International Civil Aviation Organization

ICAO CAEP/12 Assessment Report: Fuel composition effects on nvPM emissions

Prepared by:

Prem Lobo, David Delhaye, David Lee, Paul Madden, Joe Zelina, Anna Oldani, and Nate Brown

Abstract

Sustainable aviation fuels (SAFs) are being developed and deployed to augment and diversify fuel supplies, reduce CO_2 emissions, mitigate environmental impacts, and make aviation more sustainable. Worldwide, there have been more than 315,000 commercial flights powered by various blends of SAF with conventional Jet A/Jet A-1, and 9 airports are regularly distributing blended SAF. Most certified SAFs consist primarily of n-paraffinic and isoparaffinic compounds, while some have a higher proportion of cycloparaffins. All of these fuels have low to negligible quantities of aromatic and sulfur compounds. Significant reductions in PM emissions are achieved as a consequence of the fuel composition of SAF blended fuels. The lower PM emissions from SAF combustion have implications for air quality and climate impacts. Global production of SAF is concentrated in North America and Europe, and is expected to increase by a factor of 275 between 2020 and 2050 for the moderate production scenario.

Contents

Key Messages

- Most certified SAFs consist primarily of paraffinic compounds and low to negligible amounts of aromatic and sulfur compounds, which lead to significant reductions in non-volatile particulate matter (nvPM) emissions
- The reduction in nvPM number and mass emissions is highest at low engine thrust conditions, and decreases with increasing thrust
- Fuel hydrogen content has been reported to be a robust parameter for estimating nvPM emissions
- An ~80% reduction in ice crystal number has been modelled to result in a ~50% reduction in radiative forcing
- Annual global SAF near-term (2025) production shows a majority in North America followed by Europe
- Longer-term (2050) SAF production ranges from 32,967 kt to 401,924 kt

Introduction

The aviation sector has committed to the development and deployment of sustainable aviation fuels (SAFs) to augment and diversify fuel supplies, reduce CO_2 emissions, mitigate environmental impacts, and make aviation more sustainable. Worldwide, there have been more than 315,000 commercial flights powered by various blends of SAF with conventional Jet A/Jet A-1, and 9 airports are regularly distributing blended SAF (ICAO, 2021).

Conventional aviation jet fuels are a complex mixture of hydrocarbons, typically comprised of normal (n)-paraffins, isoparaffins, cycloparaffins, and aromatics (Schafer et al., 2006). n-Paraffins and isoparaffins typically dominate the class composition of all fit for purpose, petroleum-derived fuels (Dryer, 2015). Currently, most certified SAFs consist primarily of n-paraffinic and isoparaffinic compounds, while some have a higher proportion of cycloparaffins (Heyne et al., 2021). All of these fuels have low to negligible quantities of aromatic and sulfur compounds. Additionally, these fuels typically have an increased H/C ratio and have been shown to have a higher energy content when compared to conventional fuels, an important criterion when assessing the viability of these fuels (Hileman, Stratton, and Donohoo, 2010).

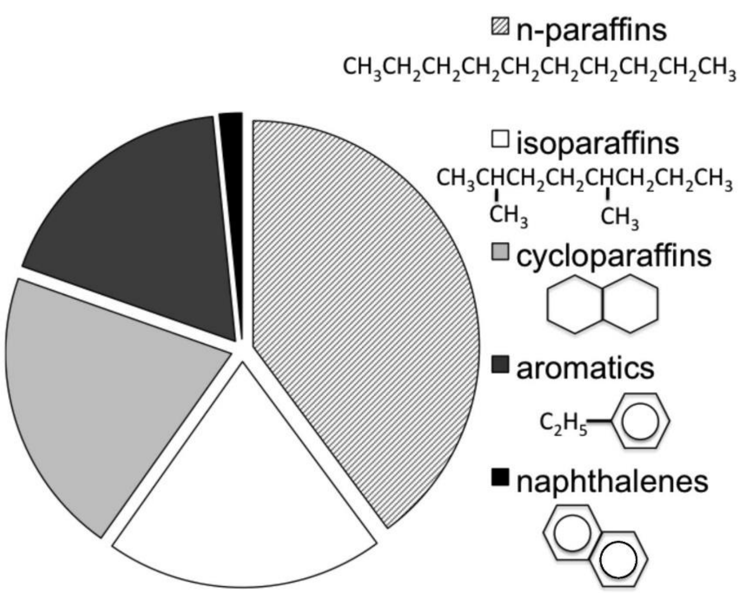

Figure 1: Typical composition of conventional fossil jet fuel (Hileman, Stratton, and Donohoo, 2010)

Any new fuel to be currently used in the aviation sector must be compatible with existing aircraft engines and fuel handling and storage infrastructure to be considered "drop-in" fuels. New fuel candidates must undergo a rigorous qualification and approval process (ASTM D4054) prior to being certified to the ASTM D7566 standard specification as a possible synthetic blending component. Various feedstocks and different conversion pathways can be used to produce SAFs (Hileman and Stratton, 2014), which differ in chemical composition and physical properties compared to conventional fossil-based jet fuel (Vozka et al., 2019).

To date, seven different annexes to D7566 have been approved. These fuels have been approved for use by blending with conventional fuel up to the following blend percentages: 50% of Fischer-Tropsch Hydroprocessed Synthesized Paraffinic Kerosene (FT SPK) (Annex A1), 50% of Synthesized Paraffinic Kerosene from Hydroprocessed Esters and Fatty Acids (HEFA SPK) (Annex A2), 10% of Synthesized Iso-paraffins (SIP) from Hydroprocessed Fermented Sugars (Annex A3), 50% Synthesized Kerosene with Aromatics derived by alkylation of light aromatics from non-petroleum sources (SPK/A) (Annex A4), 50% of Alcohol-To-Jet Synthetic Paraffinic Kerosene (ATJ-SPK) (Annex A5), 50% of Catalytic Hydrothermolysis Jet (CHJ) (Annex A6), and 10% of Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids (HC-HEFA SPK) (Annex A7). In addition to the approved pathways, there are many more potential feedstocks and production pathways that are being pursued to develop SAFs and blending components for incorporation into D7566.

In addition to SAF, lower carbon aviation fuels (LCAF) are also being developed. The main distinction between SAF and LCAF is that SAF should have lower life cycle carbon emissions compared to fossil fuels, and must not be made from biomass obtained from land with high carbon stock, while LCAF can be derived from fossil fuels with a smaller carbon footprint (Chiaramonti et al., 2021).

In 2009, the aviation industry committed to reducing emissions through (1) technology, operations, and infrastructure improvements, (2) the use of SAF, and (3) a single Global Market-Based Measure (IATA) with an ambitious target of 50% reduction in carbon emissions by 2050 compared to baseline 2005 levels. The reduction in carbon emissions cannot be achieved without the use of SAF.

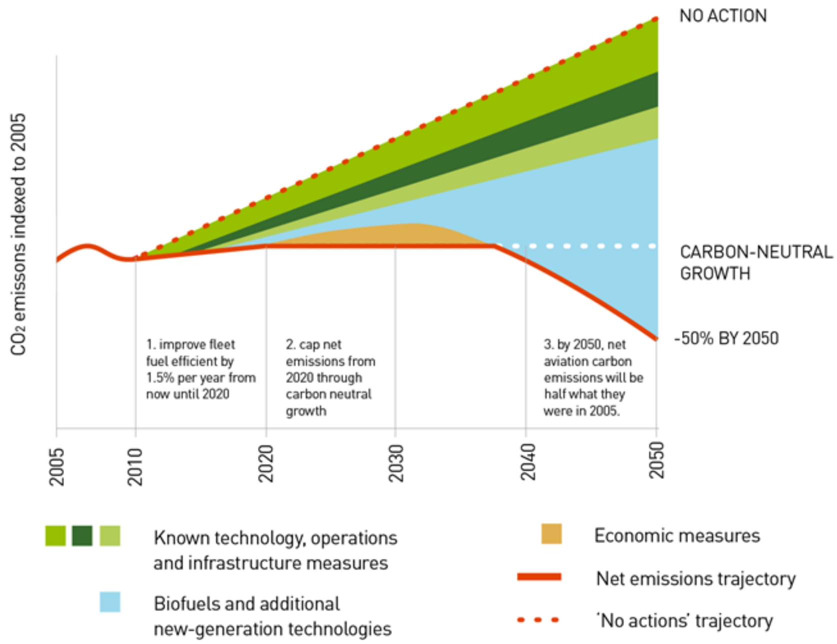

Figure 2: Pathway to carbon reductions using SAF

More recently, in October 2021, the International Air Transport Association (IATA) general meeting approved a resolution to achieve net-zero carbon emissions by 2050, aligning the aviation sector with the Paris Agreement goal for global warming not to exceed 1.5°C. It is anticipated that 65% of the carbon emissions will be abated through the use of SAF.

While considerable attention has been focused on the life cycle greenhouse gas emissions reductions with SAF, in some cases up to 80%, significant reductions in PM emissions are also achieved as a consequence of low fuel aromatic and sulfur contents with SAF blended fuels. The lower PM emissions from SAF combustion have implications for air quality and climate impacts.

Current Knowledge - SAF composition and resulting non-volatile Particulate Matter (nvPM) emissions

Aircraft engine PM emissions are composed of non-volatile and volatile components (Masiol and Harrison, 2014). The non-volatile particulate matter (nvPM[1]) emissions are formed in the combustor, while volatile particulate matter (vPM) emissions, present in the gas phase at the engine exit, condense after emission. The nvPM and vPM are constituents of total PM which affects air quality, health, and climate. The International Civil Aviation Organization (ICAO) has developed standards and recommended practices (SARPs) to for measuring limit the mass- and number-based emissions of nvPM emitted from aircraft engines with maximum rated thrust >26.7 kN (ICAO, 2017). The SARPs for nvPM specify standardized sampling and measurement protocols (SAE, 2013, 2018), which have been extensively evaluated and validated (Lobo et al., 2015b, 2020).

The combustion of neat SAFs and blends with conventional jet fuel has been shown to result in different PM emissions characteristics as a function of engine type and operating condition (Beyersdorf et al., 2014; Brem et al., 2015; Corporan et al., 2011; Lobo et al., 2011, 2015a, 2016; Moore et al., 2017; Schripp et al., 2018, 2019; Timko et al., 2010). The reduction in nvPM number and mass emissions is highest at low engine thrust conditions, and decreases with increasing thrust. In addition to changes in PM mass- and number-based emissions, SAF combustion results in changes to particle size distributions (PSD) (Beyersdorf et al., 2014; Cain et al., 2013; Kinsey et al., 2012; Lobo et al., 2011, 2015a, 2016; Schripp et al., 2018; Timko et al., 2010), chemical composition (Elser et al., 2019; Kinsey et al., 2012; Timko et al., 2013; Williams et al., 2012), morphology (Huang and Vander Wal, 2013; Kumal et al., 2020; Liati et al., 2019), hygroscopic properties (Trueblood et al., 2018), and optical properties (Elser et al., 2019).

Several studies have reported the correlation in reduction of nvPM emissions with fuel composition. In some cases, the nvPM emissions were reported to be dependent on fuel aromatic content. However the variation in aromatic content alone did not explain the changes observed in nvPM emissions. Recently,

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[1] Strictly speaking, nvPM is a measured property at the engine exit. The term is sometimes interchangeably used with 'soot' or 'black carbon' emissions, although 'soot' is usually a physical measure in the exhaust plume or further downstream

fuel hydrogen content has been reported to be a more robust correlating parameter for nvPM emissions (Brem et al., 2015; Lobo et al., 2015a; Schripp et al., 2018), and has been used in the development of the ICAO nvPM SARPs to account for differences in fuel composition for fuels used in engine emissions certification tests.

While most of these nvPM emission measurement studies have involved a small subset of engines from the overall fleet, on-going and anticipated projects will expand the database of existing information on the impact of fuel composition on nvPM emissions and their environmental impacts.

Study	**Goal**	**Anticipated completion/publication**
ND-MAX/ECLIF2	Investigate the impact of alternative fuels on contrail formation and consequently climate impacts, Correlate ground- and cruise level nvPM emissions, and Investigate nvPM physical, optical, and chemical properties as a function of fuel composition	2021-22
JETSCREEN	Develop a screening and optimization platform to assess the risks and benefits of alternative fuels, and to optimize alternative fuels for a maximum energy per kilogram of fuel and a reduction of pollutants emissions	2021-22
AVIATOR	Improved Measurement Systems for Aircraft Engine Emissions, Advancing Aircraft Plume and Airport Modelling, Bridging the gap between Aircraft Engine Certification and LAQ Regulation, and Protocols and Guidance for Air Quality and Health Impact Assessment	2021-23
ECLIF3	Investigate the emissions impact of using 100% SAF and assess the environmental impact of SAF-use on airport operations through ground tests measuring PM emissions	2021-22
ALTERNATE	Identify possibilities for extensive sustainable fuel use in aviation considering new technical areas and production procedures	2021-23
VOLCAN	Study the impact of SAF on contrail formation and emissions	2020-23

Climate Impacts, Interdependencies, and Trade-offs

The global emissions from aviation are estimated to be ~0.01 Tg (range 0.001 to 0.02 Tg yr^{-1} (Lee et al., 2021) compared with surface anthropogenic sources of around 4.8 Tg (range 3.6 to 6.0) yr^{-1} (IPCC, 2013). There are three effects that the emission of soot particles from aircraft engines may play a role in radiative forcing of climate: aerosol-radiation interactions, aerosol-cloud interactions, and the formation of contrails and contrail cirrus.

<u>Aerosol-radiation interactions</u>

Calculations of aerosol-radiation RF values using a variety of global aerosol models have yielded values of a few mW m-2 with large uncertainties (e.g., Righi et al., 2013; Gettelman and Chen, 2013; Lee et al., 2009). Lee et al. (2021) used 10 estimates from 8 models to evaluate soot normalized RFs which yields a 2018 best estimate of the soot aerosol-radiation RF of 0.9 (range 0.1, 4.0) mW m-2 for 0.0093 Tg soot emitted. This is a small effect, compared with others from aviation, i.e. ~1% of the total ERF.

<u>Aerosol-cloud interactions</u>

Aerosol-cloud interactions are those processes, by which aerosols influence cloud formation and their properties. For example, cloud droplets and ice crystals nucleate on aerosol particles. The aerosol-cloud interaction from aircraft soot emissions refers to circumstances when contrail ice crystals may have sublimated and the soot has not yet been removed from the atmosphere, or when no contrails are initially formed but the conditions of the atmosphere (ice supersaturation) later change and the soot aerosol is still present, on which ice clouds can form. The magnitude and the sign of the global RF from these aviation soot effects on background cloudiness remain highly uncertain. The uncertainties center on the difficulties in accurately simulating homogeneous and heterogeneous ice nucleation in the background atmosphere, variations in the treatment of updraft velocities during cirrus formation, and the lack of knowledge of the ice nucleating (IN) ability of aviation soot particles during their atmospheric lifetime (Zhou and Penner, 2014; Penner et al., 2018).

Two studies found small to moderate effects of soot aerosol on ice clouds, depending on the ice nucleating efficiency and the size distribution, with RF values of about 11 to 13 mW m-2 (normalized to 2018 emissions) with moderate ice-nucleating efficiencies (Pitari et al., 2015, Gettelman and Chen, 2013). By contrast, if soot processed within contrails is assumed to be an efficient IN particle, then the RF may be negative by up to -330 mW m-2 due to reductions in ice crystal number in regions dominated by homogeneous freezing (Penner et al., 2018). The RF could be significantly smaller (less negative) if additional ice-forming particles, such as secondary organic aerosol (SOA), are already present in the background atmosphere (Penner et al., 2018; Gettelman and Chen, 2013). In addition, increases in ice crystal numbers occur when the background atmosphere has much lower sulfate or haze-forming aerosol number concentrations and is dominated by heterogeneous freezing, causing forcings to be nearer zero or even positive (Zhou and Penner, 2014). Other studies predict decreases in cirrus number for smaller numbers of larger soot particles (Hendricks et al., 2011), resulting in a slight warming (Gettelman and Chen, 2013).

A dominant uncertainty for the aerosol-cloud effect from soot is the IN properties of aviation soot aerosol. Some laboratory studies indicate soot particles are not efficient ice nuclei (DeMott et al., 1999), while other studies indicate greater efficiencies (Möhler et al., 2005; Hoose and Möhler, 2012). A further related uncertainty is the emission in terms of soot number concentrations, which can vary by two orders of magnitude (Agarwal et al., 2019). More recently, Kärcher et al. (2021) concluded that the effect was potentially only small. In conclusion, this effect remains rather uncertain and the assessment of Lee et al. (2021) was unable to provide a best estimate of radiative forcing.

Soot emissions and their role in contrail and contrail cirrus formation

Contrails may initially form behind aircraft from the mixing of the hot aircraft engine plume containing water vapour and aerosol particles, primarily soot, with cooler ambient air, typically below -233 K (Kärcher, 2018). This initial occurrence of linear contrails can be robustly predicted from a knowledge of the thermodynamics of the exhaust, ambient pressure and humidity, and propulsive characteristics of the engine. If the ambient air is supersaturated with respect to ice ('ice supersaturation'), water will condense predominantly on the soot particle emissions (also present are ultrafine aqueous aerosol particles), which is shown by many measurement and modelling studies (e.g. Karcher end Yu, 2009; Heymsfield et al., 2015; Schumann and Hemsfield, 2017). These initial line-shaped contrails may become persistent and spread in to contrail cirrus, which is thought to have the much larger radiative effect than the initial line-shaped structures (Burkhardt and Kärcher, 2011). Overall, it is thought that contrail cirrus contributes a large fraction of the overall effective radiative forcing (ERF) from aviation, by approximately 57%[2] .

Fuel composition and its effect on soot emissions

Kärcher (2018) showed the dependence of ice crystal number per kg fuel vs emitted soot number particle, per kg fuel from theoretical calculations (Figure 3). Two conditions are shown; the lower curve at around contrail formation threshold temperatures, and the upper curve at temperatures well below (-12K below) threshold formation temperatures. Note that this does not illustrate any fuel-dependency assumptions, since in the soot-poor conditions, the ultrafine particles are formed from condensable vapours such as any sulfur present.

[2] It should be noted that this is an approximation, since the aviation ERF terms calculated by Lee et al. (2021) are not linearly additive and the total aviation forcing was calculated using a Monte Carlo analysis.

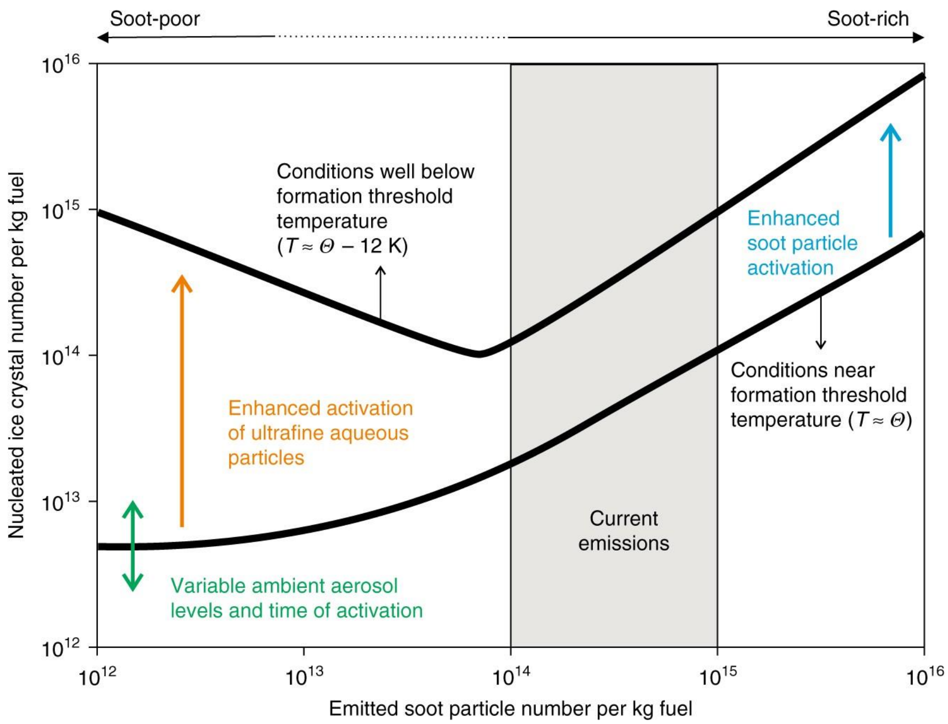

Figure 3. Taken from Kärcher (2018). Dependency of nucleated ice crystal number/kg fuel on emitted soot particle number/kg fuel for two contrail threshold formation conditions.

If the fuel was from bio-sources, or synthetic sources (e.g. 'power-to-liquid', or 'e-fuels'), sulfur is unlikely to be present in any significant concentration, along with low to zero aromatic content. Thus, it follows that if the aromatic content is reduced, the soot number index is reduced (many observations and modeling), and the ice crystal number is expected to decrease (modeling and recent measurements – Voigt et al., 2021). Should the ice crystal number reduce, it is likely that the forcing response will decrease.

Recently, some of these processes have been incorporated into a global contrail cirrus model (Bier et al., 2017). The contrail cirrus RF was calculated to reduce by decreasing the emission index for soot particle number, assuming a lower aromatic and naphthalene content. This reduces the nucleation sites for the ice crystals, resulting in fewer larger crystals, and reducing the optical density of the clouds, and also the lifetime of clouds (Bier et al., 2017; Burkhardt et al., 2018). The calculated reduction is quite clear (see Figure 4 taken from Burkhardt et al., 2018) but the real-fleet change is not well known because of large uncertainties in the emissions quantification of soot number emissions at cruising conditions, and the microphysical and optical properties of contrail cirrus. The reduction in the associated RF is less than that of the decrease in soot particles, e.g. a ~50% reduction of the initial ice particles (formed on emitted soot) results in a ~20% reduction of the positive RF; an ~80% reduction in ice crystal number results in a ~50% reduction in RF. This represents a real mitigation opportunity with no CO_2 penalty, and the reduction in soot number emissions both at ground level and cruise altitudes is well established from measurements (Moore et al., 2015; 2017).

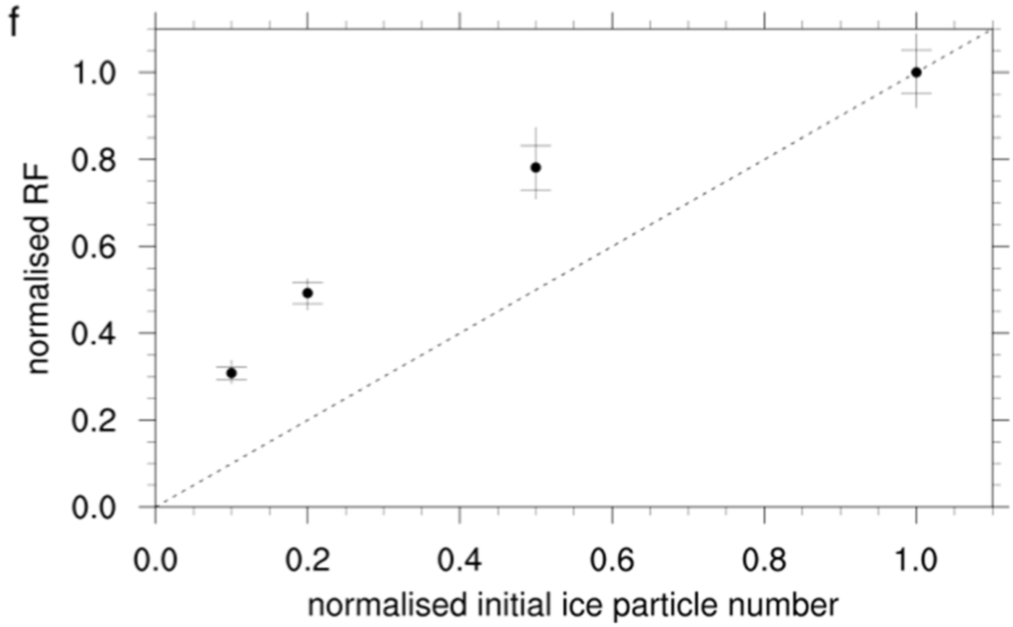

Figure 4. Global net radiative forcing (RF), given as a fraction of the radiative forcing for the ‘present-day soot number scenario’, as a function of the initial ice particle number concentration of contrails, given as a fraction of the initial ice crystal number concentration for the ‘present-day soot number scenario’. Initial ice crystal numbers were reduced to 0.5, 0.2, and 0.1 of the present-day values (taken from Burkhardt et al., 2018).

<u>Trade-Offs</u>

There are inherent trade-offs between NOx, nvPM, and CO/UHC in combustion chambers. NOx is produced at high engine power levels, is typically formed in the post-flame region, and is temperature and time at temperature driven. Therefore, engine design approaches to control NOx have focused on minimizing peak combustor temperatures and combustor residence time at those high temperatures. Minimizing combustor residence time and therefore combustor volume and length have the added benefit of reduced engine weight. Unfortunately, this can make CO, UHC, and nvPM control difficult. For short combustor residence times and low combustion temperatures where NOx formation is low, CO and UHC emissions are higher due to incomplete combustion, and the combustor liner cooling air during low power ground operations can quench reactions of CO and UHC. The nvPM emissions form in fuel-rich zones in the combustor, and adequate time (combustor volume) is needed to oxidize nvPM before being quenched in the downstream cooler region of the engine after exiting the combustor. Therefore, optimization of fuel and air placement in the dome region, along with stoichiometry optimization of the combustor, and residence time is necessary to balance all emissions requirements. Some attempts to reduce nvPM can involve leaner mixtures or changes in fuel spray at the front end of the combustor and these are often associated in reductions in operability and can also result in increases in NOx. The use of the particular chemistry composition of SAF’s can provide an additional methodology to optimize combustor performance and emissions that is outside normal combustor performance trades and design practices.

The reduction in aromatics in SAF reduces the nvPM produced within the combustor. While SAF has little or no impact on gaseous emissions such as CO, HC, and NOx there is an inherent trade-off in combustor design between NOx and nvPM as the same hot temperatures that combustor designers try to avoid to minimise NOx are the temperatures that burn off nvPM created in the primary zone of the combustor. Widespread use of SAF could open design space in gas turbine combustion systems for lower NOx.

SAFs may also be able to offer a number of performance benefits: Most SAFs have a greater energy density by mass, known as a calorific value and estimated to be ~2%. The lower weight could mean lighter aircraft, and hence better aircraft fuel efficiency. In the future there is also a potential thermal efficiency benefit of ~0.5% due to the high thermal stability of SAF, meaning that the fuel can be used to cool things like the oil system with more energy being put into the fuel than cooling the oil by technologies such as air cooled oil coolers.

There are two main downsides to the use of SAF. Due to the lower aromatic contents in SAF the lubricity of the fuel is worse, and on particularly older engines and airplanes there are seals within the fuel systems that rely on swelling to seal, and this swelling relies on aromatics. These trade-offs are addressed by airplane and engine manufacturers when clearing SAF for their aircraft and engines. These issues are also a concern for airport fuel infrastructure.

Market Penetration of SAFs and Associated Impacts

The US Department of Defense (DOD) was the primary purchaser of SAF in the early years of development and testing. Starting in 2016 with the offtake agreement between United Airlines and World Energy (previously AltAir), the majority of SAF procurements are now for commercial use. Figure shows SAF procurements over the period from 2007 through 2020.

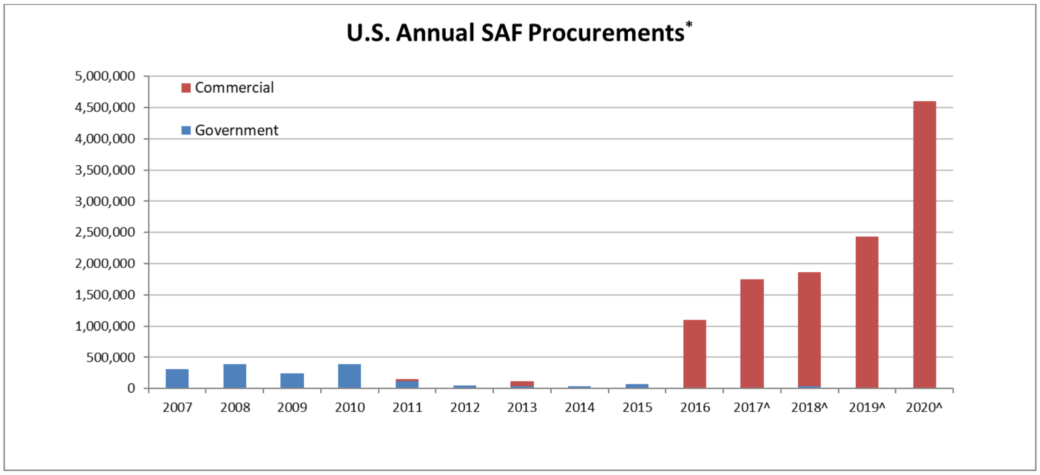

Figure 5: Historical US SAF production data

Currently, two US facilities produce SAF: World Energy Paramount in California and Gevo in Texas. Combined, these two facilities have the capacity to produce around 40 million gallons of SAF per year. Other facilities that are planned or expanded with the capability to produce SAF represent hundreds of millions of gallons of annual US SAF production capacity.

Beyond the US, the global SAF market has witnessed strong growth in recent years. Figure highlights additional global SAF facility announcements out to 2025. These projects reflect the global reach of SAF development and deployment.

Figure 6: Worldwide SAF production forecast with announced intentions (Source: CAAFI)

As shown in Figure 5, 2020 witnessed continued growth in SAF procurements despite the deep downturn in aviation due to the COVID-19 pandemic. There was a 190% increase in SAF procurements from 2019 to 2020, with over 4.5 million gallons of SAF purchased in 2020. Several international groups develop models to predict future SAF volumes to estimate the potential GHG reductions possible through SAF use. Within ICAO CAEP, the Fuels Task Group (FTG) and Long Term Aspirational Goal Task Group (LTAG-TG) work to provide SAF production projections. The FTG Fuel Production Assessment (FPA) provides detailed information on short term production potential to 2035. Longer term projections are currently under development by LTAG-TG. The FPA uses historical and planned facility operations in a market diffusion approach to model future production potential. Some key findings from the FPA are presented below.

Table 1: Annual global SAF production by scenario, in kt (Source: CAEP/FTG Fuel Production Assessment)

Year	Low	Moderate	High	High+	Max
2020	82.45	470.30	1942.41	3196.11	5391.39
2021	84.68	574.45	2700.65	4403.17	8178.48
2022	224.81	955.34	3967.40	6264.74	12025.98
2023	319.19	1271.02	5093.58	7327.57	13984.40
2024	490.64	1764.42	6410.96	9138.80	17466.93
2025*	492.91	1824.86	6619.27	9332.53	17855.92

Note: * Year 2025 data from short-term analysis is not used in final results as they potentially underestimate SAF volumes in that year. Instead, year 2025 data was generated through the market diffusion approach.

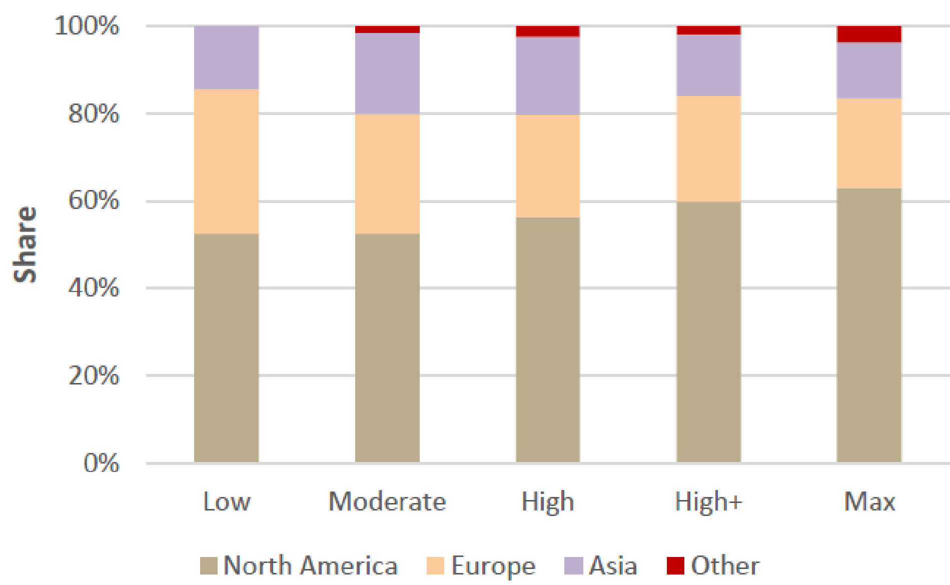

Figure 7: Production share by world region in 2025 (Source: CAEP FTG Fuel Production Assessment)

Longer term projections of SAF production are being evaluated by LTAG-TG. Preliminary results are shown below in

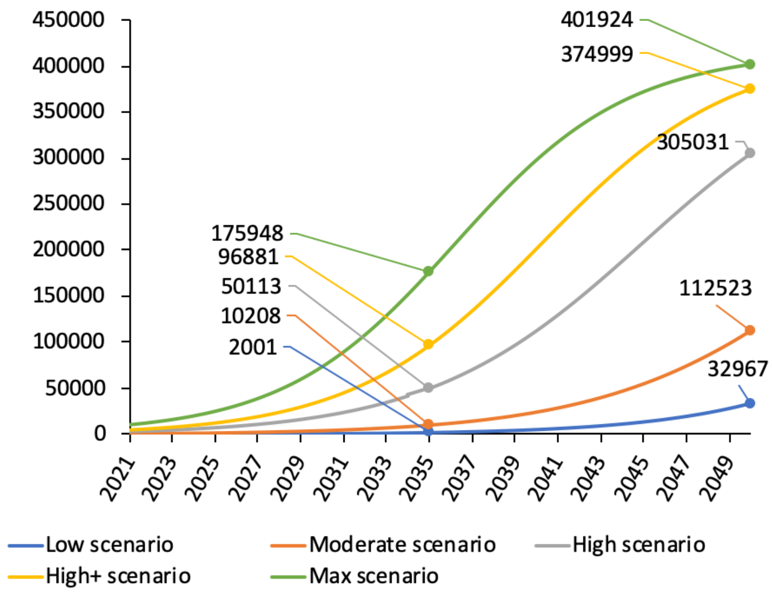

Figure 8: SAF production projections to 2050, in kt (credit: CAEP FTG Fuel Production Assessment)

The majority of existing and planned SAF production facilities employ Fischer-Tropsch or Hydroprocessing production methods to produce Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK) and Hydroprocessed Esters and Fatty Acids SPK (HEFA-SPK), respectively. The specific combination of feedstock and process defines a pathway, and each pathway has a corresponding lifecycle greenhouse gas (GHG) value. These values are used to inform users of the overall environmental impact of a particular fuel. Work under the FTG established default lifecycle values for various SAF pathways to be used in accounting for carbon reductions attributable to SAF as part of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). These default lifecycle values and additional implementation and methodology documentation are available online.

Table 2: Production share of SAF in 2025 (Source: CAEP FTG Fuel Production Assessment)

ASTM specification	Low	Moderate	High	High+	Max
FT-SPK	10.07%	11.48%	8.94%	5.64%	7.71%
HEFA-SPK	85.68%	82.91%	86.53%	90.84%	87.64%
HFS-SIP	0.00%	0.00%	0.15%	0.21%	0.22%
ATJ-SPK	0.59%	1.17%	1.21%	0.97%	1.82%
CH-SK	3.66%	2.67%	1.59%	1.21%	1.43%
Lipid coprocessing	0.00%	1.23%	1.59%	1.13%	1.18%

Combining the lifecycle GHG values, additional benefits in terms of reduced nvPM and sulfate emissions, and projected volumes of SAF uptake provides estimations of future reductions possible through SAF use. Table 3 indicates the projected replacement ratio of SAF out to 2035. Using these replacement values and research for the levels of nvPM and sulfate reductions in SAF fuels can provide estimates of the total impact of broader market uptake of SAF on nvPM and sulfate emissions.

Table 3: Projected replacement ratio of SAF production/global jet fuel demand (Source: CAEP FTG Fuel Production Assessment)

Year	Low	Moderate	High	High+	Max
2021	0.06%	0.38%	1.59%	2.41%	4.17%
2022	0.06%	0.38%	1.61%	2.49%	4.40%
2023	0.07%	0.44%	1.88%	2.98%	5.38%
2024	0.08%	0.49%	2.15%	3.50%	6.43%
2025	0.10%	0.56%	2.49%	4.17%	7.79%
2026	0.11%	0.65%	2.94%	5.02%	9.51%
2027	0.13%	0.76%	3.46%	6.05%	11.62%
2028	0.16%	0.88%	4.08%	7.29%	14.14%
2029	0.18%	1.03%	4.83%	8.78%	17.14%
2030	0.22%	1.20%	5.70%	10.57%	20.68%
2031	0.26%	1.40%	6.74%	12.68%	24.74%
2032	0.31%	1.65%	7.98%	15.21%	29.42%
2033	0.37%	1.94%	9.46%	18.17%	34.66%
2034	0.44%	2.28%	11.18%	21.60%	40.32%
2035	0.53%	2.68%	13.16%	25.45%	46.22%

Glossary of Terms

CAEP: Committee on Aviation Environmental Protection

CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation

FPA: Fuel Production Assessment

FTG: Fuels Task Group

LCAF: Lower carbon aviation fuels

nvPM: non-volatile Particulate Matter

RF: Radiative Forcing

SAF: Sustainable Aviation Fuel

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