VERSION 2
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SUSTAINABLE AVIATION FUELS GUIDE

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AMENDMENTS TO THE SUSTAINABLE AVIATION FUELS GUIDE

AMENDMENTS	SUBJECT(S)	ADOPTED EFFECTIVE APPLICABLE
Version 1		November 2017
Version 2	• Updated the terminology used throughout the document. • Updated the approved ASTM conversion processes, total number of flights that have used blends of alternative fuel, and the total number of airports distributing blended alternative fuel on a regular basis. • Added information regarding the adoption of Annex 16 Volume IV.	December 2018

PREFACE

The International Civil Aviation Organization (ICAO) and its Member States are working together to develop State Action Plans to reduce CO_2 emissions from international aviation. The development and completion of States' Action Plans on CO_2 Emissions Reduction Activities from International Aviation requires the establishment of a structured cooperation process amongst national aviation stakeholders, which aims to provide the State authority with the information it needs to set-up a long-term strategy for the mitigation of international aviation CO_2 emissions. The voluntary submission of an action plan to ICAO provides the opportunity for States to showcase policies and actions, including tailor-made measures that are selected on the basis of their respective national capacities and circumstances.

Many Member States, particularly Developing States and Small Island Developing States (SIDS), continue to investigate the institutional and financial resources necessary to develop and implement their action plans, and the actions therein. For example, many States, through their civil aviation authorities, are beginning to integrate environmental programmes into their planning and development, and these need to be coordinated with other government agencies. Some States also endeavour to establish or improve the national regulatory and policy frameworks necessary to encourage low carbon technology deployment, which is critical to stimulating private sector market activity. Others would also like to benefit from low carbon technologies that are being successfully developed in other parts of the world. This means that the State Action Plan initiative can be key to States developing coordinated activities aimed at reducing CO_2 emissions from international civil aviation.

ICAO has developed Doc 9988, *Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities,* which aims to support Member States as they develop and implement their Action Plans. As of January 2018, 106 States representing more than 90.8 per cent of global revenue tonne kilometres (RTK) have voluntarily submitted their Action Plans to ICAO. Doc 9988 presents the basket of measures that Member States can consider for reducing CO_2 emissions from civil aviation. One important opportunity for ICAO Member States to achieve their environmental and carbon emissions reduction objectives is through the use of sustainable aviation fuels (SAF).

The purpose of this guidance is to inform ICAO Member States on how sustainable aviation fuels can be deployed to reduce CO_2 emissions from international aviation activities, and describes fuel production pathways, usage constraints, environmental and other benefits, and policy perspectives on the use and development of these fuels.

Together with guidance documents on Renewable Energy for Aviation, Financing Aviation Emissions Reductions, and Regulatory and Organizational Framework to address Aviation Emissions, this guidance on sustainable aviation fuels will contribute to ICAO's comprehensive approach to support its Member States in the implementation of their Action Plans in order to address CO_2 emissions from international civil aviation.

This version of the document, Version 2, has been updated as of December 2018, in order to ensure that the most current information is available to States.

LIST OF ACRONYMS AND SYMBOLS

AFTF	Alternative Fuels Task Force
ASA	Aeropuertos y Servicos Servicios Auxiliares
ATJ	Alcohol-to-Jet
BC	Biochemical Conversion
BEFS	Bioenergy and Food Security
CAEP	Committee on Aviation Environmental Protection
CAAFCER	Canada's Civil Aviation Alternate Fuel Contrail and Emissions Research project
CAAFI	Commercial Aviation Alternative Fuels Initiative
CARB	California Air Resource Board
CBSCI	Canada's Biojet Supply Chain Initiative
CEF	CORSIA Eligible Fuel
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CO_2	Carbon Dioxide
dLUC	Direct Land Use Change
DOE	Department of Energy
DSHC	Direct Sugar to Hydrocarbons
EU	European Union
EU RED	European Union Renewable Energy Directive
EU-ETS	European Union Emission Trading Scheme
FAA	Federal Aviation Administration
FAO	United Nations Food and Agriculture Organization
FT	Fischer-Tropsch
GBEP	Global Bioenergy Partnership
GEF	Global Environment Facility
GFAAF	Global Framework for Aviation Alternative Fuels
Gha	Giga hectare
GHG	Greenhouse Gas
ha	Hectare
HEFA	Hydroprocessed Esters and Fatty Acids
HFS	Hydroprocessed Fermented Sugars
HTL	Hydrothermal Liquefaction
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
iLUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISCC	International Sustainability & Carbon Certification
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCFS	Low Carbon Fuel Standard
LUC	Land Use Change
MBM	Market Based Measures
ML	Megalitre
MSW	Municipal Solid Waste
NISA	Nordic Initiative for Sustainable Aviation
RFS	Renewable Fuel Standard
RINs	Renewable Identification Numbers
RSB	Roundtable on Sustainable Biomaterials
RTK	Revenue Tonne Kilometre
SAF	Sustainable Aviation Fuels
SARPs	Standards and Recommended Practices
SCOPE	Scientific Committee on Problems of the Environment
SCS	Sustainability Certification Schemes
SDGs	UN Sustainable Development Goals
SIDS	Small Island Developing States
SIP	Synthetic Iso-paraffin
SPK	Synthesized Paraffinic Kerosene
UCO	Used Cooking Oil
UNDP	United National Development Programme
WWF	World Wildlife Fund

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BACKGROUND

The 39th Session of the ICAO Assembly, held from 27 September to 7 October 2016, adopted Resolution A39-2: *Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change*. Resolution A39-2 reflects the determination of ICAO's Member States to provide continuous leadership to international civil aviation in limiting or reducing its emissions that contribute to global climate change.

The 39th Session of the ICAO Assembly reiterated the global aspirational goals for the international aviation sector of improving fuel efficiency by 2 per cent per annum and keeping the net carbon emissions from 2020 at the same level, as established at the 37th Assembly in 2010, and recognized the work being undertaken to explore a long-term global aspirational goal for international aviation in light of the 2°C and 1.5°C temperature goals of the Paris Agreement. The 39th Assembly also recognized that the aspirational goal of 2 per cent annual fuel efficiency improvement is unlikely to deliver the level of reduction necessary to stabilize and then reduce aviation's absolute emissions contribution to climate change, and that goals of more ambition are needed to deliver a sustainable path for aviation. To achieve international aviation's global aspirational goals, a comprehensive approach, consisting of a basket of measures has been identified, namely:

- *Aircraft-related technology development* – purchase of new aircraft and new equipment to retrofit existing aircraft with more fuel-efficient technology.

- *Alternative fuels* – investments in the development and deployment of sustainable aviation fuels.

- *Improved air traffic management and infrastructure use* – improved use of communication, navigation and surveillance/air transport management (CNS/ATM) to reduce fuel burn.

- *Economic/market-based measures* – researching and building awareness of low cost, market-based measures to reducing emissions such as emission trading, levies, and off-setting.

All of these measures, in addition to contributing to carbon neutral growth, advance the social and economic development associated with the UN Sustainable Development Goals (SDGs).

A central element of Resolution A39-2 is for States to voluntarily prepare and submit action plans to ICAO. It also lays out an ambitious work programme for capacity building and assistance to States in the development and implementation of their action plans to reduce emissions, which States were initially invited to submit by the 37th Session of the ICAO Assembly in October 2010, and update every three years thereafter. ICAO State Action Plans provide the opportunity for States to showcase policies and actions and are intended to be individualized and reflect the specific national circumstances of each ICAO Member State and the opportunities available to them in implementing measures to mitigate CO_2 emissions from international aviation activities. ICAO has prepared ICAO Doc 9988, *Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities,* to describe the process of developing or updating an action plan. As of January 2018, 106 States representing more than 90.8 per cent of global RTK have voluntarily submitted their action plan to ICAO.

This guidance has been prepared to inform ICAO Member States on how sustainable aviation fuels can be deployed to reduce CO_2 emissions from international aviation activities, and describes fuel production pathways, usage constraints, environmental and other benefits, and policy perspectives on the use and development of these fuels. It is part of a series of guidance documents developed as part of the capacity-building and assistance project implemented by ICAO, in cooperation with the United Nations Development Programme (UNDP), with financing from the Global Environment Facility (GEF). The primary focus of this assistance project is on identifying and facilitating the implementation of measures to reduce CO_2 emissions from international civil aviation. With the support of GEF and UNDP, ICAO is working with SIDS and developing States to strengthen their national capacities and improve national processes and mechanisms for the reduction of aviation emissions by:

- improving understanding the costs and environmental benefits associated with implementation of various mitigation measures for international aviation emissions;
- enhancing policy framework through a series of policy instruments, including the development of guidance documents;
- sharing knowledge and resources through an integrated environmental portal, as well as other awareness-raising initiatives; and
- developing Pilot Projects, such as the installation of solar technology at airports, thus equipping Developing States and SIDS with tools to carry on similar projects and multiplying their environmental benefits.

This guidance will show that there are several initiatives in place for research and development of sustainable aviation fuels, which illustrates the fast evolution pace of the SAF industry. Therefore, the reader should be mindful that the current guidance describes the status of the SAF industry as of December 2018. This version of the document, Version 2, has been updated in order to ensure that the most current information is available to States.

1.0 INTRODUCTION

1.1. THE WORK OF ICAO ON ENVIRONMENTAL IMPACTS AND CLIMATE CHANGE

Climate change presents a significant challenge to international aviation due to anticipated growth in the aviation sector, the potential energy demand and carbon emission associated with that growth, if unmitigated. Aviation has grown rapidly and has become vital to modern life and the global economy. In 2010, international aviation consumed approximately 142 million metric tonnes of fuel. Until 2040, fuel consumption is only expected to increase by 2.8 to 3.9 times, despite an expected increase in international air traffic by a factor of 4.2 over the same period (ICAO, 2016).

The primary impacts of aviation on the environment are due to aircraft noise and emissions. The environmental work programme of ICAO focuses on the achievement of three key objectives: (a) to limit or reduce the number of people affected by significant aircraft noise; (b) to limit or reduce the impact of aviation emissions on local air quality; and (c) to limit or reduce the impact of aviation greenhouse gas (GHG) emissions on the global climate (ICAO, 2016).

ICAO and its Member States have set clear targets to face the challenges posed by climate change. The 39th Session of the ICAO Assembly reiterated the global aspirational goals for the international aviation sector of improving fuel efficiency by 2 per cent per annum and keeping the net carbon emissions from 2020 at the same level (as shown in **Figure 1-1)**, as established at the 37th Assembly in 2010. To achieve international aviation's global aspirational goals a basket of measures has been identified, viz: Aircraft-related technology development, Alternative fuels, Improved air traffic management and infrastructure use, Economic/market-based measures. Sustainable aviation fuels (SAF) are highly relevant as a means to reduce net CO_2 emissions, depending on the feedstock and production process adopted. **Figure 1-1** shows the expected aircraft CO_2 emissions from international aviation, reflecting contributions from the ICAO Basket of Measures, including the possible impact of SAF on the evolution of life cycle GHG emissions[1] from international civil aviation.

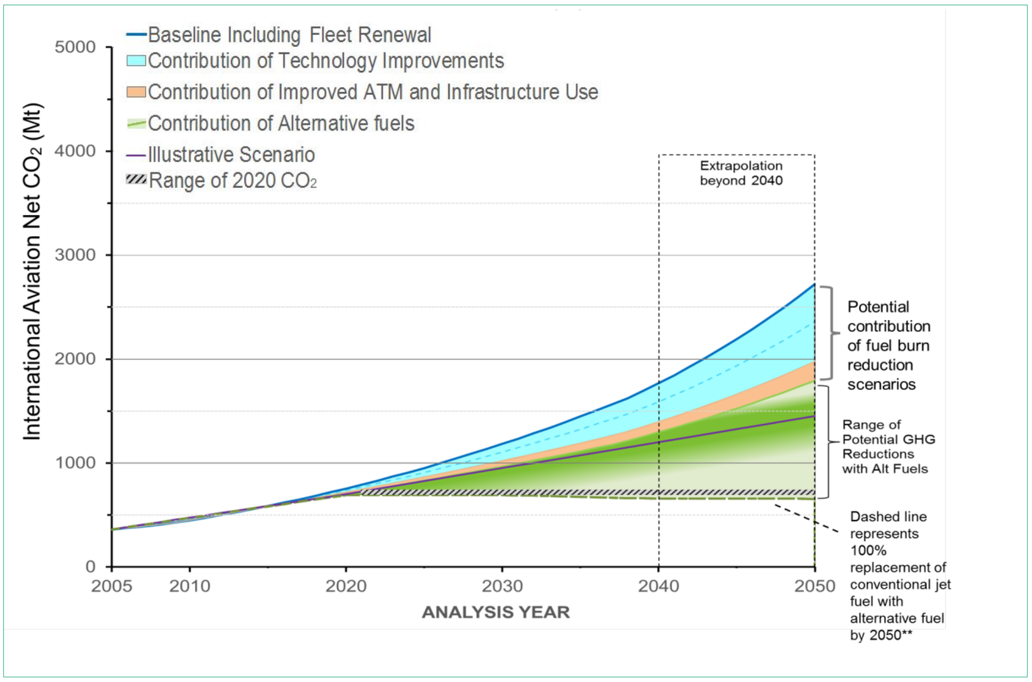

FIGURE 1-1
Expected aircraft CO_2 emissions from international aviation, reflecting contributions from the ICAO Basket of Measures towards international aviation's global aspirational goals (Source: ICAO, 2016)

[1] Life cycle GHG emission refers to greenhouse gas emissions from feedstock production (or collection, in the case of wastes) and processing to produce SAF, to that fuel's final use.

1.2. THE WORK OF ICAO ON SUSTAINABLE AVIATION FUELS

The 38th Session of the ICAO Assembly recognized the many actions that ICAO Member States have taken and intend to take in support of the achievement of the collective aspirational goals, including the development and deployment of sustainable alternative fuels, and encouraged further such efforts (Resolution A38-18, paragraph 8).

The Assembly also requested States to recognize existing approaches to assess the sustainability of all alternative fuels in general, including those for use in aviation which should (Resolution A38-18, paragraph 32 j)):

i. achieve net GHG emissions reduction on a life cycle basis;
ii. respect the areas of high importance for biodiversity, conservation and benefits for people from ecosystems, in accordance with international and national regulations; and
iii. contribute to local social and economic development, and competition with food and water should be avoided;

In order for an aviation fuel to be considered a sustainable aviation fuel (SAF), it will need to meet sustainability requirements. ICAO is currently developing sustainability criteria as part of the work on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

The first generation of alternative fuels, generally referred to as “biofuels”, are produced from biomass, such as crops, which can be subject to additional sustainability concerns beyond carbon reduction (competition with food and water, land-use changes, among others). However, current technology allows the production of fuels from non-food biomass, such as municipal wastes, used cooking oil, and agricultural residues, which raise fewer sustainability issues. This diversification of feedstocks facilitate the production of SAF with less dependence on specific natural resources or land availability, allowing the establishment of SAF industries in a variety of States (developing and developed). It will also allow the production of SAF closer to airports, which will reduce costs associated with fuel transportation. This flexibility is expected to help the ramp up of SAF production.

The Assembly also requested the ICAO Council to “adopt measures to ensure the sustainability of alternative fuels for aviation, building on existing approaches or combination of approaches, and monitor, at a national level, the sustainability of the production of alternative fuels for aviation” (Resolution A38-18, paragraph 32 j)).

To fulfil these Assembly requests, in 2013 the ICAO Committee on Aviation Environmental Protection (CAEP) established an expert group, the Alternative Fuels Task Force (AFTF), to provide technical input regarding SAFs. During the CAEP/10 cycle (from 2013 to 2016), AFTF was tasked with providing information related to alternative fuels for inclusion in the ICAO environmental trends projections. This involved the definition of a methodology for assessing fuels life cycle emissions, and projections of scenarios for alternative fuel production up to 2050, with the final objective of assessing the possible range of emissions reductions from the use of alternative fuels. The final results of this analysis were presented during the 39th Session of the ICAO Assembly (ICAO, 2016).

In addition, the CAEP has ongoing work in regard to calculating the land use change emissions attributable to alternative fuels developed from various feedstocks, calculating their default life cycle emissions values, developing guidance on potential policies, and developing a set of sustainability criteria that aviation fuels must meet in order to be considered sustainable by ICAO. These sustainability criteria are currently under consideration by ICAO.

In October 2017, ICAO convened its second Conference on Aviation and Alternative Fuels (CAAF/2) in Mexico City, Mexico. Building on the first such ICAO Conference (CAAF/1) held in 2009, the CAAF/2 agreed to a Declaration, endorsing the 2050 ICAO Vision for Sustainable Aviation Fuels as a living inspirational path and calling on States, industry and other stakeholders, for a significant proportion of conventional aviation fuels to be substituted with SAF by 2050, for international civil aviation to reduce carbon emissions significantly, and whilst pursuing all opportunities in the basket of mitigation measures to reduce emissions as necessary. The Conference further agreed that the Vision would be reviewed periodically through a stocktaking process, and elaborated at the next Conference on Aviation and Alternative Fuels, to be held no later than 2025.

1.3. THE WORK OF ICAO ON A GLOBAL MARKET-BASED MEASURE

At the 39th ICAO Assembly, in 2016, Member States agreed on a global market-based measure (MBM) which, together with other mitigation measures such as operational improvements, aircraft technology and the use of sustainable aviation fuels, will help achieve international aviation's aspirational goal of carbon neutral growth from 2020. This MBM will be implemented in the form of CORSIA.[2] In line with Assembly Resolution A39-3, the average level of CO_2 emissions from international aviation covered by the scheme between 2019 and 2020 represents the basis for carbon neutral growth from 2020, against which emissions in future years must be compared. CORSIA was adopted by the ICAO Council on the 27th of June, 2018, as Annex 16 Vol IV to the Chicago Convention of International Aviation.

In any year from 2021, the sector's offsetting requirements for that year will be the difference between the international aviation CO_2 emissions covered by the scheme and the average baseline emissions of 2019 and 2020.

The scheme will be implemented in phases, starting with participation of States on a voluntary basis, followed by participation of all States except those States which are exempt from offsetting requirements, as follows:

- Pilot phase (from 2021 through 2023) and first phase (from 2024 through 2026) would apply to States that have volunteered to participate, and
- Second phase (from 2027 through 2035) would apply to all States that have an individual share of international aviation activities in RTK in year 2018 above 0.5 per cent of total RTK or whose cumulative share in the list of States from the highest to the lowest amount of RTK reaches 90 per cent of total RTK, except least developed countries, SIDS and landlocked developing countries unless they volunteer to participate in this phase.

All ICAO Member States with aeroplane operators conducting international flights are required to undertake the monitoring, reporting and verification (MRV) of CO_2 emissions from these flights from 2019. In addition, States can decide to participate in the coverage of the CORSIA offsetting requirements from 2021. Offsetting requirements under CORSIA apply to all international flights on the routes between the participating States. Flights between a participating State and a non-participating State are exempted from offsetting requirements. For the flights between participating States, aircraft operators need to offset emissions above the baseline emissions level.

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[2] Further details about CORSIA can be found at www.icao.int.

Within CORSIA, operators may address their emissions commitments by offsetting emissions through the reduction of emissions either in the aviation sector or elsewhere, involving the concept of "emissions units". There are two main types of emissions units: "offset credits" from crediting mechanisms and "allowances" from emissions trading schemes. Therefore, offsetting could be through the purchase and cancellation of emission units arising from different sources of emission reductions that are achieved through mechanisms, programmes, or mitigation projects.

Assembly Resolution A39-3 requests the development of a methodology "to ensure that an aircraft operator's offsetting requirements under the scheme [CORSIA] in a given year can be reduced through the use of sustainable alternative fuels, so that all elements of the basket of measures are reflected" (Resolution A39-3, paragraph 6). To address this request, CAEP has developed recommendations on a procedure to determine how operators with offsetting requirements in CORSIA will be able to claim emissions reductions from the use of CORSIA eligible fuel (CEF), in which operators can deduct their CEF CO_2 benefits from their offsetting requirements.

As defined in Annex 16, Volume IV[3] any aeroplane operator that intends to claim emissions reductions from the use of CORSIA eligible fuels in a given year shall compute emissions reductions in line with CORSIA requirements.

In order for an operator to be able to claim emissions reductions from the use of aviation fuels under CORSIA, the fuel has to be categorized as a CORSIA eligible fuel, for which it must meet a set of Sustainability Criteria to be defined within the ICAO Document entitled "CORSIA Sustainability Criteria for CORSIA Eligible Fuels" that will be available on the ICAO CORSIA website after approval by the ICAO Council[4].

Amongst the considerations for such criteria is the need for a CEF to provide environmental benefits in terms of a net CO2 reduction of at least 10 per cent compared to the baseline life cycle emissions values for aviation fuel, equal to 89 gCO2e/MJ for jet fuel.

[3] Annex 16, Volume IV: https://www.unitingaviation.com/publications/Annex-16-Vol-04/#page=1
[4] ICAO CORSIA website: https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx

These CEF must also be produced by fuel producers that are certified by an approved Sustainability Certification Scheme included in the ICAO document entitled "CORSIA Approved Sustainability Certification Schemes", that will be available on the ICAO CORSIA website. Such certification schemes must meet the requirements included in the ICAO document entitled "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes", that will be available on the ICAO CORSIA website. The image below provides further clarification on the documents referenced in Annex 16, Volume IV that relate to CORSIA eligible fuels.

	Annex 16 Vol. IV References	"ICAO Documents" Referenced in Annex 16 Vol. IV
2.2.4.1	The **aeroplane operator** that intends to claim for emissions reductions from the use of CORSIA eligible fuels shall use a CORSIA eligible fuel that meets the CORSIA Sustainability Criteria as defined within **the ICAO document entitled "CORSIA Sustainability Criteria for CORSIA Eligible Fuels"** that is available on the ICAO CORSIA website.	**CORSIA Sustainability Criteria for CORSIA Eligible Fuels**
2.2.4.2	The **aeroplane operator** that intends to claim for emissions reductions from the use of CORSIA eligible fuels shall only use CORSIA eligible fuels from fuel producers that are certified by an approved Sustainability Certification Scheme included in **the ICAO document entitled "CORSIA Approved Sustainability Certification Schemes",** that is available on the ICAO CORSIA website. Such certification schemes meet the requirements included in **the ICAO document entitled "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes",** that is available on the ICAO CORSIA website.	**CORSIA Approved Sustainability Certification Schemes** **CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes**
3.3.1	The **aeroplane operator** that intends to claim for emissions reductions from the use of CORSIA eligible fuels in a given year shall compute emissions reductions as follows: $ER_y = FCF * \left[\sum_f MS_{f,y} * \left(1 - \frac{LS_f}{LC}\right)\right]$	
3.3.2	If a Default Life Cycle Emissions value is used, then the **aeroplane operator** shall use **the ICAO document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels"** that is available on the ICAO CORSIA website for the calculation in 3.3.1.	**CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels**
3.3.3	If an Actual Life Cycle Emissions value is used, then an **approved Sustainability Certification Scheme** shall ensure that the methodology, as defined in **the ICAO document entitled "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values"** that is available on the ICAO CORSIA website, has been applied correctly.	**CORSIA Methodology for Calculating Actual Life Cycle Emissions Values**

2.0 SUSTAINABLE AVIATION FUELS

Since SAF were accepted as an emission mitigation measure for international aviation, significant progress has been made in regard to the production, certification and commercial use of SAF. This chapter describes the concept of sustainability in regard to SAF and key factors that make these fuels an appropriate means for reducing emissions.

2.1. THE GROWING INTEREST IN SAF

Although revolutionary aircraft technologies have been proposed to reduce fuel consumption, such as propellers electrically powered by photovoltaic cells, fuel cells, or ultracapacitors, large commercial aircraft have no alternatives to liquid fuel for the near- to mid-term. After half a century of development, gas turbines are reliable, economically competitive, have a superb power/weight ratio and allow excellent range because of the high energy density of liquid fuels.

In this regard, drop-in SAF (as described in section 2.3) are the most promising near-term options. These fuels use the same fuel distribution infrastructure and aircraft engines already in use, with the advantage of reduced GHG emissions. The production of SAF is described further in Chapter 4 of this guidance document.

In the context of commercial airlines, the interest in SAF is often associated with reducing their dependence on conventional fuel (Daggett and others, 2008), as well as being a valuable marketing tool.

By December 2018, six conversion processes to produce SAF had been certified and over 150,000 commercial flights had been completed using these fuels. Thus, SAF production and logistics facilities are being progressively deployed, gradually introducing SAF into airlines' regular operations.

2.2. THE ESSENTIAL "DROP-IN" CONCEPT

The commercial aviation industry has adopted rigorous safety standards and procedures in the operation and maintenance of its equipment, which imposes stringent quality standards for the fuel used to power aircraft. Considering that aircraft are often refuelled in different States, including some States that have national standards for jet fuel[5], blending jet fuels within an aircraft fuel tank are often from different sources. Therefore, it is required that these technical fuel specifications are harmonized.

The standard most widely used to define the kerosene-type fuel for commercial aircraft is ASTM D1655 standard specification for aviation turbine fuels, which presents the specifications for Jet A-1 fuel, setting its requirements for composition, volatility, fluidity, combustion, corrosion, thermal stability, materials compatibility, water contamination, and additives such as "antioxidants, metal deactivators, fuel system icing inhibitor, electrical conductivity improver, leak detection additive, lubricity improvers, and biocides". Values for selected properties of Jet A-1 are summarized in **Table 2-1** (ASTM International, 2015 and ARAC, 1998).

[5] For instance, Australia, Brazil, Canada, China, France, Japan, the Russian Federation, Spain, Sweden and the United Kingdom have national jet fuel specifications (ExxonMobil, 2008).

Property	Comment	Value or range
Density @ 15°C		775.0 – 840.0 kg/m^3
Flash point	Lowest temperature at which vapours of the material will ignite, when given an ignition source	min. 38°C
Freezing point	Temperature at which wax crystals formed in the fuel as it cools completely disappear when the fuel is rewarmed	max. -47°C
Aromatics content	Related with smoke and soot formation	max. 25%, volume
Sulphur content	Produces harmful emissions	max. 0.30%, mass
Net heat of combustion	Energy liberated when completely burned, at constant pressure	42.8 MJ/kg

TABLE 2-1
Typical properties of fuel grade Jet A-1 according to ASTM D1655 (Source: ASTM, 2015 and ARAC, 1998)

Due to the strict quality control conditions for aviation fuels, the introduction of fuels from different sources requires the implementation of the "drop-in" fuel concept. Therefore, a "drop-in jet fuel blend" is a substitute for conventional jet fuel, that is completely interchangeable and compatible with conventional jet fuel when blended with conventional jet fuel. A drop-in fuel blend does not require adaptation of the aircraft/engine fuel system or the fuel distribution network, and can be used "as is" on currently flying turbine-powered aircraft.

The requirement that a fuel be "drop-in" is essential for the aviation industry because a drop-in SAF does not need to be handled separately from any other aviation fuel. Any "non drop-in" fuel would present safety issues associated with risks of mishandling, and would require a parallel infrastructure to be implemented in all airports, imposing additional, higher costs.

2.3. EMISSIONS REDUCTIONS FROM SAF

The potential of SAF to reduce aviation GHG emissions has been recognized by ICAO, Member States and the aviation industry, such that SAF are included amongst the "basket of measures" put forward to assist States in designing their action plans on CO_2 emissions reductions. According to the ICAO 2016 trends assessment, a 100 per cent substitution of aviation fuel with SAF could reduce 63 per cent of the baseline CO_2 emissions from international flights in 2050. This would be aviation's most significant contribution towards achieving carbon neutral growth. (**Fig. 1-1**)

While the combustion of SAF emits similar quantities of CO_2 to the combustion of conventional fuels, SAF still provide an environmental benefit on a life cycle basis. A fuel life cycle is made up of multiple steps from the feedstock to the final use in an engine. These steps include, for example, recovery, processing, and transport of the fuel. At each of the steps, GHG emissions are likely to be produced. The total carbon footprint of the fuel is obtained by adding all these emissions together in a life cycle assessment. When all those emissions are considered, SAF will result in decreased emissions when compared with the baseline life cycle value of 89gCO2e/MJ for jet fuel. These emissions reductions benefits will vary according to the feedstock, production practice, conversion technology, logistics, as well as the land-use change incurred by bioenergy expansion (see Annex A). Certain aspects of a SAF life cycle may be considered during the sustainability certification process.

When biomass is used to develop SAF, the plants absorb CO_2 for growth during photosynthesis in relatively short time scales. The carbon that is then emitted back into the atmosphere during combustion will return to the plants in a closed loop. Ideally in this scenario, no additional carbon would be injected into the biosphere as it would with traditional methods (ICAO GFAAF, 2017). When Municipal Solid Waste or industrial waste gases are used to produce SAF, the emissions reductions come from the multiple uses of fossil carbon.

CO_2 emissions can also be generated during the production of SAF in recovery, processing, and transport. Specific combinations of feedstock and conversion processes used for the production of SAF, called pathways, can result in fuel life cycle CO_2 emissions that are either lower or higher than the baseline value of 89 gCO2e/MJ. However, only those fuels with life cycle emissions lower than the baseline value will be environmentally beneficial (ICAO GFAAF, 2017). These emissions reductions benefits will vary according to the feedstock, production practice, conversion technology, logistics, as well as the land-use change incurred by bioenergy expansion (see Annex 1).

2.4. DRIVERS TO DEVELOP SAF

Several SAFs are forms of bioenergy, which is a prime example of how energy interlinks with other areas, including water, ecosystems, health, food security, education and livelihoods, and can harness multiple benefits and sustainable development (Nogueira and others, 2015).

However, to contribute effectively, bioenergy deployment needs to be well planned and carefully implemented so as to avoid environmental and social risks. If these risks are successfully mitigated, bioenergy can generate benefits and contribute to many policy objectives, as well as to strategic demands from society and the economy.

In the case of air transport, SAF can bolster the supply of liquid fuels, which could be critical for airlines, considering the absence of other practical options to power the vast majority of aircraft engines for the foreseeable future. Additionally, SAF production facilities do not need to be situated in the same locations as conventional oil refineries, allowing greater geographic diversification of production (IATA, 2015).

The commercial-scale production of SAF also has the potential to generate jobs and spur economic activity, especially in rural areas where feedstocks can be cultivated. Producing bioenergy locally can harness the growth of the agricultural sector for broader rural development, while not affecting food production. As a labour-intensive sector, job opportunities in agriculture can be found throughout the bioenergy value chain, which can, in turn, be the driver of economic development and a more skilled labour force, with increasing scale and sophistication over time.

The coproduction of bioelectricity and SAF fuels also enables the provision of energy services to local communities, such as irrigation, food and medicine preservation, communication and lighting. In addition, new infrastructure built to support a developing bioenergy sector can improve access to multiple markets, thereby increasing overall accessibility. The growth of a domestic SAF industry could also help net crude importers reduce exposure to foreign crude oil and refined products.

Bioenergy can also lead to beneficial effects for biodiversity when abandoned land, formerly used farmland, or moderately degraded land, is used and rehabilitated via a systemic approach to produce biomass. In terms of health effects, bioenergy production systems based on crop and urban solid residues in particular have higher potential to improve air quality (e.g. mitigation of ozone, particulate matter, acid-forming compounds, carcinogens) in the vicinity of areas where these residues are dumped and burned in open-air (Dale and Ong, 2014). The use of Municipal Solid Waste can also help to address problems and costs associated with waste management in urban centers.

A critical analysis of all these drivers, built on over 2,000 scientific studies and major assessments, was carried out under the aegis of the Scientific Committee on Problems of the Environment (SCOPE), and the results are presented in the SCOPE Bioenergy & Sustainability report (Souza and others, 2015). The report's authors see both practical and ethical imperatives to advance bioenergy in light of its potential to meet pressing human needs not easily addressed by other renewable energy sources. However, the report acknowledges that although bioenergy can be potentially beneficial, it does not mean that it necessarily will be.

Research and development, good governance, and innovative business models are essential to address knowledge gaps and foster innovation across the value chain. By implementing these measures, the authors of the SCOPE report argue that a sustainable future would be more easily achieved with bioenergy than without it, and that not using the bioenergy option would result in significant risks and costs for regions, States and the planet.

3.0 CONDITIONS FOR PROMOTING SAF

This chapter presents the main issues that are important for the development and deployment of SAF, focusing on the role of different stakeholders and specific national circumstances, such as the legal framework and other issues that must be taken into account, with examples and recommendations.

3.1. STAKEHOLDERS' ROLES AND RESPONSIBILITIES

Civil aviation is a global business, operating under international rules and protocols, including the Standards and Recommended Practices (SARPs) adopted by ICAO. In addition, airlines are bound by the national regulations of the States in which they operate. Therefore, national authorities are important stakeholders in promoting innovation in the biofuels industry through research and development.

Diverse stakeholders are directly involved in developing and deploying SAF including government institutions (e.g. civil aviation authorities, environmental, regulatory and financial agencies, and research and development institutions), airports, airlines, aircraft and associated equipment manufacturers, fuel producers and aviation fuel distributors.

Table 3-1 presents the drivers and constraints to the introduction of SAF from a stakeholder perspective. The drivers include the relevance of environmental issues and concerns with energy security and lack of technology. Among the constraints are agriculture (feedstock) supply, fuel quality and infrastructure, as well as the economic and environmental aspects. It is important to recognize these issues when defining roles and responsibilities, to properly motivate, commit and coordinate stakeholders' actions to foster innovation in SAF.

TABLE 3-1
Stakeholders' perception of drivers and constraints for promoting SAF (Source: Adapted from Gegg and others, 2015)

Drivers	Constraints
Need for reducing emissions	Feedstock supply readiness
Oil price fluctuation and fuel insecurity	High costs and funding
Carbon price	Sustainability
Lack of alternative technology	Policy incentives
New growth market for biofuels	Fuel consistency and infrastructure
Green public relations	Funding for public relations

A. GOVERNMENT INSTITUTIONS

Public policies are very important for fostering a national SAF industry. Governments can adopt diverse mechanisms, including legislation (with regard to environment and fuel quality specification), taxation, and support measures, among others. Governments should therefore define the goals and targets needed to develop a SAF market, to evaluate the impacts, benefits and implications, and coordinate the different public agencies and institutions needed to achieve them. This should be done in cooperation with the private sector.

In an increasing number of States, the government has introduced regulatory agencies to implement and monitor national policies for the energy and transport sectors. These agencies are important players in the context of SAF development.

An example of governmental measures instituted for adopting alternative fuels is the mandatory introduction of ethanol and biodiesel for automotive use, by adjusting the vehicular fuel quality specifications to meet environmental and sustainable development objectives. These biofuels have been progressively adopted in some States through national blending mandates, as presented in **Figure 3-1**. Taking into account alternative fuel demand, mandatory blending is a powerful measure to promote its use and production however, as only the domestic fleet consumes such fuels the supply and consumption are limited.

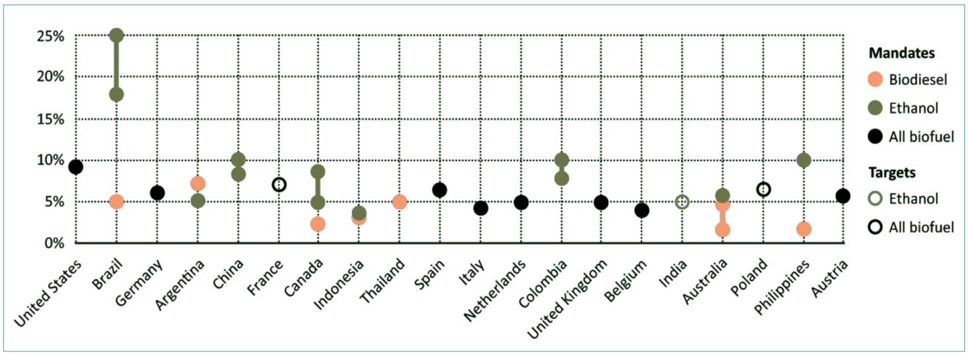

FIGURE 3-1
Blending mandates and targets for ethanol and biodiesel in some States (Source: Souza and others, 2015)

The approach for SAF must be different compared with road transport since SAF is used in a global market and needs to comply with international regulations. Some States may consider voluntary or mandatory blending of SAF into the aviation fuel supply. For example, as of October 2018, Norway became the first State to announce a biofuel mandate for aviation[6].The Norwegian Ministry of Climate and Environment announced that starting from 2020, all aviation fuel sold in Norway must contain at least 0.5 per cent advanced biofuel derived from wastes or residues.

A second important issue for national governments is to develop and implement measures to improve the economic feasibility of SAF projects to mitigate risks generally associated with innovation. With this aim, a differentiated tax regime and special financing lines can be used to reduce operational costs and investment in projects for SAF production and use. Other actions to reduce risk perception are information and demonstration programmes, such as developed in Mexico by the Aeropuertos y Servicios Auxiliares (ASA), a federal agency in charge of management and operation of Mexican airports, including aviation fuel supply.

Research and development institutions, frequently under government control or supported by governmental funds, should be encouraged to participate in SAF initiatives. There is a wide scope of subjects to be studied, from basic research to more specific and applied themes. This covers feedstock production, processing and final use. In that sense, research and development institutions can provide valuable assistance in studying processes and systems, and developing and implementing evaluation methodologies.

Chapter 5 addresses some practical and operational aspects of promoting the use of SAF, focusing on economic competitiveness and logistical issues that are generally under government control. Chapter 6 discusses national initiatives to foster the development of a SAF market, highlighting the role of the government in this task.

[6] http://biomassmagazine.com/articles/15657/norway-to-implement-biofuel-mandate-for-aviation-fuel-in-2020

B. AIRLINES

Many airlines have shown a clear interest in SAF and have been participating in their development from the outset. The initial concerns about safety have been resolved with the "drop-in" concept. In addition to the safety aspects, airlines are concerned about fuel costs and environmental benefits.

Blending SAF can represent an increase in operating costs, which represents a substantial portion of an airline's budget. Depending on the production pathway adopted, the price of SAF could be 1.5 to 3 times the price of conventional fuels, which is a clear economic burden for airlines. However, R&D efforts can help to reduce productions costs of SAF, as has been demonstrated by the United States Department of Energy (DOE). Through this research, the DOE found that the projected cost of fuel produced through fast pyrolysis, one possible SAF production pathway, at full-scale production has decreased by 75 per cent (U.S. DOE, 2016).

Additionally, recognizing the benefits of using SAF, as well as the negative externalities[7] associated with conventional fuels, this additional cost can be shared between society (economic support backed by the Treasury) and the airline customers (charged in the ticket price), by implementing a balanced tax regime.

The deployment of SAF corresponds to an environmentally responsible perspective on the part of airlines, an action in favour of mitigating climate change. By December 2018, over 30 airlines had carried out over 150,000 flights using a blend of alternative fuels[8].

As an indication of airlines' interest in SAF, associations bringing together airlines, aircraft manufacturers, environmental non-governmental organizations (NGOs), research institutions and academia have been created to promote this technology and educate stakeholders and consumers. These airline and multi-stakeholder associations are discussed in Chapter 6 and provide a good source of information for States willing to move towards developing and deploying SAF.

C. AVIATION EQUIPMENT MANUFACTURERS

Air transport equipment needs to meet rigorous operational and safety standards. Aircraft, their systems and parts, such as engines and the fuel delivery system, as well as all associated infrastructure and airport systems directly related to fuel transport, storage and fuelling operations should be reliable and with good performance across all expected operational conditions. Therefore, aviation fuel quality is crucial and aviation equipment manufacturers have expressed interest in adopting SAF. As an example, in 2012 Airbus, Boeing, and Embraer signed a memorandum of understanding to work together on developing drop-in, affordable SAF, aiming to "support, promote and accelerate the availability of sustainable new jet fuel sources" (Boeing, 2013).

For manufacturers, as for airlines, the concept of drop-in SAF is a fundamental principle, as it requires that to certify a pathway for producing SAF, the fuel should behave like conventional fuels, not affect any equipment, and not require any change in the equipment material and operational conditions. Although producing SAF under these constraints means a challenge for the biofuels industry, it also represents safety for the aviation industry and generates interest in the use of this fuel.

[7] Negative externalities are market distortions that occur when a product costs more to society than to its consumer. For instance, a polluting product can cost more to society than its shelf price.

[8] https://aviationbenefits.org/environmental-efficiency/our-climate-plan/sustainable-aviation-fuel-in-flight

Aiming to participate in the development of SAF, several aircraft manufacturers have sponsored national studies on perspectives for the production and use of SAF, assessing feedstock production, processes, logistics and legislation for introducing drop-in SAF. These studies are important initial steps for any State that aims to deploy a SAF market, and the endorsement of equipment manufacturers increases their value. Aircraft manufacturers have also supported and followed several experimental flights using alternative fuels on their aircraft.

D. FUEL PRODUCERS

Although there are several companies currently producing other alternative fuels, the regular production of SAF is still limited to a single facility at the moment. SAF needs to meet the same high quality standards as conventional fuels, which is a challenge for fuel producers. On the other hand, there are several options of feedstock and conversion process for SAF production, which can facilitate the expansion of SAF production by different fuel producers.

To date, six SAF conversion processes have been certified by ASTM, an international technical standards organization, while other processes are in development. This diversity of options and relative immaturity of the processes can be assumed as a risk for fuel producers, since a new process can reach higher performance and displace those already established.

Under these conditions, deploying a SAF production system represents an uncertain venture, deserving support or imposing high financial return. Nevertheless, it is reasonable to expect that after an initial learning stage and consolidation, aviation fuel production will operate sustainably, with progressive costs reduction, as observed in the introduction of other innovative technologies.

E. AVIATION FUEL DISTRIBUTORS

It is understandable that, for the owners and operators of the production and distribution infrastructure for aviation fuels, the arrival of new players can represent a market risk. Therefore, it is important to understand that fuel distributors are essential participants in this market. As suppliers and handlers of SAF, they must have the knowledge to comply with the regulations and procedures required by the aviation fuel market.

3.2. NATIONAL CONDITIONS TO DEVELOP A SAF MARKET

Should a State determine to pursue the development and deployment of SAF, some basic conditions must be met. Assuming that the necessary financing will be available and the international regulations and guidelines, such as the drop-in principle and certificated processes will be respected, it will be important to carefully evaluate the legal framework, the infrastructure needed and the potential for feedstock production.

A. LEGAL AND REGULATORY FRAMEWORK

The legal framework and associated institutional structure represents the first condition to be considered. A clear definition is needed of the responsibilities related to the fuel quality specifications, and their monitoring and enforcement through the adoption of transparent and consistent procedures. Legislation with clear rights and restrictions represents an important signal of government commitment to foster SAFs, and thus can reduce the risk to market players. Otherwise, the lack of legislation to regulate the aviation and fuel sectors appropriately can be considered as a barrier to the deployment of SAF.

In addition to the legislation and regulations directly related to the fuel specifications, production and commercialization of SAFs, the legal aspects of environmental protection are also important to consider in order to effectively promote SAF. For instance, laws to preserve natural resources, water sources, biodiversity, and to protect native fauna and vegetation help to avoid the implementation of unsustainable production processes.

Along the same lines, the appropriate zoning of urban and agro industrial residues, enforced by legislation, can help to promote the use of these materials as feedstock for SAF (Boeing and others, 2013).
Another field of legislation, more associated with crop-based fuel production is labour rights, which refers mainly to those workers involved in the agricultural activities associated with feedstock production. Crop-based SAF production can be labour-intensive and it is important to ensure, as an indicator of sustainability, that its social benefits are guaranteed.

It is also important to evaluate legislation to ensure that it does not impose constraints on small and independent producers, mainly with respect to feedstock production [9]. It is equally important to provide effective monitoring and enforcement resources to ensure that the legislation in place will be observed.

B. INFRASTRUCTURE

The feasibility of SAF production depends directly on the availability of sustainably produced feedstock at competitive costs, which in turn is a direct function of the existing supply infrastructure, such as roads and storage systems. For instance, for biodiesel and ethanol, the feedstock cost at the conversion plant gate corresponds to about three quarters of the final cost of the fuel, with an important contribution of the transport cost.

The cost of SAF is also subject to a trade-off between the costs of land and freight. In areas near processing plants or with good infrastructure, the cost of land is generally high, while in areas distant from those plants or without infrastructure, the cost of land is lower, but the transport of raw material has a greater impact on the final fuel cost.

Thus, to promote competitive SAF production, it is important to expand and reinforce the transport infrastructure, such as roads and storage systems, which also bring better conditions for producing other agricultural goods. The same consideration is valid for waste collection and transport, regarding the distance between the place where it is available and the processing plant.

The infrastructure for SAF transport and storage is a minor concern compared with feedstock availability. SAF are generally transported from the producer in trucks and blended at the distributor’s terminals, requiring relatively simple equipment and tanks. The amount of product to be transported, at least considering the conditions observed in developing States, does not justify the adoption of other possibilities, such as pipelines.

C. AGRICULTURE POTENTIAL FOR FEEDSTOCK PRODUCTION

Agriculture is one possible source of feedstock for SAF production. However, the agricultural potential for sustainable production of SAF feedstocks should consider other land uses (e.g. food production), and environmental constraints, such as biodiversity, natural and cultural heritage, and the conservation of water resources. This subject has been intensively studied in the last decade, which significantly improved the base of information on land availability and constraints (Souza and others, 2015).

The planet has 13 Billion Hectares (Gha) of land area. Forests, deserts, mountainous areas and urban areas encompass around 62 per cent of this land (8.09 Gha), which leaves around 4.91 Gha of land available for agriculture (FAOSTAT, 2014), from which 4.49 Gha are considered “Very Suitable” or “Suitable” for agriculture (Fisher and others, 2011).

[9] Ensuring that feedstock prices are fair and independently established and setting a tax regime with some level of exemption for small-scale producers are examples of legislation oriented to protecting small and independent feedstock producers.

Currently, about 1.54 Gha of land are being used for annual and permanent crops. Based on population growth forecasts, dietary trends, and projected increases in crop production yields and water use, the Food and Agriculture Organization (FAO) estimates that, by 2050, an additional 0.07 Gha of land will be needed to grow food crops by 2050, resulting from an increase in agriculture of 0.13 GHa in developing countries, and a decrease of 0.06 Gha in developed countries (FAO, 2012). This means that 1.61 Gha will be required for feeding directly or indirectly the world population in 2050, or about 33 per cent of global land suitable for agriculture (FAO, 2014).

These numbers show that, in theory, around 3.28 Gha would be available to expand agriculture. However, excluding the land required for urban settlements and infrastructure, forests, and protected areas for biodiversity in the next decades, results around 1.41 Gha of land potentially available for increase non-food agricultural production, including bioenergy production (FAO, 2012). A large portion of this land available is in developing States: 0.45 Gha in sub-Saharan Africa and 0.36 Gha in Latin America (FAO, 2015), most as pasture or rangeland, with very low productivity, making pasture intensification an important way to improve land use and protein production (Morishige and others, 2010).

As a consequence of this land availability, detailed studies presented by the Intergovernmental Panel on Climate Change (IPCC), the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), as well as environmentally motivated NGOs such as the World Wildlife Fund (WWF) and Greenpeace, have indicated that bioenergy can provide a substantial share of future world energy consumption. In some scenarios developed for these studies, bioenergy is the largest primary energy source supporting humanity in 2050 (Souza and others, 2015).

These estimates of bioenergy potential vary depending on the assumptions adopted, but based on two comprehensive aggregated studies (IPCC, 2014; Slade et al.,2014), between 0.05 Gha and 0.2 Gha of land could be used to produce bioenergy by 2050, which would generate additionally from 100 to 200 EJ/year. This would represent from 7 to 22 per cent of the world energy demand in 2050, in an intermediate scenario in terms of assumptions (GEA, 2012).

A synthesis of this land availability and current land use is presented in **Figure 3-2**, which also presents the estimated potential for bioenergy production.

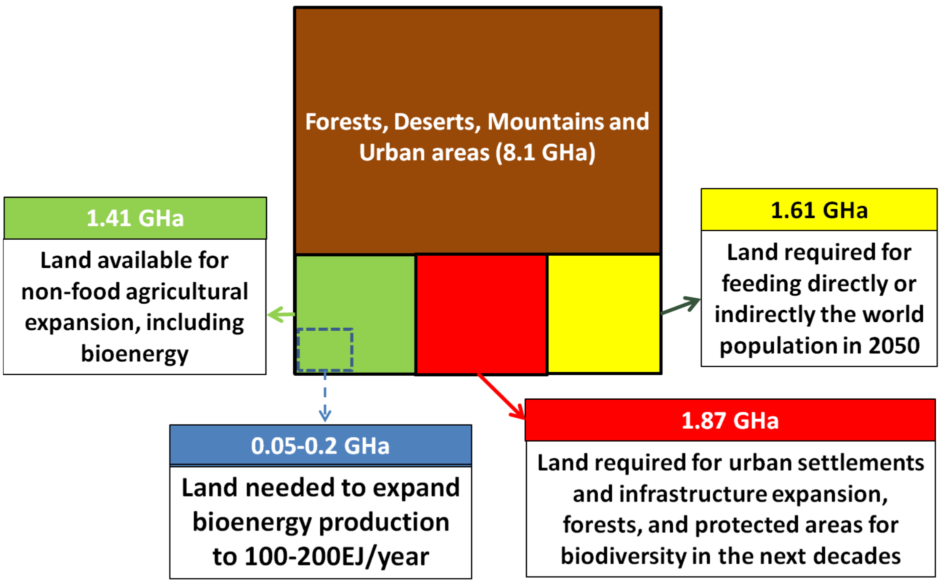

FIGURE 3-2
Global land use for food and bioenergy (approximate numbers) (Source: adapted from Souza and others, 2015)

According to these data and considering best practices in agricultural production, given the estimated demand and the actual yields of biomass, there is sufficient land to cover the global needs of the four “f’s” – food, feed, fibres and fuel – in the foreseeable future.

It should also be noted that most of these studies focused on the availability of land for either food or bioenergy production. However, current land management practices such as rotation crops and pasture intensification can allow a relevant increase in the production of animal protein, staple food and feed crops in the same land, without competition between them.

There is no simple linear relationship between cultivated land and agricultural production, as productivity gains have been promoted, with relevant results of best agricultural practices, improvement in plant varieties and appropriate use of fertilizers, among other measures.

Brazil offers a good example of the potential of productivity increase by adopting modern practices. As depicted in **Figure 3-3**, over the last 35 years the production of cereals and oil crops have grown at an annual rate of 3.6 per cent, while the cultivated area expanded on average at just 0.7 per cent per year. In cattle ranching, the pasture area was reduced by 8 per cent, but the herd increased by 155 per cent. Farm production clearly depends on much more than just the area cultivated (Nogueira and others, 2013).

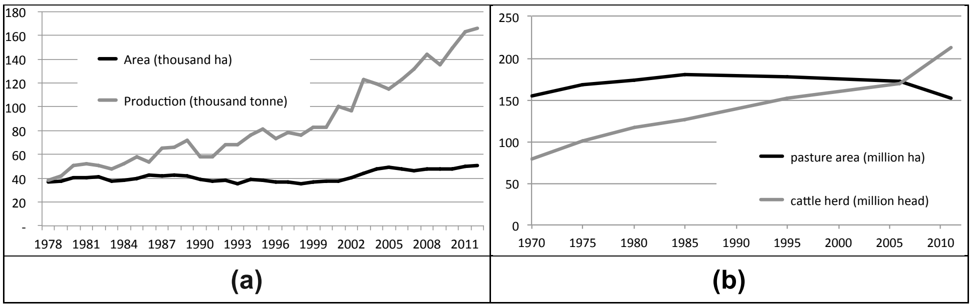

FIGURE 3-3
Impacts of productivity in Brazilian agriculture ((a) evolution of cultivated area and production of cereals and oil crops; (b) evolution of pasture area and cattle herd) (Source: Nogueira and others, 2015)

These values reflect the global average, and a detailed assessment should be done at State level to identify the actual potential for promoting SAF production, which depends on factors such as current land use, climate, infrastructure, environmental or other kind of restrictions (degraded areas, national parks, high declivity regions, low fertility or rocky soils, etc.).

An interesting approach to dealing with these issues is agro-ecological zoning for a bioenergy-prone culture in a given region or State. By using geographic information system (GIS) tools, it is possible to establish different layers with different characteristics and integrate them to plot a map with the zones best suited or not to promote feedstock for SAF production. For example, the Government of Brazil adopted this approach for zoning expansion of the sugarcane and palm oil crops to improve the sustainability of crop-based fuel production.

In the Brazilian agro-ecological zoning for sugarcane, shown in **Figure 3-4**, 19.3 million ha were considered to have the potential for high yield (greater than 81.4 ton/hectare), and 41.5 million ha are considered to have average potential (73.1 tonne/hectare). Among other restrictions, the following areas are excluded: (a) land with slopes greater than 12 per cent (a limit imposed by mechanical harvesting); (b) areas with native vegetation; (c) Amazon and Pantanal biomes; (d) environmental protection areas; (e) areas currently in agricultural use; and (f) reserved lands (Nogueira and Capaz, 2013).

This zoning has been used by financial agents as a qualifying criterion to provide credit for crop-based fuel projects. While the current sugarcane area represents approximately 1 per cent of the total area of Brazil, such zoning indicated that sugarcane production could expand to occupy 7.5 per cent of Brazilian land, making it evident that "there is more than sufficient land to meet future demands for sugar and ethanol projected for the next decades in domestic and foreign markets" (MAPA, 2009).

In several developing States, particularly in the wet tropical zone, similar conditions are available, making it both feasible and sustainable, at least from the perspective of available land, to promote SAF production.

FIGURE 3-4
Sugarcane agro-ecological zoning in Brazil (Source: MAPA, 2009)

It is also important to consider the current experience in evaluating the sustainability of bioenergy projects as a useful and consistent tool for assessing aviation fuel projects and programmes. The Global Bioenergy Partnership (GBEP) and the Commercial Aviation Alternative Fuels Initiative (CAAFI) have been working in this direction to strengthen methods, models, modelling, data/analyses and guidance (ICAO, 2012). As a part of the ICAO CAEP's work on calculating the life cycle emissions of various fuel production pathways, the impacts of land use change are also being considered.

Finally, there is increased interest in using rotation crops as feedstock for SAF production. Rotation crops are grown on the same land as food crops, during the period when the field would normally be left fallow. Ongoing research shows that there can be environmental, social, and economic benefits of using SAF feedstock in this way. One example of SAF feedstock that can be used as a rotation crop are carinata seeds, which are the focus of several research initiatives around the world (Klingenberg, 2017).

D. RESIDUES AND WASTES AS FEEDSTOCK

In some conditions, residues and by-products from agriculture, forestry, industries processing organic raw material, such as food industries and sawmills, as well as several types of municipal wastes can be considered as a valuable feedstock for SAF production. Crucial aspects to be taken into account in feasibility studies aiming at using these materials are the costs for collection and logistics and the availability in amounts adequate to reach a minimum economic scale in processing plants, which can be deployed using different technologies, as presented in the next section. It is important to highlight that, in general, there is a compromise between feedstock and conversion costs: cheap materials general impose more expensive processes, as presented in **Figure 5-1**.

There is particular interest in MSW, since they represent a relevant concern in many cities over the world, in terms of economic and environmental impacts, due to the fact it requires collection, transport, treatment and final disposal, typically in landfills.

To reduce the problems and costs associated with MSW management, after screening and separation of recyclable materials, its use as source of energy and feedstock for SAF has been increasingly considered, adding value and reducing impacts and costs for handling and treatment. Additionally, the decomposition of organic material in MSW deposited in landfills generate GHG emissions including methane and CO_2. Therefore, the diversion of MSW for the production of SAF can avoid these landfill GHG emissions, which is an additional benefit of using MSW to produce SAF. **Figure 3-5** illustrates the life cycle of MSW as a feedstock for SAF production.

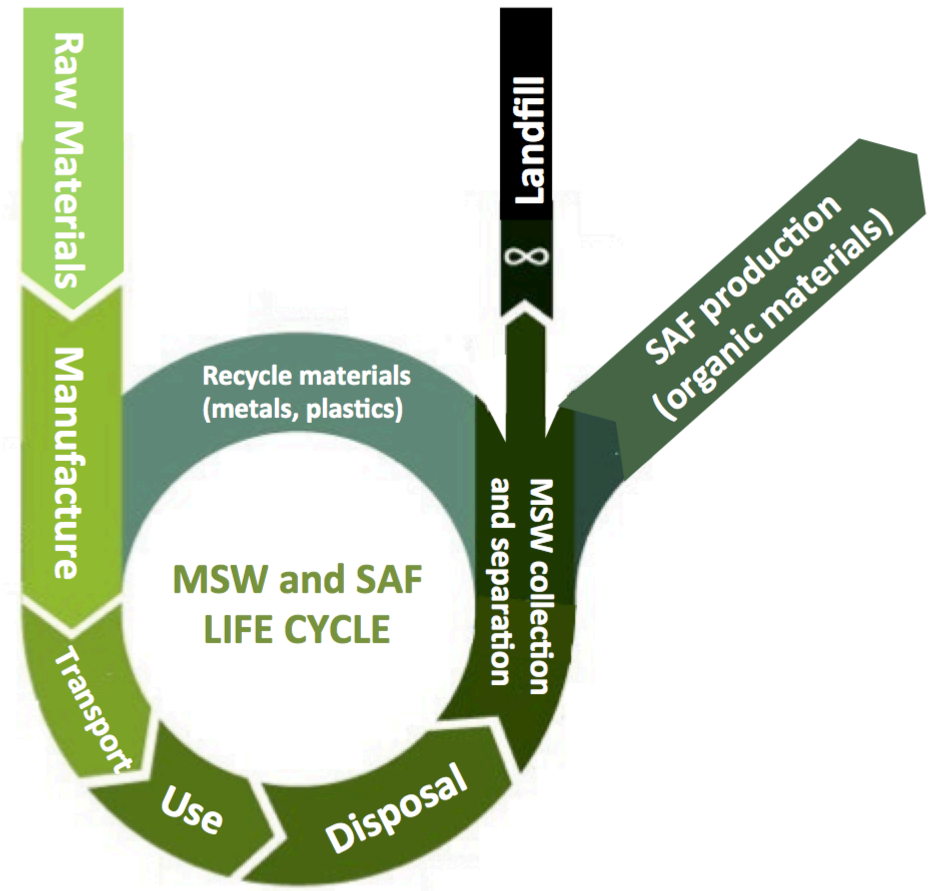

FIGURE 3-5
MSW lifecycle as a SAF feedstock
(Source: adapted from southwest-environmental.co.uk)

The use of MSW as a source of energy is possible due to its high content in biomass, in natura or processed. Organic materials such as paper and paperboard and food residues represents a major fraction of MSW, ranging from 59 per cent in high income countries to 69 per cent in low income countries (World Bank, 2013). The MSW availability depends also on the income level; the annual MSW generation is 0.21 ton/year/capita in Southern and Central Asia and 0.65 ton/year/capita in North America (IPCC, 2006).

When evaluating prospects of using residues and wastes as feedstock for aviation biofuels production, it is necessary to consider also the costs of opportunity, that sometimes occur due to alternative use of these materials in other processes that may be more economically attractive or simpler to implement in a reliable way. For instance, composting systems to produce organic fertilizers, or the direct use of the organic fraction of MSW as a fuel, known as Refuse Derived Fuel (RDF) in boilers and furnaces, should be considered. Anyway, the large availability of these residues and wastes and the actual need of manage then properly make them a feedstock worth consideration.

4.0 HOW TO PRODUCE SAF

A fuel "production pathway" contains a sequence of stages, starting with feedstock production, followed by its pre-treatment in order to achieve the requirements of the conversion processes, and finally the conversion processes to produce aviation fuel (**Figure 4-1**). The feasibility of fuel production is strongly linked to the configuration of the production pathway, which includes the transport of products through the stages.

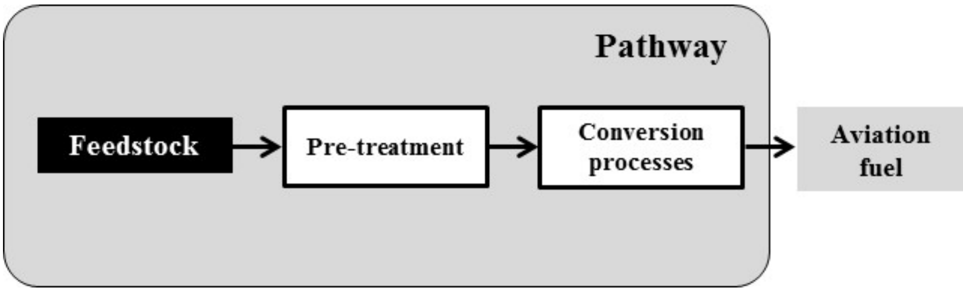

FIGURE 4-1
SAF pathway concept
(Source: author)

This chapter introduces the main feedstocks and conversion processes that have been studied and, in some cases, have already been approved to produce SAF. As of December 2018, ASTM have certified alternative fuels from six conversion processes under the standard ASTM D7566: Synthesized Paraffinic Kerosene (SPK) from the Fischer-Tropsch process (FT-SPK); SPK from Hydroprocessed Esters and Fatty Acids process (HEFA-SPK) Synthetic Isoparaffins (SIP) from Hydroprocessed Fermented Sugars (HFS-SIP); SPK from the Alcohol-to-Jet process (ATJ-SPK), FT-SPK with increased aromatic content, the so-called synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources (FT-SPK/A) and co-processing. Four types of feedstocks can be used on these conversion processes: oil, sugar, starch, and lignocelluosic feedstocks (**Figure 4-2**).

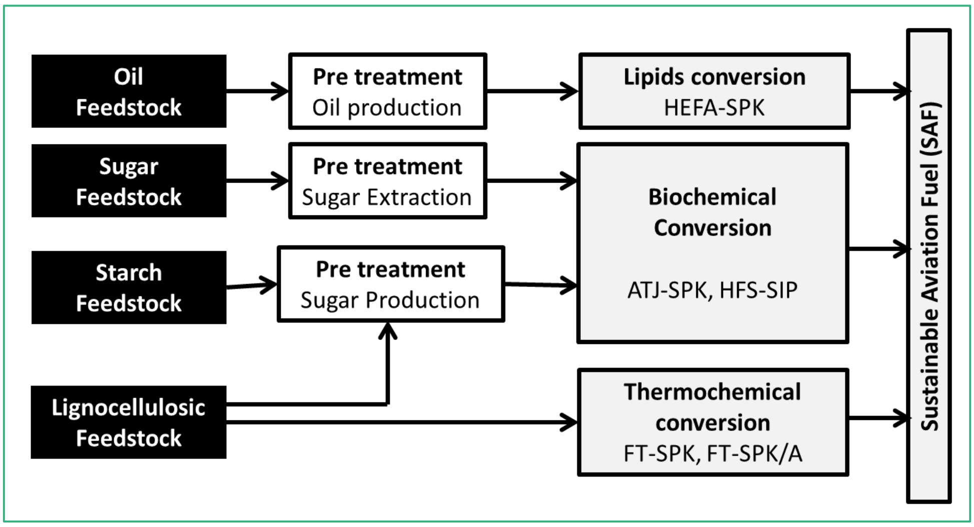

FIGURE 4-2
General view of SAF pathways
(Source: author)

It is important to note that only alternative fuels that are certified for both quality and sustainability should be considered for widespread use. This chapter presents the production pathways already certified for use in commercial aviation, as well as the sustainability indicators (environmental and social aspects) of the main pathways (certified and in development), and the schemes for sustainability certification relevant to aviation fuels. Only pathways certified for quality and sustainability should be considered for supplying drop-in SAF.

4.1. APPROVED CONVERSION PROCESSES

The operating conditions in the aviation sector, with fuel supply in different States and high safety requirements, demand strict quality assurance of fuel, based on globally accepted standards.

Complementary to its general standard for aviation turbine fuels (ASTM D1655), in 2009 ASTM introduced a standard for alternative drop-in aviation fuels, ASTM D7566, related to the specification for aviation turbine fuel containing synthetized hydrocarbons (ASTM, 2016). Every time a new process is certified, this standard is amended, incorporating a new annex.

As of December 2018, there were six conversion processes approved for SAF production under the standard ASTM D7566 and ASTM 1655, which specify blending limits for these fuels (as shown in **Table 4-1**). The first certified conversion process was announced in 2009, the FT-SPK, derived from coal, natural gas or biomass. Its current restriction blend is 50 per cent (in volume terms).

In 2011, the HEFA-SPK process was approved, with the same current restriction blend (ASTM, 2011). The HFS-SIP process, restricted to 10 per cent by blend, was approved in 2014. In 2016, the ATJ-SPK process from isobutanol was certified, being eligible to be used up to 30 per cent by blend (Gevo, 2016). In 2018, ASTM updated the maximum blend percentage to 50 per cent, and added the possibility for co-processing fats, oils, and greases from petroleum refining (ICAO GFAAF, 2018).

Furthermore, FT-SPK with increased aromatic content (FT-SPK/A) has been certified. Even though the certification allows for a blending with conventional Jet A or Jet A-1 fuel up to 50 per cent by volume, the higher aromatic content may be a route to 100 per cent SAF.

TABLE 4-1
Conversion processes approved by ASTM International
(Source: ICAO GFAAF, 2018)

	Annex	Conversion Process	Abbreviation	Possible Feedstocks	Blending ratio by Volume	Commercia-lization Proposals
ASTM D7566	1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT-SPK	Coal, natural gas, biomass	50%	Fulcrum Bioenergy, Red Rock Biofuels, SG Preston, Kaidi, Sasol, Shell, Syntroleum
	2	Synthesized paraffinic kerosene produced from hydroprocessed esters and fatty acids	HEFA-SPK	Bio-oils, animal fat, recycled oils	50%	World Energy, Honeywell UOP, Neste Oil, Dynamic Fuels, EERC
	3	Synthesized iso-paraffins produced from hydroprocessed fermented sugars	SIP-HFS	Biomass used for sugar production	10%	Amyris, Total
	4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	SPK/A	Coal, natural gas, biomass	50%	Sasol
	5	Alcohol-to-jet synthetic paraffinic kerosene	ATJ-SPK	Biomass from ethanol or isobutanol production	50%	Gevo, Cobalt, Honeywell UOP, Lanzatech, Swedish Biofuels, Byogy
ASTM D1655	Annex	Co-processing		Fats, oils, and greases (FOG) from petroleum refining	5%	

4.2. FEEDSTOCK OPTIONS

Feedstock production is the first step in producing SAF. Feedstock can be produced from a variety of sources including agriculture, forestry, organic residues, or other waste materials.

4.2.1. SUGAR/STARCH FEEDSTOCKS

Sugar or starch-bearing plants provide fermentable feedstock, easily transformed into alcohol (such as ethanol or butanol), from which SAF can be obtained. In some processes, SAF can be directly produced from sugars.

In the case of sugar-bearing plants such as sugarcane, sugar beet, and sorghum, the fermentable sugars are readily available on the feedstock and are obtained by mechanical processes such as milling or diffusion. The highest production of sugar-bearing plants results from sugarcane, a semi-perennial crop. Brazil is the major global producer, followed by India and China (see **Table 4-2**). Sugarcane is generally used to produce sugar and ethanol. The sugarcane bagasse (a by-product after the juice extraction) is also used as fuel in boilers for electricity generation.

In the case of starch-bearing plants such as maize, wheat and cassava, the sugars are not readily available but can be obtained from the starch through chemical reactions. Maize is currently the mostly produced starch-bearing plant for fuel production. Its production is concentrated in North America, with the United States being the main producer.

Brazil and the United States produce over 85 per cent of the world's ethanol, using sugars from sugarcane and maize, respectively. Global ethanol production was 98.3 billion litres in 2015 (REN21, 2016). The use of ethanol to produce SAF is one of the pathways discussed in this chapter.

The fuel producer Amyris is currently producing fuel from sugarcane. Once a week, from October 2014 to October 2015, Air France used a 10 per cent blend of this fuel for operations between Toulouse and Paris. Then in 2016, a two-year agreement was signed stating that a 10 per cent blend of Amyris/Total sugarcane derived fuel would be used for all deliveries of Airbus A350 aircraft to Cathay Pacific over the next two years.

4.2.2. OIL FEEDSTOCKS

Vegetable oils or oil residues can be transformed into SAF with the HEFA process, a well-developed, widely used process which relies on hydrogen addition.

The main oil-bearing plants in terms of the amount of vegetable oil globally produced are palm oil and soybean. Both are currently used largely for food and biodiesel production. Around 30 billion litres of biodiesel were produced in 2015. The United States and Brazil are the major producers, 4.8 and 3.9 billion litres, respectively (REN21, 2016), using soybean as the main feedstock.

The production of palm oil is relevant in tropical Asian States such as Indonesia and Malaysia, which accounted for 82 per cent of global production in 2013 (see Table 4-1), with an increasing participation in the biodiesel market. Besides its higher productivity, the palm oil crop is also perennial. The plant typically requires five years after cultivation to start commercial production, which extends about 20 years. Due to this advantage, other palm species are being evaluated for SAF production, such as babassu (*Attalea speciosa*) and macauba (*Acrocomia aculeata*), but the information available about these crops is still limited (Capdeville, 2016).

On the other hand, annual oil crops such as soybean, rapeseed and sunflower are cultivated every year, imposing higher costs and environmental impacts.

Innovative plants such as jatropha (*Jatropha curcas*) and camelina (*Camelina sativa*) have been identified as possible alternative sources of vegetable oil for SAF production on account of their non-edible character, potential high oil yields (see **Table 4-2**) and possible cultivation in marginal lands (Cortez and others, 2014; Chuck, 2016). However, these crops still do not have the same maturity and diffusion of traditional oil crops, and therefore require more research to confirm their potential.

Kant and Wu (2011) reported the disappointing results of jatropha crops cultivated in some Asian States for biodiesel production. They said that technical limitations must be overcome before it is more widely cultivated. Camelina originated in Northern Europe and is now being experimented with across the United States and Canada, but also without remarkable results to date.

Many initiatives have already used jatropha and camelina as feedstock for aviation fuel production. In 2017, Egypt's National Research Centre used treated wastewater to successfully cultivate jatropha plants in a desert environment. The research team extracted the plant oils to produce fuel, however they found that the high cost was inhibitive to commercial-scale development in Egypt. The first commercial flight to use alternative fuel in Colombia was conducted by LAN Colombia in 2013, using a 50 per cent blend of camelina-based fuel.

The United Arab Emirates have established an aviation fuel supply chain derived from halophoytes, plants that can be grown on arid land using salt water. While this supply chain has not yet reached a commercial scale, Etihad Airways performed a demonstration flight using this fuel in 2016. The partners involved in this project, hosted by Masdar's Sustainable Bioenergy Research Consortium, hope to perform a commercial flight in 2018.

An additional non-food crop that can be used for the development of SAF is modified tobacco. South African Airways conducted Africa's first flight on alternative fuel in 2016. This flight was a result of the Project Solaris partnership, which brought together a diverse group of stakeholders to establish a supply chain for locally produced feedstock for fuel production within South Africa.

Algal crops are also a potential source of vegetable oil for SAF production. They have the advantage of a high oil yield in relation to other oil-bearing plants, with possible accumulation of over 60 per cent lipids by dry weight. Moreover, they do not pose competition for land use. However, control of algae cultivation and its costs are still obstacles to be overcome, demanding research and development to reach commercial production (Ullah and others, 2014).

TABLE 4-2
Feedstock production in 2013
(Source: FAO, 2015)

Feedstock	Agricultural yield (ton/ha)	Global production (million tons)	Share of global production (percentage)
Sugar/Starch-bearing plants			
Sugarcane	70.7 (sugar content: 12-16%)	1 877.1	Brazil (39), India (18), China (7)
Maize	5.5 (starch content: 62%)	1 016.7	United States (35), China (21), Brazil (8)
Oil-bearing plants			
Palm	15.7 Oil content: 21%–37%	282.2	Indonesia (45), Malaysia (37), Thailand (5)
Soybean	2.5 Oil content: 18%–21%	276.4	USA (32), Brazil (30), Argentina (18)
Camelina[(1)]	Up to 2.2 (seed yield) Oil content: 30%–40%	-	-
Jatropha[(2)]	3.5 (seed yield) Oil content: 27%–40%	-	-

[(1)] Data from USDA (2016). [(2)] Data from Chuck (2016).

Included in the group of oil feedstocks are used cooking oil (UCO) and residual animal fats from the meat-processing industry such as tallow and yellow grease. The interest to use them, generally, is motivated by low costs and the possibility of reducing the environmental impacts associated with their disposal.

It is estimated that 25 million tonnes of UCO and 5 million tonnes of animal fats are produced yearly around the world (Chuck, 2016; Yakoob and others, 2013), which, as a whole, is equivalent to 10 per cent of current world aviation fuel production (IEA, 2016). Nevertheless, the feasibility of using this potential for SAF production has to be well assessed considering the quality of these wastes. The composition of UCO is different from virgin oils due to the frying process, which significantly affects the yields of the fuel production processes. In this case, pre-treatment processes are required. The logistics to collect UCO can also have a high impact on the final production cost.

In 2017, Air Canada, as a part of Canada's Civil Aviation Alternate Fuel Contrail and Emissions Research project (CAAFCER), conducted a series of five test flights using fuels derived from used cooking oil. This fuel was produced by AltAir Fuels and supplied by SkyNRG. This study measured the impact of alternative fuel blends on contrail formation. At the time this report was published, the results of the CAAFCER study were not yet available.

4.2.3. LIGNOCELLULOSIC FEEDSTOCKS

When the sustainability of biofuels is discussed, concerns about food security are raised. In this context, abundant non-food lignocellulosic material [10] is an interesting alternative. From this feedstock, SAF can be obtained in two ways: thermal processes, employing high temperature reactions; and biochemical conversion.

Wood and wood residues are examples of lignocellulosic feedstock (see **Table 4-3**). This feedstock has the potential to be used for SAF production through advanced processes. This feedstock can be obtained directly from short rotation forestry (for instance adopting species of eucalyptus, poplar, willow and other) or as woody residues or by-products from wood processing industries, such as sawdust. Additionally, other sources of lignocellulosic material have been proposed such as perennial grasses (miscanthus or switchgrass). In general, these biomasses are characterized by their relatively high yield, low costs, and potential to grow on marginal lands.

TABLE 4-3
Lignocellulosic biomass production (Source: Adapted from Chuck, 2016)

Crop	Biomass yield (ton/ha/year)	Suitable geographic location
Willow	5–11	Temperate
Poplar	2–10	Temperate
Eucalyptus	10–12	Temperate, subtropical, tropical
Miscanthus	5–43	Temperate
Switchgrass	5–19	Temperate

In turn, agricultural residues refer to the biomass of the crop such as leaves, straw, bagasse, stalks and husks. Their properties and composition are diversified, but are typically constituted by lignocellulose. Despite their occasional use in agriculture, their potential to produce fuels has been considered.

To illustrate, according to IEA (2010), 10 to 25 per cent of the residues could be used sustainably without competing with traditional uses. This amount would provide 4 to 10 per cent of global transport fuel demand in 2030 if it was used to produce ethanol or diesel, as assumed in this report.

Nordic States have been particularly active in establishing wood-waste supply chains for developing aviation fuels. The Nordic Initiative for Sustainable Aviation (NISA), established in 2013, has brought together stakeholders from airlines, airports, governments, fuel producers, and other organizations in order to support research and to engage customers in contributing to the purchase of alternative fuel. These stakeholders hope that by strengthening cooperation throughout the supply chain and across the region that they will be able to accelerate the commercial-scale deployment of SAF.

Finally, as introduced in the previous chapter, municipal solid waste can also be used to produce aviation fuels from its organic or lignocellulosic share, after removing the recyclable materials (glass, plastics and metals). The heterogeneous composition of these wastes can be a constraint to the feasibility of this pathway (Cortez and others, 2014).

[10] "Lignocellulose" is a general term to define the major components of vegetal biomass. They are complex carbohydrate molecules (cellulose and hemicellulose) bonded to lignin. The amount of the cellulose, hemicellulose and lignin varies among the different types and species of vegetable biomass.

Anyway, projects are maturing and some of them are already commissioning facilities. Created in 2007, Fulcrum BioEnergy started in October 2017 the operation of its first commercial-scale plant, in Reno, Nevada, designed to process annually 200,000 tons of MSW to make 42 million liters of aviation biofuel. In November 2017 this company launched the project of a second plant in Illinois, aiming to supply O'Hare Airport in Chicago and informed that is planning to implement other eight plants in the forthcoming years (Biofuels Digest, 2017), claiming that its costs will be less than USD 0.26 per liter (IRENA, 2017). Fulcrum has established partnerships with Cathay Pacific and United Airlines as off-taker of its product (Fulcrum Bioenergy, 2017).

4.3. PROCESSING ROUTES

Different processing routes can be adopted to convert feedstocks into a liquid drop-in SAF. Several combinations of feedstocks and conversion processes have been proposed and the product of some of them has been certified to be used as a drop-in fuel. These several possible processing routes are detailed in **Figure 4-3.** The feedstocks are shown in the black boxes on the left, the intermediary products are presented in the grey boxes. Between the feedstocks and the final product (SAF), it is possible to observe the processes, which are briefly described as follows:

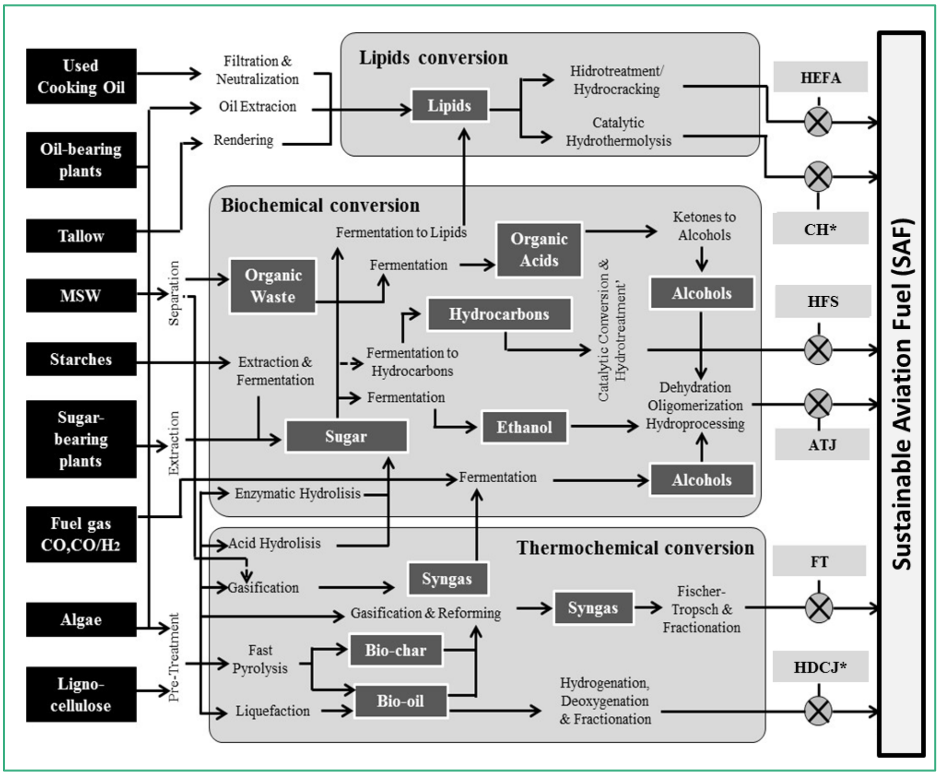

FIGURE 4-3
Several possible processing routes to produce SAF (Source: Adapted from Boeing and others, 2013)

*CH: Catalytic hydrothermolysis – not yet approved
HDCJ: Hydrotreated depolymerized cellulosic to jet – not yet approved

4.3.1 LIPIDS CONVERSION

Lipids are the main component of vegetable oils and oleaginous residues. Hydrotreating or hydroprocessing lipids can produce hydroprocessed esters and fatty acids (HEFA)[11] that have similar characteristics to conventional fuels.

The HEFA process is currently the best-known process for producing SAF and it is similar to refining petroleum. It consists of reacting vegetable oils in the presence of hydrogen and catalysts[12] to produce aviation fuel, naphtha, diesel and gasoline.
Hydroprocessing technologies using vegetable and waste oils represent the only conversion pathways that are ready for large-scale deployment, according to Chuck (2016) and other studies. However, some challenges to this conversion process must be overcome in order for it to become a competitive option:

a) High hydrogen requirement: important questions to consider are related to the hydrogen supply – where and how to obtain it, and how much it will cost.
b) High heat generation from the reaction, which requires rigorous process control.
c) Continuous feed supply for large production, which suggests a well-developed supply chain. The HEFA process is highly dependent on the feedstock costs, which can represent up to 70 per cent of the final cost of the fuel (Cortez and others, 2014). Therefore, the cost of feedstock production and logistics must be well evaluated.
d) Pre-treatment of the feedstock because of the typical impurities that must be removed from the vegetable oil to maintain high yields in the process. The feasibility of using UCO as feedstock must be evaluated considering possible low quality of the oil.

4.3.2 THERMOCHEMICAL CONVERSION

In this group of conversion processes, one possibility is gasification of the solid biomass at elevated temperatures to obtain a mixture of gases, mostly carbon monoxide (CO) and hydrogen (H_2), which is called “synthesis gas” or “syngas”. After purification, the syngas is synthesized into a mixture of liquids and gases containing hydrocarbon chains with different sizes, in a catalytic reaction known as the Fischer-Tropsch process (FT).[13] Depending on the temperature of the process, the catalysts used and the post-refining steps (e.g., when the components of the mixture are separated), it is possible to obtain products with similar characteristics to aviation fuel.

Other thermochemical pathways have been studied but did not get approval by ASTM to the moment, such as HDCJ: Hydrotreated depolymerized cellulosic to jet (also known as pyrolysis), which is a thermal decomposition of biomass in an atmosphere without oxygen, producing a gaseous, a liquid (bio-oil) and a solid (bio-char) share. The range of the temperatures during the process and the time of the reactions can induce the major formation of one share. In fast pyrolysis, the bio-oil production is maximized and can be further upgraded using hydrotreating processes, from which SAF is obtained.

Similarly, hydrothermal liquefaction (HTL) of biomass can produce bio-oil, with some different characteristics to those of the bio-oil from pyrolysis. Some studies about HTL of algae have been reported, but challenges to its commercial production must be overcome (Biddy and others, 2013).

[11] Other names used: hydroprocessed renewable jet (HRJ) or hydrogenated vegetable oil (HVO).
[12] A catalyst is a substance that speeds up a chemical reaction, but is not consumed by the reaction.
[13] The FT process was invented in 1925 and used in Germany during the Second World War to make liquid fuels from coal. Today, this process is used in some companies to produce gasoline, diesel and jet fuel from natural gas.

4.3.3 BIOCHEMICAL CONVERSION

Two routes are included in the biochemical conversion category. In the alcohol-to-jet (ATJ) process, SAF is produced from alcohol molecules, such as ethanol or isobutanol, made from sugar/starch-bearing plants, lignocellulosic materials or innovative processes.[14] ATJ is composed of processes such as dehydration (removal of water), oligomerization (conversion of small molecules in more complex ones) and hydrogenation (addition of hydrogen). Technical improvements in the oligomerization steps and the developments of more selective catalysts are aspects to be considered when aiming at a competitive production scale.

The HFS-SIP process (Synthetic Iso-Paraffins produced from hydroprocessed esters and fatty acids, formerly known as DSHC: Direct fermentation of sugars to hydrocarbons) employs genetically modified microorganisms to convert sugar into hydrocarbons or lipids. In one of these cases, these microorganisms, instead of producing ethanol, produce substances such as farnesene (synthetic iso-paraffin (SIP)) that can be converted into a product with as good characteristics as aviation fuel. In this specific case, the low feasibility linked to low conversion yields is an important constraint (Cortez and others, 2014; Moreira and others, 2014).

4.4. SUSTAINABILITY OF AVIATION FUELS

This section discusses the sustainability of aviation fuels, including the main environmental, economic and social aspects of the production pathways for SAF, covering the routes already certified and those still in research and development. Although preliminary, this assessment is very important to rank SAF.

4.4.1. ENVIRONMENTAL ISSUES

Life Cycle Assessment (LCA) (see Annex A), has been used to assess the agricultural and conversion stages of the production pathway. As reported by Capaz and Seabra (2016), few LCA studies on SAF have been developed to date compared with other products. This study registered 19 scientific publications from which 17 addressed GHG emissions, a crucial indicator associated with the climate change mitigation impact of a given fuel. The results are summarized in **Figure 4-4**, comparing the specific GHG emissions for the processes. As a function of different methodological choices, some studies presented more than one result for a particular pathway. In these cases, methodological considerations also explained the range of results for each pathway.

[14] An innovative path for jet fuel production has been proposed by LanzaTech (www.lanzatech.com/): The waste gas from steel mills is fermented to ethanol by bioengineered microbes, which is destined to the ATJ process to obtain jet fuel.

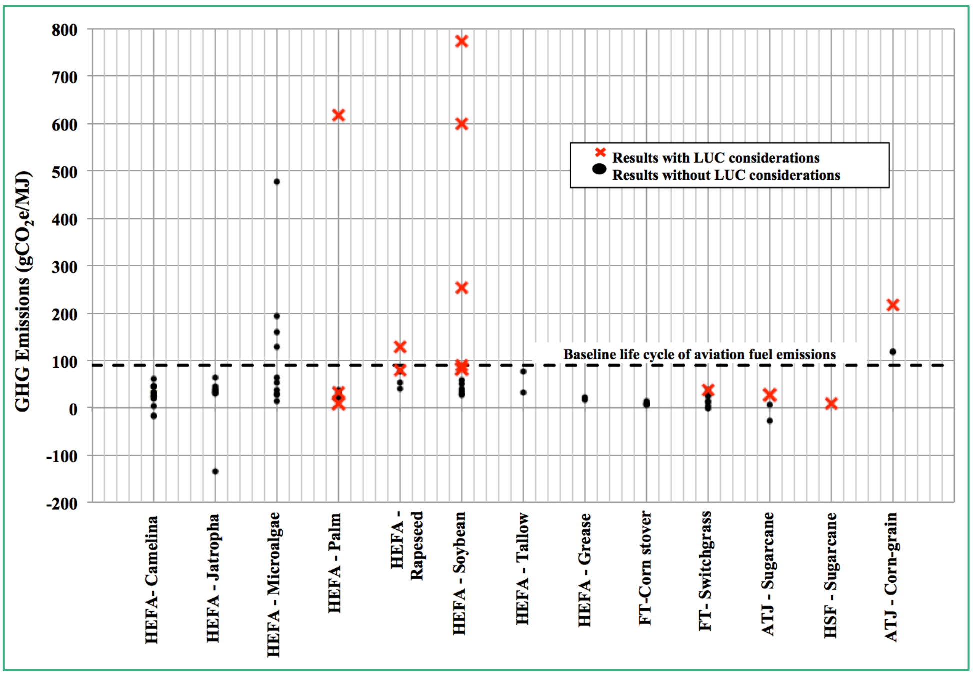

FIGURE 4-4
Main results from LCA studies for aviation fuels. (Source: Adapted from Capaz and Seabra, 2016)

In terms of GHG emissions, almost all pathways performed better than the aviation fuel baseline along its life cycle (without land use change (LUC) effects), with the exception of HEFA from microalgae and ATJ by isobutanol from corn grains[15]. The accounting of avoided emissions from by-product use can justify the negative values and the low emissions from the SAF pathway. For instance, when producing SAF by a biochemical conversion (BC) process using sugarcane as feedstock, the associated use of bagasse to generate electricity in sugarcane mills displaces conventional power generation and brings an additional mitigation effect.

HEFA from oil-bearing plants has been the most studied pathway. For this fuel, the analyses showed that the environmental performance of the plants strongly depends on the agricultural stage and where the crops were cultivated. SAF from jatropha and microalgae featured a wide range of variation, in part due to methodological differences and cultivation conditions.

The ICAO CAEP is currently developing an unified methodology to assess SAF life cycle emissions, which should help to mitigate the effect of methodological differences in the SAF LCA values.

On the other hand, the ranges for HEFA from soybean and camelina were narrower, without the consideration of LUC effects. In turn, HEFA from palm oil proved to be an attractive route too. The thermochemical conversion was analysed for FT processes. The biochemical conversion considered the ATJ process for corn grains and the HFS process for sugarcane in Brazil.

The results in Figure 4-4 also show that LUC effects can present strong implications for overall LCA performance. For HEFA from palm and soybean, the results show that LUC effects can negate all the benefits of the fuel in terms of mitigating GHG emissions. However, for the SIP-HFS with sugarcane in Brazil, the mitigation benefit would be verified even considering the emissions from the indirect DSHC, according to this study (Chuck, 2016)

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[15] LUC or Land Use Change concepts are presented in Annex A: Sustainability concepts – Life Cycle Assessment and Land Use Changes.

This evaluation of the environmental benefits in producing and using SAF is still based on a limited number of studies and will surely be improved in the coming years. Nevertheless, the impact of SAF on mitigating GHG emissions can be very positive, but depends on the production pathway. In this regard, the low maturity level of some technologies and production scale has to be considered.

4.4.2. SOCIOECONOMIC ISSUES

Specific studies on the social aspects of alternative fuel production have been carried out, such as the one developed by Gilio and Moraes (2016), using socioeconomic indicators which may be relevant for SAF. Generally, in bioenergetic systems, the social impacts are more relevant during the agricultural stage, involving labour conditions, labour rights, food competition, and others. Employment generation and salaries along the supply chain must also be considered.

4.5. SUSTAINABILITY CERTIFICATION SCHEMES

As bioenergy policies emerged in the mid-2000s, environmental groups pressured governments to ensure that mandates produced environmental and social gains over the business-as-usual baseline (Endres, 2011). Thus, sustainability certification for bioenergy arose in part due to regulatory requirements, such as the 2009 European Union Renewable Energy Directive (RED) and the United States Renewable Fuel Standard (RFS).

Yet, even before the advent of SAF sustainability certification, sustainability certification schemes (SCS) had been developed for a wide range of products, addressing good resource management and responsible entrepreneurship to gain market access, developing a green business profile, obtaining price premiums, and improving supply chain efficiency (Pelkmans and others, 2013). These are generally “performance-based” schemes aiming to achieve a certain standard (versus “practice-based”),” and include a number of principles, criteria and indicators to verify compliance.

With regard to biomass for energy, SCS have become available for almost all feedstocks and products covering parts of, or the complete, supply chain, from production and processing to trade of biomass and alternative fuels. Some of these SCS exist on a national level, and others are internationally recognized and applicable. As these SCS have been developed with different interests and priorities (governments, NGOs, companies), the scope, approach and complexity vary from scheme to scheme (Scarlat and Dallemand, 2011; Souza and others, 2015; van Dam and others, 2010).

Table 4-4 presents a comparison of the objectives of the initiatives covered by the Bioenergy and Food Security (BEFS) project within FAO. These initiatives include regulatory frameworks, voluntary standards/certification schemes and scorecards. Other comparative studies can be found in the literature, such as in Potts and others (2014), which presented a comprehensive evaluation and comparison of the most important voluntary schemes active in the agriculture, forestry and biofuels sectors with global reach.

A recent trend among some of these initiatives has been to expand into broader SCS (Endres and others, 2015). For example, the Roundtable for Sustainable Biofuels, which is already actively engaging with the aviation industry, was transformed into the Roundtable on Sustainable Biomaterials (RSB), and the International Sustainability & Carbon Certification (ISCC) now has an ISCC+ certification to cover all end-uses.

TABLE 4-4
Sustainability aspects/issues addressed under the initiatives reviewed in BEFS (Bioenergy and Food Security) (Source: FAO, 2011)

	REGULATORY FRAMEWORKS	Biofuels Life Cycle Assessment Ordinance (BLCAO) - Swiss Confederation	Biomass Sustainability Order (BioNachV) - Germany	EU Renewable Energy Directive (RED)	Low Carbon Fuel Standard (LCFS) - California (USA)	Renewable Fuel Standard (RFS2) – USA	Renewable Transport Fuel Obligation (RTFO) - UK	Social Fuel Seal – Brazil	Testing Framework for Sustainable Biomass ("Cramer Criteria") - The Netherlands	**VOLUNTARY STANDARDS/CERTIFICATION SCHEMES**	Basel Criteria for Responsible Soy Production	Bonsucro (BSI)	Council on Sustainable Biomass Production (CSBP)	Forest Stewardship Council (FSC)	Global Bioenergy Partnership (GBEP)	Green Gold Label 2: Agriculture Source Criteria (GGLS2)	International Sustainability & Carbon Certification (ISCC)	Nordic Ecolabelling of Fuels	Roundtable on Sustainable Soy (RTRS)	Roundtable on Sustainable Biofuels (RSB)	Roundtable on Sustainable Palm Oil (RSPO)	SEKAB Verified Sustainable Ethanol Initiative	Sustainable Biodiesel Alliance (SBA)	**SCORECARDS**	IDB Biofuels Sustainability Scorecard	WB/WWF Biofuels Environmental Sustainability Scorecard
1. ENVIRONMENTAL																										
1.1 Land-use changes (both direct and indirect)		√		√		√			√			√	√	√	√	√	√	√	√		√	√	√		√	√
1.2 Biodiversity and ecosystem services		√	√	√		√	√	√	√		√	√	√	√	√	√	√	√	√	√	√	√	√		√	√
1.3 Productive capacity of land		√	√	√		√	√		√		√	√	√	√	√	√	√		√	√	√	√	√		√	√
1.4 Crop management and agrochemical use		√	√				√		√		√	√	√	√	√	√	√		√	√	√		√		√	√
1.5 Water availability and quality		√	√	√	√		√		√		√	√	√	√	√	√	√		√	√	√	√	√		√	√
1.6 GHG emissions		√	√	√	√	√	√		√			√	√		√		√	√	√	√	√	√	√			√
1.7 Air quality		√	√	√		√	√		√		√	√			√		√	√	√	√	√		√		√	√
1.8 Waste management		√		√		√	√		√		√	√	√	√		√	√		√	√	√		√		√	√
1.9 Environmental sustainability (cross-cutting)		√		√				√	√		√	√	√	√		√	√		√	√	√	√	√		√	
2. SOCIO-ECONOMIC																										
2.1 Land tenure/access and displacement				√			√		√		√	√		√	√	√	√		√	√	√				√	√
2.2 Rural and social development							√	√	√		√	√		√	√	√	√	√	√	√	√	√	√		√	
2.3 Access to water and other natural resources							√				√	√	√	√			√			√					√	
2.4 Employment, wages and labour conditions				√			√		√		√	√	√	√	√		√	√	√	√	√	√	√		√	√
2.5 Human health and safety					√		√		√		√	√	√	√	√		√	√	√	√	√		√		√	√
2.6 Energy security and access									√			√			√				√		√		√		√	
2.7 Good management practices and continuous improvement					√	√			√		√	√	√	√	√	√	√	√	√	√	√		√		√	√
2.8 Social sustainability (cross-cutting)				√				√	√		√	√		√	√		√	√	√		√		√		√	
3. GOVERNANCE																										
3.1 Compliance		√	√	√	√	√	√	√	√		√	√	√	√			√	√	√	√	√	√	√		√	√
3.2 Participation and transparency				√	√		√	√	√		√	√	√	√		√	√	√	√	√	√		√		√	√
4. FOOD SECURITY																										
4.1 Food availability				√				√	√						√	√	√	√		√			√		√	√
4.2 Food access				√				√	√					√	√		√		√	√					√	√
4.3 Food utilization							√	√	√		√	√	√		√		√		√	√	√				√	
4.4 Food stability								√							√					√					√	
4.5 Food security (cross-cutting)								√							√					√						

Compared with more general agricultural certification systems, alternative fuel-specific standards are particularly required to address GHG emissions because of the regulatory requirements for life cycle emissions mitigation in comparison to their petroleum counterparts. Additionally, other principles frequently shared among the SCS for the certification of biomass, alternative fuels, and bioenergy, including those considered by the International Air Transport Association (IATA, 2015) for SAF, are as follows (Pelkmans and others, 2013):

- **Sustainable production:** Raw materials for biofuels may not come from land that has been converted (e.g. primary forest, protected area, highly biodiverse grassland, areas with high stocks of carbon, or peatlands) and must come from legal sources. Raw materials in the European Union (EU) must be cultivated in accordance with the Common Agricultural Policy or correspond to criteria or guidelines for Sustainable Forest Management.
- **Other environmental impacts:** The production, conversion and logistics may not lead to negative impacts on soil, water and air quality.
- **Efficient energy conversion:** Bioenergy chains should strive for maximum energy efficiency in feedstock production, conversion and logistics.
- **Protection of biodiversity:** The production of biomass may not negatively affect biodiversity.

- **Contribute to local prosperity and welfare:** Bioenergy chains should contribute towards social well-being for employees and local population.

Despite the overwhelming proliferation of different standards and certification approaches in recent years, there is still no global definition of how the sustainability concept should be translated into practice, i.e. how to measure sustainability and which criteria and indicators should be included.

Examples of other initiatives that try to reach consensus at a high level are the standards EN 16214 and ISO 13065. ISO 13065:2015, for instance, specifies principles, criteria and indicators for the bioenergy supply chain, which can be applied to the whole supply chain as well as to parts of a single process in the supply chain. This standard, however, does not establish thresholds or limits.

Even though these SCS facilitate comparability of various bioenergy processes or products (or bioenergy and other energy options), methodological improvements can be introduced. Furthermore, impacts on a meta- or macro level, such as on water basins or biodiversity in a larger region, the indirect land use change effects and landscape-level carbon balances, cannot be addressed through certification alone but need other forms of governance or legislation (Pelkmans and others, 2013).

Some SCS, notably RSB, have attempted to address the issue of indirect effects by: (a) measures to increase yield; (b) use of by-products and residues to increase system efficiency; and (c) reduction of land requirements by utilizing feedstocks from degraded lands, developing biomass (e.g. algae) that can be grown on non-arable land, and feedstocks from residues (with sustainable removal levels) and end-of-life products (without alternative uses).

Other proposals considered by RSB included using an indirect LUC factor in GHG calculations based on volume of production or area of land used, requiring certified producers to help others increase yields, and contribute to indirect impacts funds to facilitate investment in agricultural productivity gains in developing States (Endres and others, 2015).

In January 2019, World Energy (then AltAir Fuels) became the first aviation fuel producer to receive a sustainability certification[16]. They achieved this certification by applying the RSB Global Standard to guide their fuel production processes. World Energy produces fuel from waste feedstocks, which help them to achieve a 60 per cent reduction in emissions.

On a multilateral level, the GBEP also created a framework of 24 sustainability indicators to guide and measure the government programmes and policies in the development of biomass and bioenergy. Although this is a positive action towards harmonization, there is still a long way to go, especially as scientific consensus has not yet been reached.

[16] https://rsb.org/2018/01/29/altair-rsb-certification-biofuel-refinery/

Finally, it is important to mention that at the 39th session of the ICAO Assembly (2016), the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) was created, with the objective of addressing any annual increase in total CO_2 emissions from international civil aviation above the 2020 levels, “taking into account special circumstances and respective capabilities” (ICAO A39-2, 2016). CORSIA will include the possibility to reduce emissions from international aviation through the use of CEF. In order for aviation fuels to be considered under the CORSIA, the fuels will need to meet ICAO’s sustainability criteria. Finding a common language on “what is sustainable and how it has to be verified/documented” remains a challenge that is being addressed by ICAO in the framework of CORSIA. The CAEP AFTF has specifically focused on the development of an "umbrella standard" in which, existing SCS that meet the requirement detailed in the ICAO document entitled "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes" can be approved for inclusion in the ICAO document entitled "CORSIA Approved Sustainability Certification Schemes". These CORSIA Approved SCS can then approve fuels as CEF, as described in Section 1.3. The Work of ICAO on a Global Market-Based Measure.

5.0 HOW TO PROMOTE THE USE OF SAF

This chapter addresses practical and operational considerations related to the development and deployment of SAF that are associated with governmental action; specifically, how to improve their economic competitiveness and how to ensure an appropriate system for transport, distribution and storage of these fuels. Both aspects are crucial to ensure a robust market for SAF. These aspects can be also considered by a State interested in promoting the use of imported fuels while national production is being developed. Finally, some guidelines are presented on setting a national programme for promoting SAF.

5.1. ECONOMIC CONSIDERATIONS

From an economic perspective, an essential aspect for sustainability, **Table 5-1** presents some results from detailed techno-economic analysis conducted on alternative fuels production. Generally, the production of alternative fuel is more expensive, but the conversion of lipids (HEFA) has been reported as the best technology available on a commercial-scale, with lower investment costs than FT or ATJ processes, and very independent of feedstock costs. As a comparison, the average price of United States Gulf Coast Kerosene was USD 0.59/L between January 2013 and April 2016, when the average oil (WTI) price was USD 76.8/bbl (EIA, 2016).

TABLE 5-1
Some results from the techno-economic analysis of alternative fuels (Source: author)

Conversion process	Feedstock	Cost (feedstock contribution)	Reference
HEFA	Camelina oil	$0.80/L	(Natelson and others 2015)
	Palm oil	$0.70–0.79/L (75% of OPEX)	(Hilbers and others 2015)
	Soybean oil	$1.01–1.16/L (up to 70%)	(Pearlson and others 2013)
	Yellow grease Tallow	$0.88–1.06/L (MSP)* $1.05–1.25/L (MSP)* (65%–76%)	(Seber and others 2014)
	Waste oil	$1.03/L (70%)	(De Jong and others 2015)
FT	Corn-stover (gasification)	US$ 0.90/L	(Agusdinata and others 2011)
	Switchgrass (gasification)	US$ 1.10/L	
	Lignocellulose (gasification)	US$ 1.96/L (MSP)*	(Diederichs and others 2016)
	Wood (gasification)	US$ 1.14–1.22/L (MSP)*	(Zhu and others 2011)
	Wood (gasification)	US$ 1.13/L	(Ekbom and others 2009)
ATJ	Sugarcane (ethanol) Corn (ethanol) Switchgrass (ethanol)	US$ 1.56/L (MSP)* US$ 1.75/L (MSP)* US$ 2.30/L (MSP)*	(Staples and others 2014)
	Lignocellulose (syngas)	US$ 1.80/L (MSP)*	(Atsonios and others 2015)
	Lignocellulose (syngas)	US$ 2.00/L (MSP)*	(Diederichs and others 2016)
	Sugarcane (ethanol)	US$ 2.76/L (MSP)*	(Diederichs and others 2016)

* MSP = Minimum Selling Price

Figure 5-1 represents the economic trade-off observed when selecting pathways for SAF production. In this figure, moving towards the centre of the diagram, the feedstocks usually become more expensive, but the conversion technology is simpler or less costly; the reverse is true moving away from the centre.

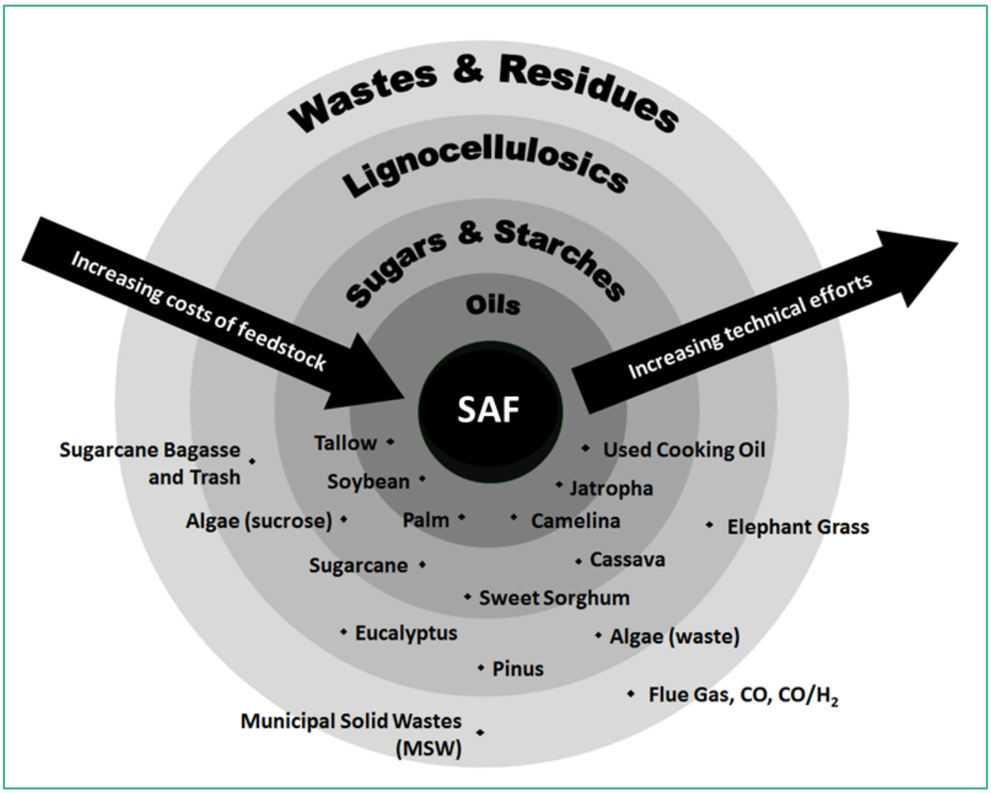

FIGURE 5-1
Feedstocks and their relative position according to costs and technical effort to be converted to SAF
(Source: Boeing and others, 2013)

5.2. SUPPORTING MEASURES FOR SAF INDUSTRY

SAFs are currently more expensive than conventional fuels, mainly as a result of its relative maturity in relation to conventional fuels. This represents a barrier that must be addressed to build a strong, vibrant and competitive market for them. Governments play a significant role in developing supporting mechanisms such as tax exemption or direct subsidy, which may be needed in the early years of building a market.

Even recognizing the advantages of SAF, the supporting measures create an additional cost, which is a burden to be shared between the society and the air transport sector. This means distributing the differential cost of using SAF to the whole population and to the passengers and transporters.

A balanced approach is possible, for example with the adoption of specific tax regimes that charge aviation fuels differently from SAF. Such an action can, however, affect the national budget. A mandatory blend or consumption target for biofuels could also be implemented. However, this may directly impact airlines' operational costs and, as a consequence, their customers.

To reduce the need for support and progressively reach full market competitiveness, reducing feedstock cost is a priority since it represents a significant portion of the final fuel cost (around 75 per cent). To reduce this cost, two complementary approaches can be taken (Cortez and others, 2015):

1) **Increase feedstock yield:** Increasing the amount and accessibility of feedstocks is a significant issue for most agricultural materials. Increased productivity can be achieved for even the most mature feedstocks, such as sugarcane, through advanced genetic breeding and crop management programmes, with promising results. Yields of non-agricultural feedstocks, such as industrial and municipal solid wastes can be increased through improvements in the separation process.

2) **Reduce production costs (for the same yield):** Strategies to reduce feedstock production costs include genetic improvement, breeding and crop management programmes, reducing inputs such as nutrients and improving harvesting, and collection logistics and transportation. Reducing production costs is equally important for non-agricultural feedstocks, although the means to achieve the reductions are mainly related to logistics and collection, especially in the case of residues and wastes.

Cost-benefit analyses of production, transport, blending and distribution of SAF have demonstrated their potential competitiveness (IATA, 2015). In the scenarios evaluated, the base case assumed an investment of USD 260 million, covering the cost of land, equipment and construction of a refining plant, with the cash flow becoming positive from the third year of operation.

Assuming a conservative discount of 9 per cent, this analysis indicated a negative net present value and an internal rate of return on the funds employed of 3.82 per cent, indicating an unattractive project. However, if better financing conditions are considered in the base case, such as a grant of USD$ 100 million in the investment, an interest-free loan for 10 years of USD 150 million, or a 10 per cent subsidy in the SAF price, the project's estimated profitability increases significantly (IATA, 2015).

Figure 5-2 shows that aviation fuel prices have fluctuated greatly between 0.50 to 4 USD/gallon between the years 2000 and 2016. The international oil price depends on factors such as market dynamics, political issues and innovation processes, which makes it difficult to forecast future prices. SAF can bring stability to the international aviation fuel market and improve environmental performance of the world's airlines.

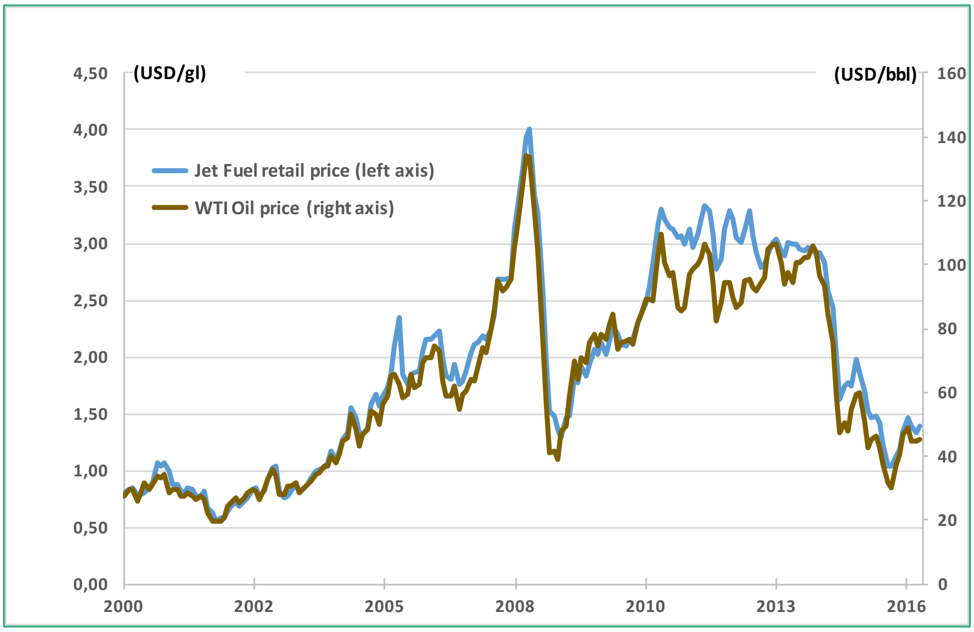

FIGURE 5-2
Jet fuel retail price at United States and WTI (West Texas Intermediate) oil prices (Source: EIA, 2016)

5.3. LOGISTICS OF AVIATION FUELS

Aviation fuel must meet strict quality standards. Conventional aviation fuel is produced in petroleum refineries and distributed by transportation and logistics companies following controlled procedures and protocols to guarantee that the product remains within specification, without deterioration or contamination during transport and storage.

To ensure an active and viable market for SAF, public policies and commitment from airlines are needed to introduce and support their use. This in turn fosters infrastructure development and reinforces the creation of commercial relationships between producers and purchasers.

This was further proven by a recent research project conducted by Canada's Biojet Supply Chain Initiative (CBSCI) at the Montréal–Pierre Elliott Trudeau International Airport. This CBSCI project was focused on the logistics of developing a supply chain that could help the airport move beyond demonstration flights and towards the regular distribution of SAF from the airport's main fuelling infrastructure, as shown in **Figure 5-3** below.

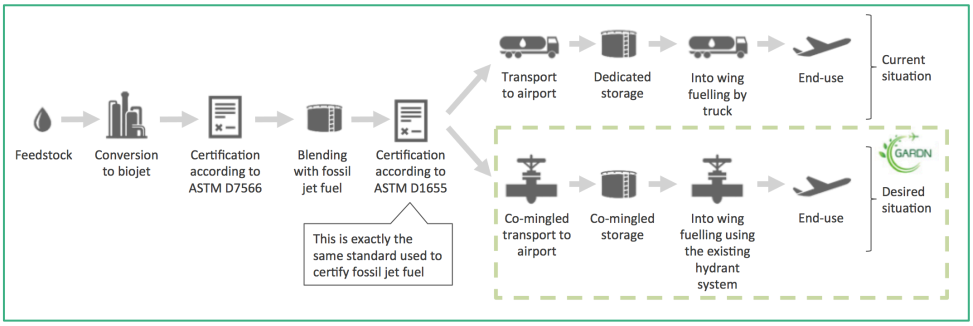

FIGURE 5-3
CBSCI Project Overview
(Source: SkyNRG, 2017)

Table 5-2 summarizes targets set in some States and regions by various stakeholders from the aviation sector. Current off-take agreements between airlines and SAF producers are presented in **Table 5-3**. These mandates or consumption targets and supply agreements are good indicators of SAF market development.

TABLE 5-2
Alternative fuel blending targets set by States and aviation organizations
(Source: IATA, 2015, updated)

State/region	Organization	Target (percentage)	Timeframe
European Union	European Commission (Biofuels Flightpath)	3–4 (2 Mt)	2020
Norway	Norwegian Ministry of Climate and Environment	0.5	2020
Germany	Aviation Initiative for Renewable Energy in Germany	10	2025
Israel	Fuel Choice Initiative (Programme of the Government of Israel)	20	2025
European Union	European Commission (Transport White Paper)	40	2050
Australia	Australian Initiative for Sustainable Aviation Fuels	50	2050

TABLE 5-3
Alternative fuel off-take agreements
(Source: ICAO GFAAF, 2018)

Producer	Purchaser	Off-take production per year		Start/Length of agreement (years)
		(million gallons)	(Mt)	
Air Total	Airbus / China Airlines	5 A350-900 deliveries at 10% blend		2017 / N/A
World Energy (AltAir Fuels)	United Airlines	5	0.015	2016 / 3
	Gulfstream / World Fuel	N/A	N/A	N/A / 3
	SkyNRG / KLM – Los Angeles International Airport	N/A	N/A	2016 / 3
	SkyNRG / KLM - Växjö Småland Airport	0.032	0.000	2018 / N/A
World Energy (AltAir)/Neste	KLM / SAS / Lufthansa / AirBP	0.33	0.001	N/A / 3
Amyris / Total	Airbus / Cathay Pacific	48 A350 deliveries at 10% blend		2016 / N/A
Fulcrum	Cathay Pacific	35	0.106	N/A / 10
	United Airlines	90-180	0.274-0.547	N/A / 10
	Air BP	50	0.152	N/A / 10
Gevo	Lufthansa	8	0.024	N/A / 5
RedRock	Southwest	3	0.009	N/A / N/A
	FedEx	3	0.009	N/A / 7
SG Preston	Jet Blue	10	0.030	2019 / 10
	Qantas	8	0.024	2020 / 10
TOTALS		212.36 to 302.36	0.646 to 0.919	

SAF has been progressively introduced in the market, starting with experimental flights, then with demonstrations, followed by a significant number of commercial flights. Following this initial stage, the regular use of SAF at select airports will allow rapid expansion of the market.

Air traffic is concentrated in a limited number of airports, with about half of current global cargo and passenger transport operations taking place in fewer than 50 airports worldwide (Thrän and Ponitka, 2016). As such, fuel demand is also concentrated, providing opportunities for wide SAF distribution with limited investment in airport fuel infrastructure.

The first airport to successfully distribute alternative fuels to all airlines on a regular basis was Oslo Airport, Norway starting in 2015. This was achieved through a long-term research partnership that involved academia, fuel producers, fuel distributers, airlines, and other stakeholders. The project partners needed to overcome administrative and legal barriers, communication issues, and cost distribution logistics (Mosvold Larsen, 2017).

The achievement at Oslo was quickly followed by successful deployment of alternative fuels at Los Angeles International Airport (United States, since 2016), Stockholm Arlanda Airport (Sweden, since 2017), Bergen Airport (Norway, since 2017), Växjö Småland Airport (Sweden, since 2018), and San Francisco Airport (United States, since 2018). In addition, batches of alternative fuels have been delivered to Stockholm Bromma Airport (Sweden), Åre Östersund Airport (Sweden), Göteborg Landvetter Airport (Sweden), Karlstad Airport (Sweden), Halmstad Airport (Sweden), Brisbane Airport (Australia), Chicago O'Hare International Airport (United States), and Toronto Pearson International Airport (Canada).

5.4. QUALITY CERTIFICATION OF SAF

The following sections reviews how fuel quality is ensured during transport and storage operations with aviation fuels and addresses the implications associated to fuel blending.

Fuel quality is based on two key concepts: batches and traceability, principles that should be accomplished by SAF. The batches principle guarantees that a minimum volume is homogeneous; and traceability imposes a custody chain regarding the fuel specification. These principles should be observed in all States deploying SAF and it is typically the role of the government to define the national authority responsible for establishing and enforcing them.
At the plant where the SAF is processed, blended and made ready for delivery and use, the producer must issue a certificate of quality to certify that the batch of fuel complies with all of the requirements set by standards ASTM D1655 or D7566 as appropriate, as explained in Section 4.3 of this Guide. The certificate covers not only the quantitative limits, but all other requirements set out in those standards as well. Representative samples of every batch are drawn, adopting the recommended procedures such as defined in ASTM D4054 (Thrän and Ponitka, 2016). After the initial production scale-up, it is not necessary to analyse each batch of certified fuel for compliance with the ASTM specification once it has been shown that the process scheme is adequately controlled to support the expectation that these requirements are always met (ASTM D7566).

Quality documentation is provided by the supplier to the purchaser to show that the fuel meets the requirements of those standards and confirms traceability to the point of manufacture. Upon request, the technical authority or end user may be provided with a certificate of quality issued by the producer/blender, identifying that batch blend as a jet fuel satisfying ASTM D1655 or ASTM D7566 specifications (Thrän and Ponitka, 2016).

Aviation fuel, whether blended or not with SAF, can come into contact with incidental materials or water during manufacture and distribution. Appropriate control of standard values must therefore be undertaken at manufacturing locations, and distribution and storage facilities to maintain product integrity and detect any contamination, as indicated in **Figures 5-4 to 5-6**.

Exactly the same procedures, monitoring the same properties, must be followed for the fuel blended with SAF. In summary, the only difference is that the SAF must be certified according to ASTM D7566 at the point where they are blended. Under these conditions, blends using SAF can be distributed and used as conventional ones.

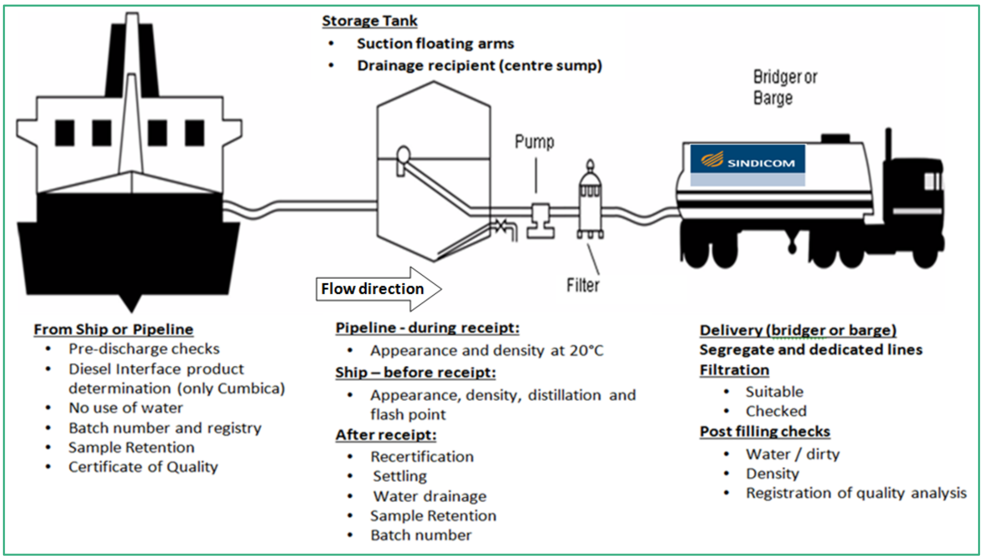

FIGURE 5-4
Jet fuel quality control procedures from tanker or pipeline to depot (Source: Schumman, 2013)

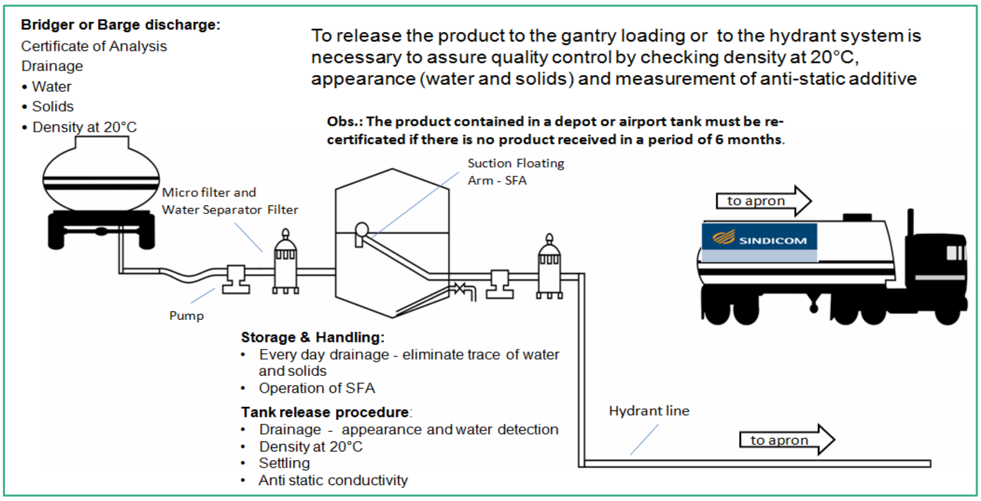

FIGURE 5-5
Jet fuel quality control procedures at airport facilities (Source: Schumman, 2013)

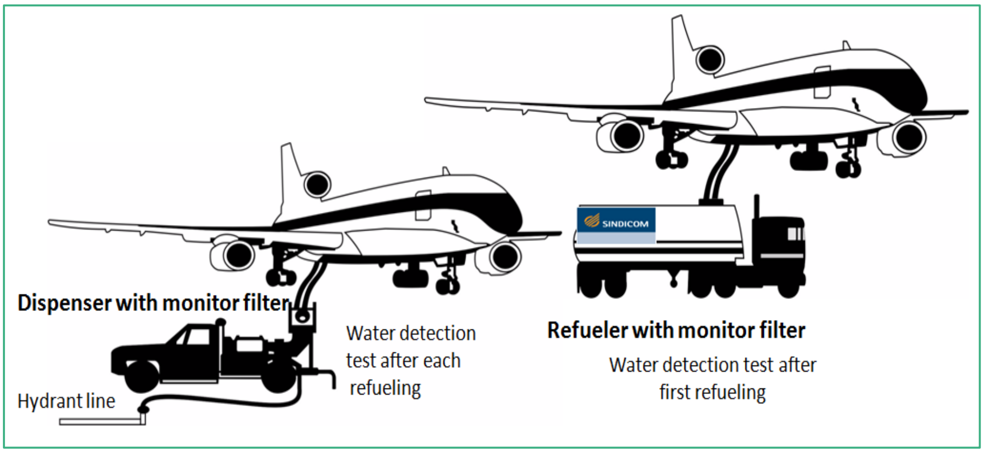

FIGURE 5-6
Quality control procedures at airport apron (Source: Schumman, 2013)

5.5. DEVELOPING A NATIONAL SAF PROGRAMME

The first step in creating a national SAF production programme is to identify and involve the many stakeholders, public and private, that will be essential for the success of the programme. This establishes a common understanding and identifies mutual interests and objectives regarding SAF. This first action, contacting people and institutions, is important to engage them and create a cooperative group.

The second step is to join the stakeholders and appropriate institutions to promote preliminary studies and assessments, set up meetings and develop a draft plan for a national programme.

As suggestions for actions to be taken in the framework of a national programme, the following table can be adapted for each case. To keep the stakeholders motivated and involved, periodic workshops reviewing intermediate results are recommended.

1. Inventory the availability of feedstocks for SAF production
    a. Quantify available feedstocks and estimate harvesting and recovery costs of fatty and lignocellulosic residues.
    b. Identify potential feedstock crops that can feasibly be cultivated in the State.
    c. Develop agro-ecological zoning to identify suitable land available for the most promising crops, considering possible restrictions in land use.

[17] The airport apron is the area of an airport where aircraft are parked, unloaded or loaded, refueled, or boarded.

d. Classify the areas for promoting feedstock production in terms of infrastructure and estimated production cost.

2. Evaluate production pathways feasible for processing these feedstocks
    a. Identify feasible production pathways for SAF considering the most competitive feedstocks, the maturity of available technology, the level of performance and the local availability of equipment, services, maintenance capabilities, and similar support.
    b. Assess the final production cost for each pathway in a pre-feasibility study of an agro-industrial plant, considering the actual and projected costs, performance, and define required investment.
    c. Establish prospective best case production scenarios, estimating the timeline for implementing the feedstock production and processing schemes.

3. Forecast demand for SAF
    a. Study the local demand for aviation fuel, including transportation logistics, prices and costs, operators, etc.
    b. Conduct a preliminary evaluation of potential trade of SAF in neighbouring States and in the global market, for both current and prospective scenarios.

4. Develop an integrated evaluation of potential SAF supply and demand
    a. Define production scenarios and conduct a technical-economic evaluation of the most promising scenarios for production and use/trade of SAF, estimating total fuel production, feedstock demand, production capacity to deploy, investment, production cost, possible impact on GHG emissions, etc.
    b. Study the need for supporting mechanisms to improve the economic competitiveness of SAF production, considering alternative scenarios of conventional fuel and SAF costs, covering measures for stimulating production capacity, e.g. adjustments in the tax regime for aviation fuels.

5. Consider the need for other supporting actions
    a. Evaluate available human resources related to SAF production, use, evaluation, logistics and environmental aspects.
    b. Implement a programme to foster research and development related to SAF.
    c. Implement a communication programme to inform the public about the programme, its objectives and development.

These actions will result in a clear plan, defining objectives and a timeline for implementation, phases of development, measures and resources required and identifying responsible parties and a goal for each phase. The concept of drop-in fuels, along with a well-designed and widely accepted certification process for quality and sustainability, opens opportunities for aviation to capture the benefits of SAF use while contributing to the attainment of environmental objectives and fostering innovation and development.

6.0 CASE STUDIES AND BEST PRACTICES

The transition to a low-carbon economy depends upon overcoming current challenges and giving the right signals to innovators and financiers within an appropriate market structure (IEA, 2010). Government intervention is therefore essential to create sustainable markets for low-carbon technologies, to fill in funding gaps in research, development and demonstration, to create the enabling infrastructure and to encourage international collaboration.

For the aviation industry, policy support can be built on road transportation policies, but taking into account the unique aspects of aviation. Similar to renewable energy policies in general, implementing SAF follows different overall targets in different States and regions. These include policies on climate, energy security, agriculture and economy; hence the lack of a global agreed-upon target regarding the amount or share of SAF.

A wide variety of policy instruments and measures are available to achieve the desired goal of limiting GHG emissions, and which can influence the market introduction of SAF. Several of these measures are summarized in **Table 6-1**.

TABLE 6-1
Typical support schemes for renewable energies (Source: Thrän and Ponitka, 2016)

Instrument	Principle	Cost burden
General instruments for climate policy		
European ETS	For the emission of GHG, certificates need to be possessed/bought	Supplier/end user
Taxation	For products with higher GHG-related emissions, higher tax rates have to be paid	Supplier/end user
Dedicated instruments for renewable energy implementation		
Feed-in tariffs	Producer gets a guaranteed price for the provided renewable energy	End user
Investment support programmes	Producer gets investment support for certain parts of the conversion plant and/or infrastructure	Government
Taxation [(1)]	For renewable products, lower tax rates have to be paid (tax credit, tax exemption)	Government
Quotas/blending mandates	Suppliers have to provide a certain share of renewables in their portfolio	Supplier/end user

After the establishment of CAAFI in 2006, several networks have emerged worldwide aiming at promoting the use of SAF through a process of awareness and involvement. As can be seen in **Figure 6-1**, the number of active initiatives each year sharply increased after 2009.

Some of these initiatives and policies are further discussed in this chapter, while a comprehensive list of the initiatives and projects for the development and deployment of SAF is available through the ICAO Global Framework for Aviation Alternative Fuels (GFAAF) database (ICAO GFAAF, 2017).

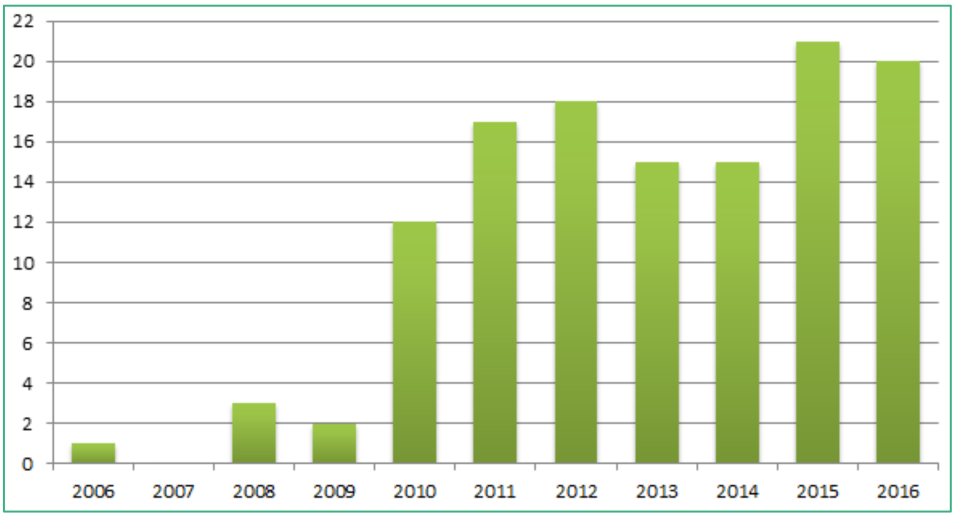

FIGURE 6-1
Number of active initiatives promoting the use of SAF each year
(Source: ICAO GFAAF, 2017)

AUSTRALIA

In Australia, a coalition of diverse participants from business, government and academia, Australian Initiative for Sustainable Aviation Fuels (AISAF), was founded in 2012 and later absorbed into the United States Studies Centre's Alternative Transport Fuel Initiative at the University of Sydney. Its goal was to support the development and introduction of commercial supply chains for SAF in the State, while engaging and collaborating with partners in the United States and other States (USSC, 2016).

Additionally, the Queensland Sustainable Aviation Fuel Initiative was created to help enable the construction and operation of a SAF manufacturing facility in Queensland. The project started in 2010 at the University of Queensland and evaluated the specific business case for a SAF production plant in Mackay (AIBN, 2016).

BRAZIL

Brazil has longstanding experience with biofuels in the transport sector, with all gasoline having been blended with ethanol by mandate since 1931. Currently, even though no specific federal policies exist for SAF, initiatives are in place at the State level.
In 2010, the Aliança Brasileira para Biocombustíveis de Aviação (ABRABA) was created as a forum to discuss the various aspects of developing SAF, driven by the growing demand to meet the requirements for reducing GHG emissions in aviation, as well as to provide support for Brazil's energy security. This initiative aims to make Brazil a major world player in SAFs, similar to what's already being done in ground transportation. The goal is to promote public and private initiatives that streamline the development, certification, and commercial production of sustainable biofuels for aviation (ABRABA, 2016; Hamelinck and others, 2013).

In 2011, Brazil and the United States signed a memorandum of understanding to cooperate on the development of renewable aviation fuels. In 2013, Sustainable Aviation Biofuels for Brazil was formed as a result of a combined effort between the industry and research stakeholders. This action plan is a national assessment of the technological, economic and sustainability challenges and opportunities associated with the development and commercialization of SAF in Brazil (Cortez and others, 2014).

Also in 2013, the Brazilian Biojetfuel Platform was formally structured as an open, collaborative platform to bring together key stakeholders to promote the implementation of a highly integrated SAF and renewable value chain to fill the gaps identified by the study carried out by Sustainable Aviation Biofuels for Brazil (Curcas, 2016).

CANADA

In Canada, an aviation task force was created within the second phase of the national research network BioFuelNet Canada (BFN), which targeted strategic areas in research such as SAF and forestry-based fuel production. The network looked at the barriers to advanced biofuels production, such as policy and availability of suitable and inexpensive feedstock.

EUROPEAN UNION

The EU Renewable Energy Directive (EU RED) sets a binding target of 20 per cent final energy consumption from renewable sources by 2020. To achieve this, EU States have committed to reaching their own national renewables targets ranging from 10 per cent in Malta to 49 per cent in Sweden. They are also each required to have at least 10 per cent of their transport fuels come from renewable sources by 2020.

Looking further ahead, EU States have already agreed on a new renewable energy target of at least 27 per cent of final energy consumption in the EU as a whole by 2030 as part of the EU energy and climate goals for 2030 (EC, 2016).

The EU biofuels policy is regulated by the EU RED 2009/28/EC and Fuel Quality Directive (FQD) 2009/30/EC, which came into force in 2009. In principle, alternative fuels count towards the RED target provided they comply with the sustainability criteria. This means that when alternative fuels are deployed in a Member State, that Member State is allowed to count it towards its national target.

However, this does not automatically mean that SAF are incentivized, as EU Member States are free to decide which fuels will be incentivized and in what manner (Hamelinck and others, 2013). For instance, in the Netherlands the sales of alternative fuels are included in the biofuel mandates of economic operators. Companies that sell SAF in the Netherlands market earn bio tickets that other operators with a biofuels obligation can use to fulfil their obligation.

To help spur the commercial development of SAF, the European Commission and its partners have launched the European Advanced Biofuels Flightpath. The Flightpath aims to get sustainably produced biofuels to the market faster, through the construction of advanced biofuels production plants in Europe and to get the aviation industry to use 2 million tonnes of biofuels by 2020 (EC, 2016).

For the sake of comparison, Figure 6-2 provides the operational and planned facilities with the capability to produce SAF. As of 2015, these facilities summed up to a production capability of 6.2 million tonnes of SAF/year.

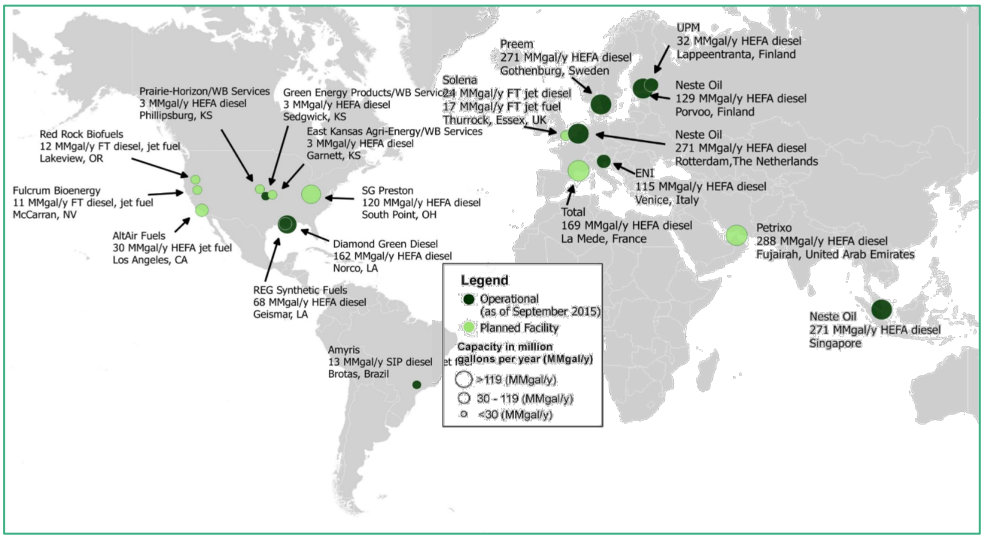

FIGURE 6-2
Fuel production facilities with capability to produce SAF (Source: adapted from Radich, 2015)

The aviation sector is also included in the European Union Emission Trading Scheme (EU-ETS). Emissions from all flights arriving and departing from airports in the EU were to be incorporated into the scheme, covering around a third of global aviation emissions. In 2012, 85 per cent of the allowances were allocated for free, based on benchmarks.

For the period 2012-2020, 15 per cent of allowances are to be auctioned and 82 per cent allocated for free, based on benchmarks. The remaining 3 per cent constitutes a special reserve for new entrants and fast-growing airlines (Ščeponavičiūtė, 2016; Thrän and Ponitka, 2016).

In April 2013 the EU temporarily suspended enforcement of the EU-ETS requirements for flights operating from or to non-European States, while continuing to apply the legislation to flights within and between States in the European Economic Area, regardless of the carriers' origin.

In the light of the progress on CORSIA, the EU has proposed to continue the current approach beyond 2016 (EC, 2016). The EU proposes to bring the pace of aviation emissions reductions in line with the efforts of other sectors covered by the EU-ETS. This would entail that the cap on aviation emissions declines by 2.2 per cent each year from 2021 onwards. The proposal further includes a review clause to assess the details of CORSIA implementation in Europe as of 2021.

Within this policy context, national and international SAF networks have been established across EU Member States. For example, the Initiative Towards sustainable Kerosene for Aviation (ITAKA) is a collaborative project that aims to link feedstock growers, fuel producers, distributors and end users in establishing a large scale (4,000 t) European drop-in HEFA (camelina) SAF supply chain. Research and development trials have been conducted in Spain and Romania for improving the productivity of different varieties of camelina, for adaptation to the soil and climatic conditions, as well as to study its behaviour regarding sustainability drivers, type of land used, fertilization, and tilling (ITAKA, 2016).

GERMANY

In Germany, a biofuels initiative of the aviation industry was started in 2011, combining the engagement and know-how of airlines, airports, research organizations and companies in the aviation and feedstock industries. The objective of the Aviation Initiative for Renewable Energy in Germany e.V. (AIREG) is to support the production and use of SAF, with a bio jet target of 10 per cent of the jet fuel consumed domestically by 2025 (AIREG, 2016).

ICAO

The joint International Civil Aviation Organization (ICAO) and European Union (EU) assistance project Capacity building for CO^2 mitigation from international aviation aims at providing assistance to a selected group of 14 States in Africa and the Caribbean to support their efforts in developing and implementing their States' Action Plans on CO^2 emissions reduction from international aviation, to establish aviation environmental systems for emissions monitoring at the State level and to identify, evaluate and implement mitigation measures in selected States.

Within the context of this ICAO-European Union Assistance Project, ICAO has completed SAF feasibility studies in the Dominican Republic[18], Trinidad and Tobago[19], Burkina Faso[20] and Kenya[21].

[18] https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_DomRep_ENG_Web.pdf
[19] https://www.icao.int/environmental-protection/Documents/FeasabilityStudies_TrinidadTobago_Report_Web.pdf
[20] https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_BurkinaFaso_Report-Web.pdf
[21] https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_Kenya_Report-Web.pdf

INDONESIA

In 2013, Indonesia submitted its State Action Plan to Reduce Emissions in the Aviation Sector to ICAO, with a basket of measures including carbon emission reductions in flight operators, air traffic management, airport operations and application of carbon markets, as well as the use of renewable energy sources.

In August 2014, the Aviation Biofuels and Renewable Energy Task Force was created, composed of four “sub task forces” to work on the following: formulation of policy, regulation and capacity-building programme; research and development; testing and certification; commercial, risk analysis and sustainability. Since October 2014, the ICAO Technical Cooperation Bureau has supported the Task Force through the MSA Annex 5 INS13801 project (ICAO, 2016).

The original decree of the Ministry of Energy and Mineral Resources (NEMR) established a bio jet fuel mandate at the national level, requiring 2 per cent blending in 2016, 3 per cent by 2020, and 5 per cent by 2025. Owing to national circumstances, the Task Force concluded that the 2016 goal would not be achieved.

However, Indonesia’s oil producers have shown their commitment to starting production by late 2018, with a production capacity of 257,000 kl/year (ICAO GFAAF, 2017). Now, the NEMR Regulation 12/2015 requires the aviation industry to use 2 per cent alternative fuels by 2018, 3 per cent by 2020 and 5 per cent by 2025.

MEXICO

Since 2009, the Ministry of Transportation and Communications (SCT), through ASA, has been fostering the development of SAF and coordinating actions towards the establishment of this industry at the national level (ASA, 2016).

As a first effort, during 2010-2011 ASA led, with the participation of more than 300 institutions, the study “Flight Plan Towards Sustainable Aviation Biofuel in Mexico”, aiming at identifying and analysing the existing and missing elements in the supply chain of SAF, with a focus on the HEFA track (ICAO GFAAF, 2017). Similar regional exercises were later developed in 2013-2014 in the Mexican States of Hidalgo and Morelos (ASA, 2016).

The Flight Plan study concluded that there were great opportunities for SAF in Mexico, with a strong interest from all stakeholders in participating in the initiative. Sustainability appeared as a key, and the main bottlenecks identified were the insufficient production of the required quantities of feedstock and the lack of appropriate legislation and a biorefining infrastructure.

As an outcome, it is expected that by 2020, with the right funding structure in place, four SAF refineries will be operating, producing 800 megalitre (ML) of SAF per year. Additionally, the Flight Plan made it possible for ASA (the single jet fuel supplier in the State) to get involved in the whole SAF supply chain, which allowed the first flights with alternative fuels in Mexico to be carried out (ASA, 2016).

UNITED STATES

CAAFI has been a pioneer initiative in this field, formed by three industry associations in the United States representing airports, airlines and original equipment manufacturers, and the Federal Aviation Administration (FAA). It is also supported by over 800 members and 350 organizations from around the globe. Efforts are accomplished via the support of the sponsors and members who engage in four work teams, as well as several public private partnership activities, which leverage the interests of government agencies and other aviation stakeholders (CAAFI, 2016; IATA, 2015).

CAAFI is engaged in various activities to enable and facilitate the near-term development and commercialization of SAF. It serves the primary roles of thought leadership, project execution, collaboration, instigation and communication. It also serves as a coordinator/clearinghouse, facilitating the exchange of information about private-sector and governmental initiatives supporting the development and commercialization of drop-in aviation fuels. While its efforts are focused on opportunities in the United States, CAAFI also recognizes the need to foster similar efforts around the globe and, as such, works with similar organizations and other interested parties in many States (IATA, 2015).

Furthermore, the Departments of Agriculture, Energy and Defence have coordinated their activities to support the future construction or retrofit of multiple domestic commercial- or precommercial-scale production facilities to produce alternative fuels, including SAF. One example is the Farm-to-Fly initiative, which has brought together the United States aviation community, government stakeholders, and four federal executive departments. As a result of its initial success, in 2016 the programme was extended to Farm-to-Fly 2.0 (Thrän and Ponitka, 2016).

Another prominent form of federal policy support in the United States is the Renewable Fuel Standard (RFS), created under the Energy Policy Act of 2005 (EPAct), where a minimum volume of biofuels must be used in the national transportation fuel supply each year.

RFS is a market-based compliance system in which refiners and importers of fossil fuels ("obligated parties") have to submit credits (Renewable Identification Numbers (RINs)) generated by fuel producers, to cover their obligations (EPA, 2016). Since 2013, alternative fuels can earn RINs in the United States under three categories: advanced biofuel (D5), biomass-based diesel (D4), or cellulosic biofuel (D7) (van Dyk and Saddler, 2016).

CONCLUSIONS

ICAO Member States are encouraged to develop and implement an individualized State Action Plan for CO_2 emissions reductions activities for international aviation. Many Member States, particularly Developing States and SIDS, continue to investigate the institutional and financial resources necessary to develop and implement their action plans, and the actions therein. The implementation of SAF could be one of the measures selected by States to reduce their emissions from international civil aviation.

In addition to contributing to the ICAO global aspirational goal of carbon neutral growth, the development and deployment of SAF can advance the social and economic development associated with the UN Sustainable Development Goals (SDGs). In this regard, ICAO has prepared this guidance document to help States, particularly Developing States and SIDS, further understand the process of developing a SAF supply chain, the challenges associated with the implementation of these projects, and the benefits of establishing a commercial scale SAF project.

As shown throughout this document, States, airports, airlines, and other aviation stakeholders around the world are already involved in SAF deployment projects, ranging from small scale research projects, to commercial scale SAF production facilities. There is a multitude of feedstocks and conversion processes available for SAF production, which allow flexibility for setting up SAF supply chains tailored to each State particular characteristics. By the time of publication of Version 2 of this document in December 2018, over 30 airlines had carried out over 150,000 flights using a blend of alternative fuels and 6 airports were deploying alternative fuels on a regular basis. Since the first version of this document was published in November 2017, a new alternative fuel production pathway was certified by ASTM, an estimated additional 50,000 flights used a blend of alternative fuels, and two additional airports began deploying alternative fuels on a regular basis. The success of these initiatives proves that the SAF industry is evolving fast, making it a viable option for the aviation industry to address its environmental sustainability.

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ANNEX A

SUSTAINABILITY CONCEPTS– LIFE CYCLE ASSESSMENT AND LAND USE CHANGES

The growing societal concern with sustainability requires appropriate tools to inform decision-making. In this regard, the life cycle assessment (LCA) methods have been increasingly used in the private and public sectors to provide a conceptual basis for identifying and understanding the impacts associated with a given process or product, from the extraction of raw materials, through production, use, final disposal and recovery, as depicted in **Figure A-1**.

Particularly with respect to the environment, LCA addresses the environmental aspects and their potential impacts throughout a product's life cycle. The comprehensive scope of LCA aims to avoid shifting problems, for example, from one phase of the life cycle to another, from one region to another, or from one environmental problem to another (Finnveden and others, 2009). Therefore, in the case of aviation SAF, LCA can be applied as a basic resource to assess such innovation, allowing the evaluation, with a broad scope, of the actual impacts and effects of each production route. In Chapter 4 different production routes for SAF were introduced and compared, thus making it worthwhile to advance some concepts and information on LCA methods.

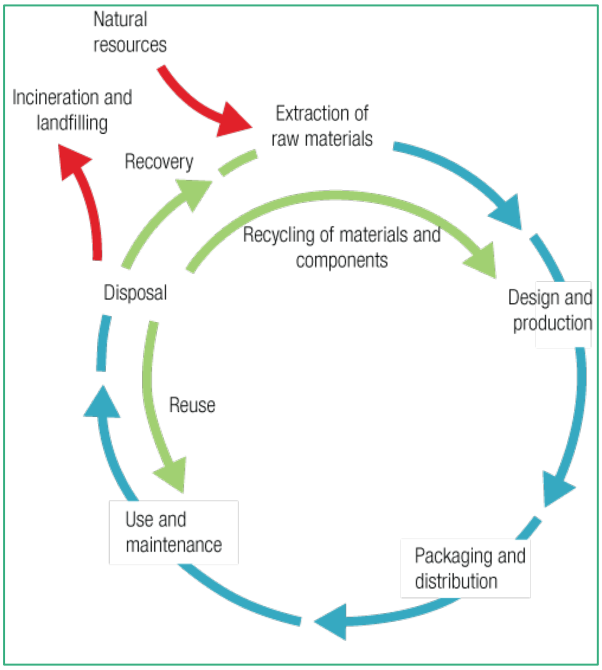

FIGURE A-1
Typical product life cycle diagram (UNEP/SETAC, 2016)

After two decades of conception and improvement, even though LCA is a structured, comprehensive and internationally standardized method, there is no single method for conducting an LCA (ISO, 2006; JRC, 2010). Nevertheless, a standardized framework and terminology, and a platform for debate and harmonization of LCA methods are available (Guinée and others, 2011). Currently, ISO provides two international standards on the general principles and requirements of LCA: ISO 14040:2006 and ISO 14044: 2006.

Even though LCA considers all attributes or aspects of the natural environment, human health and resources, the challenges that climate change poses to our society have brought special attention to the GHG emissions during the life cycle of products. As a consequence, new standards and methods were developed, focused on the assessment of the life cycle GHG emissions and removals[22] (also referred to as carbon footprint) of products.

The GHG Protocol Product Standards, PAS 2050:2011 and ISO/TS 14067:2013 are examples of these new standards, while the RSB Methodology is an example of a specific method developed in the context of biofuels certification. These new standards are founded on the same basic principles set in the ISO LCA standards, except they address only one impact category: climate change. For some methodological aspects, however, more specific guidance is provided, for example, on how to deal with land use change associated with alternative fuel production.

In the context of alternative fuel policies, European and American regulatory schemes have used different approaches based on the LCA technique to estimate the GHG emissions in biofuels production. For example, the impact assessment developed by the United States Environmental Protection Agency (EPA) for the Renewable Fuel Standard (RFS2) volumes and the California Air Resource Board (CARB) analysis for the Low Carbon Fuel Standard (LCFS) vary considerably not only with one another, but also in relation to the EU-RED (Khatiwada and others, 2012).

For the aviation industry, assessing a fuel's GHG emissions during its life cycle is a particular topic for which increased harmonization among aviation stakeholders is important in order to acquire a shared understanding of the potential benefit of SAF (IATA, 2015).

Therefore, the ICAO CAEP AFTF was created and tasked with the development of a methodology to assess the fuels' life cycle emissions, which should be applied for the quantification of the emissions associated with a projected production of SAF by 2050, relevant parameters for implementing CORSIA, as discussed in Chapter 6. Currently AFTF is consolidating studies to define LCA parameters and sustainability criteria.

Particularly for States with relevant agriculture activities, GHG emissions associated with LUC have been one of the most contentious issues regarding LCA and deserve some remarks. Land use changes can generate CO_2 emissions, decomposing organic matter and soil organic matters, or CO_2 sequestration, owing to capture and the long-term storage of atmospheric CO_2 as organic matter,[23] which may translate into major impacts on the environmental profile of bioenergy. When dealing with LUC impacts, the distinction between direct land use change (dLUC) and indirect land use change (iLUC) is frequently used, especially for certification purposes.

ISO/TS 14067, for instance, defines dLUC as a change in the use or management of land within the product system being assessed, as indicated in **Figure A-2**, while iLUC is a change in the use or management of land which is a consequence of direct land use change, but which occurs outside the product system being assessed (ISO, 2013). Differently from dLUC, iLUC cannot be directly measured or observed; instead, it is projected with economic models, which are only able to capture both effects together.

[22] Removals is the general term for GHGs subtractions from the atmosphere, through emissions mitigation or carbon sequestration techniques. The net effect, GHG emissions minus removals, is also referred to as "carbon footprint".

[23] For instance, land use changes such as deforestation produce CO_2 emissions, while planting perennial cultures in areas formerly occupied by grass can increment the organic carbon stock in plants and soil, a CO_2 sequestration process.

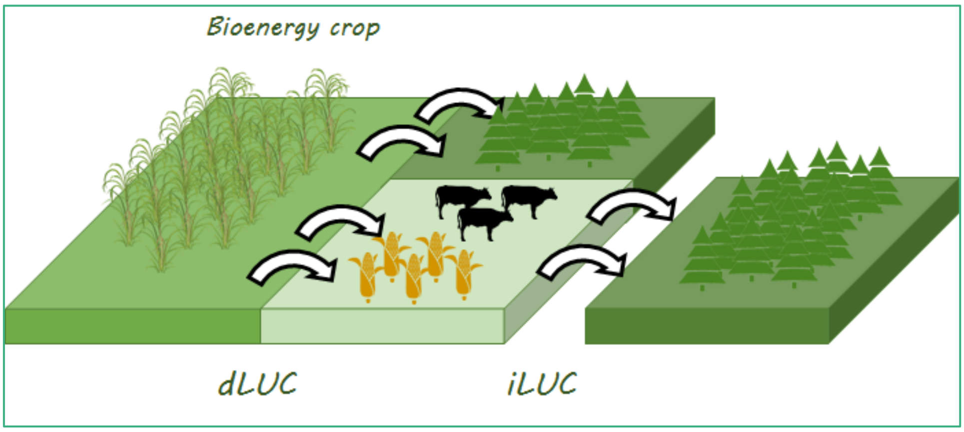

FIGURE A-2
Schematic representation of direct and indirect land use change (prepared by authors)

The iLUC is caused by economic linkages among different economic sectors where commodity prices are affected by the additional demand for alternative fuel. When there is an increase in demand for a commodity used for the production of fuels, the increased demand can induce an increase in the price of the commodity. This price increase causes some combination of the following market mediated responses:

- **Crop switching:** when the demand for one crop increases and the demand for others remains unchanged, crop switching will likely occur to the crop with the increased demand and higher prices.
- **Land conversion:** addition of land to the cropland area by converting pasture, grassland, shrub land, or forest to cropland.
- **Yield improvement:** higher commodity prices can increase profitability of farming activities, which can lead to investments in yield improvement either by the farmer or other actors in the agricultural supply system.
- **Reduced consumption:** with higher prices for the commodity in question, less of it tends to be consumed.
- **Reduced stocks:** in the short term, a common response to increased demand for agricultural goods is to draw down global stocks.
- **Trade impacts:** changes in international trade and production of the commodity and its substitutes.

These responses can happen at either the local level (i.e. within the State in which demand for alternative fuel increases) or at the global level (i.e. in other States). Most of them are built into economic models that are able to estimate aggregate LUC results from all responses together. While the models can produce LUC results by global region, they do not include assumptions about which parcels of land are directly supplying feedstock to SAF facilities. As there is no information about how feedstock from a newly cultivated land parcel will be used, there is no concept of dLUC within the models. Thus, some authors refer to the LUC modelled in economic models as induced land use change.

Economic models rely on many parameters that are based on historical trends or macroeconomic principles. It is common for some input parameters to be inferred from others because of a lack of adequate amount of historical data to directly estimate every parameter.

Further, historical trends may not always be representative of what will happen in future, and microeconomic conclusions are not always valid, creating a large degree of uncertainty in quantifying GHG emissions from LUC, which are also affected by the large uncertainties concerning soil carbon stocks[24]. Nonetheless, researchers who work in estimating induced LUC have made considerable progress to improve the models and model parameter estimates (JRC, 2010), essential elements for LCA application in the context of civil aviation.

[24] Mineral soils are a carbon pool that is influenced by land-use and management activities. Land use can have a large effect on the size of this pool through activities such as conversion of native grassland and forest land to cropland or management practices. To incorporate these effects, LCA studies usually rely on IPCC default carbon stocks, which feature considerable uncertainties. Other studies make use of locally measured data, which do not necessarily capture the complete transition to the new equilibrium soil carbon content (since the process takes several years to reach this equilibrium).

SUSTAINABLE DEVELOPMENT GOALS

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