JIG

JOINT INSPECTION GROUP

TECHNICAL INFORMATION DOCUMENT

SUSTAINABLE AVIATION FUELS

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CONTENTS

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1. The Industry's Commitment to Sustainable Aviation Fuel (SAF).

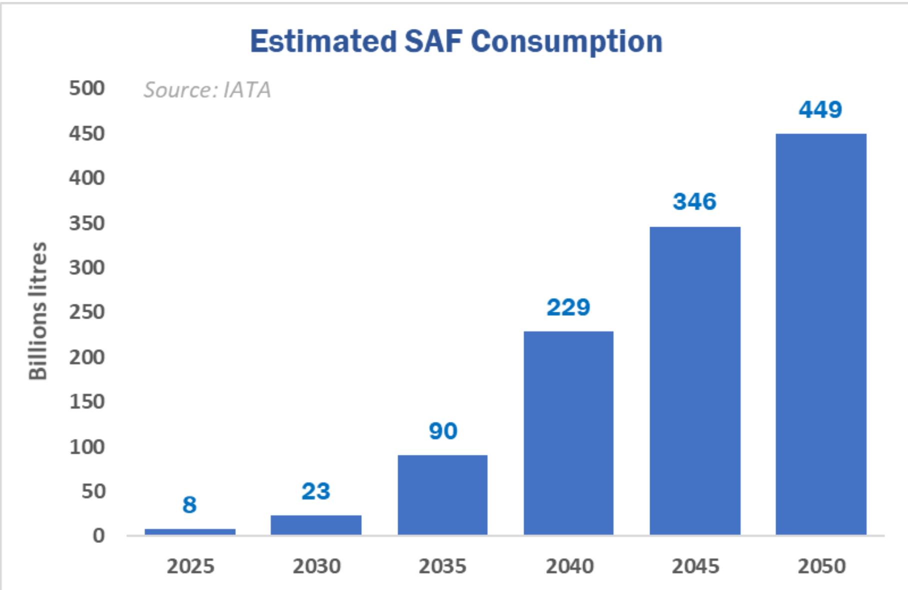
The airline community first established some voluntary emissions reduction targets in 2010, committing at the time, to reduce emissions by 50% in 2050. A lot of progress has been made since then, resulting in the commitment to net-zero emissions in 2050 being adopted at the 77th IATA General Meeting in 2021.

The industry called for several support measures to help it meet its aim:

- Government support to reduce inefficiencies in air traffic management.
- Aircraft and engine manufacturers to produce more efficient technologies
- The rapid availability of large and cost competitive SAF volumes in the market
- Airport operators providing the infrastructure to supply and mange SAF cheaply and effectively

IATA has an ambitious target, requiring it, by current estimates, to abate 1.8 gigatons of carbon in 2050 - 65% of that abatement is expected to come from the use of SAF, with a further 19% that cannot be eliminated being offset either by carbon trading or by carbon capture. New technologies (and this includes electric aircraft) are only expected to represent 13% of the overall reductions in 2050.

Sustainable aviation fuel, therefore, is the subject to which the airlines can be expected to devote a lot of attention. Several announced SAF production projects may well permit the worldwide consumption of 8 billion litres per year in 2025, though the investment required to reach 449 billion litres in 2050 is considerable. This quantity of fuel will also require breakthroughs in the type of feedstocks that are available to produce sustainable blend components (SBCs). A shortage of feedstocks to produce the most common SBC, HEFA (Hydroprocessed Esters & Fatty Acids) is currently causing price spikes and a disconnect between the market value of SBCs and that of conventional jet fuel. Cost competitiveness is one of the support measures IATA has asked for and is certain to be a recurring theme in the short to medium term.



Many new and existing suppliers of fuel are committing time and investment in the identification of new production methods and feedstock sources in order to meet market needs. The production, transportation and integration of SAF will be a key aspect of our activities in future years and decades.

This Technical Information Document (TID) therefore summarises the principal subject areas that suppliers and operators need to be familiar with.

2. What is Sustainable Aviation Fuel?

Sustainable aviation fuel (SAF) is a fuel certified for use in jet-engined aircraft that contains components generated from a "sustainable" source. SAF is currently the most important building block in the airline industry's commitment to reduce its CO_2 emissions to net zero by the year 2050.

However, the term "sustainable aviation fuel" is currently used by various industry stakeholders to mean different substances ranging from synthetic components that can be blended into jet fuel to the finished product delivered to aircraft for immediate use. For example, some documents refer to "synthetic blend components", whereas others use "neat SAF" to describe the same product. To avoid confusion in the terminology, this TID will use the following terms throughout:

- Synthetic Blend Component (**SBC**): A synthetic product manufactured and certified according to ASTM D7566 – Annexes for blending into conventional jet fuel.
- <u>Sustainable Aviation Fuel</u> (**SAF**): A jet fuel conforming to an international specification, (technical + environment or sustainability criteria), ready for delivery to aircraft, that contains a SBC.
- <u>Conventional Jet Fuel</u>: jet fuel, refined and produced from conventional hydrocarbons such as crude oil, condensates, shale oil and tar sands, to meet international jet fuel specifications such as ASTM D1655 and Def Stan 91-091.

Synthetic components were first certified for use in 1998 following the generic approval of semi-synthetic jet fuel containing kerosene produced using the Fischer Tropsch process into Def Stan 91-091. Jet fuel containing up to 50% synthetic blend components has been permitted in the JIG AFQRJOS Checklist since August 2012 (see also Bulletin 57). These products and other sources are covered by the ASTM D7566 specification. This specification and the certification of SBCs is covered in Section 3.

SBCs are not yet certified to be used in a 100% concentration in aircraft. They are required to be blended with conventional, fossil-derived components, so that the subsequent blend (SAF) conforms to an international specification. After blending and testing, SAF is transported, handled, comingled, and delivered to aircraft in the same way as conventional jet fuels.

As the industry increases its use of SAF, so does the communication around it. There are frequent newsflashes about airports, airlines and other stakeholders "approving" SAF for use in their organisation. Whilst this communication positively supports the introduction and consumption of SAF, it can cause confusion with suppliers and into-plane operators, as SAF – once blended and certified – needs no further approvals for use.

Whether SBCs are truly sustainable or not is a key factor for the airline consumer. If SBCs do not represent a reduction in lifetime CO_2 emissions, they cannot be used by the airlines for their voluntary or regulatory carbon reduction goals. The airlines or suppliers consequently use approved sustainable certification bodies to certify that their SBC meets the requirements to be classified "sustainable".

SAFs containing a range of SBCs are tested and approved by the ASTM to be drop-in fuels and can be used in place of conventional jet fuels with no impact on engine or airframe performance. The SBCs themselves do, however, have somewhat different physical characteristics to conventional jet fuel. The correct blending of various components to create a SAF therefore requires knowledge and skill from the operator of the final blending point. As stated earlier, an SBC is not approved for use on its own, and therefore cannot be blended in airport facilities (see Section 5). All blending operations for routine supply are anticipated to take place upstream of the airport. Blending, certification and handling of SAF is covered in Sections 5 and 6.

3. The Fuel Specification for Sustainable Blend Components (SBCs).

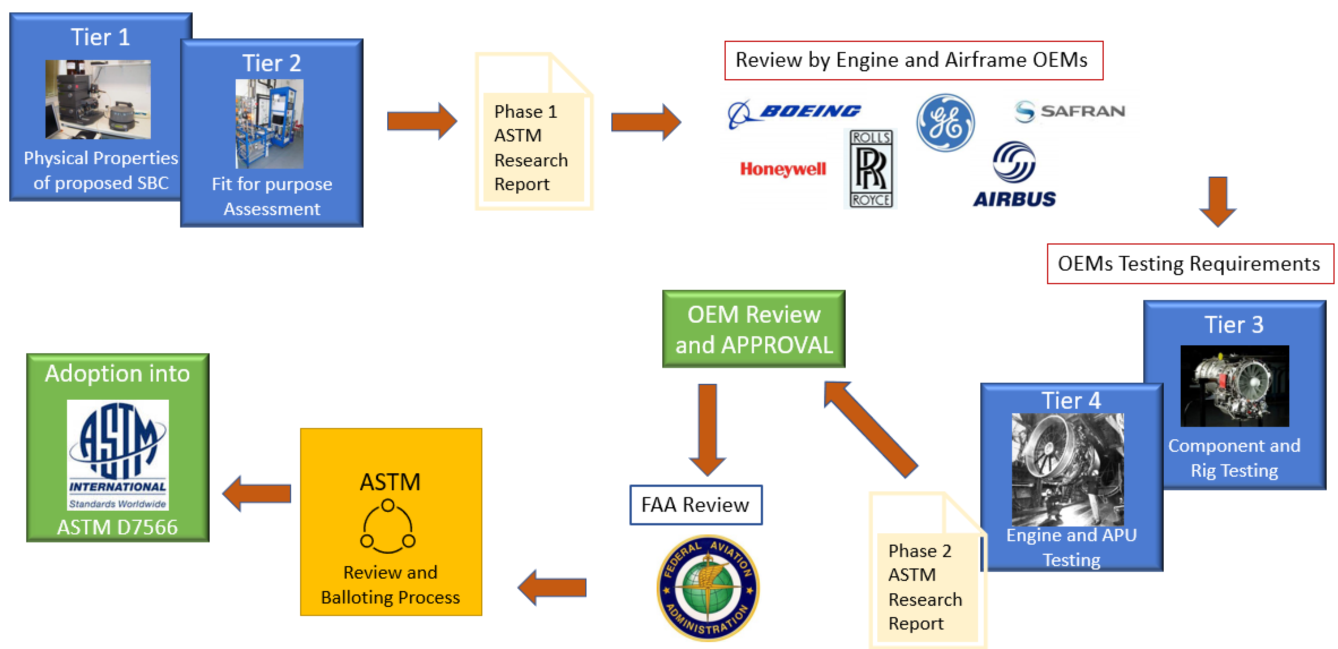
The process of assessing a SBCs fitness for purpose, control of components, blending and testing requirements and the suitability for subsequent inclusion as an approved material within the jet fuel standards is undertaken by the ASTM. The process for conducting this assessment is documented in ASTM D4054 *Standard practice for qualification and approval of new aviation turbine fuels and fuel additives*.

SBCs that have been assessed as fit for purpose using ASTM D4054 are subsequently listed in the ASTM Product Specification ASTM **D7566**, *"Standard Specification for Aviation Fuel Containing Synthesized Hydrocarbons"*.

D4054: Evaluation and Approval of Sustainable Blend Components.

The ASTM follows a rigorous process with key industry stakeholders to examine, test and approve new blend components for incorporation into SAF as shown in the table below:

Table 1 : ASTM D4054 certification process



The testing of physical properties and further engine and component testing by the manufacturers is very thorough and typically lasts for many months or even years. It ensures that any products that will be adopted as annexes of ASTM D7566 behave in an equivalent manner to conventional jet fuel and that fuels meeting ASTM D7566 can then be recertified as meeting one of the conventional jet fuel standards, such as ASTM D1655 or Def Stan 91-091. This is important as it allows additional requirements, specific to SAFs, to be controlled via ASTM D7566 It also allows the fuel to be re-categorised as meeting a conventional jet fuel specification that is already approved for use in aircraft. This avoids the complex regulatory issue of needing to add a new fuel specification to all the aircraft and engine certifications, while maintaining adequate controls that might be specific to SBCs and SAF production.

From a product supply and specification point of view, the ASTM process ensures that once SBCs are blended into conventional jet fuel, the resulting SAF can be shipped, handled, and delivered using the existing jet fuel supply chain and infrastructure.

The ASTM D4054 process assesses both the SBC molecules and the manufacturing methods. Any necessary control of the products is then listed within the applicable annex of ASTM D7566. Any changes to manufacturing methods and processes are required to be accompanied by a Management of Change process and may need a re-evaluation under ASTM D4054.

New potential SBCs are regularly presented to the ASTM for evaluation and either integrated into existing annexes of ASTM D7566 or detailed in new ones. Each annex fixes a percentage limit to which the SBC can be blended into SAF.

There is also a recently introduced "fast track" process to allow the industry to more quickly to adopt new technologies/methods and respond to the growing need for SAF. However, the blend percentage of these "fast track" SBCs are currently limited to 10 vol% versus other SBCs which have gone through the full ASTM D4054 process and may be blended up to 50 vol%.

It is important to note that although most SBCs come from a sustainable, biological source, this does not mean that any biofuels can be incorporated into jet fuel. Notably, FAME (Fatty Acid Methyl Ester) which is a common component of biodiesel may not be blended into jet fuel and has a strict specification limit of max. 50ppm.

Figure 1: Approved SBCs listed in Annexes of ASTM D7566

	Approval Date	Acronym	Full Name	Max Blend %
Annex A1	2009	SPK	Fischer Tropsch Hydroprocessed **S**ynthesized **P**arafinic **K**erosene	50%
Annex A2	2011	HEFA	Synthesized Paraffinic Kerosene from **H**ydroprocessed **E**sters and **F**atty **A**cids	50%
Annex A3	2014	SIP	**S**ynthesized **I**so-**P**arafins from Hydroprocessed Fermented Sugars	10%
Annex A4	2015	SPK/A	**S**ynthetised **P**arafinic **K**erosene with **A**romatics derived by Alkylation of Light Aromatics from Non-Petroleum Sources	50%
Annex A5	2016 / 2018	ATJ/SPK	**A**lcohol-**T**o-**J**et **S**ynthetic **P**araffinic **K**erosene	50%
Annex A6	2020	CHJ	Synthetised Kerosene from **H**ydrothermal **C**onversion of Fatty Acid Esters and Fatty Acids	50%
Annex A7	2021	HHC-SPK HC-HEFA	Synthetised Paraffinic Kerosene from **H**ydroprocessed **H**ydro**C**arbons (e.g.,. algae that produce tri-terpenes), Esters and Fatty Acids	10%

ASTM D7566: Specification for SBCs and SAF.

ASTM D7566 serves two purposes. Its annex structure defines the type of SBCs that have been approved through the ASTM4054 process and the main body of the document sets out the Specification for SAF.

The Annexes describe the physical characteristics and production methods of each approved SBC; the controls needed to produce that particular type of component as well as the maximum blend percentage of that component allowable in finished jet fuel. The annexes also list any additives – such as antioxidants – that must be added at the point of manufacture prior to any product movements.

The main body of ASTM D7566 then determines the properties and testing requirements once any given SBC is blended with conventional components to produce a finished fuel. Table 1 of ASTM D7566 shows the physical characteristics required of a SAF that is blended with an SBC and conventional jet fuel or conventional blending components.

It is important to note that Part 2 of Table 1 lists some further parameters that shall be met by SAFs. They include fluidity requirements, a minimum aromatics content of 8% and a minimum lubricity requirement.

Figure 2: Extract from ASTM D7566 – 20b. TABLE 1 Part 1 - Basic Requirements for SAF

TABLE 1 Detailed Requirements of Aviation Turbine Fuels Containing Synthesized Hydrocarbons[A]

Part 1—Basic Requirements			
Property		Jet A or Jet A-1	Test Method[B]
COMPOSITION			
Acidity, total mg KOH/g	Max	0.10	D3242/IP 354
Aromatics: One of the following requirements shall be met:			
1. Aromatics, volume percent	Max	25	D1319 or IP 156[C]
2. Aromatics, volume percent	Max	26.5	D6379/IP 436
Sulfur, mercaptan,[D] mass percent	Max	0.003	D3227/IP 342
Sulfur, total mass percent	Max	0.30	D1266, D2622, D4294, D5453, or IP 336
VOLATILITY			
Distillation			
Distillation temperature, °C:			D86,[F] D2887/IP 406,[E] D7344,[G] D7345,[G] IP 123[F]
10 % recovered, temperature (T10)	Max	205	
50 % recovered, temperature (T50)		report	
90 % recovered, temperature (T90)		report	
Final boiling point, temperature	Max	300	
Distillation residue, percent	Max	1.5	
Distillation loss, percent	Max	1.5	
Flash point, °C	Min	38[H]	D56 or D3828[I], IP 170[I] or IP 523[I]
Density at 15 °C, kg/m³		775 to 840	D1298/IP 160 or D4052 or IP 365
FLUIDITY			
Freezing point, °C	Max	–40 Jet A[J] –47 Jet A-1[J]	D5972/IP 435, D7153/IP 529, D7154/IP 528, or D2386/IP 16
Viscosity –20 °C, mm²/s[K]	Max	8.0	D445/IP 71, Section 1, D7042[L] or D7945
COMBUSTION			
Net heat of combustion, MJ/kg	Min	42.8[M]	D4529, D3338, D4809 or IP 12
One of the following requirements shall be met:			
(1) Smoke point, mm, or	Min	25.0	D1322/IP 598
(2) Smoke point, mm, and	Min	18.0	D1322/IP 598
Naphthalenes, volume, percent	Max	3.0	D1840
CORROSION			
Copper strip, 2 h at 100 °C	Max	No. 1	D130/IP 154
THERMAL STABILITY			
2.5 h at control temperature of 260 °C, min			D3241[N] /IP 323[N]
Filter pressure drop, mm Hg	Max	25	
Tube rating: One of the following requirements shall be met:[O]			
(1) Annex A1 VTR, VTR Color Code	Less than	3 No peacock or abnormal color deposits	
(2) Annex A2 ITR or Annex A3 ETR, nm avg over area of 2.5 mm²	Max	85	
CONTAMINANTS			
Existent gum, mg/100 mL	Max	7	D381, IP 540
Microseparometer,[P] Rating			D3948
Without electrical conductivity additive	Min	85	
With electrical conductivity additive	Min	70	
ADDITIVES		See 6.3	
Electrical conductivity, pS/m		[Q]	D2624/IP 274

The additional requirements of Table 1, Part 2 are discussed in the next section of this TID.

To date there are 7 active annexes for SBCs:

Annex A1 – FISCHER-TROPSCH HYDROPROCESSED SYNTHESIZED PARAFFINIC KEROSINE (SPK).

The feedstocks for this process are municipal solid waste, and wood and energy crops, as well as coal. The feedstock is gasified at high temperatures to produce a "syngas". The short gas molecules are then combined into longer paraffins and olefins via the FT process an using an iron or cobalt catalyst. The products may be subsequently treated in classic refining processes such as hydrotreating, hydrocracking, isomerisation and fractionation. Only certain forms of non-coal based SPK that meet sustainability criteria are used to make this SBC. SPK may be blended into SAF to a maximum of 50%.

Annex A2 - SYNTHESIZED PARAFFINIC KEROSINE FROM HYDROPROCESSED ESTERS AND FATTY ACIDS (HEFA).

The feedstocks for this process are fatty acids and fatty acid esters derived from vegetable oils, used oils and animal fats. They are hydrotreated to remove oxygen and other unwanted molecules, before being subsequently treated in classic refining processes such as hydrotreating, hydrocracking, isomerisation, and fractionation. Due to the origin and availability of feedstocks, HEFA is currently the most used SBC with worldwide annual supply (in 2021) of 2-3 million tonnes and further capacity announced. HEFA may be blended into SAF to a maximum of 50%.

Annex A3 - SYNTHESIZED ISO-PARAFFINS FROM HYDROPROCESSED FERMENTED SUGARS (SIP)

The feedstock is generally biomass treated by hydrolysis, with the resulting sugars fermented using modified yeast to produce farnesene – a hydrocarbon (C_{15}). This product is then hydrotreated to create synthesised iso-paraffins; further hydrotreatment and fractionation yield synthetic kerosene components in the jet fuel range. SIP may be blended into SAF to a maximum of 10%.

Annex A4 - SYNTHESIZED KEROSINE WITH AROMATICS DERIVED BY ALKYLATION OF LIGHT AROMATICS FROM NON-PETROLEUM SOURCES (SPK/A)

This process uses biomass to produce SPK which is further enhanced with non-petroleum-based benzene. Benzene is an aromatic compound. SPK/A may be blended into SAF to a maximum of 50% and is a useful blendstock due to its aromatic content making it easier to meet the minimum 25% aromatic range required for SAF.

Annex A5 - ALCOHOL-TO-JET SYNTHETIC PARAFFINIC KEROSENE (ATJ-SPK)

The feedstock for this process is alcohol derived from starch/sugar (from field corn, sweet sorghum, cane, sugar beets, tubers) or biomass whose fermented sugars are turned into alcohol. Though the Annex caters for several alcohols it currently only allows the individual use of ethanol and isobutane. The alcohol is dehydrated, and the molecules combined into longer chemical chains through an oligomerisation process. The resulting feedstock is then distilled and fractionated into a jet fuel molecular range. ATJ-SPK may be blended into SAF to a maximum of 50%.

Annex A6 - SYNTHESIZED KEROSINE FROM HYDROTHERMAL CONVERSION OF FATTY ACID ESTERS AND FATTY ACIDS (CHJ)

This process uses clean free fatty acids (FFA) derived from the processing of waste oils. The FFA is combined with preheated water and reacted at high pressure and temperature in a Catalytic Hydrothermolysis unit. The resulting mixture of chemicals contain molecules with a very wide boiling range that are further treated in classic refining processes such as hydrotreating, hydrocracking, isomerisation before being distilled and fractionated. CHJ may be blended into SAF to a maximum of 50%.

Annex A7 - SYNTHESIZED PARAFFINIC KEROSINE FROM HYDROPROCESSED HYDROCARBONS, ESTERS AND FATTY ACIDS (HC-HEFA)

This is another HEFA based product that integrates hydrocarbon-hydroprocessed esters derived from algae. This product was developed in Japan and the first to obtain fast-track approval using the ASTM D4054 process. HC-HEFA may be blended into SAF to a maximum of 10%

4. Incorporation into Industry Specifications (ASTM, DefStan..)

ASTM D1655: Once a product has been blended and correctly certified to ASTM D7566, it may immediately be released and regarded as ASTM D1655 fuel and treated as such thereafter.

> *"Aviation turbine fuel manufactured, certified, and released to all the requirements of Table 1 of this specification (D7566), meets the requirements of Specification D1655 and shall be regarded as Specification D1655 turbine fuel. Duplicate testing is not necessary; the same data may be used for both D7566 and D1655 compliance. Once the fuel is released to this specification (D7566) the unique requirements of this specification are no longer applicable: any recertification shall be done in accordance with Table 1 of Specification D1655."*

Table 1 (physical properties) of ASTM D1655 and Table 1, Part 1 of ASTM D7566 are strictly identical, though manufacturers of SAF have also to adhere to the additional requirements of Table 1, Part 2 of ASTM D7566 that manage some specific characteristics of synthetic components.

Figure 3: Extract from ASTM D7566 – 20b. TABLE 1 Part 2 - Extended Requirements for SAF

Part 2—Extended Requirements			
Property		Jet A or Jet A-1	Test Method[B]
COMPOSITION			
Aromatics: One of the following requirements shall be met:			
1. Aromatics, volume percent	Min[R,S]	8	D1319 or IP 156 or D8305[X]
2. Aromatics, volume percent	Min[R,S]	8.4	D6379/IP 436
VOLATILITY			
Distillation			D2887/IP 406[E] or D86[F] or IP 123[F] or D7344[G,Y] or D7345[G]
T50-T10, °C	Min[S,T]	15	
T90-T10, °C	Min[S,T]	40	
LUBRICITY			
Lubricity, [F]mm	Max	0.85	D5001
FLUIDITY[U]			
Viscosity –40 °C, mm²/s	Max	12	D445/IP 71, Section 1[W], or D7945

Note in particular an additional viscosity requirement for SAF containing or blended with SBC obtained according to Annex 2, 3 and 6, or Annex 5 components in a concentration >30%.

ASTM allows SBCs to be blended either with certified conventional jet fuel (Jet A or Jet A-1) or with conventional blend components. It considers the initial blend of the SAF to be the point of origin, requiring a Certificate of Quality (COQ). Recertification tests are not permitted. Note that historically it has been common parlance for the point of origin to produce a Refinery Certificate of Quality (RCQ) as all jet fuels have historically been made in refineries. However, SAF may be blended at non refinery locations. This means that the point of origin for SAF may be outside of the refinery, creating a desire by the aviation industry to move to referring to the certification document as a COQ. The RCQ is just a special case where a COQ happens to be produced in a refinery. Note: if the SAF is subsequently released as ASTM D1655 jet fuel, then it is not required to report the percentage of synthetic components on the COQ. This is different if releasing the SAF to Def Stan 91-091 which currently does require the percentage of synthetic components to be reported.

Co-Processing

ASTM D1655 and Def Stan 91-091 permit conventional jet fuel to be produced with up to 5% “co-processing” of alternative feedstocks (e.g., fatty acids, vegetable oils) with the crude oil stream. This is different to the ASTM D7566 process as it is a ‘no-harm’ approval (meaning that the incidental co-processed components do not materially affect the conventional jet fuel). This activity is generally performed by refiners to increase the renewable content of other products; consequently, this process results in most of the bio-feed appearing in the diesel stream and a smaller amount in the jet stream.
The jet fuel specifications require the COQ to note that the fuel may contain up to the permitted 5% volume percentage of co-processed synthesised kerosene. However, for the purposes of blending SAF, co-processed jet fuel as described above is considered “conventional” fuel and does not influence the maximum allowable percentage of SBC that can be blended into it.

Def Stan 91-091: This Standard contains a specific Annex B *Additional Requirements Applicable to Fuels from Non-Conventional Sources*. In order to avoid duplication between standards, it directly adopts all the requirements of ASTM D7566. Any SAF produced in conformance to D7566, and its annexes and meeting the Table 1 requirements of Def Stan 91-091, can be recertified as meeting this specification.

There are however some subtle differences regarding blending of SAF. Def Stan 91-091 currently requires that conventional components are certified as finished jet fuel meeting Def Stan 91-091 before being used as a conventional blend component. This means that in most cases SBCs will be blended with an already certified conventional jet fuel.

Def Stan 91-091 also requires reporting of the SBC percentage on the COQ. This allows traceability of SAF batches downstream and is particularly valuable if ever a SAF may be blended a second time.

2.6	Refining Components, at point of manufacture			(see Note 8)
2.6.1	Non-Hydroprocessed Components	% v/v	Report	
2.6.2	Mildly Hydroprocessed Components	% v/v	Report	
2.6.3	Severely Hydroprocessed Components	% v/v	Report	
2.6.4	Synthetic Components	% v/v	Report, For limits see Annex B	(See Note 9 and Annex B)

This is an important difference compared to ASTM and is further explained in Clause B.5

> *"In addition to the requirements set out in B.2 and B.3, this Standard requires that the originator’s Certificate of Quality must be available for each synthetic blend component and be quoted as part of the reporting requirements in Table 1 of this Standard. Note that the lubricity test (BOCLE) is mandatory at the point of manufacture. Documentation shall follow the certified batch clearly stating the concentration of synthetic component. This is to ensure that the maximum limit on synthetic components is not exceeded by any blending downstream of the production of the semi-synthetic batch.”*

Similar to ASTM D1655, the Def Stan 91-091 specification allows co-processing up to a limit of 5% but does not require the percentage to be reported in Table 1.

Legacy approvals within Def Stan 91-091 mean that there are some synthetic components permitted that are not controlled specifically by ASTM D7566. Def Stan 91-091 also contains a section (B3) specific to synthetic and semi-synthetic kerosenes produced by Sasol, first approved in 2009, some of which are allowed for use in aircraft at 100% concentration.

Other Standards: Many other national fuel standards have been updated to permit the integration of SBCs. Users in those areas are recommended to check their local requirements before engaging in SAF use or blending.

5. Operational requirements for Blending and Certification

Blending at Airports: An SBC is not on-specification jet fuel. It therefore shall not be brought to, and blended with, conventional jet fuel in airport storage. This requirement is specified in JIG 2: 2.3.2(b);

> *"The location at which a semi-synthetic Aviation Turbine Fuel meeting this Standard is blended shall be upstream of the airport fuel storage depot. All fuels brought onto a JIG 2 facility shall meet the Jet Fuel Specification being used at the location (see section 4.1.2). This prevents synthetic blend components being brought into the facility as they do not meet the Jet Fuel Specification being used at the location by definition and so any blending of semi synthetic aviation fuels shall be performed upstream of the airport."*

The same requirements can be found in Def Stan 91-091: B5.3 and EI/JIG 1530: 11.2. ASTM D7566 remains silent about where blending may take place.

There is a relaxation in Def Stan 91-091 for test flights provided the volume of SBC brought in is less than one or two fuellers. This relaxation recognises the need to occasionally blend single flight quantities on airport in exceptional circumstances:

> *".....except in development phase where the volumes involved are small (no more than the capacity of one or two fuellers for example). In this case the blending could be done at the airport depot in a dedicated tank or dedicated fueller. In this case the synthetic component shall be segregated to ensure that this product shall not be provided to an aircraft. After blending the fuel shall be quarantined until a Certificate of Analysis is provided according to all the requirements of Table 1 and Annex B of this Standard."*

Significant future increases in SAF consumption may put pressure on supply chains to the extent that on-airport blending may have to be reviewed in the medium to long term on condition that facilities are modified. Airport depots are not designed nor equipped for effective blending unless blending is done in facilities totally separate from the airport's storage tanks. This is due to the SBC not meeting the finished jet fuel requirements and as such shall be treated as a different product grade, as would be the case for diesel fuel for instance. This brings with it all the attendant requirements for physical separation and isolation from finished jet fuel that is a feature of managing other grades in the same facility as finished jet fuel. As these are not typically features of airport storage tanks, on-airport blending for routine supply of SAF is not permitted.

Blending at Refineries: SAF is often blended in refinery facilities as they typically have all the equipment required for efficient blending, have access to a variety of blend components, and have testing laboratories on-site for analysis and the production of a COQ (or RCQ). The expectation in both ASTM D1655 and Def Stan 91-091 is that as the point of origin, refineries will produce a COQ for their SAF. Under Def Stan 91-091, the COQ would also contain details of the percentage of severely hydroprocessed components as well as the percentage of synthetic components (SBCs).

Blending at Intermediate Installations: SAF is increasingly being blended immediately before airport in intermediate terminals and the percentage is likely to increase. This change in point of origin may pose future issues if these installations are not properly equipped (see below) and also requires their operators and staff to undertake duties and conduct due diligence in a manner that has not been required before.

All the standards bodies refer to the blending location as "point of origin", and as such all of the requirements that would be expected of a point of origin are required. This means a COQ, which includes the requirement for a competent person to be accountable for all the components meeting all of the detailed compositional requirements of the components (as defined in the supporting standards such as ASTM D7566), quality assurance of those components (how they were transported, contamination-free to the point of blending), control of the blend percentages, any additive composition and dosing as well as the components and finished products meeting all of the physical test requirements. In producing the batch of SAF, the blender is certifying its own quality control (QC) and processes, as well as the origins of components, which supports the need for a COQ rather than the simpler COA.

When bringing tanks that have been used for SAF and SAF blending back into conventional *jet fuel* use, then installations should consult the controlling standards, Def Stan 91-091 Clause B5.5. and ASTM D7566 Clause 7.3. Residual volumes of synthetic components from line clearance or tank heels that constitute less than 1% of a finished blend may be considered negligible for the purposes of reporting documentation, lubricity testing and traceability per Def Stan 91-091 Clause B5.6.

Operational Aspects of Producing SAF:

The various SBCs that may be used to make SAF have different physical characteristics to those of conventional jet fuel. They may be less dense, may have different viscosity; many contain no aromatics, and most synthetic molecules have low lubricity characteristics. The controlling standard, ASTM D7566, may allow properties that could form other blend constraints, such as the SBC properties permit a lower flash point and may have a higher (worse) freeze point than is desired for Jet A-1 blending. This is why care is needed by the blender, and specific tank arrangements and equipment may be needed to meet the specification's requirement for homogeneity of the final SAF blend. The potential negative impacts of not achieving a correct blend are partial batches of fuel that may:

- contain aromatics below the 8% minimum threshold, which can cause elastomer seals in aircraft to shrink, potentially leading to leaks in the fuelling system.
- have densities outside the specification limit or at a compliant but very low level that reduces the operating range of the aircraft.
- have a very narrow distillation range, impacting the combustion performance of aircraft engines.

The differing characteristics of approved SBCs are listed here:

Comparison of ASTM D7566 Annexes

	Table 1	Annex A1 SPK	Annex A2 HEFA	Annex A3 SIP	Annex A4 SPK/A	Annex A5 AJT/SPK	Annex A6 CHJ	Annex A7 HHC-SPK HC-HEFA
Distillation 10% recovered	205	205	205	250	205	205	205	205
Final Boiling Point	300	300	300	255	300	300	300	300
Flash Point (min)	38	38	38	100	38	38	38	38
Density @ 15°C (min)	775	730	730	765	755	730	775	730
Density @ 15°C (max)	840	770	772	780	800	770	840	800
Freeze Point °C (max)	-40	-40	-40	-60	-40	-40	-40	-40
Thermal Stability °C Min		325	325	355	325	325	325	325
Aromatic Mass %	*[>25% BY VOL.]*	0.5	0.5	0.5	20	0.5	8-20	0.5

The risk of tank layering is illustrated by the range of acceptable SBC densities between 730 and 840 kg/m³, whereas the finished fuel shall be in the range of 775 – 840 kg/m³. The different viscosity requirements of some annexes have already been highlighted. The minimum aromatic requirement of 8% may also be difficult to meet if a blender has a synthetic SBC with no aromatics and low levels of aromatics in the conventional jet fuel component (for example kerosenes coming from a Hydrocracker unit). Effective blending may therefore require multiple tanks and a variety of different blend components to choose from. ASTM D7566 notes that though it has set maximum blend limits for each annex, the likely limitation for blending is the requirement to meet the Table 1 requirements.

For effective blending to take place, the blending location needs physical tank blenders and/or in line injection systems to agitate and homogenise the fuel. This activity will significantly expose the product to air, hence the importance of accurate and effective addition of antioxidant additive at the SBC point of manufacture.

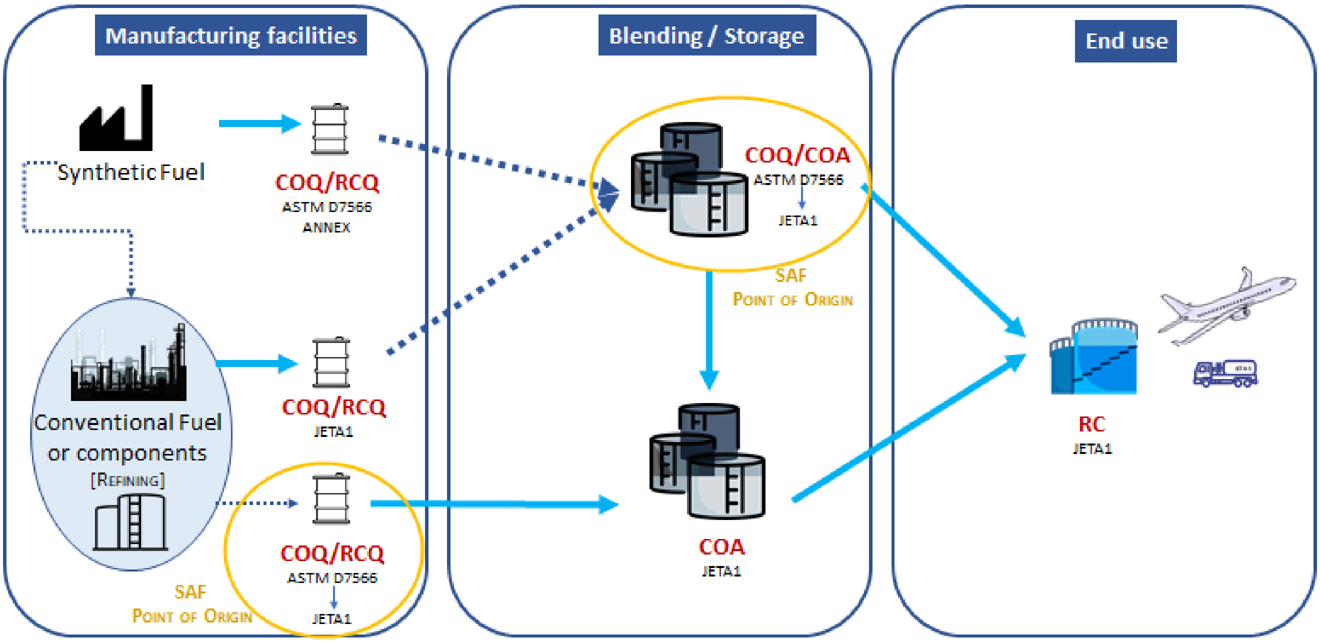
It is important to note that the product specifications require homogenous blends for certification at the point of manufacture / point of origin. Layered batches of already certified fuel may still be managed in certain circumstances in the supply chain provided that each of the layers meets the fuel specification, but this is not permitted at the point of manufacture. Therefore, layered tanks are <u>not permitted</u>, for locations blending SAF. No COQs may be produced if a tank is layered. (EI/JIG 1530: Ch 8.4.3.2)

> *"The procedure for layered tank release (described in 8.4.3.4) is not acceptable for refineries or other points of manufacture blending synthetic fuels."*

Depending on the usage of blending tanks and their downstream configuration (see EI/JIG 1530: Ch 9), tanks containing components not yet blended and certified as jet fuel shall be equipped with positive segregation between it and the SAF blend tank. As an SBC is not certified jet fuel, its tank shall be separated (i.e. have no physical connection) from any other direct connection with grade-dedicated systems containing certified aviation fuel such as active airport tanks or dedicated pipelines.

This increased care and complexity at the point of blending of SAF brings the advantage that the testing and recertification requirements downstream of the point of origin are identical to those of conventional jet fuel. Mixing of batches in intermediate installations requires either a Recertification Test Certificate or a COA (as is the case with conventional aviation fuel). Care may be required in the future if blending of SAF with different SBC percentages becomes commonplace. After the SAF has entered dedicated distribution systems, simple Release Certificates, as required by the Operating Standards, are produced; again, this is the same as conventional aviation fuel handling standards.

Figure 4 : Blending and Certification of SAF



6. Handling and Transport of SAF and Synthetic Blend Components

Handling SBC Prior to Blending

Due to the increased blending of SAF in mid-stream installations (e.g., terminals and depots), and the frequent use of COAs, any SBC is required to be handled and transported in the same way as jet fuel from its point of manufacture to the point at which it is blended into SAF. (EI/JIG 1530: 11.2)

> *"After production to the point of blending, all synthetic blend components shall be handled and transported in the same manner as finished jet fuel in order to maintain product integrity and traceability."*

Consequently, the same requirements for separation and segregation as appropriate will apply, as well as the necessity for dedicated transport or recertification testing upon receipt and change of product procedures in the supply chain where necessary. Storage, filtration, quality checks, etc. are all identical to those practiced on jet fuel. This needs care while volumes start to increase from a low base as often non-standard methods of transport of SBC can be used, such as iso-tanks. In these cases, prior loads in the iso-tanks and grade change procedures need to be carefully considered. This is all part of what a responsible party, signing the finished SAF COQ, needs to have oversight of.

Handling SAF after Blending of SBC

As soon as a batch of SAF has been produced, it shall be handled in the same way as conventional jet fuel. (Def Stan 91-091: B.2)

> *"Any fuel containing a synthetic component meeting the above requirements shall be deemed to meet the requirements of Def Stan 91-091 and shall be accorded the same limitations and privileges of any fuel meeting this Standard. Specifically, the fuel can be designated as Def Stan 91-091 and handled and supplied to aircraft as such."HM50*

The same expectations are written into ASTM D7566 and EI/JIG 1530.

In long or complex supply chains, SAF is likely to be further commingled with other jet fuel batches and may be transported in non-dedicated systems. Recertification using a Recertification Test Certificate (or COA where appropriate) shall be required – as for conventional fuels. Def Stan 91-091 requires the synthetic characteristics of the fuel to be carried over from the COQ to the COA so that traceability and quantity of synthetic component present is maintained until the point of use.

> *"To avoid the need to view excessive documentation at each point in the supply chain, traceability shall be fulfilled by listing unique identifier of the appropriate quality document (RCQ, CoA or RT as defined in D.1) for each of the component batches that make up the new batch on the new certification document together with their respective volumes. By listing the component batches, the certifying authority (for example depot or laboratory manager, or subcontracted laboratory manager) is confirming that it has the documents for each of the component batches in their possession and that each document meets the requirements stated in Def Stan 91-091."*

ASTM D1655 does not include this requirement.

By the time it arrives at an airport, SAF is treated as a conventional aviation fuel ready for use or commingling as required for the needs of the operation. There are no additional constraints for vehicles and equipment, nor are there any additional product testing regimes outside those already required for conventional aviation fuels.

SAF is not expected to perform any differently or result in any different performance and reliability of the equipment used in fuel handling, as fuelling equipment performance is part of the ASTM D4054 assessment process. This statement includes materials used for the storage and handling of fuels, fuel system elastomers and seals, flexible hoses, meters, filters, etc. Additionally, SAF does not need to be handled any differently for emergency response, product spills etc. Other than the source of the carbon content, SAF is indistinguishable from conventional jet fuel.

For both SAF and SBCs it should be noted that:

1) SAF and SBCs shall be handled the same as jet fuel (including using the same testing requirements contained within EI/JIG 1530 for movement in non-dedicated white oil systems).
2) The compositional requirements of the fuel standards require the fuel to consist only of hydrocarbons from the synthetic annexes, approved additives, or to be derived from petroleum. Current quality control procedures are constructed around the assumption that jet fuel will be moved in systems containing essentially petroleum-derived hydrocarbon products. Any contamination that is not hydrocarbon-based cannot be controlled adequately through measurement of the specification property limits, and so where non-hydrocarbon contamination is possible, unique quality controls outside of the current standards are likely to be required to prevent and detect potential contamination.
3) Unusual means of transport will likely be employed in the initial phases of SAF volume ramp-up (iso tanks, chemical carrier vessels etc). Specialist knowledge and advice (for example Dr Wervey, Intertanko etc.) is required when considering prior cargoes and cleaning regimes, especially when industrial chemicals are involved, to ensure that the risk of non-hydrocarbon contamination is eliminated.
4) The competent person signing the COQ after SAF blending is responsible for assuring that all aspects of the composition meet the specification requirements before release of the fuel, which shall include consideration of items such as those listed in items 1-3 above.

Handling SAF on airports

According to the requirements for manufacturing SBC and blending SAF, the only product permitted to be received within airport facilities is fully blended and certified SAF. As such the fuel will generally enter the facilities as DefStan 91-091 or ASTM D-1655. It is therefore stored, comingled and tested according to the traditional requirements of JIG Standards. There are no special requirements for handling SAF on airports and it does not to our knowledge affect fixed or mobile equipment.

It is noted in section 5 that small quantities of pure SBC may be brought to an airport for testing purposes. In these cases, no special equipment is required, but operators are expected to have conducted a full MOC for the test in order to ensure that on specification fuel is introduced to the aircraft and that the SBC remains correctly segregated as required by blending and handling expectations detailed above.

This position may change in the future if the expansion of SAF use leads to blending on airport in correctly configured facilities, but at the time of writing SAF is to be treated on airport as a conventional fuel.