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# Refinery Co-processing for Sustainable Aviation Fuel Production

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# Agenda

1. Introduction
2. Aviation Fuel Manufacturing Routes
3. Refinery Co-processing
4. Pilot Plant Program
5. Refinery Program
6. Summary

# Introduction

- Jet A / A-1 kerosene has been adopted as the primary fuel for global aviation:
  - Liquid with moderate flash point (≥+38 °C) for easy of handling.
  - High energy content per unit weight & volume.
  - Good low temperature flow characteristics.
  - Readily manufactured from crude oil around the world.
- To retain this product and meet the IATA aspiration for carbon neutral operations by 2050 requires technical imagination and innovation:
  - Development of alternative manufacturing routes using sustainable feedstocks to give synthetic blending components (SBCs) for sustainable aviation fuel (SAF) production.
  - Formal review and approval through ASTM and industry groups to maintain operational performance.

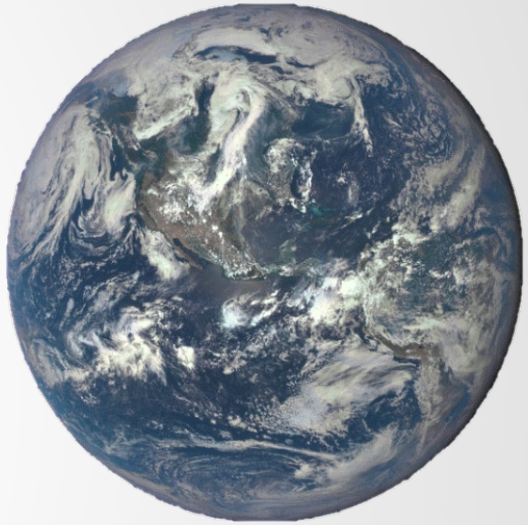


Image: NASA

*Each day the aviation industry transports up to 12 million passengers – the aim is to achieve this in the future with minimum carbon foot-print.*

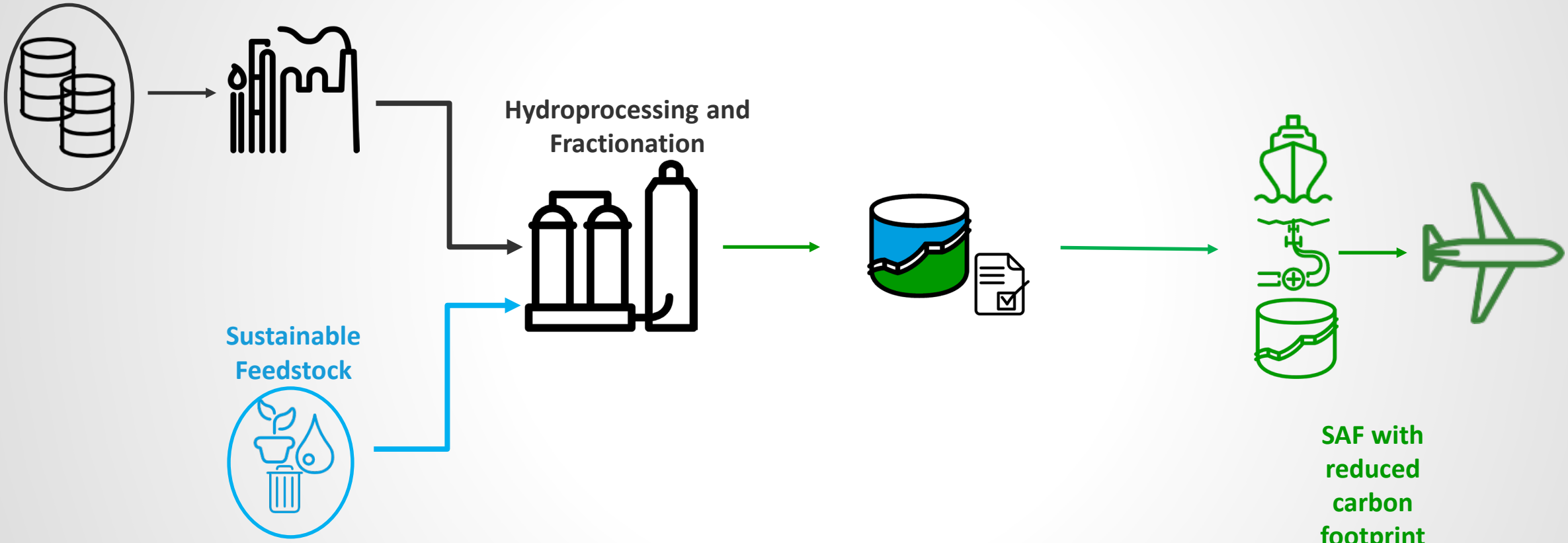
# Aviation Fuel Manufacturing Routes

- In addition to traditional D1655 aviation turbine fuel production 8 Synthetic Blending Component (SBC) manufacturing routes and one re-processing route have been approved by the aviation industry.
- These routes are available to make Sustainable Aviation Fuel (SAF) given appropriate feedstocks.
- For 2 routes the hydroprocessing / fractionation steps can also be undertaken at conventional refineries in mixture with crude oil distillates.
- Significant advantages for CAPEX, production flexibility, supply security, operational expertise and time-to-market.

# Aviation Fuel Manufacturing Routes

| Technology process type | Common name | ASTM annex | Feedstock | Max % blend / feed |
|---|---|---|---|---|
| Fischer-Tropsch Hydroprocessed synthesized paraffinic kerosene | **FT-SPK** | A1 (D7566) | Waste $CO_2$ and renewable power. Municipal solid waste. Agricultural waste / waste wood | **50** |
| **Co-processing** of Fischer-Tropsch **(FT)** to yield synthesized paraffinic kerosene in mixture with petroleum distillates | **-** | A1.2.2.2 (D1655) | | **5% (feed & product)** |
| Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids | **HEFA SPK** | A2 (D7566) | Vegetable and waste oils (fats, oils and greases) | **50** |
| **Co-processing** of hydroprocessed esters and fatty acids **(HEFA)** in mixture with petroleum distillates | **-** | A1.2.2.1 (D1655) | | **5% (feed & product)** |
| Synthesized iso-paraffins from hydroprocessed fermented sugars | **SIP** | A3 (D7566) | Fermentable sugars | **10** |
| Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources | **FT-SPK/A** | A4 (D7566) | Waste $CO_2$ and renewable power. Municipal solid waste. Agricultural waste / waste wood | **50** |
| Alcohol to jet synthetic paraffinic kerosene *(to also include synthetic isobutene)* | **ATJ - SPK** | A5 (D7566) | Ethanol, isobutanol and *isobutene* from sugars and other sources. | **50** |
| Synthesized kerosene from hydrothermal conversion of fatty acid esters and fatty acids | **CHJ** | A6 (D7566) | Vegetable oils and waste oils (e.g. used cooking oil) | **50** |
| Synthesized paraffinic kerosene from hydroprocessed hydrocarbons, esters and fatty acids | **HC- HEFA SPK** | A7 (D7566) | Botryococcus braunii species of algae | **10** |
| Alcohol-to-jet synthetic kerosene with aromatics | **ATJ-SKA** | A8 (D7566) | C2 – C5 alcohols derived from sugars and other sources. | **50** |
| *Re-processing* of hydrotreated esters and fatty acids in mixture with petroleum distillates | **-** | A1.2.2.3 (D1655) | Already processed HEFA - Included to manage refinery re-processing of retuned product / pipeline interfaces | **24%(feed) 10%(product)** |

# Refinery Co-Processing



# Refinery Co-Processing

- Co-processing is popular in Europe to meet SAF demand with refinery production recorded in:
  - UK.
  - Germany.
  - Spain.
  - Italy.
  - Austria.
  - France.
- Increasing the 5% limit offers a good transition route for future SBC / SAF manufacture as the automotive pool diversifies to low carbon alternatives.

*Co-processing offers an early transition route to SAF while units adopt 100% operation or stand-alone units are built .*

# Refinery Co-Processing

- The International Civil Aviation Organization (ICAO) have assessed new synthesis routes for carbon life-cycle emissions.
  - Carbon Off-Setting and Reduction Scheme of International Aviation (CORSIA) Default Life Cycle Emissions Values for CORSIA Eligible Fuels, June 2022.
- SBC carbon reduction is similar for standalone and co-processed molecules:

| Region | Feedstock | Pathway | Life Cycle Emissions Factor ($gCO_2e/MJ$) | Life Cycle Emissions Versus Crude Oil Jet |
|---|---|---|---|---|
| **BaseLine** | Crude Oil | Conventional | 89.0 | 0% |
| **Global** | Tallow | D7566 Annex 2 Unit | 22.5 | -75% |
| | Tallow | Refinery Co-Processing | 27.2 | -69% |
| **Global** | Used Cooking Oil | D7566 Annex 2 Unit | 13.9 | -84% |
| | Used Cooking Oil | Refinery Co-Processing | 16.7 | -81% |

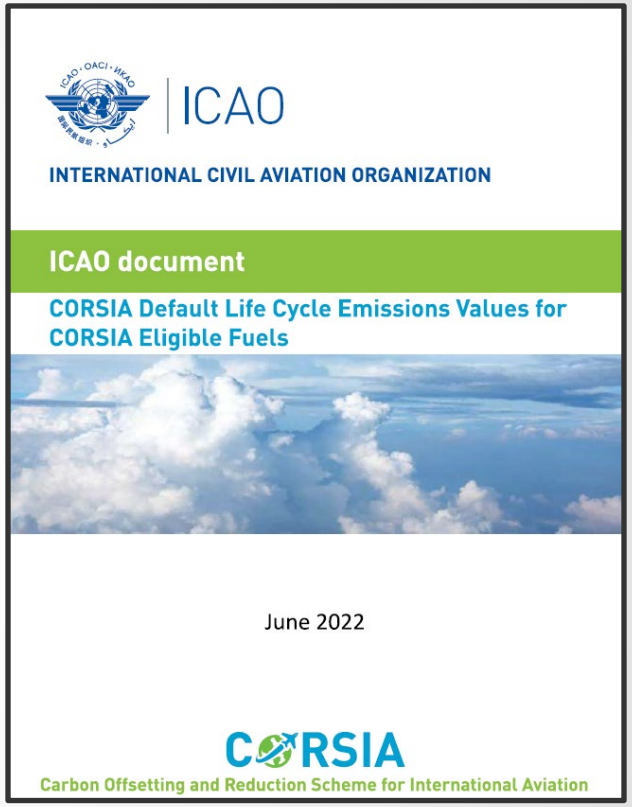



Image: ICAO

# Refinery Co-Processing

- An ASTM Task Force is seeking to:
  - Increase refinery co-processing approval from maximum 5 to maximum 30% v/v for HEFA or FT feedstocks.
  - Permit co-processing of mixed HEFA + FT feedstock mixtures.
- Research Report / D4054 technical evidence is required to demonstrate manufacture as fit-for-purpose.
- A major project featuring:
  - 8 pilot plant campaigns.
  - A full-scale refinery demonstration.

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Source: www.astm.org

# Pilot Plant Program

- Feedstocks featured:
  - Petroleum crude oil hydrocracking feedstock (2 samples, Crude Oil Feedstock 1, Crude Oil Feedstock 2)
  - Coconut oil – short chain HEFA feedstock
  - Mustard seed – long chain HEFA feedstock
  - Used cooking oil – typical commercial HEFA feedstock

*Feedstocks were selected to build Aviation Industry technical understanding and demonstrate both short, long and intermediate carbon chain length HEFA feedstocks can be successfully co-hydroprocessed, rather than for sustainability.*

# Pilot Plant Program

- The two crude oil feedstocks were sourced from the refining network.
- Standard hydrocracking material – heavy, aromatic, high sulfur.

| Analysis | Units | Petroleum Feedstock 1 | Petroleum Feedstock 2 |
|---|---|---|---|
| Appearance | - | Black / Pasty | Black / Pasty |
| Density at 50°C | kg/m³ | 874.9 | 889.8 |
| Density at 20°C calculated | kg/m³ | 895.6 | 910.2 |
| Mono aromatics | % m/m | 20.7 | 19.3 |
| Di aromatics | % m/m | 11.8 | 10.2 |
| Higher aromatics | % m/m | 2.5 | 4.3 |
| Total aromatics | % m/m | 35.0 | 33.8 |
| Sulfur | % m/m | 1.279 | 0.639 |

# Pilot Plant Program

- HEFA Feedstocks were analysed to confirm density, sulfur, water content and carbon number range.

Coconut Oil

Image: britannica.com

Used Cooking Oil

Image: bioukfuels.co.uk

Mustard Seed Oil

Image: britannica.com

| Analysis | Units | Coconut Oil | Mustard Oil | Used Cooking Oil |
|---|---|---|---|---|
| Density @ 15 °C | kg/m³ | 924.1 | 914.2 | 896.9 |
| Sulphur | mg/kg | <0.10 | <0.10 | <0.10 |
| Water content | mg/kg | 266 | 183 | 598 |
| C06:0 | % m/m | 0.73 | 0.00 | 0.03 |
| C08:0 | % m/m | 8.22 | 0.00 | 0.12 |
| C10:0 | % m/m | 5.87 | 0.02 | 0.08 |
| C12:0 | % m/m | 42.85 | 0.28 | 0.52 |
| C14:0 | % m/m | 15.95 | 0.23 | 0.76 |
| C16:0 | % m/m | 7.63 | 2.15 | 18.43 |
| C16:1 | % m/m | 0.03 | 0.15 | 0.37 |
| C18:0 | % m/m | 2.35 | 0.96 | 4.79 |
| C18:1 | % m/m | 5.45 | 23.53 | 40.50 |
| C18:2 | % m/m | 1.99 | 8.70 | 22.86 |
| C18:3 | % m/m | 0.10 | 8.35 | 0.96 |
| C20:0 | % m/m | 0.15 | 0.61 | 0.34 |
| C20:1 | % m/m | 0.00 | 8.86 | 0.33 |
| C22:0 | % m/m | 0.05 | 0.56 | 0.49 |
| C22:1 | % m/m | 0.33 | 34.96 | 0.06 |
| C24:0 | % m/m | 0.00 | 0.35 | 0.20 |
| C24:1 | % m/m | 0.10 | 2.75 | 0.14 |

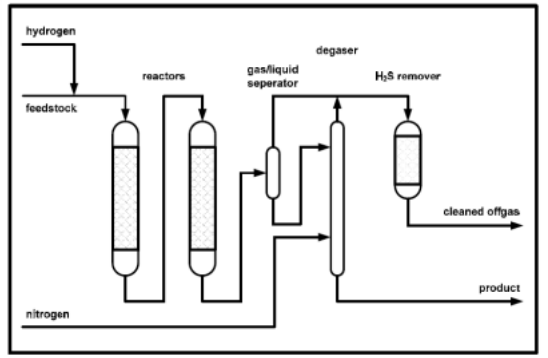
# Pilot Plant Program

- Task Force test matrix developed to demonstrate 30% v/v co-processing product quality.
  - 2 additional 5 and 10% v/v runs included.

| | Crude Oil Feedstock 1 % v/v | Crude Oil Feedstock 2 % v/v | Used Cooking Oil % v/v | Mustard Seed Oil % v/v | Coconut Oil % v/v |
|---|---|---|---|---|---|
| 1 | 100 | | | | |
| 2 | 95 | | 5 | | |
| 3 | 70 | | 30 | | |
| 4 | | 100 | | | |
| 5 | | 70 | | 30 | |
| 6 | | 70 | | | 30 |
| 7 | | 70 | | | 10 |
| 8 | | 90 | 10 | 10 | 10 |

# Pilot Plant Program

- The Test Matrix was hydrocracked on a pilot plant, using standard refinery catalyst / conditions as used for earlier aviation studies:
  - Jet Fuel Desulfurization (IASH 2011).
  - 5% HEFA Feedstock Co-processing (IASH 2013, ASTM 2017).
- Samples were distilled according to ASTM D2892 Standard Test Method for Distillation of Crude Petroleum (15-Theoretical Plate Column) to recover a fixed jet fuel fraction (150 to 260 °C) for comparison.




# Pilot Plant Program

- C14 and C=O data confirmed the HEFA feedstocks were successfully hydrocracked to yield sustainable carbon in the finished product:

| Analysis | C14 | Bio-carbon % m/m | Unreacted C=O (IP 583) |
|---|---|---|---|
| Units | dpm/ml | % m/m | mg/kg |
| 100% v/v Crude Oil Feedstock 1 | 0.140 | Background | <10 |
| 95% v/v Crude Oil Feedstock 1+ 5% v/v UCO | 0.365 | 2.44 | <10 |
| 70 % v/v Crude Oil Feedstock 1+ 30% v/v UCO | 1.294 | 12.60 | <10 |
| 70% v/v Crude Oil Feedstock 2 +30%v/v Mustard Seed Oil | 1.296 | 11.09 | <10 |
| 70% v/v Crude Oil Feedstock 2<br>+10% v/v UCO<br>+10% v/v Coconut<br>+10% v/v Mustard | 2.321 | 22.49 | <10 |
| 70% v/v Crude Oil Feedstock 2 + 30% v/v Coconut Oil | 3.738 | 38.73 | <10 |
| 90% v/v Crude Oil Feedstock 1 + 10% v/v Coconut Oil | 2.222 | 21.27 | <10 |
| 100% v/v Crude Oil Feedstock 2 | 0.249 | Background | <10 |

# Pilot Plant Program

- All co-processed product met ASTM D1655 A1.2.2.1 developed for 5% v/v co-processed HEFA:
  - Aromatic content was low, 2.5 to 12.9% v/v, a reflection of the HEFA formed and hydrocracking saturating C=C bonds in a large proportion of the feedstock aromatics.
  - Naphthalene concentration low, ≤0.13% v/v.
  - Sulfur content was very low, 0.0064% w/w maximum, <0.0003% w/w typical.
  - Viscosity @ -40 °C ranged from 8.06 to 10.07 cSt.
  - Freeze point ranged from -41.7 to -69.3 °C and could further be improved with slack on flash point, +44.5 to +59.5 °C .
  - 280 °C Thermal Stability visual ratings of 1, ≤39.58 nm deposit and minimal ΔP, ≤2 mmHg.
  - Unconverted C=O was below the detection limit of 10 mg/kg.

# Pilot Plant Program

| Analysis | Units | Limits | 100% v/v Petroleum Feedstock 1 | 95% v/v Petroleum Feedstock 1+ 5% v/v UCO | 70 % v/v Petroleum Feedstock 1+ 30% v/v UCO | 70% v/v Petroleum Feedstock 2 +30% v/v Mustard Seed Oil | 70% v/v Petroleum Feedstock 2 +10% v/v UCO +10% v/v Coconut +10% v/v Mustard | 70% v/v Petroleum Feedstock 2 + 30% v/v Coconut Oil | 90% v/v Petroleum Feedstock 2 + 10% v/v Coconut Oil | 100% v/v Petroleum Feedstock 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| COMPOSITION | | | | | | | | | | |
| Acidity | mgKOH/g | 0.10 max | 0.003 | 0.003 | 0.001 | <0.001 | 0.003 | 0.003 | 0.004 | 0.004 |
| Aromatics (D6379) | % v/v | 26.5 max | 4.3 | 3.5 | 2.5 | 8.6 | 7.8 | 5.9 | 7.6 | 12.9 |
| Mercaptan Sulfur | % m/m | 0.003 max | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| Total Sulfur | % m/m | 0.30 max | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | <0.0003 | 0.00064 | <0.0003 |
| VOLATILITY | | | | | | | | | | |
| Distillation | | | | | | | | | | |
| IBP | °C | | 168.9 | 169.0 | 169.1 | 169.5 | 174.1 | 175.3 | 174.9 | 170.6 |
| T10% | °C | 205 max | 181.4 | 178.8 | 178.4 | 182.3 | 186.6 | 186.4 | 187.3 | 184.2 |
| T50% | °C | Report | 200.7 | 196.3 | 195.0 | 202.9 | 205.8 | 200.2 | 207.5 | 205.9 |
| T90% | °C | Report | 231.6 | 227.4 | 226.2 | 228.7 | 233.3 | 215.9 | 234.5 | 235.1 |
| FBP | °C | 300 max | 245.0 | 249.9 | 242.9 | 246.8 | 246.4 | 226.7 | 248.1 | 249.4 |
| Residue | % v/v | 1.5 max | 1.5 | 1.5 | 1.4 | 1.2 | 1.2 | 1.1 | 1.2 | 1.2 |
| Loss | % v/v | 1.5 max | 0.4 | 0.4 | 0.4 | 0.7 | 0.8 | 0.7 | 0.6 | 0.6 |
| Flash Point | °C | +38 min | 54.5 | 53.0 | 44.5 | 53.5 | 57.0 | 57.0 | 59.5 | 55.5 |
| Density @ 15 °C | kg/m3 | 775 - 840 | 803.8 | 797.9 | 790.2 | 802.1 | 798.6 | 782.5 | 804.1* | 819.1 |
| FLUIDITY | | | | | | | | | | |
| Freeze Point | °C | -40 max (Jet A) | -67.5 | -65.2 | -65.4 | -63.6 | -47.3 | -41.7 | -49.9‡ | -69.3 |
| Viscosity @-20 °C | mm2/s | 8.0 max | More severe specification of viscosity @-40°C applies – See below | | | | | | | |
| COMBUSTION | | | | | | | | | | |
| Net Heat of Combustion | MJ/kg | 42.8 min | 43.5 | 43.5 | 43.6 | 43.39 | 43.48 | 43.67 | 43.42 | 43.17 |
| Naphthalenes | % v/v | 3.0 max | 0.01 | 0.01 | 0.01 | 0.05 | 0.05 | 0.04 | 0.07 | 0.13 |
| Smoke Point | mm | 18.0 min | 29.7 | 31.3 | 35.2 | 28.3 | 30.1 | 36.4 | 28.7 | 22.8 |
| CORROSION | | | | | | | | | | |
| Copper Corrosion | Rating | 1 max | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

* Average of 2 results (802.7, 805.4 kg/m$^3$)
‡ Average of 2 results (-48.7, -51.1 °C)

# Pilot Plant Program

| Analysis | Units | Limits | 100% v/v Petroleum Feedstock 1 | 95% v/v Petroleum Feedstock 1+ 5% v/v UCO | 70 % v/v Petroleum Feedstock 1+ 30% v/v UCO | 70% v/v Petroleum Feedstock 2 +30% v/v Mustard Seed Oil | 70% v/v Petroleum Feedstock 2 +10% v/v UCO +10% v/v Coconut +10% v/v Mustard | 70% v/v Petroleum Feedstock 2 + 30% v/v Coconut Oil | 90% v/v Petroleum Feedstock 2 + 10% v/v Coconut Oil | 100% v/v Petroleum Feedstock 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| THERMAL STABILITY @ 260°C | | | More severe specification of thermal stability @ 280°C applies – See below. | | | | | | | |
| Visual Rating | Rating | <3 max/no P or A | | | | | | | | |
| dP | mmHg | 25 max | | | | | | | | |
| Thickness | ETR nm | 85 max | | | | | | | | |
| CONTAMINANTS | | | | | | | | | | |
| Existent Gum† | mg/100ml | 7 max | <1 | 1 | <1 | <1 | 0 | 1 | 1 | 4 |
| MSEP | Rating | 85 min (no SDA) | 95 | 99 | 97 | 99 | 99 | 100 | 90 | 86 |
| ADDITIVES | | | | | | | | | | |
| Conductivity + 0.5 mg/L SDA | pS/m | 50 – 600 (For information) | 168 | 167 | 160 | 235 | 170 | 160 | 160 | 190 |
| Conductivity temperature | °C | Report (For information) | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 | 20.5 |

† Without any anti-oxidant added to samples.

# Pilot Plant Program

| Analysis | Units | Limits | 100% v/v Petroleum Feedstock 1 | 95% v/v Petroleum Feedstock 1+ 5% v/v UCO | 70 % v/v Petroleum Feedstock 1+ 30% v/v UCO | 70% v/v Petroleum Feedstock 2 +30% v/v Mustard Seed Oil | 70% v/v Petroleum Feedstock 2 +10% v/v UCO +10% v/v Coconut +10% v/v Mustard | 70% v/v Petroleum Feedstock 2 + 30% v/v Coconut Oil | 90% v/v Petroleum Feedstock 2 + 10% v/v Coconut Oil | 100% v/v Petroleum Feedstock 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| THERMAL STABILITY @ 280°C | | | | | | | | | | |
| Visual Rating | Rating | <3 max/no P or A | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| dP | mmHg | 25 max | 0 | 0.0 | 2.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Deposit Thickness | ETR nm | 85 max | 13.95 | 22.71 | 14.47* | 12.20‡ | 9.44 | 9.66 | 39.58 | 21.47 |
| | ITR nm | 85 max | 14.7 | 24.0 | 22.9 | 13.4 | 15.2 | 14.9 | 25.3 | 32.4 |
| Viscosity @-40 °C | $mm^2/s$ | 12.0 max | 9.24 | 8.39 | 8.06 | 9.37 | 9.68 | 8.18 | 9.97 | 10.07 |
| Unconverted esters and fatty acids (IP 583) | mg/kg | Δ15 max | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |

* Average of 2 results (12.00, 16.94 nm)
‡ Average of 2 results (7.00, 17.39 nm)

# Pilot Plant Program

To ensure finished product will be ‘typical’ additional criteria have been proposed for Jet containing 5 – 30% co-processed HEFA:

- 7000 kPa hydrogen partial pressure to help define hydrocracking.
- Aromatic concentration limits based on CRC Project AV-2-04a:
  - 8 (D1319) / 8.4 (D6379) % v/v minimum
  - supported by 50% v/v maximum co-hydrocracked Jet blending limit
- Additional distillation parameters:
  - T50% - T10% ≥ 15 °C
  - T90% - T10% ≥ 40 °C
- Lubricity, BOCLE 0.85 mm maximum.
- Anti-oxidant 17 – 24 mg/l (similar to MIL-DTL-83133 JP-8).

# Pilot Plant Program: Peroxides

| Sample (17 mg/l RDE/A/609 Aviation Anti-Oxidant) | Peroxides ASTM D3703 | |
|---|---|---|
| | Initial<br><br>mg/kg | After ASTM D5304 Aging (16 Hours / 100 °C / 100 psi Oxygen)<br>mg/kg |
| Jet A-1 | 0.911 | 2.041 |
| 50:50 Blend Jet A-1 + Co-processed HEFA (19% HEFA to demonstrate ruggedness). | 0.812 | 2.015 |

# Refinery Program

- A full-scale refinery trial has been completed in support of the Task Force:
  - Carinata feedstock (sustainable cover-crop).
  - Standard refinery petroleum feedstock.
  - 10% v/v campaign.
- All product sent to diesel (no limitation on HEFA co-processing):
  - Kerosene sample taken and blended 50:50 with Jet A-1 run-down streams to demonstrate aviation fuel quality which would have been present in finished product tank.

# Refinery Program

- Petroleum and Carinata feedstock analysis:

| Analysis | Units | Petroleum Feedstock 3 |
|---|---|---|
| Density at 15°C | kg/m³ | 914.8 |
| Initial Boiling Point | °C | 269.0 |
| Final Boiling Point | °C | 595.1 |
| Sulfur | % m/m | 0.62 |

| Analysis | Units | Carinata Oil |
|---|---|---|
| Density @ 15 °C | kg/m³ | 916.6 |
| Sulfur | mg/kg | - |
| Water content | mg/kg | 400 |
| C06:0 | % m/m | <0.1 |
| C08:0 | % m/m | <0.1 |
| C10:0 | % m/m | <0.1 |
| C12:0 | % m/m | <0.1 |
| C14:0 | % m/m | <0.1 |
| C15:0 | % m/m | 0.1 |
| C15:1 | % m/m | <0.1 |
| C16:0 | % m/m | 4.0 |
| C16:1 | % m/m | <0.1 |
| C17:0 | % m/m | <0.1 |
| C17:1 | % m/m | <0.1 |
| C18:0 | % m/m | 1.2 |
| C18:1 | % m/m | 15.0 |
| C18:2 | % m/m | 20.6 |
| C18:3 | % m/m | 13.1 |
| C19:0 | % m/m | 0.1 |
| C20:0 | % m/m | 0.9 |
| C20:1 | % m/m | 1.0 |
| C22:0 | % m/m | <0.1 |
| C22:1 | % m/m | 40.3 |
| C22:2 | % m/m | 1.2 |
| C24:0 | % m/m | <0.1 |
| C24:1 | % m/m | 1.8 |

# Refinery Program

- Jet A-1 Quality

| Analysis | Units | Limits | Refinery Co-processed HEFA Jet A-1 |
|---|---|---|---|
| COMPOSITION | | | |
| Acidity | mgKOH/g | 0.10 max | 0.002 |
| Aromatics (D6379) | % v/v | 26.5 max | 18.0 |
| Mercaptan Sulfur | % m/m | 0.003 max | 0.0002 |
| Total Sulfur | % m/m | 0.30 max | 0.0009 |
| VOLATILITY | | | |
| Distillation | | | |
| IBP | °C | | 167.5 |
| T10% | °C | 205 max | 179.5 |
| T50% | °C | Report | 196.8 |
| T90% | °C | Report | 226.6 |
| FBP | °C | 300 max | 256.3 |
| Residue | % v/v | 1.5 max | 1.2 |
| Loss | % v/v | 1.5 max | 0.6 |
| Flash Point | °C | +38 min | 52.0 |
| Density @ 15 °C | kg/m3 | 775 - 840 | 810.5 |
| FLUIDITY | | | |
| Freeze Point | °C | -47 max (Jet A-1) | -51.3 |
| Viscosity @-20 °C | mm2/s | 8.0 max | 4.262 |
| COMBUSTION | | | |
| Net Heat of Combustion | MJ/kg | 42.8 min | 43.15 |
| Naphthalenes | % v/v | 3.0 max | 0.17 |
| Smoke Point | mm | 18.0 min | 22 |
| CORROSION | | | |
| Copper Corrosion | Rating | 1 max | 1a |

# Refinery Program

- Jet A-1 Quality

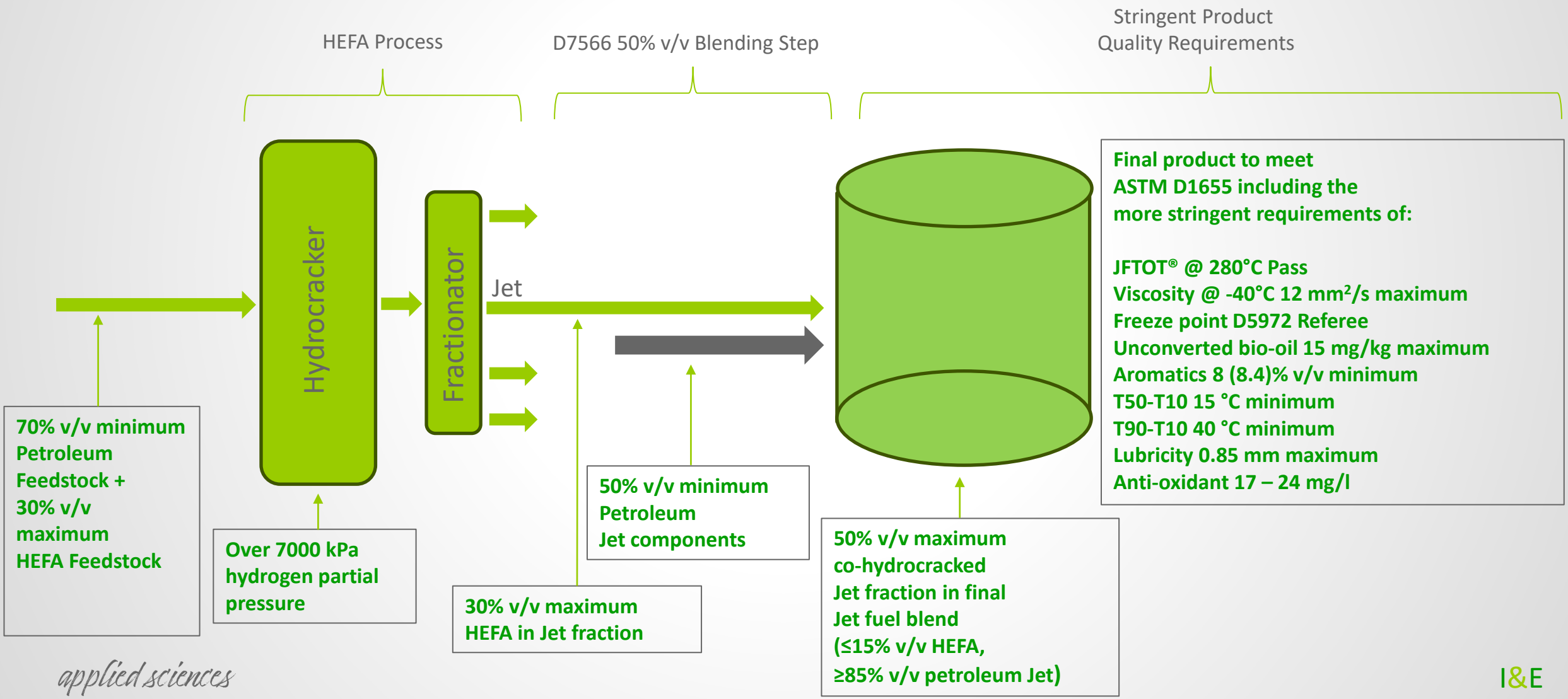
| Analysis | Units | Limits | Refinery Co-processed HEFA Jet A-1 |
|---|---|---|---|
| THERMAL STABILITY @ 260°C | | | More severe specification of thermal stability @ 280°C minimum applies – See below. |
| Visual Rating | Rating | <3 max/no P or A | |
| dP | mmHg | 25 max | |
| Thickness | ETR nm | 85 max | |
| CONTAMINANTS | | | |
| Existent Gum | mg/100ml | 7 max | <0.5 |
| MSEP | Rating | 85 min (no SDA) | 92 |
| ADDITIVES | | | |
| Anti-oxidant RDE/A/609 | mg/L | 17 - 24 | 20 |

# Refinery Program

- Jet A-1 Quality

| Analysis | Units | Limits | Refinery Co-processed HEFA Jet A-1 |
|---|---|---|---|
| THERMAL STABILITY @ 285°C | | | |
| Visual Rating | Rating | <3 max/no P or A | 0 |
| dP | mmHg | 25 max | 0.0 |
| Deposit Thickness | ETR nm | 85 max | 63.34 |
| Viscosity @-40 °C | $mm^2/s$ | 12.0 max | 8.559 |
| Freeze Point D7153 | °C | -47 max (Jet A-1) | -51.3 |
| Unconverted esters and fatty acids (IP 583) | mg/kg | Δ15 max | <10 |
| Aromatics (D6379) | % v/v | 8.4 min | 18.0 |
| T50 - T10<br>T90 - T10 | °C<br>°C | 15 min<br>40 min | 17.3<br>47.1 |
| Lubricity | mm | 0.85 max | 0.64 |

# Summary


HEFA Process
D7566 50% v/v Blending Step
Stringent Product Quality Requirements
Hydrocracker
Fractionator
Jet
70% v/v minimum Petroleum Feedstock + 30% v/v maximum HEFA Feedstock
Over 7000 kPa hydrogen partial pressure
30% v/v maximum HEFA in Jet fraction
50% v/v minimum Petroleum Jet components
50% v/v maximum co-hydrocracked Jet fraction in final Jet fuel blend (≤15% v/v HEFA, ≥85% v/v petroleum Jet)
Final product to meet ASTM D1655 including the more stringent requirements of:
JFTOT® @ 280°C Pass
Viscosity @ -40°C 12 mm²/s maximum
Freeze point D5972 Referee
Unconverted bio-oil 15 mg/kg maximum
Aromatics 8 (8.4)% v/v minimum
T50-T10 15 °C minimum
T90-T10 40 °C minimum
Lubricity 0.85 mm maximum
Anti-oxidant 17 – 24 mg/l

# Summary

- To meet the IATA aspiration of carbon neutral operations by 2050 requires production of new synthetic kerosene blend components from sustainable feedstocks.
- To meet this goal utilization of refinery hydrotreatment and fractionation facilities offers advantages - CAPEX, production flexibility, supply security, operational expertise and time-to-market.
- An ASTM Task Force has demonstrated the current 5% HEFA feedstock co-processing limit can be increased up to 30% v/v:
  - 8 pilot plant campaigns.
  - A full-scale refinery demonstration at 10% v/v.
- All product met current D1655 ≤5% v/v HEFA co-processing requirements.
- Additional requirements have been included to promote industry approval.

*Co-processing: A flexible Jet manufacturing route to assure product availability and reduce environmental foot-print.*

# Thank You