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CAPACITY BUILDING ON SAF & CORSIA ELIGIBLE FUELS NAMIBIA

A ‘Step-by-Step’ guide to Sustainable Aviation Fuel (SAF)

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Working for quieter and cleaner aviation.

Your safety is our mission.

An introduction to Sustainable Aviation Fuel

Contents

What is Sustainable Aviation Fuel?

- Sustainable Aviation Fuel or ‘SAF’ is a generic word for non-conventional aviation fuel
- SAF is almost chemically identical to conventional fossil-based jet fuel and is a safe replacement for it
- SAF is produced from feedstocks that absorb CO_2 and can provide a net reduction in CO_2 emissions compared to conventional aviation fuel
- These feedstocks can be either biological or non-biological in origin

SAF – key principles

→ There are three key principles to Sustainable Aviation Fuel or 'SAF'

→ **S**ustainability

→ **A**lternative

→ **F**uel

Sustainability

"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"
Source: Brundtland Report, Our Common Future, 1987

- What does this mean?
  - Sustainability means that it can be resourced again and again without depleting natural resources
  - Sustainability means that social and economic as well as environmental considerations are important

Alternative

“An activity that departs from the norm”
Source: Oxford Languages

- What does this mean in relation to aviation?
  - Normal or conventional aviation fuel is made from petroleum (oil) – like coal and natural gas this is a fossil-source
  - SAFs are ‘alternative’ as they are made from substances that can be made into fuel, but aren’t from these fossil sources, e.g., cooking oils and fats, plant oils, agricultural residues, municipal wastes and waste gases
  - They are processed in an alternative way to conventional aviation fuel

Fuel

- What does this mean?
  - SAF must meet the required technical and certification requirements for use in commercial aircraft
  - Fuel isn’t just used for combustion with an aircraft – it’s also used inside the aircraft and engine as a lubricant, cooling fluid and hydraulic fluid
  - Important that SAF is a **‘drop-in’** fuel, so manufacturers don’t have to redesign engines or aircraft, and that fuel suppliers and airports don’t have to build new infrastructure/fuel delivery systems

Types of SAF

- **Aviation Biofuels** – are fuels that are produced from biomass (renewable organic matter), such as waste cooking oils and fats, agricultural and forestry residues, municipal solid waste
- **Synthetic Aviation Fuels or 'Renewable Fuels of Non-Biological Origin' (RFNBOs)** – are fuels that are derived from renewable sources other than biomass (e.g., wind or solar)
- **Recycled Carbon Aviation Fuels** – are fuels that are produced from liquid or solid waste streams of non-renewable origin (fossil wastes) that cannot be prevented, reused, or recycled. Feedstocks include the fossil fraction of municipal solid waste (MSW) (e.g., non-recyclable plastic) and industrial waste gases

What are the benefits of SAF?

- SAF commercially available today can have a reduction of between 80 and 90% in carbon emissions over the lifecycle of the fuel compared to traditional jet fuel. With Carbon Capture Utilisation and Storage (CCUS) the savings could be >100% in the future
- It contains fewer impurities (e.g., sulphur and aromatic hydrocarbons) and can reduce soot, sulphur dioxide and particulate matter emissions
- Additional environmental benefits (e.g., diversion of waste from landfill)
- Possible reduction in contrail formation
- Improved fuel efficiency – higher energy content
- Economic and social benefits (e.g., use of non-productive land)

Aviation Fuel – Technical Specifications

Aviation Fuel Specifications

- Safety is the aviation industry's top priority, and it is highly regulated
- To ensure technical and safety compliance, aviation fuel must be fit for purpose and meet internationally recognised standards
- There are several global standards, but the ASTM International standards which define the technical specifications of a fuel are most widely recognised
- New types of fuel must undergo strict tests – in the lab, on the ground and in the air to meet these requirements
- Aviation fuel is tested and certified before use

ASTM (ASTM International)

- Originally known as the American Society for Testing and Materials
- ASTM produce standards that are formal, technical requirements that establish quality specifications for a wide range of materials, products, systems, and services
- ASTM standards serve as the basis for manufacturing, procurement, and regulatory activities globally
- Standards approved via consensus of industry stakeholders
- This includes several standards for the aviation industry

ASTM Standards

→ ASTM standards relevant to aviation fuel and SAF

ASTM D1655

Standard Specification for Aviation Turbine Fuels

- This standard is the conventional jet fuel specification for Jet A and Jet A-1 produced from petroleum
- It has been used globally since 1959 to ensure that safe and consistent jet fuel is available for all aircraft
- The Defence Standard (Def-Stan) 91-091 is the UK equivalent. Others include TS-1 fuel (Russia) and No.3 Jet Fuel (China)

ASTM D4054

Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives

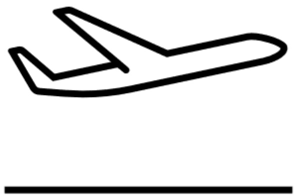
- This standard was developed to ensure the safe operation of aircraft using alternative fuels
- Each new fuel (production pathway) must go through this qualification process, including testing in the lab, on the ground and in the air
- If approved and adopted the new fuel is added to the ASTM D7566 standard

ASTM D7566

Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons

- This standard details the technical specification for alternative fuel or ‘neat SAF’ including feedstocks, the conversion process, the final characteristics of the ‘neat’ product and blending requirements
- The fuel ‘pathways’ are identified in the standard and its Annexes

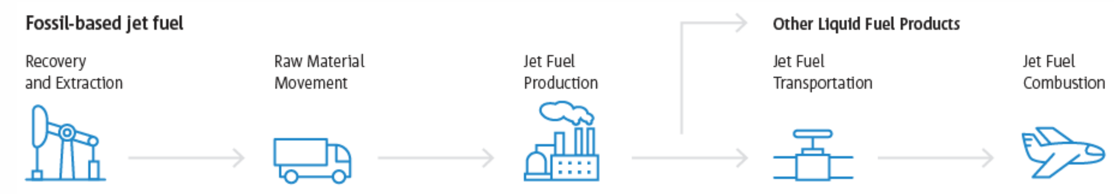
EASA



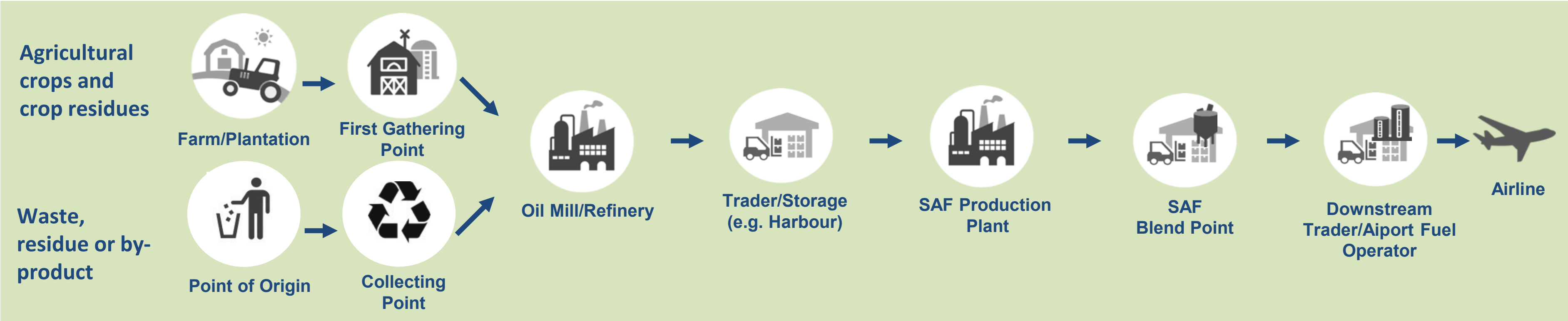
The SAF Value Chain
‘from Feedstock to Flight’

EASA

SAF Supply/Value Chain – an example



Source: European Aviation Environmental Report 2022 (EASA)



Source: ISCC

The SAF Value Chain

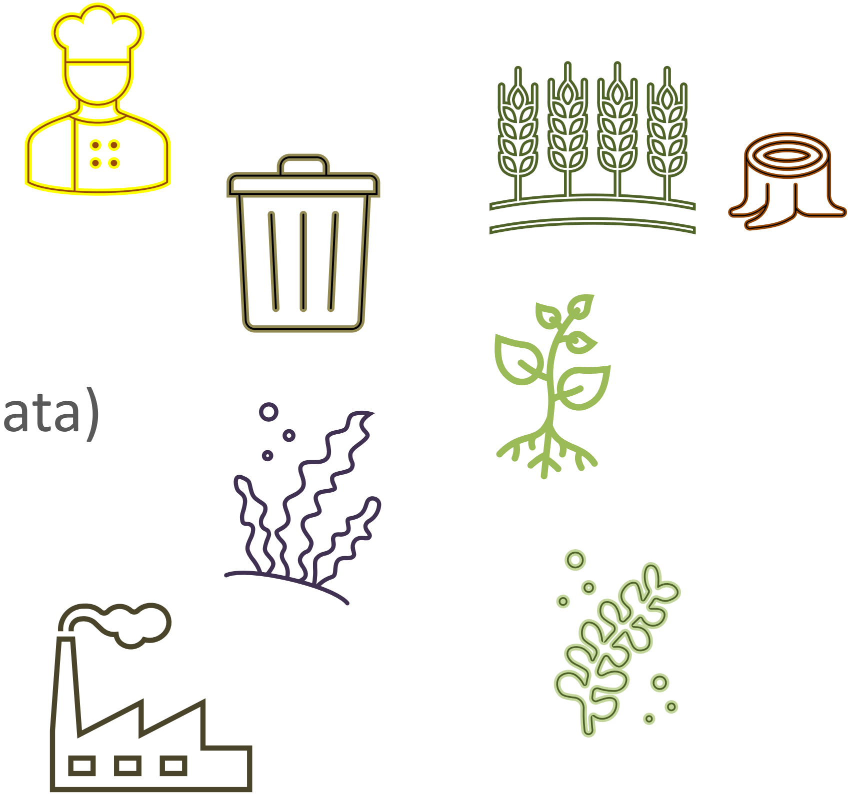
'... the full lifecycle of a product or process..'

Source: University of Cambridge

- → Feedstocks
- → Pathways
- → Blending and Certification
- → Downstream Logistics
- → End Use

SAF Feedstocks

- Waste oils and fats
- Municipal solid waste
- Cellulosic waste
- Cover crops (e.g., camelina, carinata)
- Jatropha
- Halophytes
- Algae
- Non-biological alternative fuels



SAF Pathways (ASTM Approved)

ASTM reference	Conversion process	Abbreviation	Possible Feedstocks	Maximum Blend Ratio	Approval Date
ASTM D7566 Annex A1	**Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene**	**FT**	**Coal, natural gas, biomass**	**50%**	**2009**
ASTM D7566 Annex A2	**Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids**	**HEFA**	**Vegetable oils, animal fats, used cooking oils**	**50%**	**2011**
ASTM D7566 Annex A3	Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%	2014
ASTM D7566 Annex A4	**Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources**	**FT-SKA**	**Coal, natural gas, biomass**	**50%**	**2015**
ASTM D7566 Annex A5	**Alcohol to jet synthetic paraffinic kerosene**	**ATJ-SPK**	**Ethanol, isobutanol and isobutene from biomass**	**50%**	**2016**
ASTM D7566 Annex A6	Catalytic hydrothermolysis jet fuel	CHJ	Vegetable oils, animal fats, used cooking oils	50%	2020
ASTM D7566 Annex A7	Synthesized paraffinic kerosene from hydrocarbon - hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10%	2020
ASTM D7566 Annex A8	**Synthetic Paraffinic Kerosene with Aromatics**	**ATJ-SKA**	**C2-C5 alcohols from biomass'**	**50%**	**2023**

Source: adapted from ICAO 2023

Main SAF Pathways

- Biomass Gasification + Fischer-Tropsch (Gas+FT) or FT-SPK
- Hydroprocessed Esters and Fatty Acids (HEFA-SPK)
- Alcohols to Jet (AtJ - SPK)
- Synthetic Aviation Fuels (e.g., Power to Liquid or ‘PtL’)

Biomass Gasification + Fischer Tropsch

- **Product:** Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene
- **Abbreviation**: FT-SPK
- **Feedstock:** Energy crops, lignocellulosic biomass, solid waste
- **Process:** The Fischer Tropsch process involves a series of chemical reactions that convert syngas (a mixture of carbon monoxide and hydrogen) into liquid hydrocarbons
- **Blend Ratio**: 50%
- **TRL:** 7-8
- **ASTM D7566**: Annex 1

Source: TRL: European Aviation Environmental Report 2022 (EASA).

Hydroprocessed Esters and Fatty Acids

- **Product**: Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids
- **Abbreviation**: HEFA-SPK
- **Feedstock**: Vegetable and animal fats
- **Process**: Feedstock is converted using hydrogen to remove oxygen and produce hydrocarbon fuel components
- **Blend Ratio**: 50%
- **TRL:** 8-9
- **ASTM D7566**: Annex 2

Source: TRL: European Aviation Environmental Report 2022 (EASA).

Alcohol to Jet

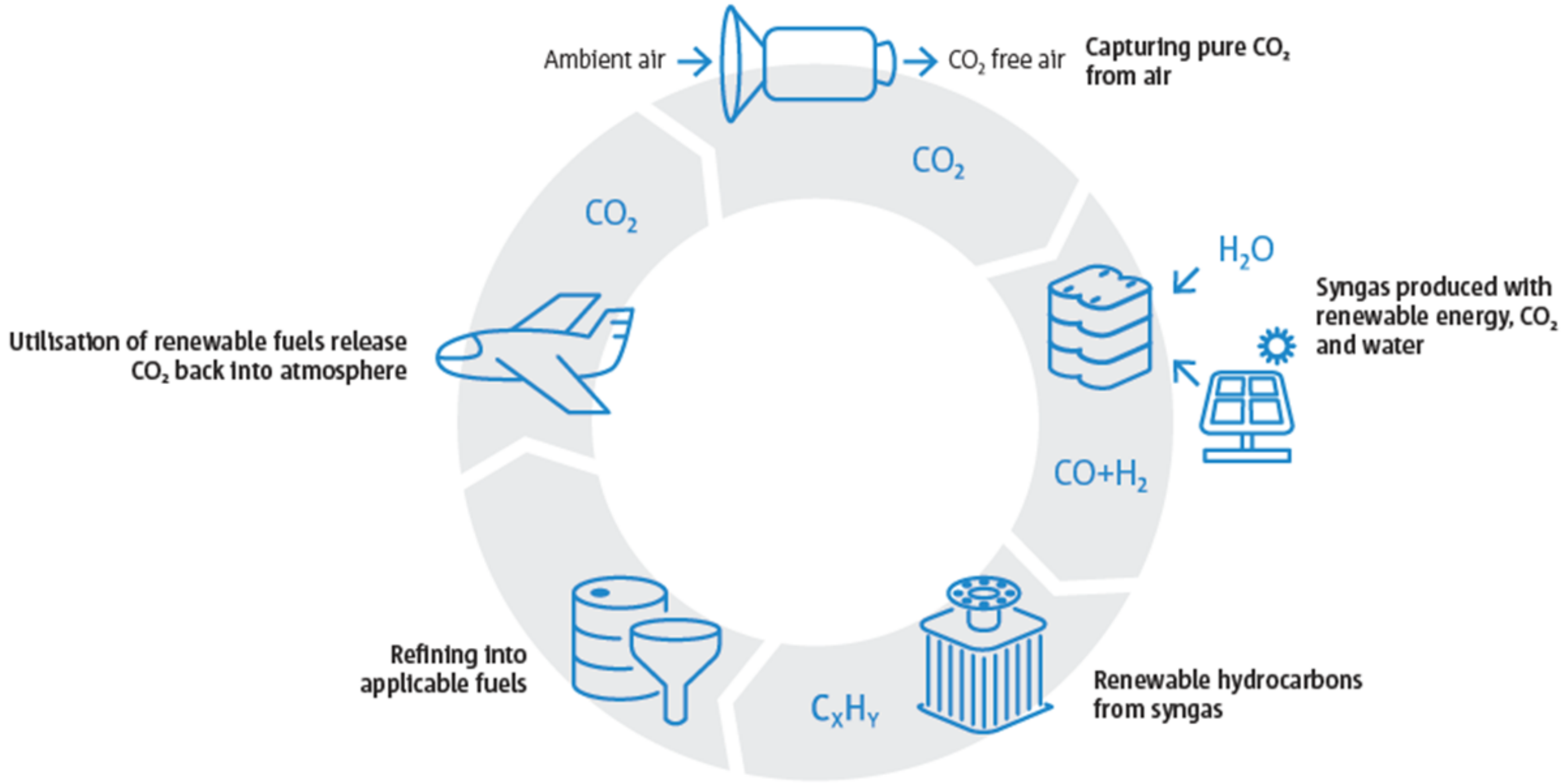
- **Product:** Alcohol to Jet synthetic paraffinic kerosene
- **Abbreviation**: AtJ-SPK
- **Feedstock:** Sugar, starch crops, lignocellulosic biomass
- **Process:** Alcohol (ethanol or iso-butanol) is converted to SAF by removing the oxygen and linking the carbon molecules together to get the required carbon chain length
- **Blend Ratio**: 50%
- **TRL:** 7-8
- **ASTM D7566**: Annex 5

Source: TRL: EASA Environment Report 2022.

Synthetic Aviation Fuels

- Synthetic Aviation Fuels or Renewable Fuels of Non-Biological Origin (RFNBOs) include 'e-fuels' or Power to Liquid 'PtL' fuels
- The process typically involves creating jet fuel through a process involving electric energy, water and CO_2
- The energy content of these fuels is derived from renewable sources other than biomass (e.g., wind or solar)
    - The renewable energy and water are used in an electrolyser to produce hydrogen
    - This is subsequently synthesised with CO_2 into syngas
    - This syngas is then further processed into fuel by the Fischer-Tropsch (FT) process or alternatively by methanol synthesis
- The CO_2 needed can be sourced from industrial waste gases, biomass or captured directly from the atmosphere
- These fuels are already approved if produced through the Fischer-Tropsch or AtJ production pathways
- The production of the electricity and the sourcing of CO_2 are the determining factors in the sustainability as well as the overall costs of these types of fuel

Power to Liquid (PtL)



Co-processing

- **What is co-processing?**
  Co-processing is the simultaneous processing of biobased material with fossil-based feeds in an existing refinery
- Current approved methods:

ASTM reference	Conversion process	Abbreviation	Possible Feedstocks	Maximum Blend Ratio
ASTM D1655 Annex 1	co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery	n/a	Vegetable oils, animal fats, used cooking oils from biomass processed with petroleum’	5%
ASTM D1655 Annex 1	co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery	n/a	Fischer-Tropsch hydrocarbons co-processed with petroleum	5%
ASTM D1655 Annex 1	Co-Processing of HEFA	n/a	Hydroprocessed esters/fatty acids from biomass’	10%

Source: ICAO 2023

Commercial Use of SAF

- → The fact that a technology is certified does not mean that the fuel is also produced on a commercial scale
- → The technological maturity of each production pathway can be defined through a Fuel/Technology Readiness Level, which ranges from 1 for basic ideas, to 9 for an actual system proven in an operational environment
- → HEFA is currently the main pathway to commercial SAF production
- → In addition to the current SAF pathways, there are other feedstock/technology combinations for SAF production are currently under development and in the process of getting ASTM qualification

Towards ASTM Qualification

Conversion process under evaluation	Abbreviation	Lead developer
Synthesized Aromatic Kerosene	SAK	Virent
Integrated hydropyrolysis and hydroconversion	IH2	Shell
Single Reactor HEFA (Drop-in Liquid Sustainable Aviation and Automotive Fuel)	DILSAAF	Indian CSIR-IIP
Pyrolysis of non-recyclable plastics	ReOIL	OMV
Co-processing of pyrolysis oil from used tires	TPO	Phillips 66
Methanol to jet	MTJ	ExxonMobil
Increase in fatty acid/ester co-processing from 5% to 30%		
HEFA with higher cycloparaffins’		Revo
Biomass pyrolysis		Alder
Biomass/Waste pyrolysis		Green Lizard
Cycloalkanes from Ethanol		Vertimass

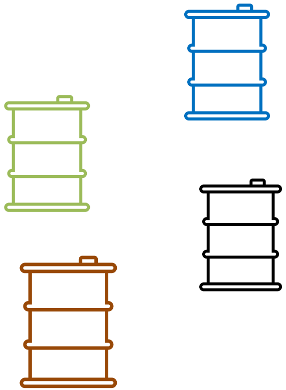
Source: ICAO 2023

Challenges to commercial SAF Development

- Technology – the move from the research phase to small-sale demonstration and then the commercial phase can be extremely challenging and require significant investment
- Funding – small-scale demonstration plants require a fraction of the CAPEX compared to commercial plants. Bridging this gap requires investment
- Risk – the jump from a successful small-scale demonstration plant to a full-scale commercial plant has risks
- Cost of SAF – currently between 2-4 times greater than standard jet fuel – this is expected to drop when costs of production fall and supply increases

Producing ‘neat’ SAF

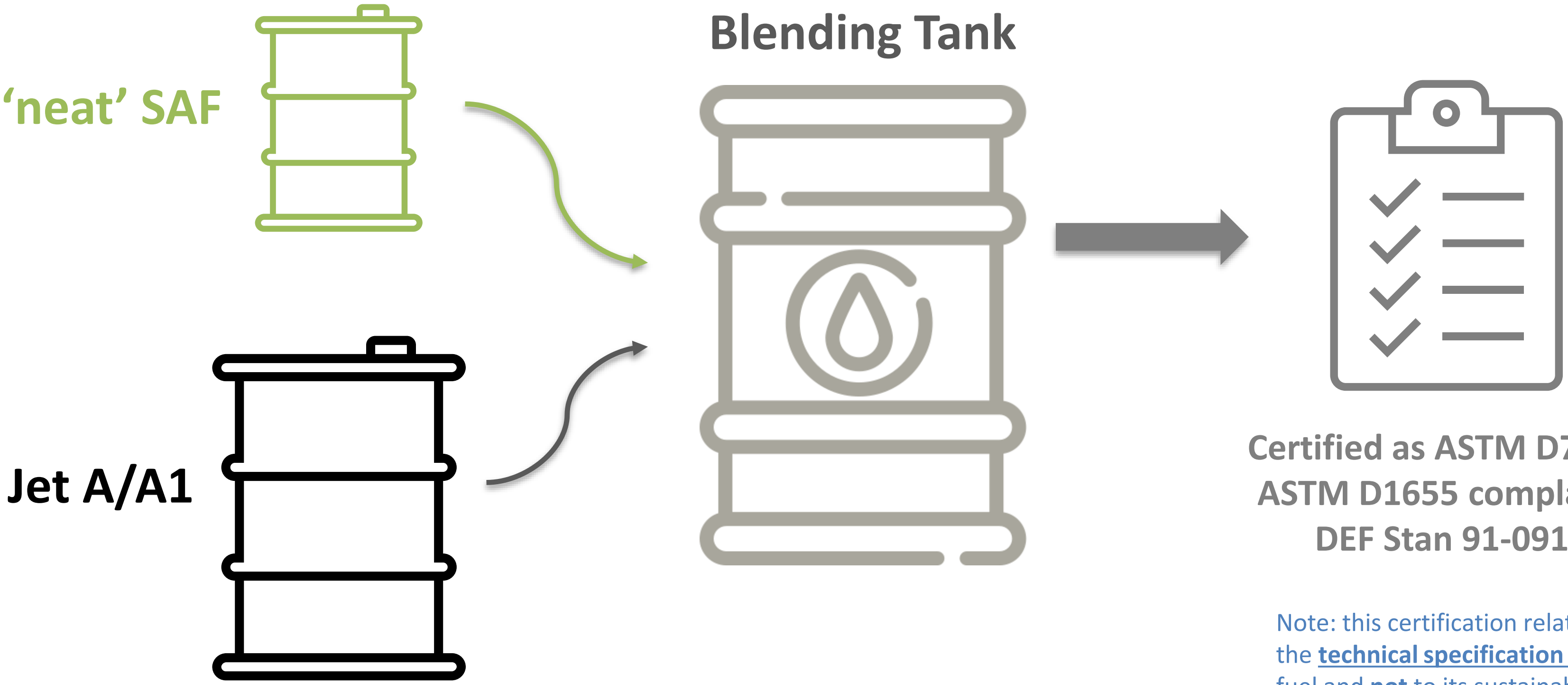
- When a barrel of oil is refined, several products are often produced e.g., diesel, jet aviation fuel, petrol, lubricants and plastics
- This is the same when alternative/renewable fuels (including ‘neat’ SAF) are produced e.g., renewable diesel, green naptha, green LPG, SAF
- The range of products from alternative fuels is often more specialised and can be adjusted to produce more SAF, or more renewable diesel depending on market conditions



Percentage Product Distribution at DILSAAF Process (CSIR-IIP)

- Green LPG: 17.5%
- Green Naptha: 20.9
- Renewable Diesel: 29.3%
- SAF: 32.3%

Blending and Certification



Certified as ASTM D7566
ASTM D1655 complaint
DEF Stan 91-091

Note: this certification relates to the **technical specification** of the fuel and **not** to its sustainability

Blending in Europe

- As the product specification adhered to in Europe, DEF STAN 91-091, does not allow continuous blending at airport depots, blending must take place in upstream terminals or refineries
- There are currently very few SAF blending facilities in operation in the UK and mainland Europe – this will need to change as the majority of announced SAF projects will require blending services
- Most SAF producers are specialist sustainable fuel producers that do not have access to fossil jet, and do not intend to invest in on-site blending facilities
- Significant investments in upgrade terminals by adding SAF blending capabilities are underway (e.g., Essar in Stanlow, Vopak in Antwerp)

Downstream Logistics – getting to the wing

→ **Once blended**, the SAF it needs to be distributed to the airport where it will be used

→ This can be done in several ways, depending on how an airport receives its fuel, the fuelling infrastructure at that airport and how the blended SAF is to be treated

→ Is it to be kept separate and segregated from the existing conventional jet fuel supply, or is it to be integrated into the existing supply infrastructure?

Types of Fuel Distribution

ISO Tank

- Typical capacity is roughly 30,000 L
- Benefits from multi-modal transport capability
- Impractical for continuous supply solutions

Road Tanker

- Typical capacity 35,000 – 45,000 L
- Subject to weight restrictions
- Supplies majority of small –med airports

Rail Tank Car

- Capacity in the order of 1,500,000 L
- Rail tank cars must be lined for airport delivery
- Typically discharges to airport via a pipeline

Vessel

- Large variety in capacity, 1,000 – 90,000 tonne DWT
- SAF is increasingly being loaded as a split cargo
- Cleaning procedures are key

Pipeline

- Throughput capacity determined by diameter, flow rate etc. but also ‘line rights’
- Most efficient mode for supply to large airports

Downstream Logistics – integrated supply chain

- SAF delivered straight to the airport fuel storage tanks (comingled)
- Distributed through standard operation e.g., hydrant system/fuel truck
- All aircraft using the airport physically receive a portion of the blended SAF – it can’t be identified as being on an individual aircraft
- The SAF volume allocated to the airline holding the SAF supply contract, and that airline may claim the benefits

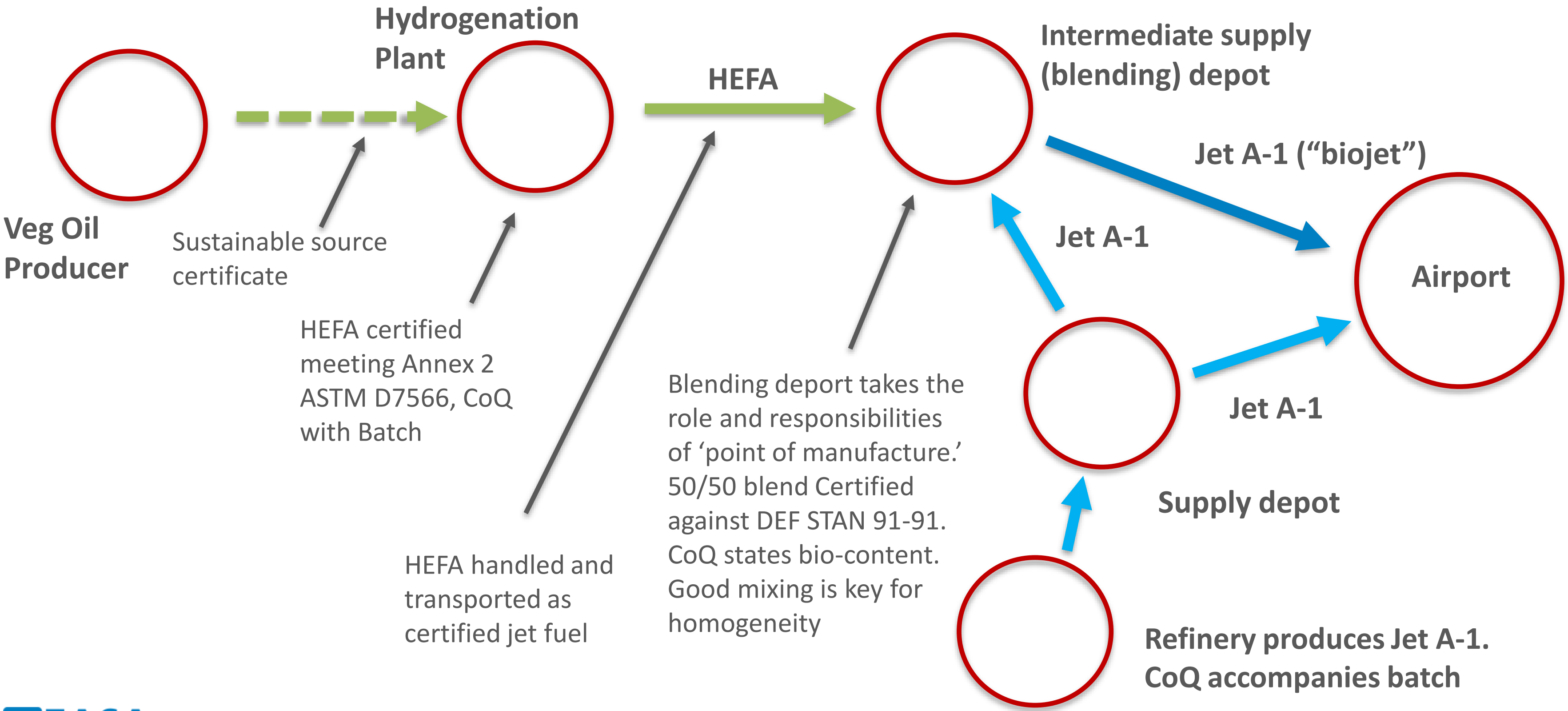
Downstream Logistics – segregated supply chain

→ SAF arrives at the airport in dedicated fuel truck or other transport mode

→ SAF transferred to dedicated airport storage or into dedicated airport refuelling truck

→ the SAF can be physically delivered to a specific aircraft and can be accounted for in that way

SAF Certification – HEFA example



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Achieving 100% SAF

- Maximum blending limit is currently 50% due to safety and compatibility requirements
- Research and test flights to evaluate the effects of 100% SAF on emissions and the performance of aircraft taking place
- AIRBUS A319neo – October 2021
- Virgin Atlantic – first 100% transatlantic flight by a commercial airline took place on 28 November 2023 (LHR to JFK)

Source: European Aviation Environmental Report 2022 (EASA)

Are these alternative fuels always 'sustainable'?

No!

- SAF is a is a generic word for non-conventional aviation fuel
- An alternative fuel (‘neat SAF’) that meets the technical ASTM specifications **doesn’t** make it ‘sustainable’
- Sustainable means that it is resourced in a manner consistent with economic, social and environmental aims
- Sustainability is assessed through ‘Sustainability Criteria’ and assessed by Accredited Certification Bodies*

* Accredited by an approved Sustainability Certification Scheme

Next Session:

An introduction to Sustainability Criteria, Life Cycle Emissions and Sustainability Certification

EASA

Capacity Building

GHG Emissions

Sustainability

FT-SPK

Drop-in Fuel

RSB

Sustainability Criteria

Certification

PtL

Used Cooking Oil (UCO)

Safety

CAPEX

Life Cycle Emissions

ASTM D1655 DEF Stan 91-091

SAF

HEFA

Co-processing

'neat' SAF

ASTM D4054

ISCC

Environmental

Feedstock

Alternative

Cost

Municipal Solid Waste

ASTM D7566

CORSIA Eligible Fuels

Sustainability Certification Schemes

Socio-Economic

Approved ASTM Pathways

AtJ

Risk

CO_2

Land use change

Technology

Blending

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