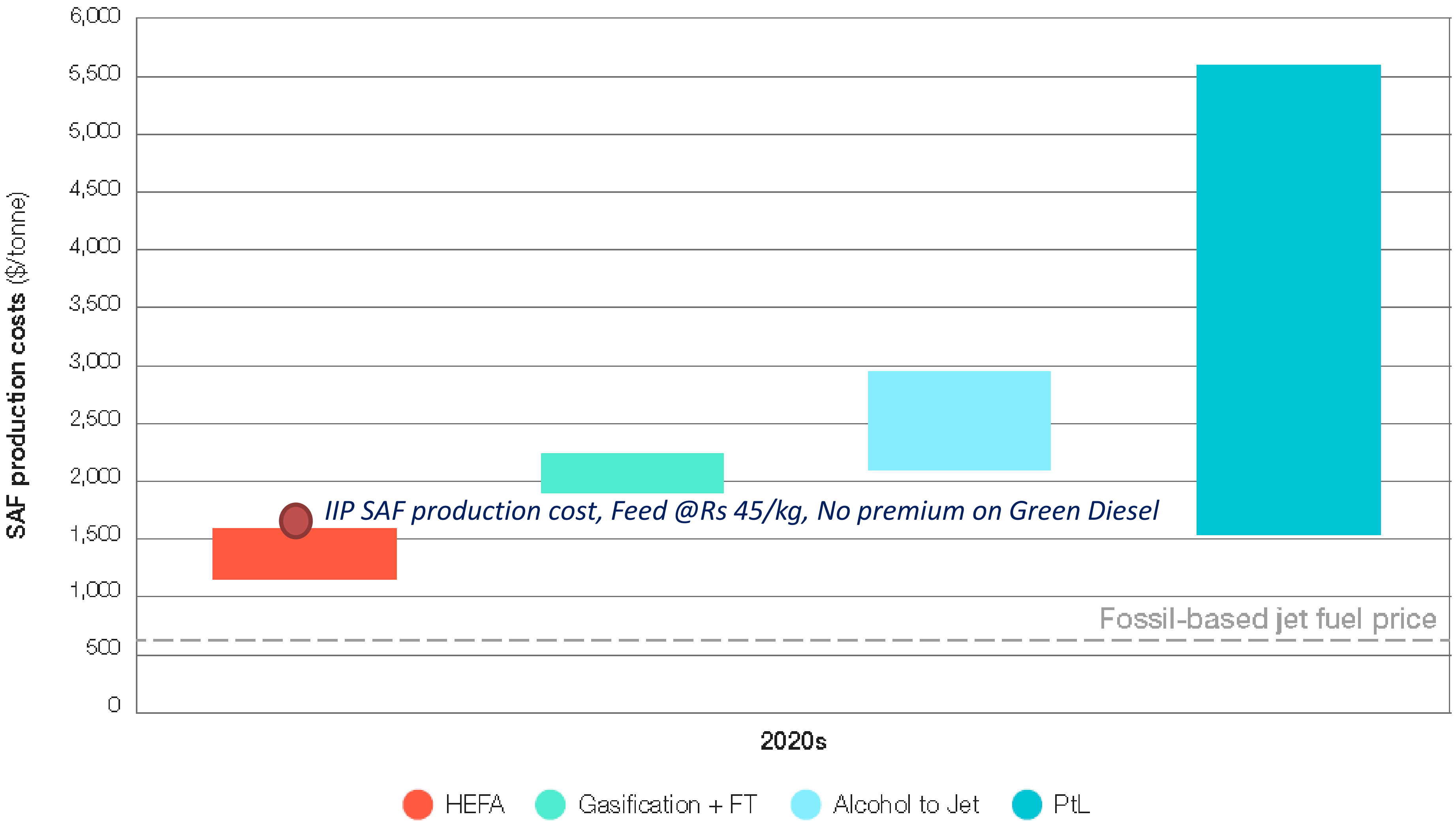
SAF Production Costs - Pathways



Drive: SAF blending mandate for European aviation to be enforced by no later than 2025 with a blending level increasing progressively over time to 2050

Source: World Economic Forum, Clean Skies for Tomorrow: Sustainable Aviation Fuel as a Pathway to Net-Zero Aviation, 2021

INDICATIVE SAF COSTS BY PRODUCTION PATHWAY

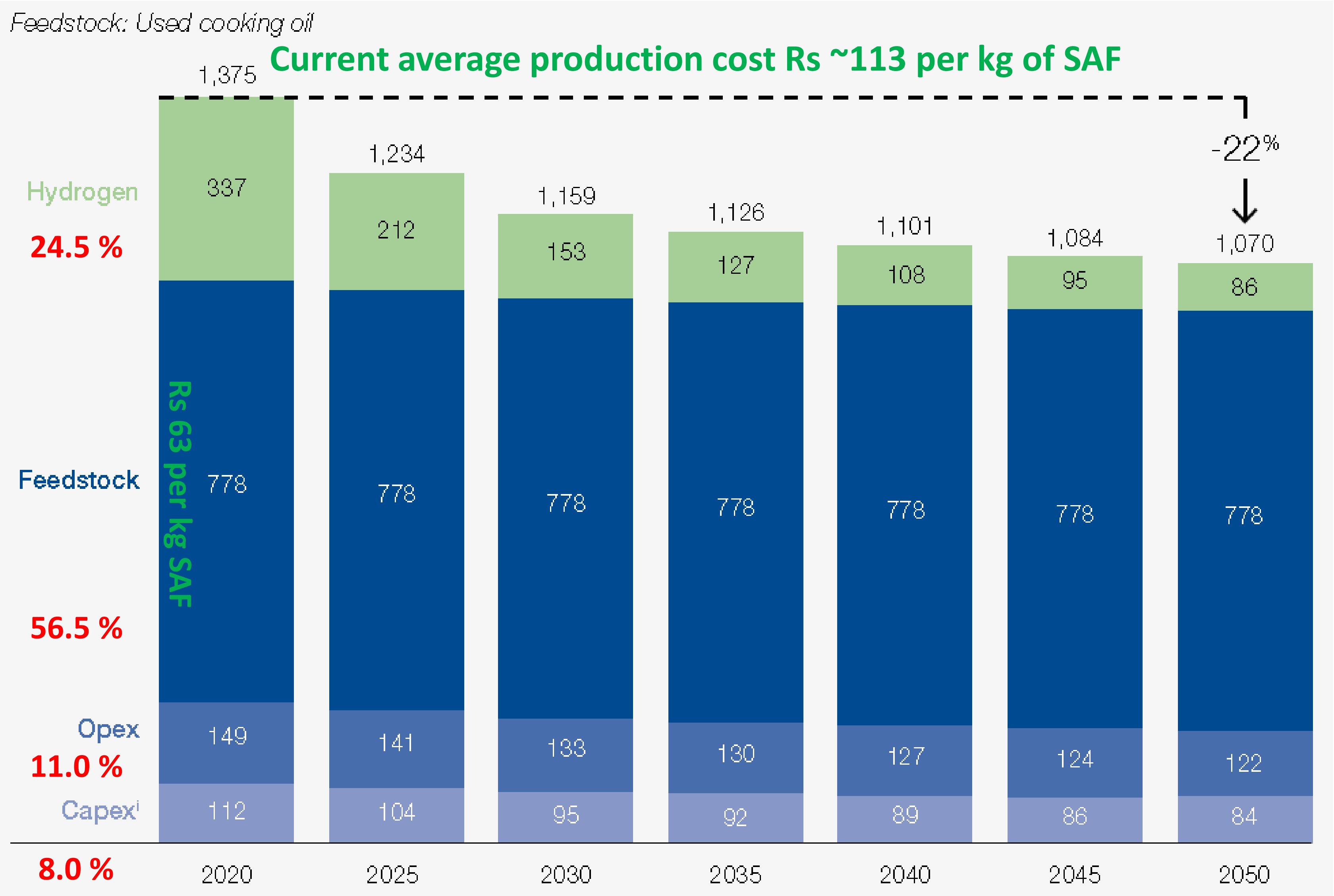


Source: World Economic Forum, Clean Skies for Tomorrow: Sustainable Aviation Fuel as a Pathway to Net-Zero Aviation, 2021

HEFA production costs
SAF production cost US Dollars per ton of jet fuel

Second area to be focused is H_2 usage Green hydrogen use)

This area to be focused to decrease overall cost?



Current average production cost Rs ~113 per kg of SAF

Rs 63 per kg SAF

24.5 %

56.5 %

11.0 %

8.0 %

Clean Skies for Tomorrow, Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation Insight report, Nov 2020, In Collaboration with McKinsey & Company

Domestic Lipid Sources

- **Used Cooking oil**
  - –Estimated ~2 million tons annually @ 10% of total edible oil consumed in India
  - –If goes “down the drain” (environmental burden); Adulteration (Health concern)

- **Tree borne oils (FRI)**
  - Over 400 species identified in India, growing wild
  - Lack of demand and no incentives for collection of seeds limits supply side

- **Short rotation crops (PAU)**
  - Non-edible oilseeds like niger, carinata, camelina etc (mustard family)
  - Can be planted and grown between staples as a second or third crop
  - Agriphotovoltaic

Re-purpose Used Cooking Oil ("RUCO")

Major non-volatile by-products of frying are Total Polar Compounds (TPC):

- Dimeric fatty acids
- Triglyceride monohydroperoxides
- Polymerized triglycerides (PTG)
- Cyclic fatty acid monomers and
- Aldehydic triglycerides

Linked diseases include hypertension, atherosclerosis, Alzheimer's disease and fatty liver / hepatomegaly.

UCO from starchy foods may contain traces of acrylamide, a potential carcinogen

Use vegetable oils for frying.

Ideally, use cooking oil only once for frying.

Used frying oil can be filtered and reused once for making curries.

Avoid reusing cooking oil. Guard your health.

Consume used frying oil within two days.

Fry at the lowest frying temperature. Oil should not give off smoke.

While frying, remove food particles frequently from the oil before they turn black.

Use a fryer or utensils made of material such as stainless steel for frying.

Avoid iron pans for frying to prevent unpleasant taste or odour.

The study, said to be the first of its kind in India, carried out by the Observer Research Foundation, Koan Advisory Group and Neste, found that despite food safety regulations outlawing the consumption of UCO in any form, more than half of it is reused. - 2022

India is the world's second-largest consumer of vegetable oil, and the per capita consumption is around 19-19.80 kg per person per annum.

Used Cooking Oil is India's "lowest-hanging fruit"

/www.indiatimes.com/news/india/more-than-half-of-cooking-oil-gets-reused-in-india-and-it-can-cause-serious-health-issues.html

Chinese government announced an urgent regulation to prevent the worsening of the WCO issue, intended to alleviate the concerns of Chinese consumers regarding food safety (China Food and Drug Administration, 2010; Lu et al., 2013).

China collects and trades over 10 MM TPA already of its domestic UCO (Reuters, USDA)

From 1st July, 2018 onwards, all Food Business Operators (FBOs) are required to monitor the quality of oil during frying by complying with the said regulations. - FSSAI

“Annually, about 23-million tonne cooking oil is consumed in India. There is potential to recover and use about 3 million tonnes of this after cooking,” FSSAI

As of now, used cooking oil is either disposed in an environmentally hazardous manner and sometimes even finds it way to smaller restaurants, *dhaabas* and street-vendors and probably adulteration.

- Jet fuel consumption, 8 MMTPA (23-24 year)
- India UCO- 3- 10 MMTA
- SAF: 1.5 – 5 MMTA (20%-60% Blend with Jet Fuel) (2024-2029)

or

- Green Diesel: 1.5 – 5 MMTA (0.8-2.5%) @200 MMTPA Diesel consumption

https://www.reuters.com/markets/commodities/bidens-ira-drives-surge-us-imports-chinese-used-cooking-oil-2023-09-22/

TheGlobalEconomy.com

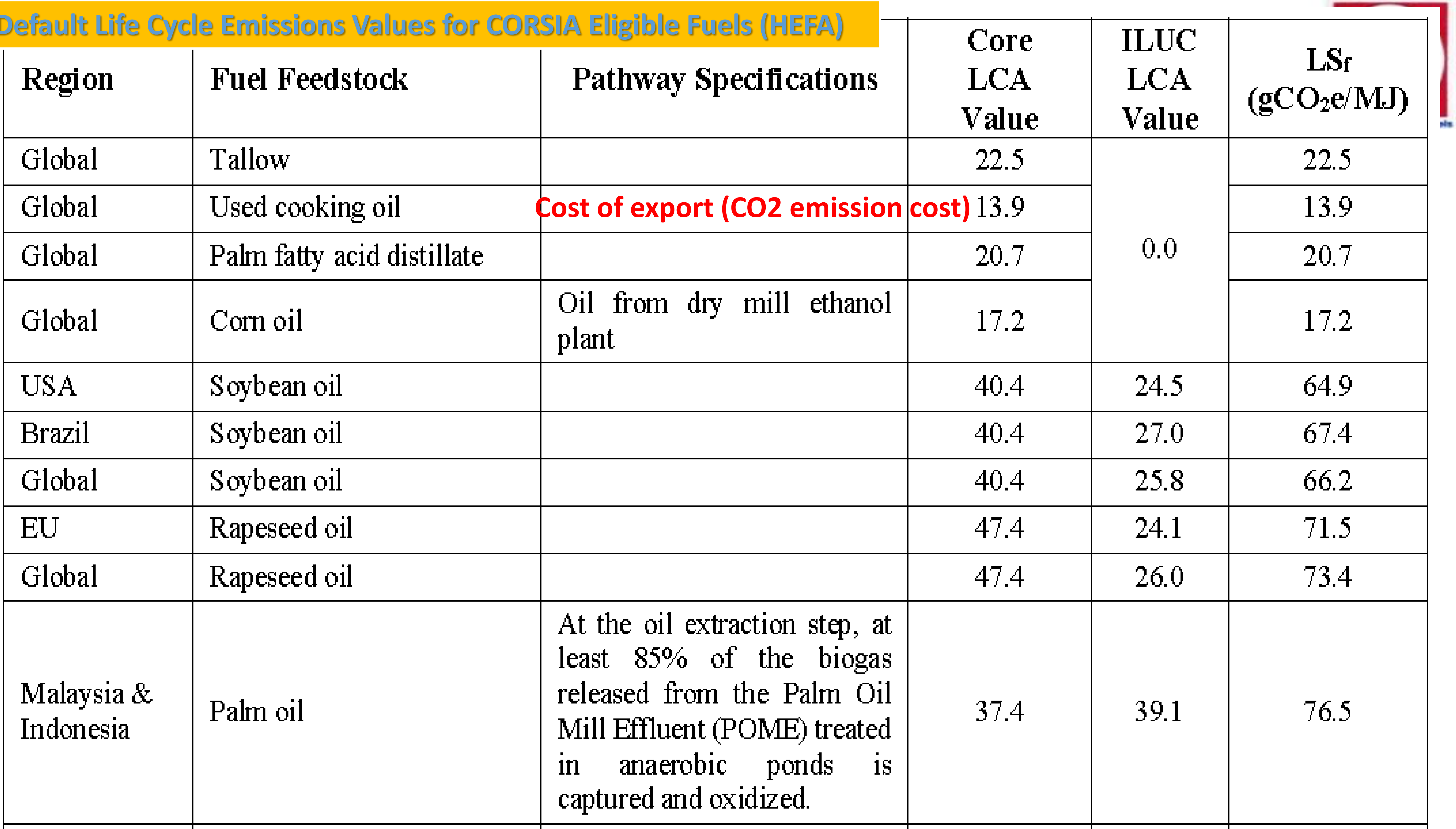
https://www.thehindubusinessline.com/economy/policy/new-regulations-for-used-cooking-oil-come-into-effect/article24314377.ece

China is the world's largest producer of UCO, generating around 11.4 billion litres annually, - U.S. Department of Agriculture (USDA),
Lack of domestic policy support has limited its use in the country.

Powered by incentives, U.S. demand for UCO has displaced European purchases.
Exports to Europe from China in the first eight months of 2023 fell by almost 56% from a year earlier.

In June, Germany asked the European Commission to investigate the flow of possibly mislabelled Chinese biofuels into the European Union.
These concerns have "made some of the EU buyers potentially a bit more nervous

Default Life Cycle Emissions Values for CORSIA Eligible Fuels (HEFA)



Region	Fuel Feedstock	Pathway Specifications	Core LCA Value	ILUC LCA Value	LS_f (gCO_2e/MJ)
Global	Tallow		22.5	0.0	22.5
Global	Used cooking oil		13.9		13.9
Global	Palm fatty acid distillate		20.7		20.7
Global	Corn oil	Oil from dry mill ethanol plant	17.2		17.2
USA	Soybean oil		40.4	24.5	64.9
Brazil	Soybean oil		40.4	27.0	67.4
Global	Soybean oil		40.4	25.8	66.2
EU	Rapeseed oil		47.4	24.1	71.5
Global	Rapeseed oil		47.4	26.0	73.4
Malaysia & Indonesia	Palm oil	At the oil extraction step, at least 85% of the biogas released from the Palm Oil Mill Effluent (POME) treated in anaerobic ponds is captured and oxidized.	37.4	39.1	76.5

Cost of export (CO2 emission cost)

Malaysia & Indonesia	Palm oil	At the oil extraction step, less than 85% of the biogas released from the Palm Oil Mill Effluent (POME) treated in anaerobic ponds is captured and oxidized.	60.0	39.1	99.1
Brazil	Brassica carinata oil	Feedstock is grown as a secondary crop that avoids other crops displacement	34.4	-20.4	14.0
USA	Brassica carinata oil	Feedstock is grown as a secondary crop that avoids other crops displacement	34.4	-21.4	13.0
Global	Brassica carinata oil	Feedstock is grown as a secondary crop that avoids other crops displacement	34.4	-12.7	21.7
Global	Camelina oil	Feedstock is grown as a secondary crop that avoids other crops displacement	42.0	-13.4	28.6
India	Jatropha oil	Meal used as fertilizer or electricity input	46.9	-24.8	22.1
India	Jatropha oil	Meal used as animal feed after detoxification	46.8	-48.1	-1.3

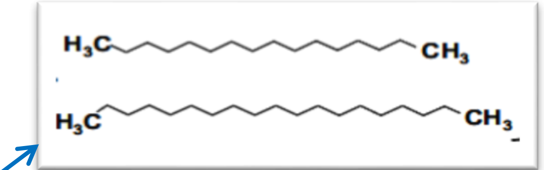
Scope for R&D

Drivers for R&D	Status/ Requirements
1. Hydro-processed vegetable oil	
Abundant oils at low costs are required	Identification of land for cultivation on a crop rotation basis for optimized land utilization; Creation of value chains for biomass supply and the establishment of collection networks, increase crop yields
Extraction and pre-treatment of oil	Better contaminants removal technology
Valorization of different types of feed	Standardization of feedstock
Hydrogen is expensive and not available everywhere	Cheaper, renewable more abundant hydrogen source
2. Alcohol-to-jet fuel	
Technology for increased selectivity and efficiency for improving product yield	Improvement in technology required for selective catalysis, which would convert the alcohols more efficiently to jet fuels, more investment
Complexity and economic viability	Requires simpler technology with reduced operation steps and complications for improved economics
3. Fischer-Tropsch Fuel	
Technological improvements	Better catalysts needed, at present too expensive. Reduction in pressure
Abundant Biomass availability for reducing costs	Requires more concentrated/dense feedstock and optimization of cost
4. Power To Liquid (E-Fuel)	
Technological improvements with cheaper catalysts	Expensive catalysts used / Improvement in Catalyst activity and life
Efficient Hydrogen management	Molecular hydrogen use and Requires hydrogen transfer from cheap sources

CSIR-IIP Drop-In Liquid Sustainable Aviation and Automotive Fuel (DILSAAF)

2-Step Process

Pretreated



Deoxygenation/Isomerization

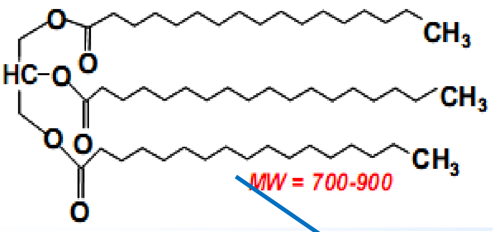
Current technologies

(require additional Isomerization/cracking to Jet)

Light Gases
Light HC, H_2 and CO_2

Diesel Range (C15+)

H_2O



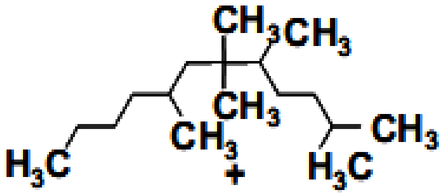
$+H_2$

CSIR-IIP Technology

Na, P, K, Ca, Fe

Pretreater

Deoxygenation/Selective Cracking/Isomerization



Light Gases
Light HC, H_2 and CO_2

Naphtha (C5-C9)

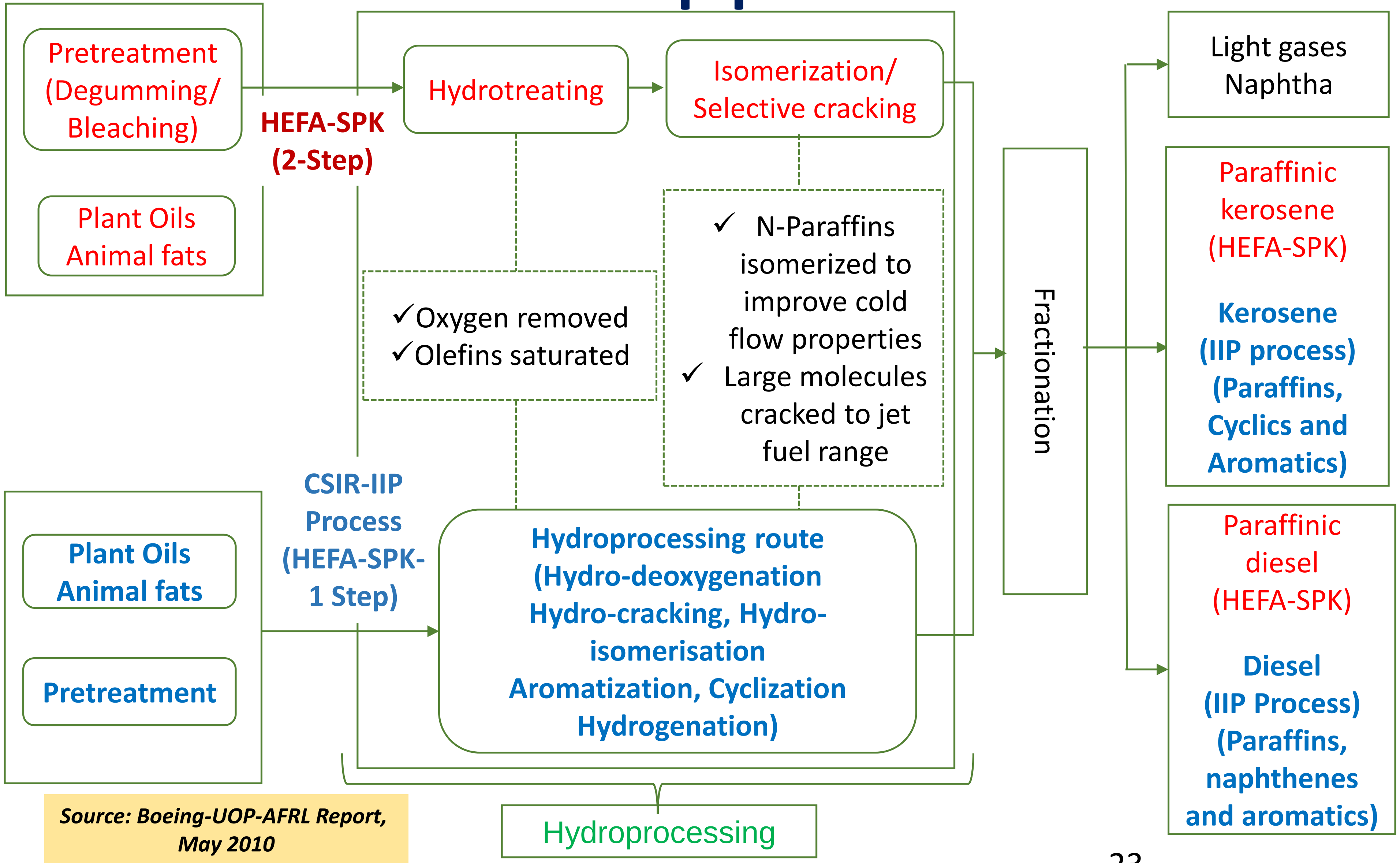
Bio-Jet Fuel (C9-C15)

Diesel Range (C15+)

H_2O

CSIR-IIP Technology

HEFA-SPK - CSIR-IIP (1-Step) process and 2-Step process



Pretreatment (Degumming/ Bleaching)

Plant Oils
Animal fats

HEFA-SPK (2-Step)

Hydrotreating

Isomerization/ Selective cracking

✓Oxygen removed
✓Olefins saturated

- ✓ N-Paraffins isomerized to improve cold flow properties
- ✓ Large molecules cracked to jet fuel range

Plant Oils
Animal fats

Pretreatment

CSIR-IIP Process (HEFA-SPK-1 Step)

Hydroprocessing route (Hydro-deoxygenation Hydro-cracking, Hydro-isomerisation Aromatization, Cyclization Hydrogenation)

Hydroprocessing

Fractionation

Light gases
Naphtha

Paraffinic kerosene (HEFA-SPK)

Kerosene (IIP process) (Paraffins, Cyclics and Aromatics)

Paraffinic diesel (HEFA-SPK)

Diesel (IIP Process) (Paraffins, naphthenes and aromatics)

Source: Boeing-UOP-AFRL Report, May 2010

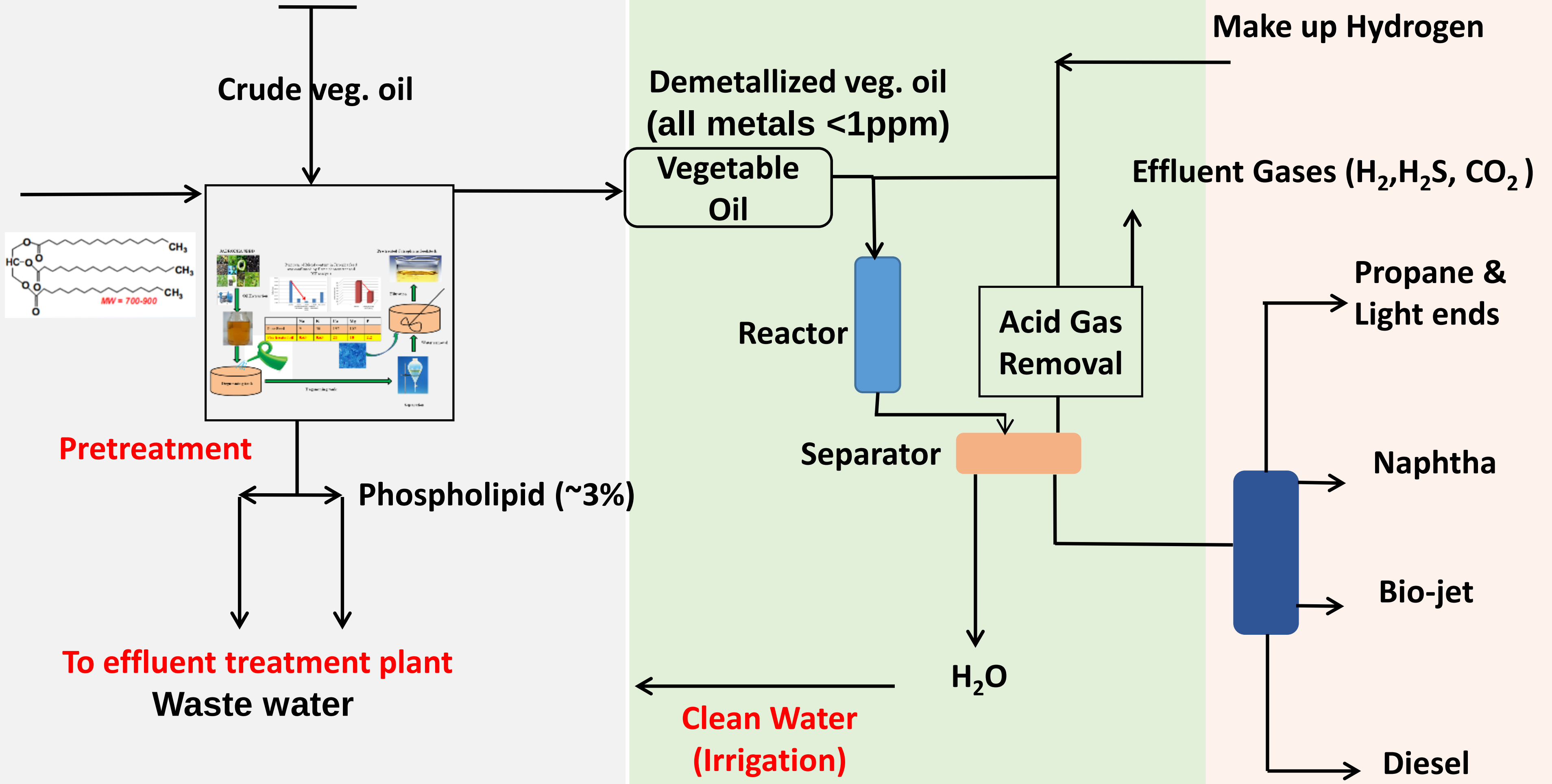
Both CSIR-IIP (1 Step) and HEFA-SPK (2 Step) processes are based on lipid hydroprocessing

CSIR-IIP process for 110TPD feed processing

Pretreatment Section

Reaction Section
Hydroprocessing unit

Fractionation section



Crude veg. oil

Pretreatment

Phospholipid (~3%)

To effluent treatment plant
Waste water

Demetallized veg. oil
(all metals <1ppm)

Vegetable Oil

Reactor

Separator

Acid Gas Removal

H_2O

Clean Water
(Irrigation)

Make up Hydrogen

Effluent Gases (H_2,H_2S, CO_2)

Propane & Light ends

Naphtha

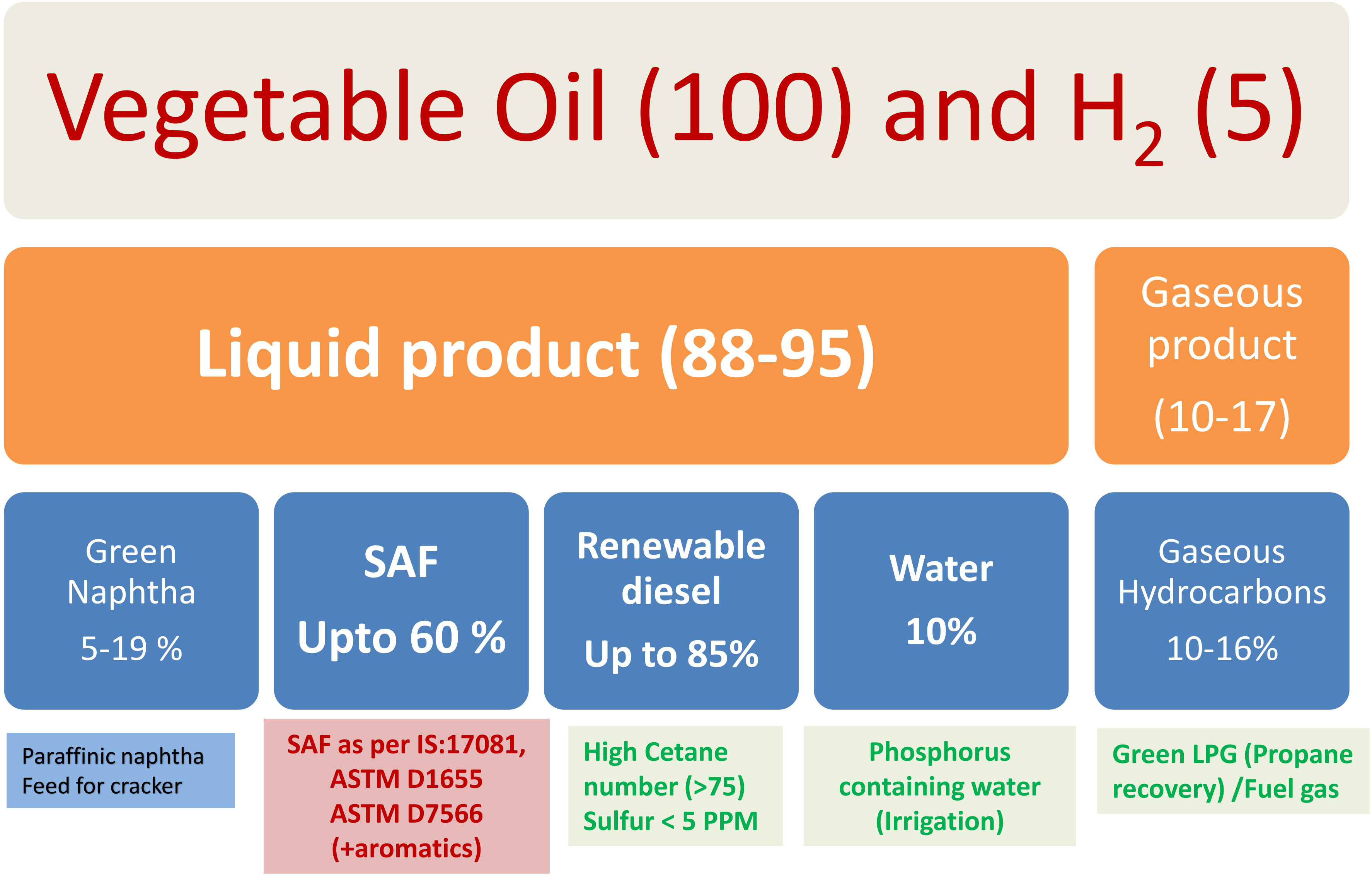
Bio-jet

Diesel

Similar to Petroleum refinery hydrocracking configuration with additional pretreatment section

Product Distribution (Mass %)

Indicative yields based on jatropha and UCO



Vegetable Oil (100) and H_2 (5)

Liquid product (88-95)

Gaseous product

(10-17)

Green Naphtha

5-19 %

SAF

Upto 60 %

Renewable diesel

Up to 85%

Water

10%

Gaseous Hydrocarbons

10-16%

Paraffinic naphtha
Feed for cracker

SAF as per IS:17081, ASTM D1655 ASTM D7566 (+aromatics)

High Cetane number (>75)
Sulfur < 5 PPM

Phosphorus containing water (Irrigation)

Green LPG (Propane recovery) /Fuel gas

Salient features of the CSIR-IIP Technology

✓ **Single step** catalytic HEFA process (hydroprocessing route) with 6-8% aromatics

✓ **The process is feed flexible** (Non-edible tree borne oils and fats)

✓ **Multiple reactions in a single reactor**: (1) hydrodeoxygenation, (2) selective cracking (3) decarboxylation, decarbonylation (4) hydroisomerization (5) cyclization and (6) aromatization

✓ A single **patented non-noble-metal catalyst** is used

✓ Typical yield of Sustainable Aviation Fuel (SAF) ~ 25-55%, depending on feed

✓ Properties/composition similar to Jet A / Jet A-1 **ASTM D1655** specifications and D 7566 Annex A2 (after aromatics removal) and IS :17081

✓ Simple, minor variant of petroleum refinery hydrocracking process; **easily adapted to existing refinery infrastructure**

✓ In addition to aviation fuel range hydrocarbons, other useful by-products are naphtha (C5-C9 paraffinic hydrocarbons) and high cetane diesel (C15+, cetane number >70)

Patents Granted : EP3191565A1, US 10,351,782, US 10,457,875

Current activities

- ✓ **Construction of demonstration plant at a refinery using DILSAAF CSIR-IIP technology-MRPL-EIL:** *Working towards technology deployment*

- ✓ ***Aviation fuel being produced for trial and demonstration on Dornier aircraft (Do228) -IAF***

- ✓ **Green diesel made from DILSAAF process being used in IIP car in campaign mode-** *10000 kms successful run using 100% neat Renewable diesel*

- ✓ **Working towards ASTM approval and inclusion**
  - *Improving handling procedures and protocols*
  - *Seeking ASTM support and guidance for fast-track approval as a variant of HEFA under Annex A2 with relaxation in aromatics specification, or as a new Annex*
  - *ASTM Work Group for CSIR-IIP fuel created*
- ✓ Feedstock Supply Chain:
  UCO: Aggregator-Refinery agreement
  New feedstocks: poultry/animal fat etc.
  Rotation Crop: Carinata (Ethopian Mustard plantation)

Thank You Very Much