AFCAC AND ECAC JOINT ENVIRONMENTAL WORKSHOP ON THE ICAO LONG-TERM GLOBAL ASPIRATIONAL GOAL (LTAG)

29 NOVEMBER 2022

The Role of Sustainable Aviation Fuels (SAF) in Decarbonizing Air Transport: Challenges & Opportunities

Robert Malina, Hasselt University, Belgium

Megersa Abate, The World Bank

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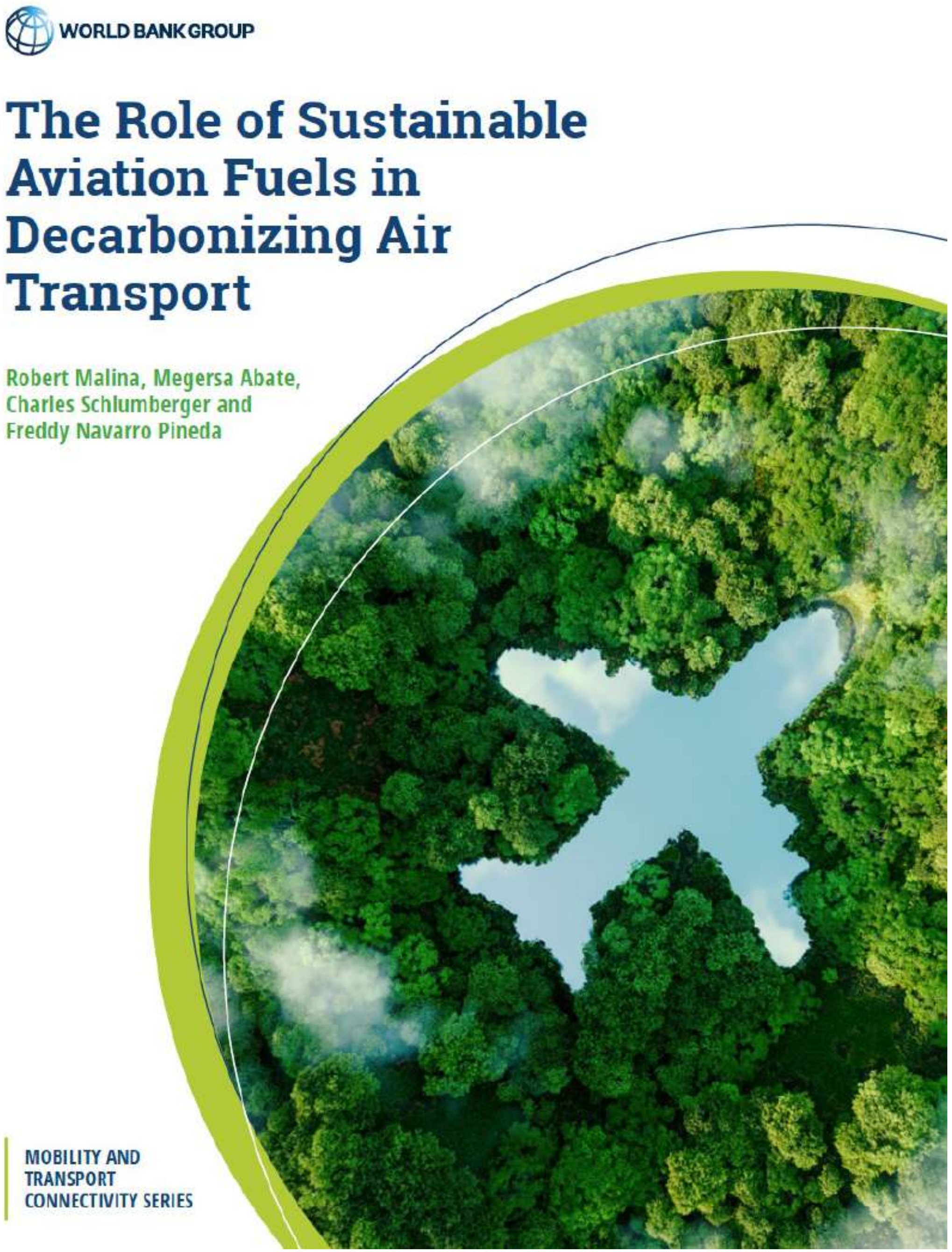

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The Role of Sustainable Aviation Fuels in Decarbonizing Air Transport

Robert Malina, Megersa Abate,
Charles Schlumberger and
Freddy Navarro Pineda

MOBILITY AND
TRANSPORT
CONNECTIVITY SERIES

Contents

https://openknowledge.worldbank.org/handle/10986/38171

The tension between policy ambition and emissions reality

Increased mitigation ambition…

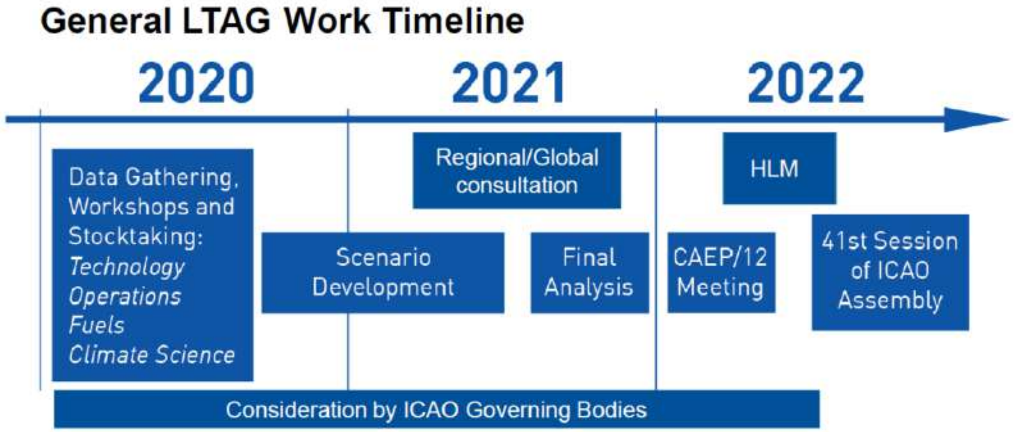
	"Old" ambitions	"New" ambitions
Industry Ambition	- 50% by 2050	Net zero by 2050
"National" Ambitions	Diverse targets	Net zero by 2050
ICAO Ambition	Carbon Neutral Growth from 2020	Long-Term aspirational goal for 2050+

FLY NET ZERO

Department of Energy

DOE Releases Roadmap to Achieve Carbon Neutral Aviation Emissions

SEPTEMBER 23, 2022

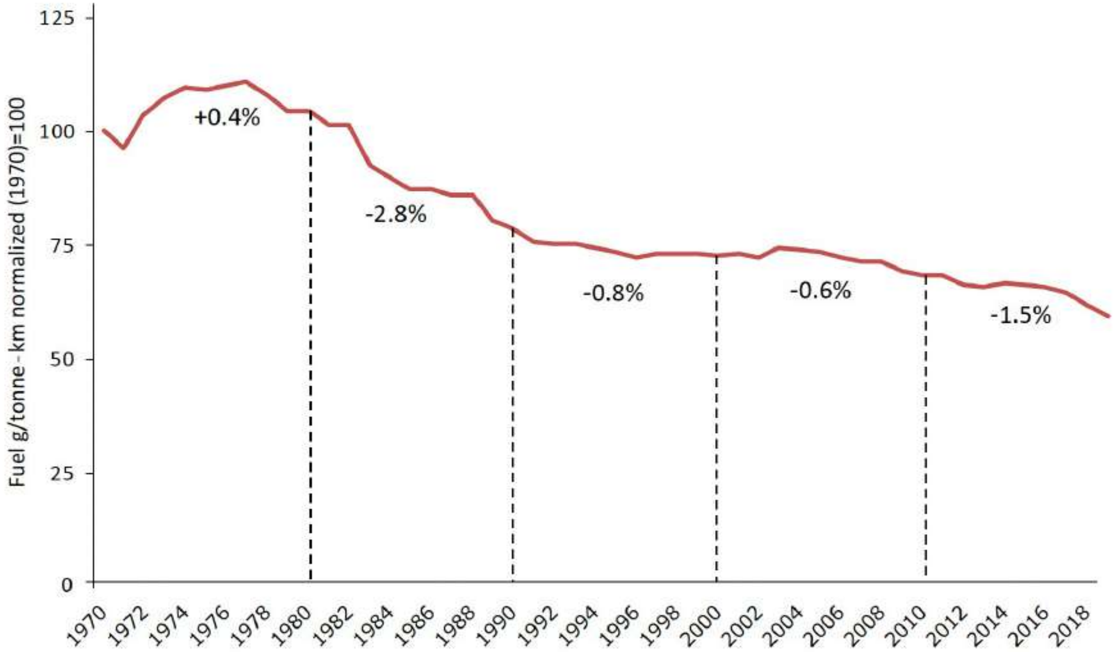


The tension between policy ambition and emissions reality

Increased mitigation ambition…

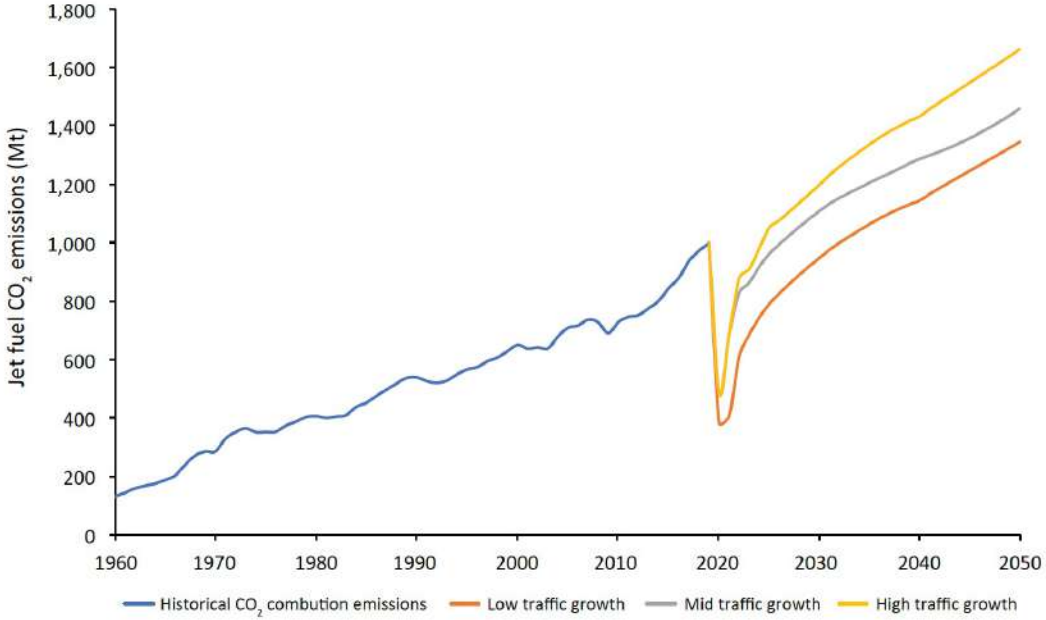
… meets a reality in which a continuation of historical increase in fuel efficiency is outpaced by traffic growth.

Figure 2.2. Fuel Efficiency Development 1970 to 2019



Source: Figure adapted from data obtained from ICCT, based on analysis by Zheng and Rutherford 2020. Percentage changes provided in the figure refer to the average annual change of fuel efficiency in a specific decade.

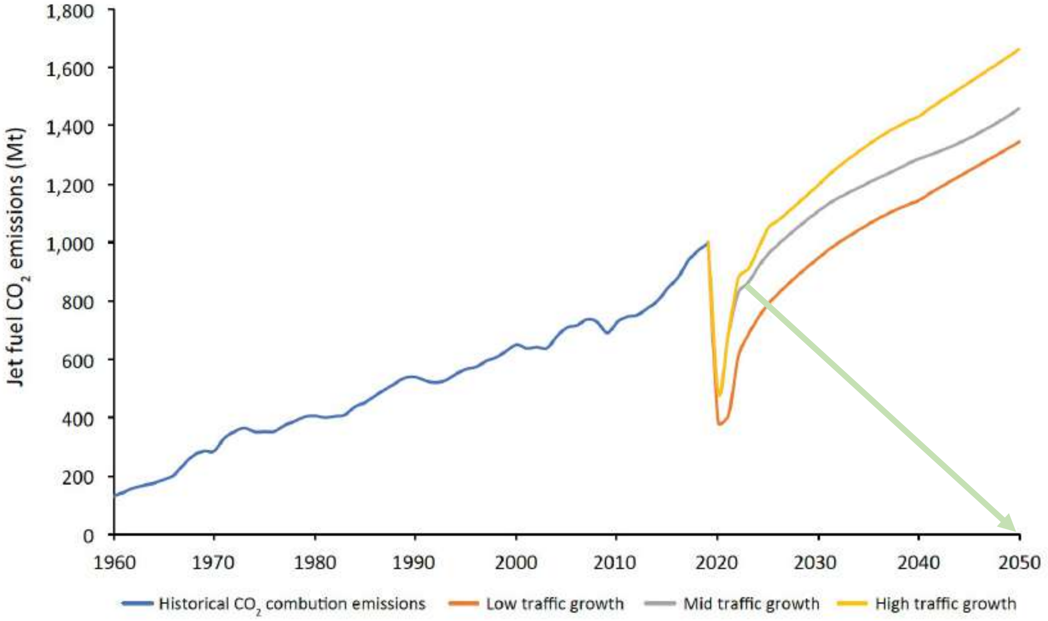
Figure 1.2. CO_2 Combustion Emissions of Global Aviation: Historical Emissions and Forecast Out to 2050 Assuming a Continuation of Historical Efficiency Trends



Source: Original figure produced for this publication, with historical CO_2 emissions from 1990 to 2018 based on EIA jet fuel demand data. For the year 2019, demand data was taken from Statista. The forecast of CO_2 emissions is based on ATAG (2020a) fuel burn projections out to 2050. The analysis is purely based on jet fuel combustion-related CO_2 emissions. For all years, a CO_2 emissions factor of 3.16 kilograms of carbon dioxide ($kgCO_2$) per kilogram of jet fuel is assumed.

The Challenge

Figure 1.2. CO_2 Combustion Emissions of Global Aviation: Historical Emissions and Forecast Out to 2050 Assuming a Continuation of Historical Efficiency Trends



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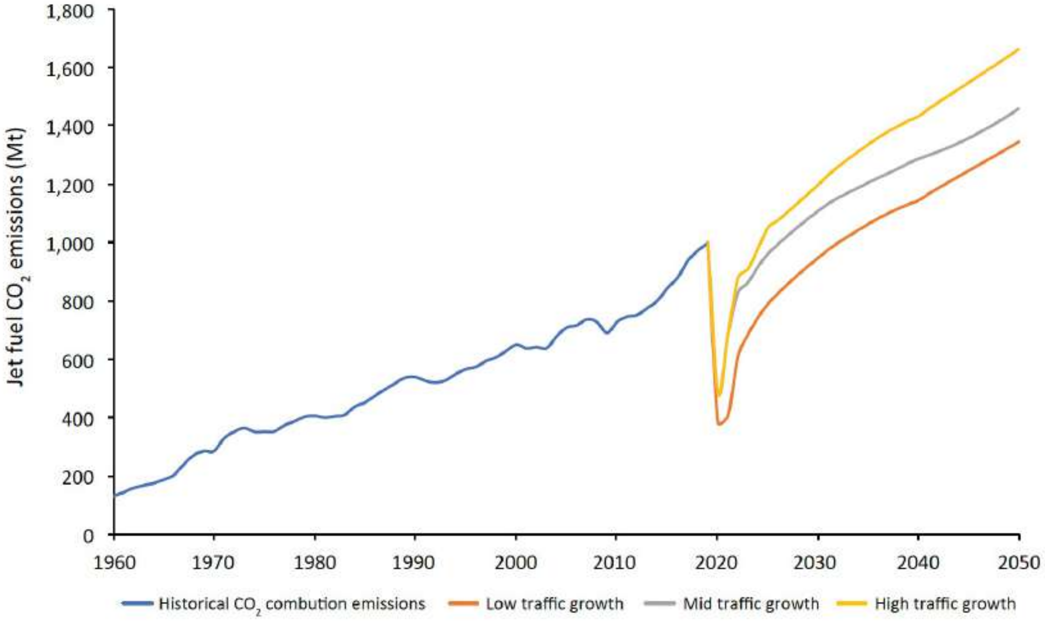
How can you get aviation down to net zero (CO_2) emissions?

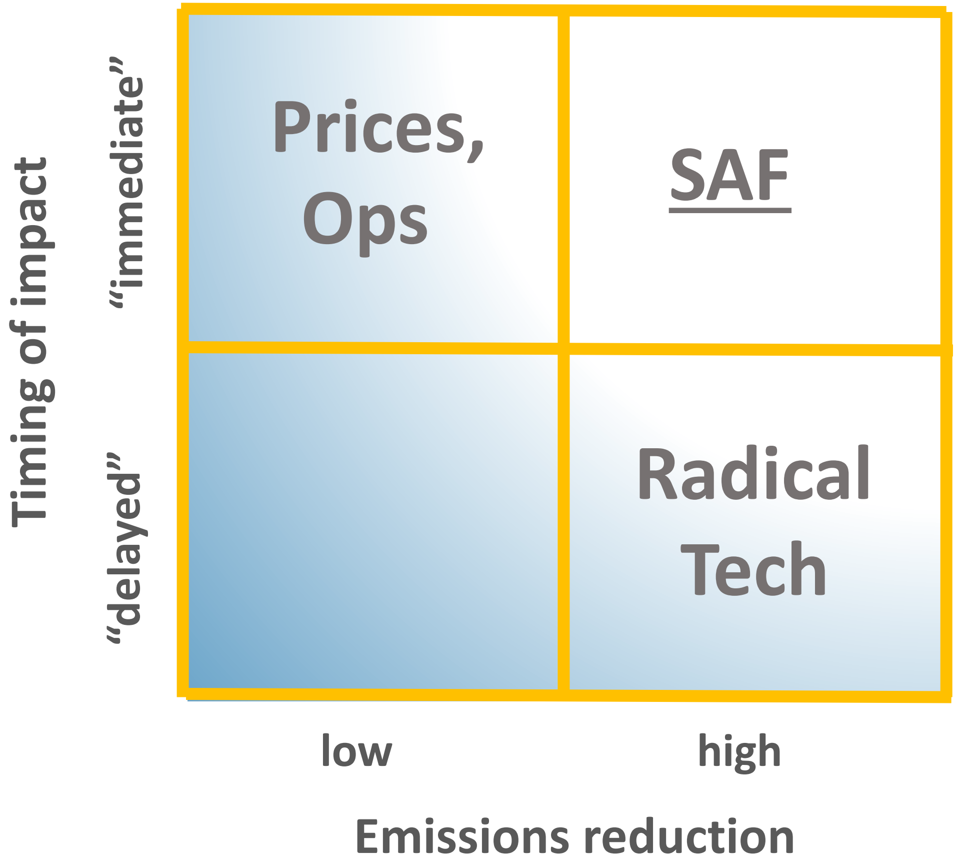
The option space

Figure 1.2. CO_2 Combustion Emissions of Global Aviation: Historical Emissions and Forecast Out to 2050 Assuming a Continuation of Historical Efficiency Trends



Source: Original figure produced for this publication, with historical CO_2 emissions from 1990 to 2018 based on EIA jet fuel demand data. For the year 2019, demand data was taken from Statista. The forecast of CO_2 emissions is based on ATAG (2020a) fuel burn projections out to 2050. The analysis is purely based on jet fuel combustion-related CO_2 emissions. For all years, a CO_2 emissions factor of 3.16 kilograms of carbon dioxide ($kgCO_2$) per kilogram of jet fuel is assumed.

How can you get aviation down to net zero (CO_2) emissions?



Timing of impact

"immediate"

"delayed"

Prices, Ops

SAF

Radical Tech

low

high

Emissions reduction

What is Sustainable Aviation Fuels (SAF)?

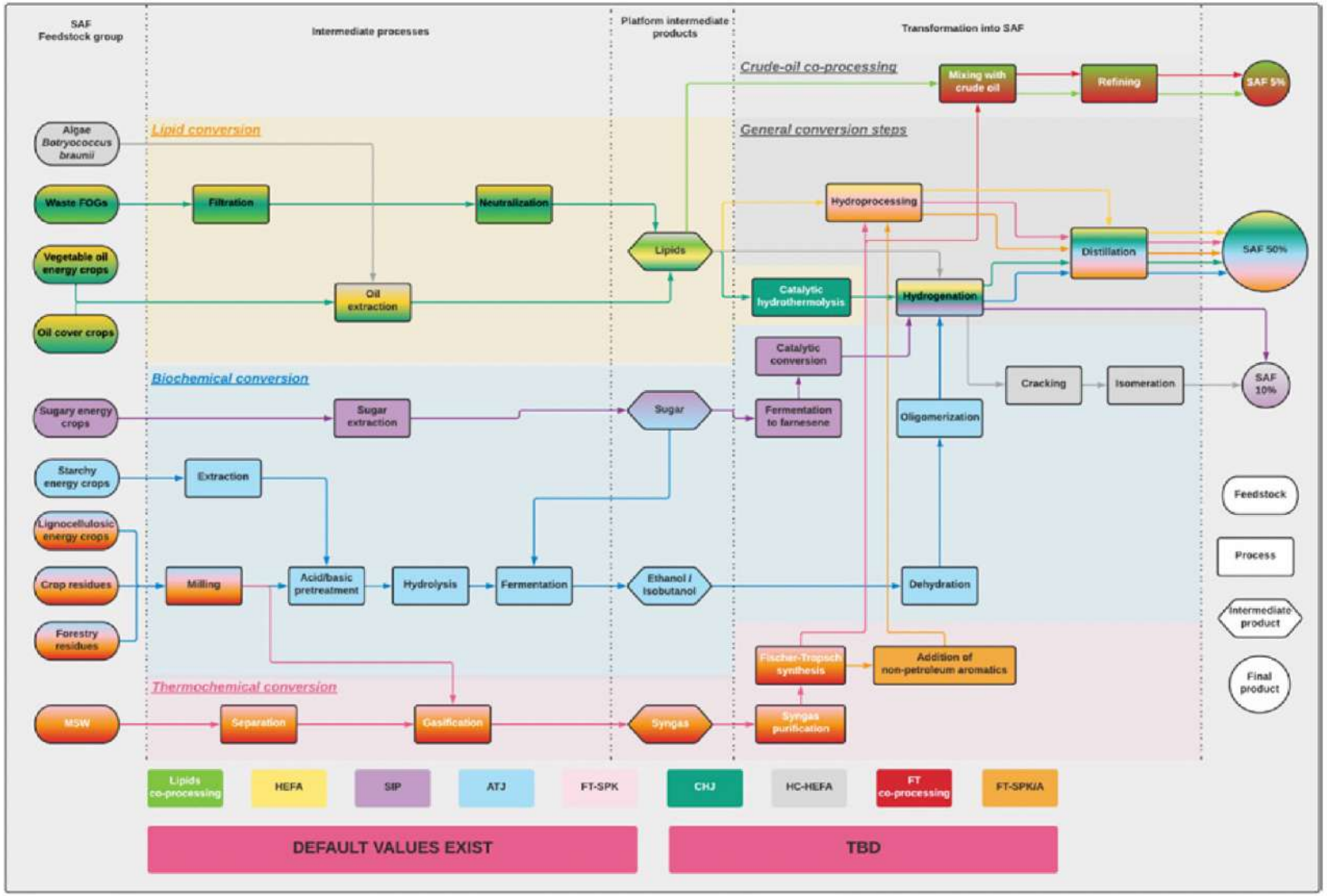
Photo taken at the ICAO Assembly, 2022.

SAF is made by heterogenous set of technologies regarding feedstock & conversion technologies: **Biomass to Liquid, Waste to Liquid and Power to Liquid**.

SAF are drop-in fuels that can be used up to 50% blend, but there has been test flights with 100% SAF.

SAF’s CO_2 reduction can be as high as 100% (or more), on lifecycle basis compared to conventional jet fuel.

“Approved” SAF pathways



Source: Original figure produced for this publication.

This flow diagram shows current 9 SAF pathways that are ASTM-certified for use in jet engines.

Environmental performance and economics of SAF

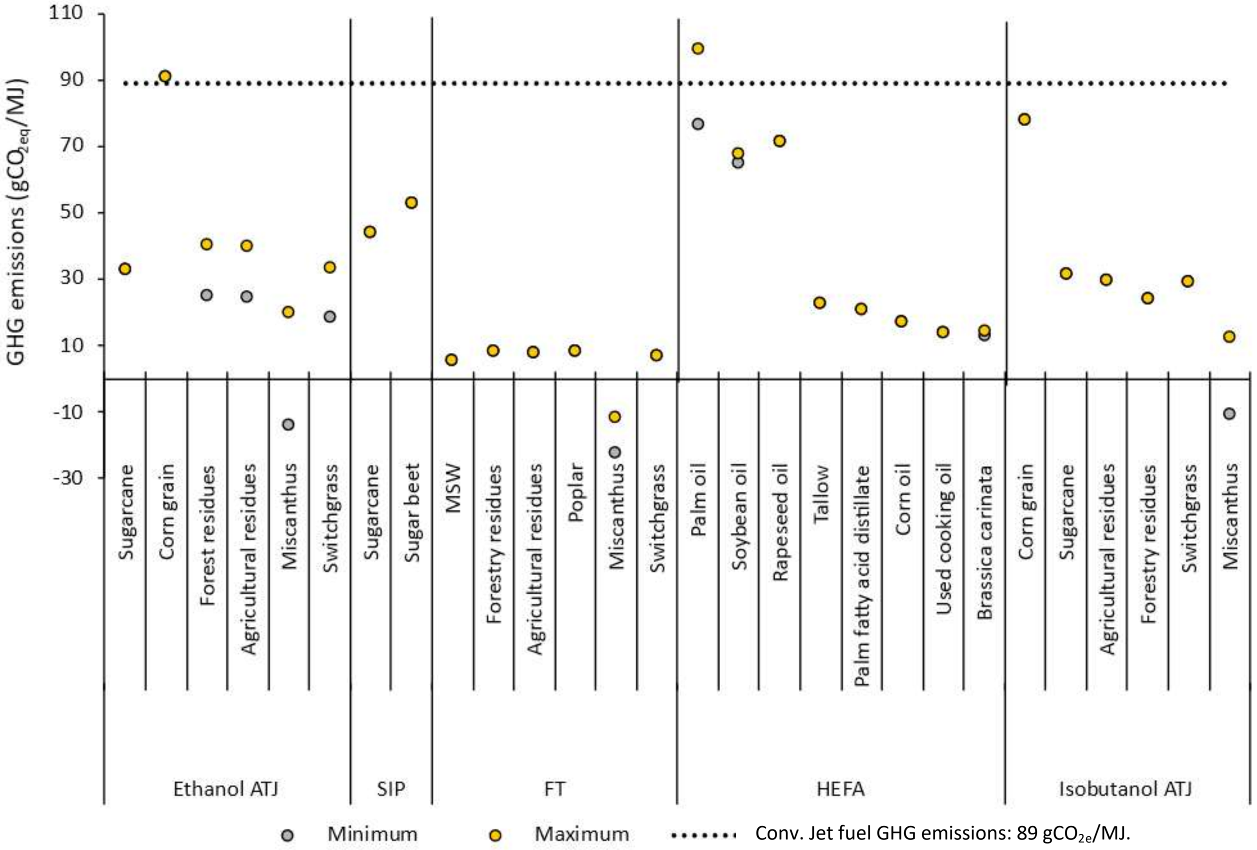


Figure based on CORSIA default LCA values for the full lifecycle, including induced land-use change, where applicable. For MSW , the non-biogenic share is assumed to be 0%, no recycling or avoided landfill emission credits accounted for.

Environmental performance and economics of SAF

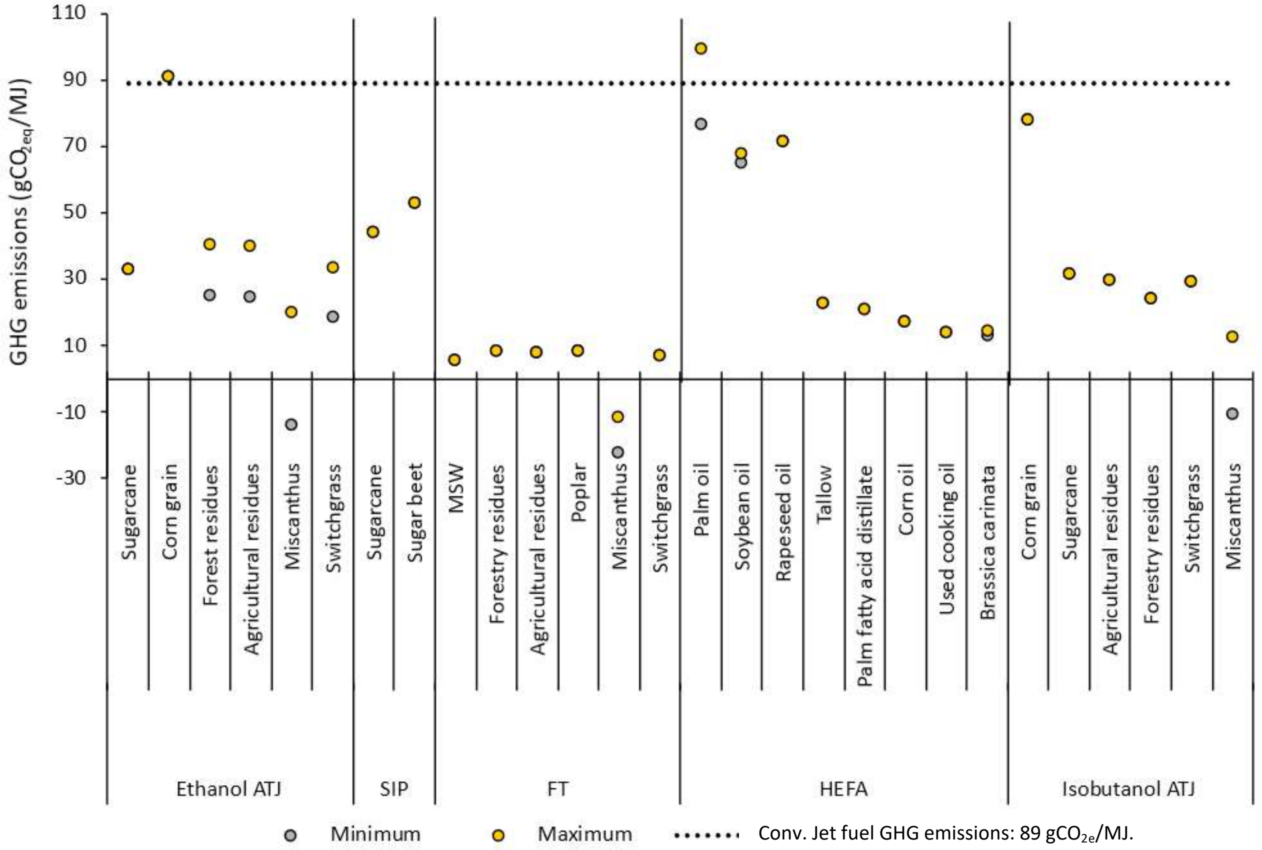
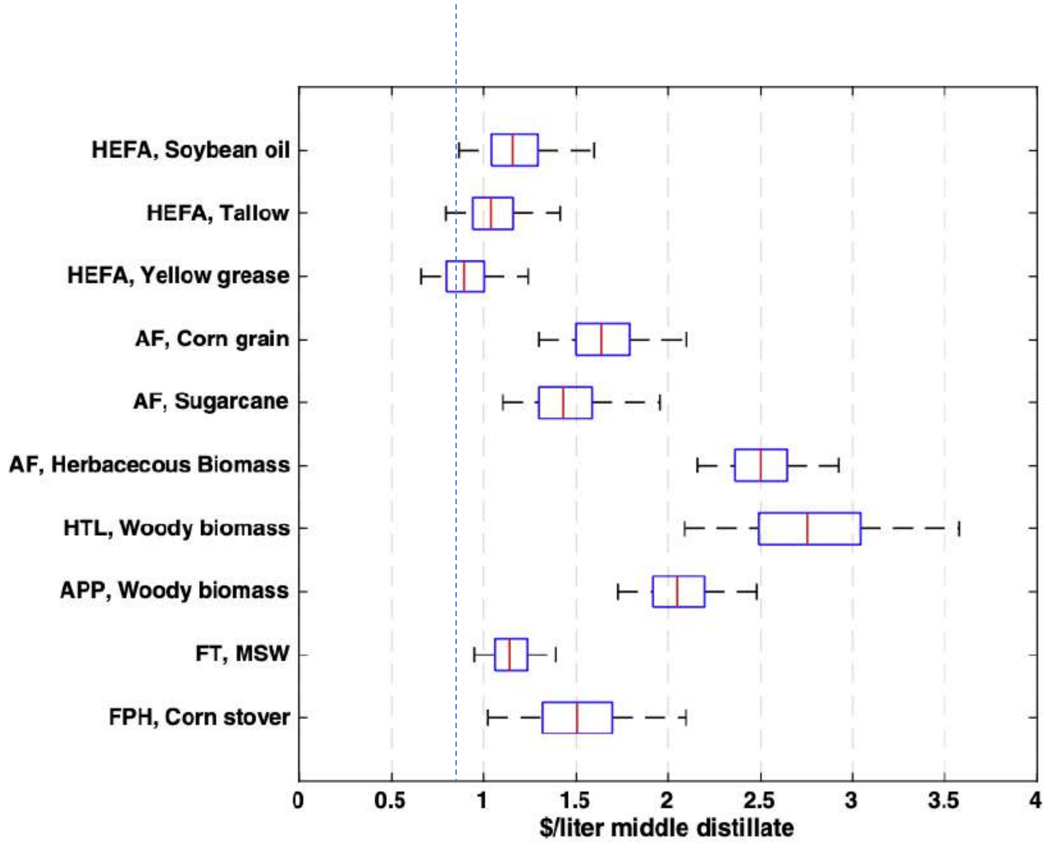


Figure based on CORSIA default LCA values for the full lifecycle, including induced land-use change, where applicable. For MSW , the non-biogenic share is assumed to be 0%, no recycling or avoided landfill emission credits accounted for.

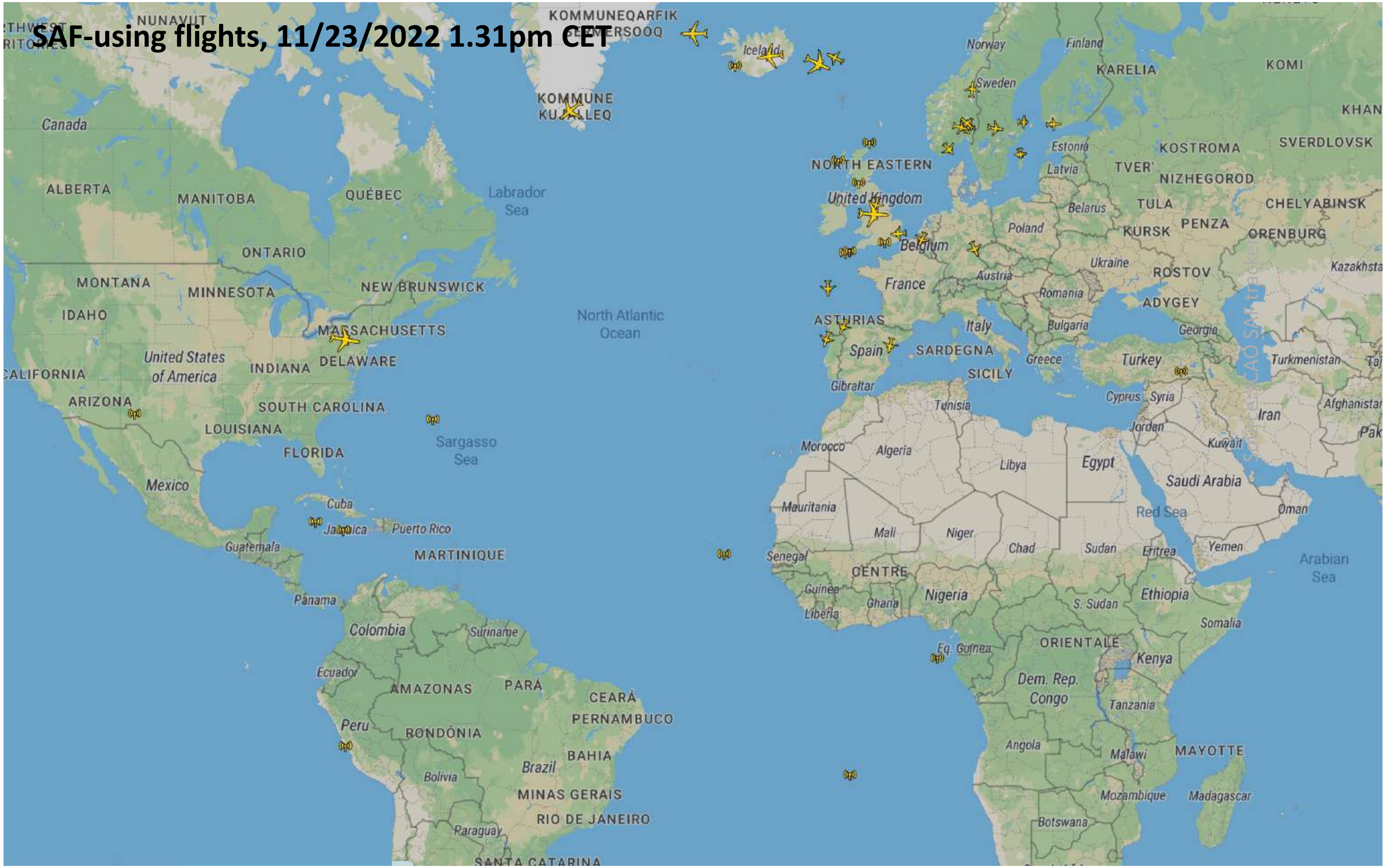
Spot-market jet A 1 price Nov 22 2022: 0.83 $/liter



Bann SJ, Malina R, et al.: The costs of production of alternative jet fuel: A harmonized stochastic assessment. Bioresource technology. 2017 Mar 1;227:179-87.

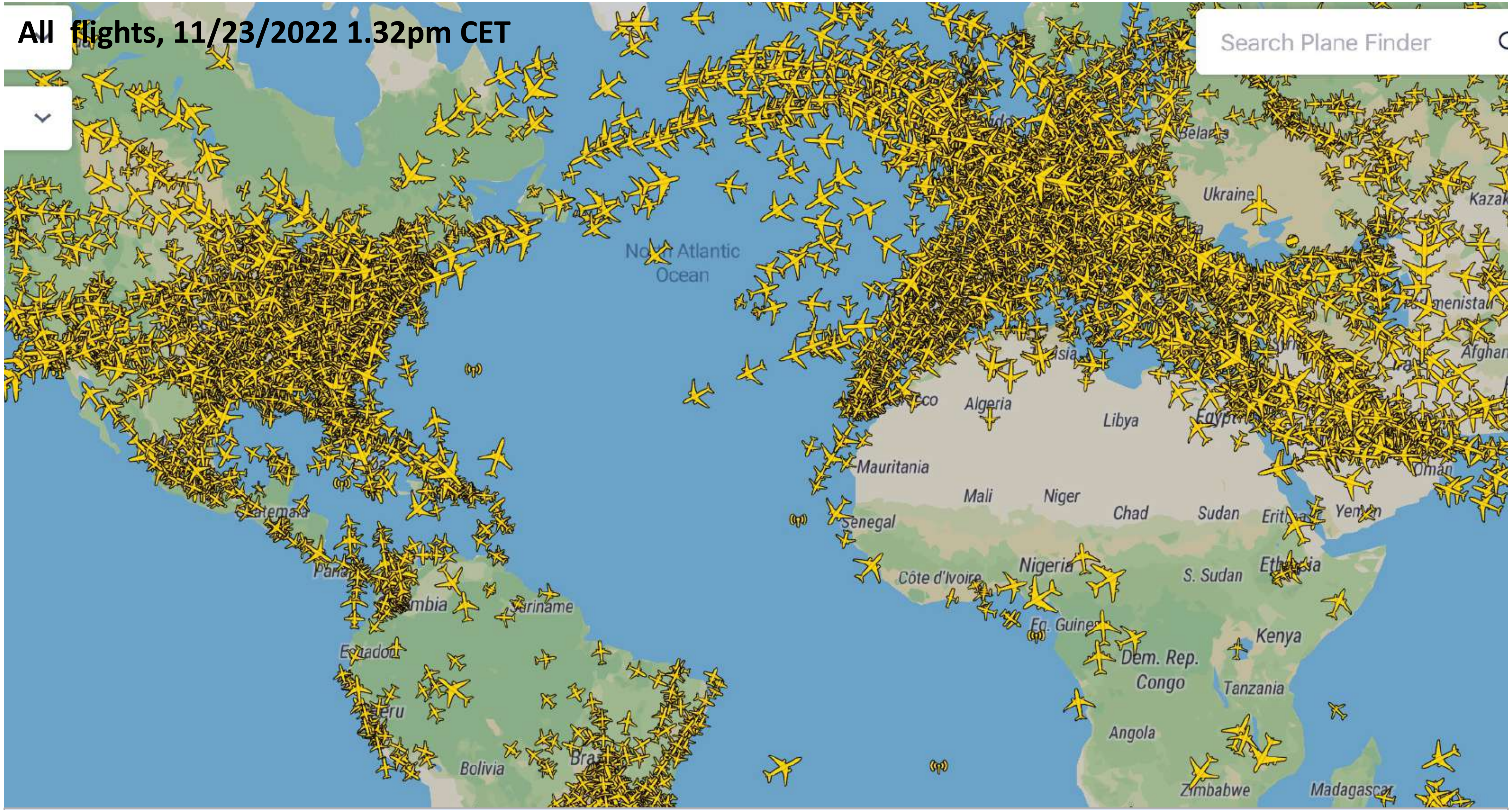
SAF shows **high GHG mitigation potential**, but is currently still **significantly more expensive** than conventional jet fuel.

Current SAF usage



SAF-using flights, 11/23/2022 1.31pm CET

Current SAF usage



All flights, 11/23/2022 1.32pm CET

Source: Planefinder.net

SAF usage in the year 2022 will be **less than 0.1% of total jet fuel consumption**.

Some recent SAF announcements

Shell aims to produce ~2M tonnes of sustainable aviation fuel per year by 2025

21 September 2021

Royal Dutch Shell announced its ambition to produce around 2 million tonnes of sustainable aviation fuel (SAF) a year by 2025. It also aims to have at least 10% of its global aviation fuel sales as SAF by 2030.

United, Honeywell invest in Alder Fuels; 1.5-billion-gallon SAF offtake agreement

10 September 2021

Air France KLM signs 210M gallon SAF offtake agreement with DG Fuels

10 November 2022

DG Fuels (DGF), a provider of cellulosic drop-in sustainable aviation fuel (SAF), signed a multi-year SAF offtake agreement with Air France KLM for up to 60,408 metric tons (21 million gallons) per year from DGF's initial plant to be located in Louisiana. The contract is expected to make Air France... Read more →

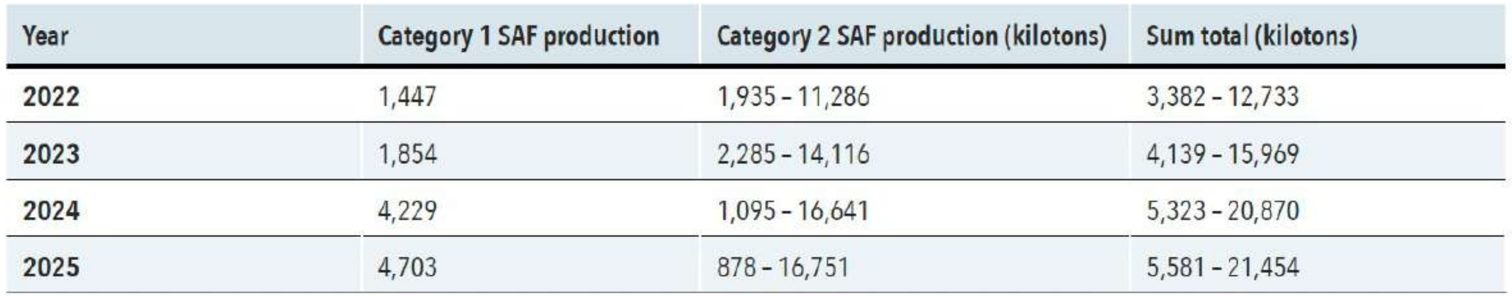
All headlines taken from:

Green Car Congress

Energy, technologies, issues and policies for sustainable mobility

Short-term SAF outlook

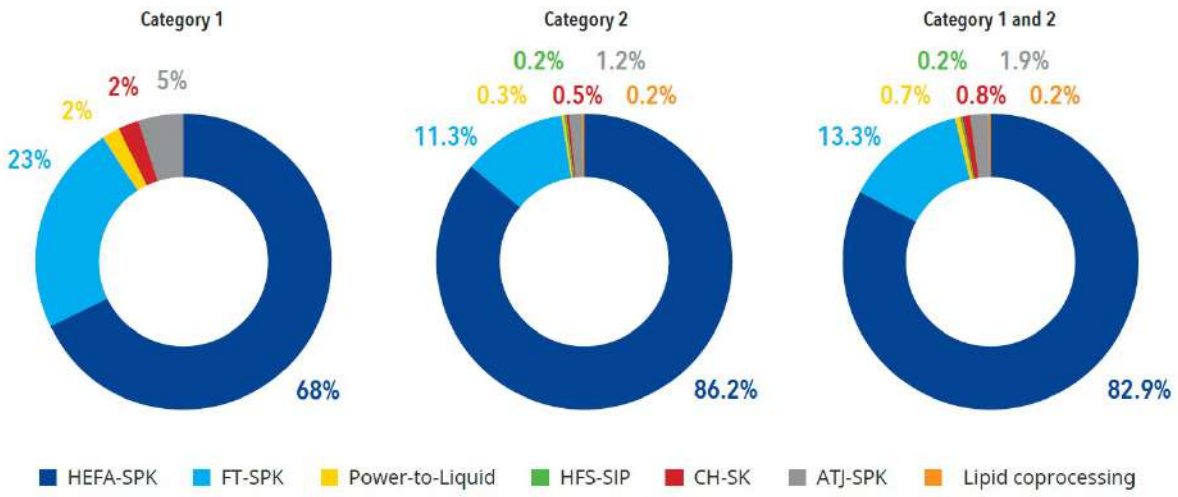
Table 3.2. Annual SAF Production 2022 to 2025 Based on Company Announcements, by Category



Year	Category 1 SAF production	Category 2 SAF production (kilotons)	Sum total (kilotons)
2022	1,447	1,935 - 11,286	3,382 - 12,733
2023	1,854	2,285 - 14,116	4,139 - 15,969
2024	4,229	1,095 - 16,641	5,323 - 20,870
2025	4,703	878 - 16,751	5,581 - 21,454

Source: Original calculations produced for this publication.
Note: Category 1 production is directly taken from the announcements. For category 2 production, a range is estimated based on the product slates from table 3.1.

Figure 3.1. Announced SAF Production in 2025, by Conversion Technology



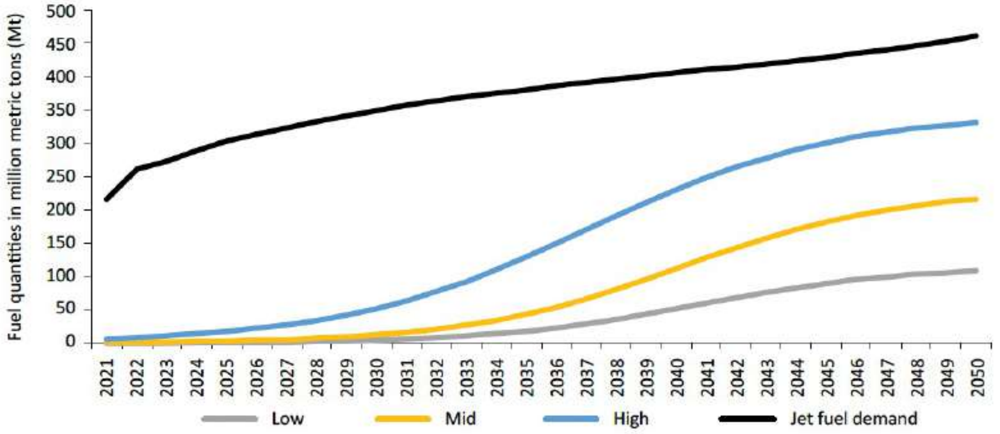
Source: Original figure produced for this publication.
Note: SAF volumes are based on announcements of fuel producers for category 1 facilities. For category 2 facilities, the pie chart is based on the high jet share from table 3.1. HEFA-SPK = hydroprocessed esters and fatty acids, synthetic paraffinic kerosene; FT-SPK = Fischer-Tropsch synthetic paraffinic kerosene; HFS-SIP = hydroprocessed fermented sugars to synthetic isoparaffins; CH-SK = catalytic hydrothermolysis synthesized kerosene; ATJ-SPK = alcohol-to-jet synthetic paraffinic kerosene.

For comparison purposes, ATAG expects total jet fuel demand in 2025 at approx. 300,000 kt, so **if all announcements were to become reality** and jet fuel would be prioritized, approx. **7% of jet demand** could be **satisfied by SAF in 2025**.

SAF ramp-up out to 2050 and associated GHG emissions reductions

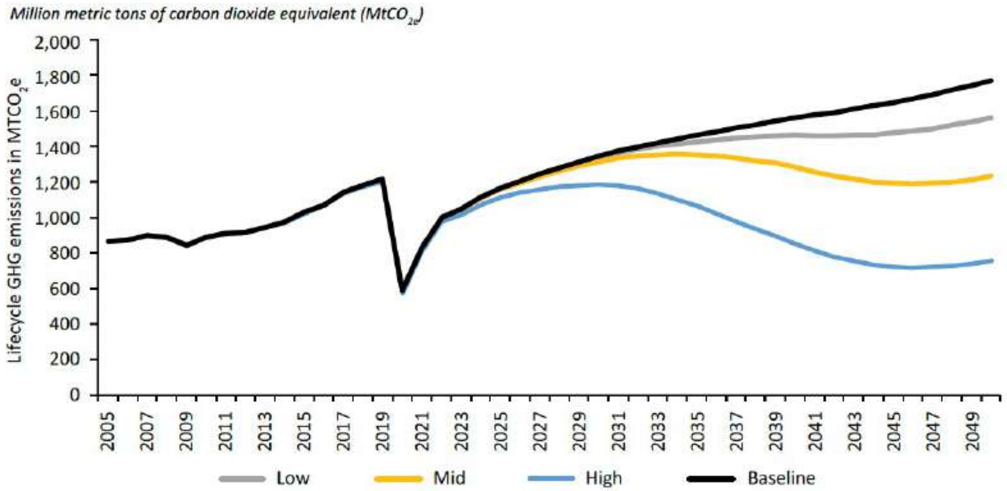
Results shown are derived from a diffusion model on three SAF production scenarios that vary with regard to the type of facilities considered, success rates, SAF share in total output, and GHG emission reductions achievable. These scenarios are indicative of a policy gradient of SAF emphasis.

Figure 3.4. SAF Production Projection, by SAF Scenario, out to 2050, Compared to Projected Jet Fuel Demand



Source: Original figure produced for this publication.
Note: Total jet fuel demand (black curve) taken from the "continuation of current trends scenario." See ATAG (2020).

Figure 3.5. Life-Cycle GHG Emissions Due to the Use of SAF Compared to a Petroleum-Derived Baseline Out to 2050

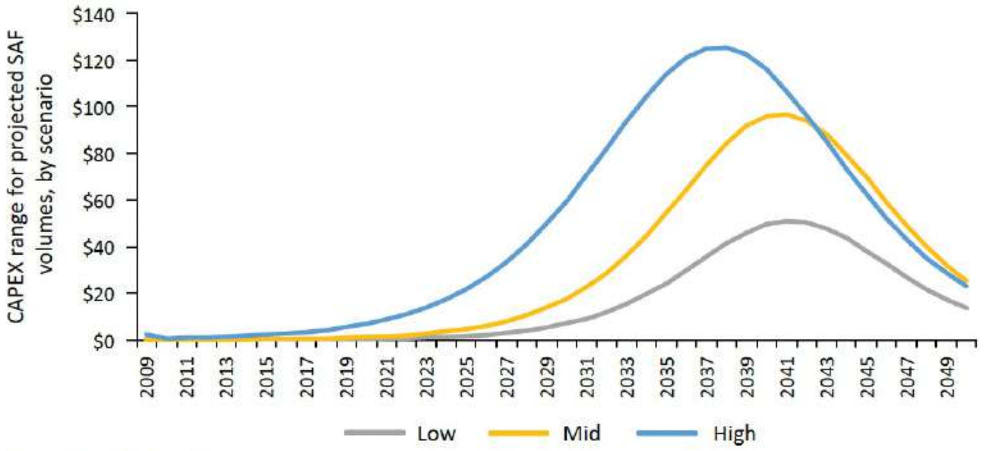


In the high scenario, GHG emissions can be stabilized at pre-COVID levels in the 2020s and be reduced to around 2010 levels due to the large-scale use of SAF. **Reduction compared to 2050 BAU: 58%.**

Required SAF CAPEX investment

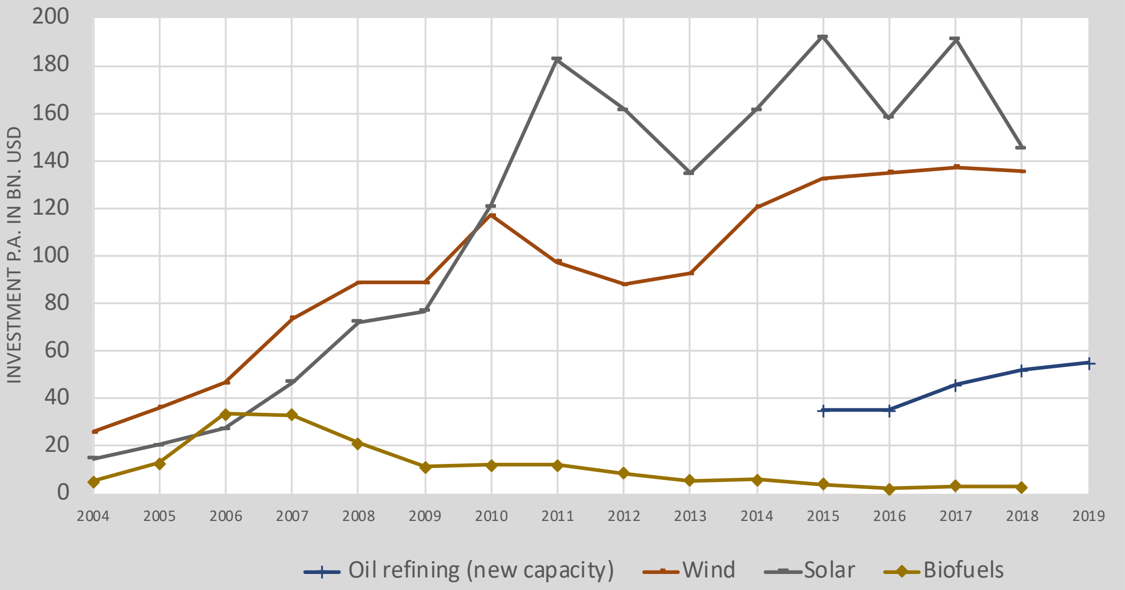
Figure 3.7. CAPEX Estimates for the Production of Projected SAF Volumes, by Scenario Out to 2050

US$, billions (2020)



Source: Original figure produced for this publication

Note: Assumes a jet fuel share in total output of 65 percent, representative of an average SAF-optimized product share (WEF 2020) and greenfield investment. Capital expenditure (CAPEX) for a nominal capacity of 2,000 barrels per day (bpd) derived as mid-point estimate of the CAPEX of SAF production pathways assessed in Bann et al. (2017).



Historical investment into energy technologies, in bn. USD

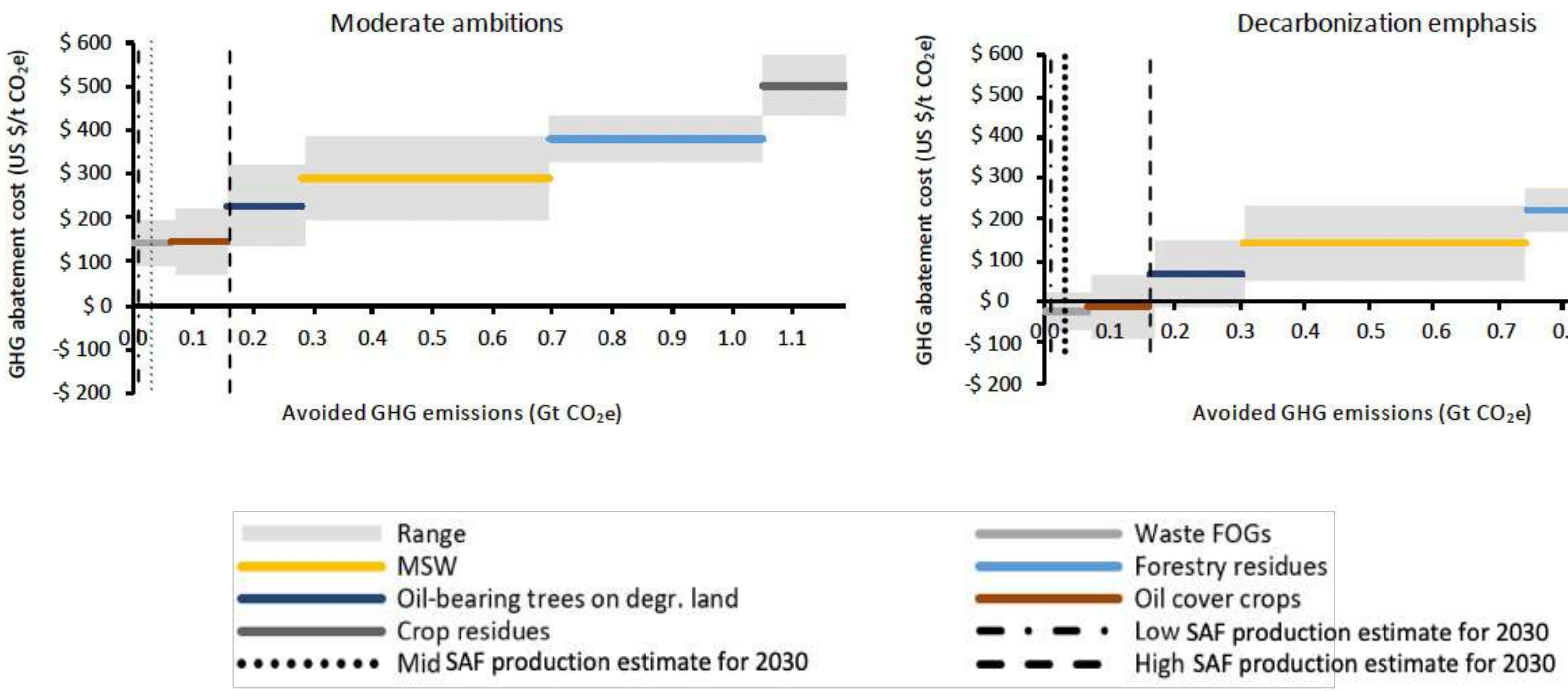
Source: Own depiction based on IEA/EIA data.

Required **investment** in the high scenario peaks at approximately **125 bn. $,** which is equivalent to more than **370 SAF producing facilities** coming online during the peak year. For comparison purposes, 2019 investment into new petroleum refining capacity was approximately 54 bn. $., peak solar energy investment was approx. 190 bn. $.

Marginal Abatement cost curves of SAF

2030

Figure 3.8. Marginal Abatement Cost Curves for SAF for 2030



CO_2 abatement costs of SAF in **2030** can be **below <100 USD** per t CO_2 for some highly mature and GHG-beneficial pathways, **in case on decarbonization emphasis**.

Marginal Abatement cost curves of SAF

2050

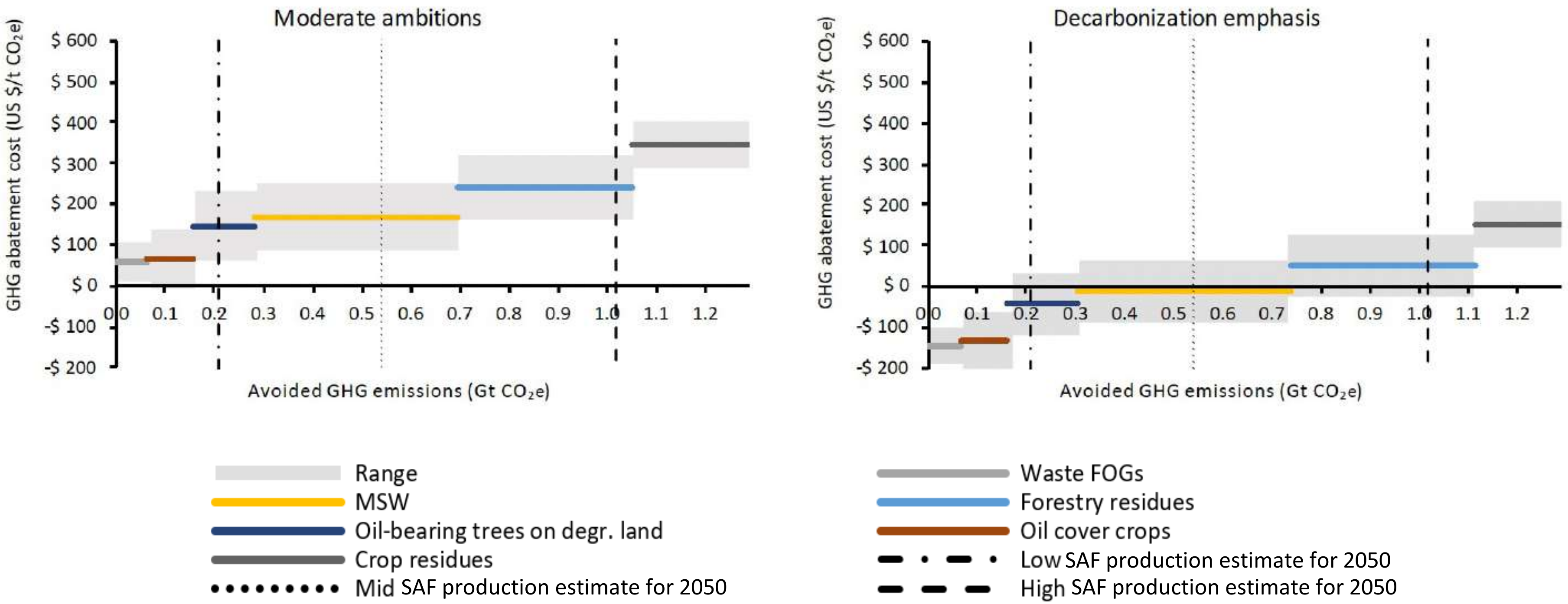
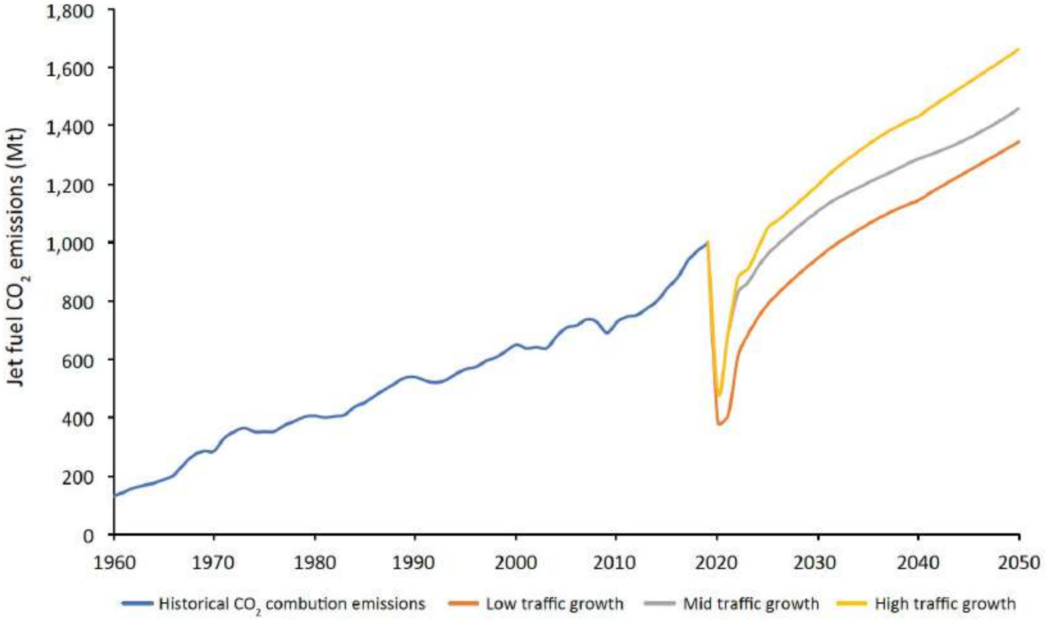


Figure 3.9. Marginal Abatement Cost Curves for SAF for 2050

By **2050**, under the assumptions of aggressive policies for mitigating climate change, large volumes of SAF could be provided at **below zero**, or **close to zero abatement costs**.

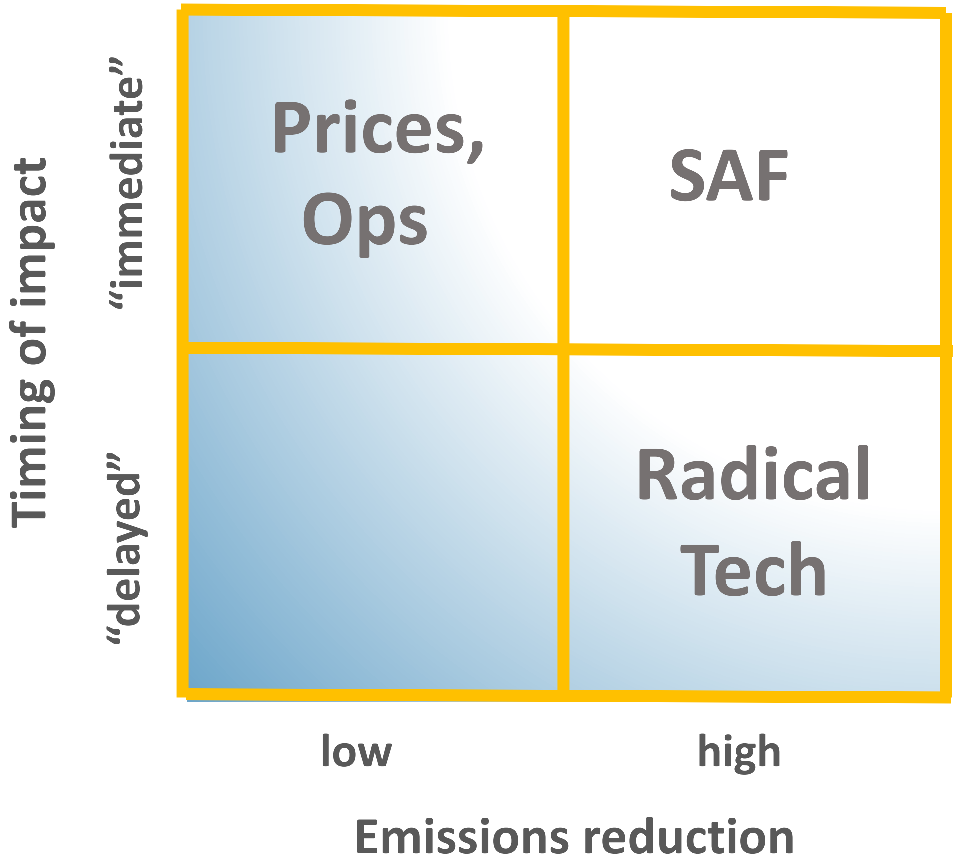
Net Zero in 2050?

Figure 1.2. CO_2 Combustion Emissions of Global Aviation: Historical Emissions and Forecast Out to 2050 Assuming a Continuation of Historical Efficiency Trends



Source: Original figure produced for this publication, with historical CO_2 emissions from 1990 to 2018 based on EIA jet fuel demand data. For the year 2019, demand data was taken from Statista. The forecast of CO_2 emissions is based on ATAG (2020a) fuel burn projections out to 2050. The analysis is purely based on jet fuel combustion-related CO_2 emissions. For all years, a CO_2 emissions factor of 3.16 kilograms of carbon dioxide ($kgCO_2$) per kilogram of jet fuel is assumed.

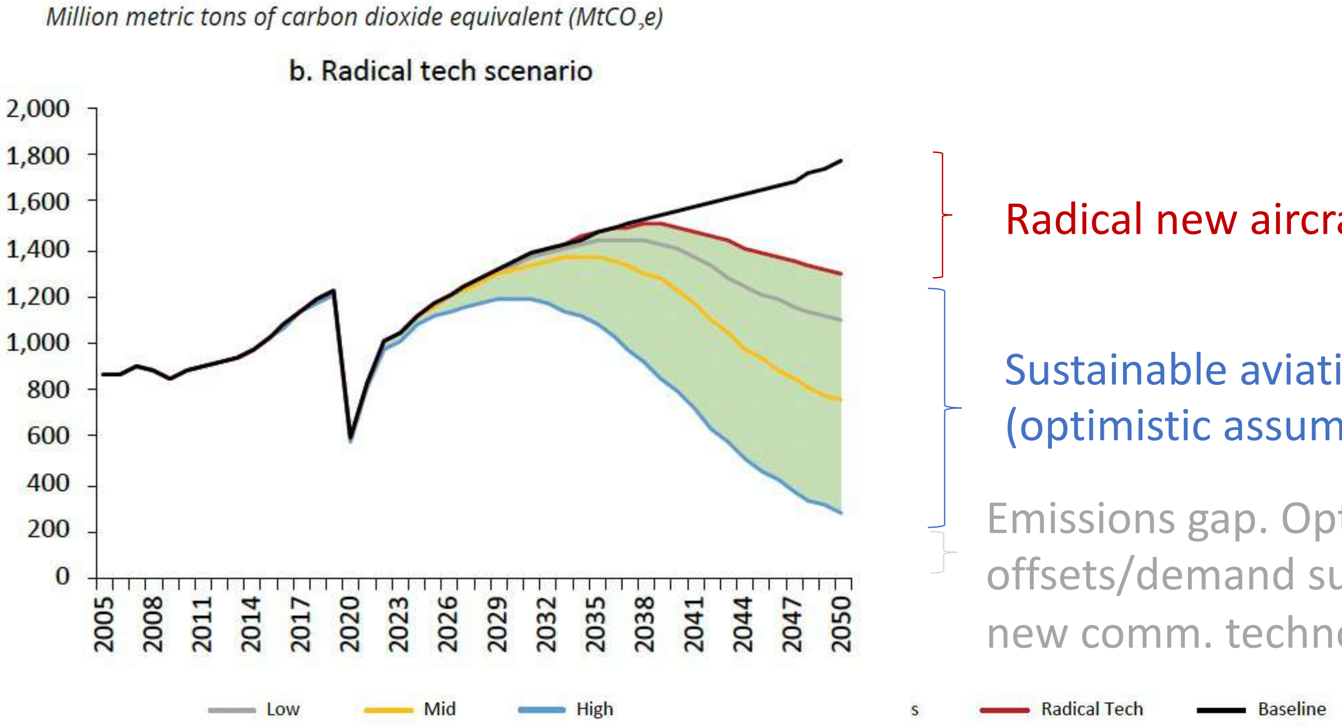
How can you get aviation down to net zero (CO_2) emissions?



Timing of impact	low	high
"immediate"	**Prices, Ops**	**SAF**
"delayed"		**Radical Tech**

Emissions reduction

Net Zero in 2050



Radical new aircraft tech plus ops improv.

Sustainable aviation fuel
(optimistic assumptions)

Emissions gap. Options: Lower GHG emission SAF/
offsets/demand suppression/
new comm. technology

Source: Original figure produced for this publication

Note: Baseline emissions 2005 to 2019 are historical life-cycle emissions. The baseline emissions from 2020 onward are derived from the "continuation of current trends" fuel demand projection by the Air Transport Action Group out to 2050 (ATAG 2020) and assume zero SAF usage and conventional, petroleum-derived jet fuel with a life-cycle GHG emissions intensity of 89 grams of carbon dioxide equivalent per megajoule (gCO_2e/MJ) of fuel. The "pushing tech and ops" scenario is derived from the ATAG1 fuel burn scenario (ATAG 2020), and the "radical tech" scenario is derived from the ATAG3 scenario, in both cases assuming again a life-cycle GHG emissions intensity of 89 gCO_2e/MJ for conventional, petroleum-derived jet fuel. No adjustments have been made for the slightly higher energy density of SAF compared to conventional jet fuel. The green areas depict the range of additional GHG emissions reductions from the use of SAF in addition to the technological and operational improvements.

Combination of **large scale deployment of SAF** together with **advanced to radical new aircraft technologies** and **accelerated operational improvements** can reduce lifecycle GHG emissions to approx. 279 to 479 million t, which is a reduction of **up to 78 % in 2050,** compared to the BaU.

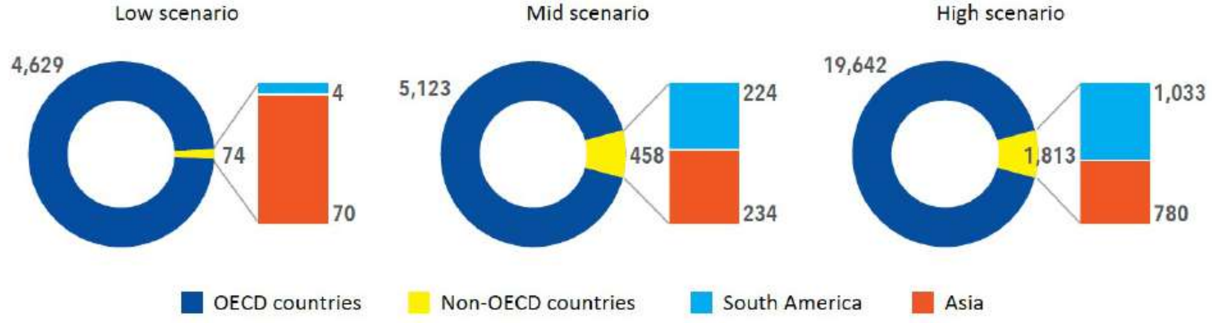
SAF in non OECD countries and World Bank Activities

SAF in non-OECD countries

Developing countries are underrepresented in **short-term SAF production** plans…

Figure 3.3. SAF Production in 2025, by Scenario, OECD and Non-OECD Countries

Kilotons

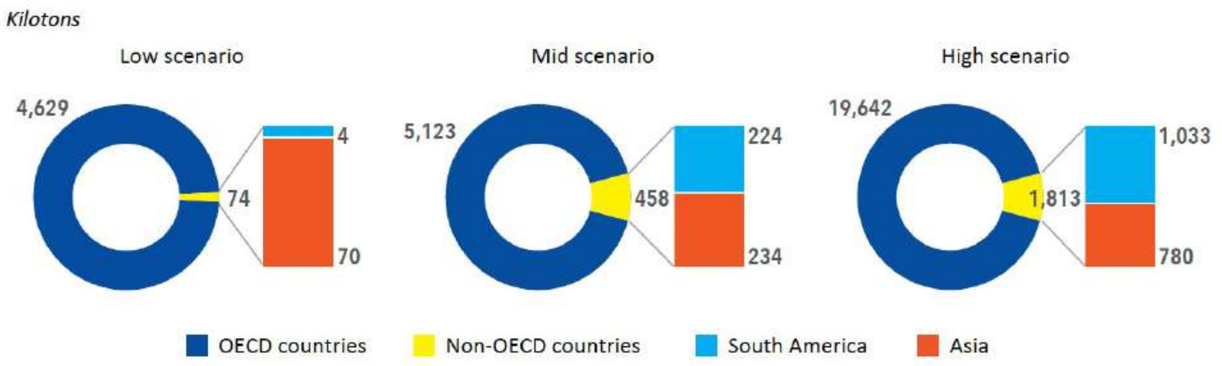


SAF in non-OECD countries

Developing countries are underrepresented in **short-term SAF production** plans…

but that is not due to a lack of potential for sustainably sourced feedstock

Figure 3.3. SAF Production in 2025, by Scenario, OECD and Non-OECD Countries



Based on Cat 1+2 announcements, assuming high jet share in product slate

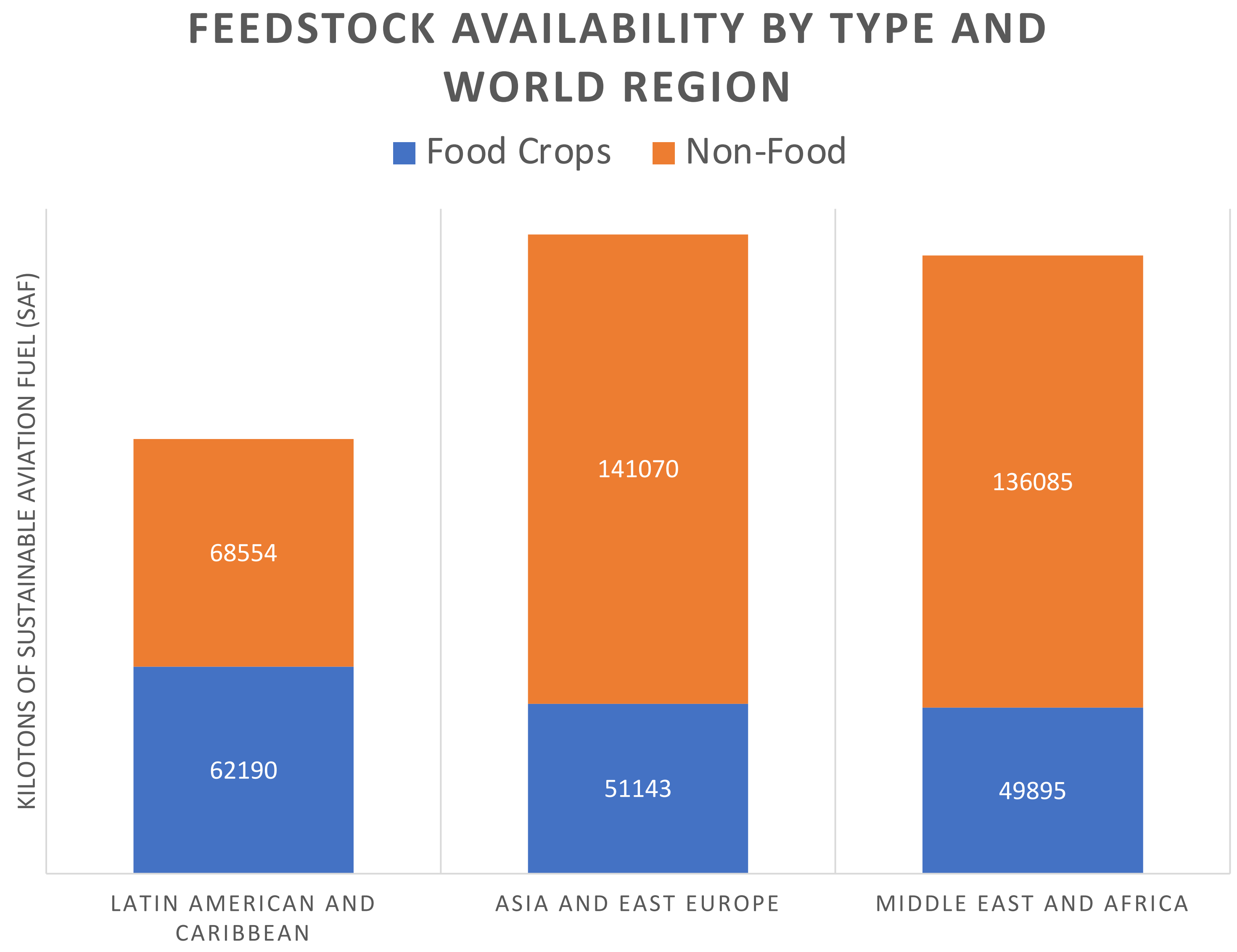
Feedstock production potential, by type, 2050, in kt. SAF

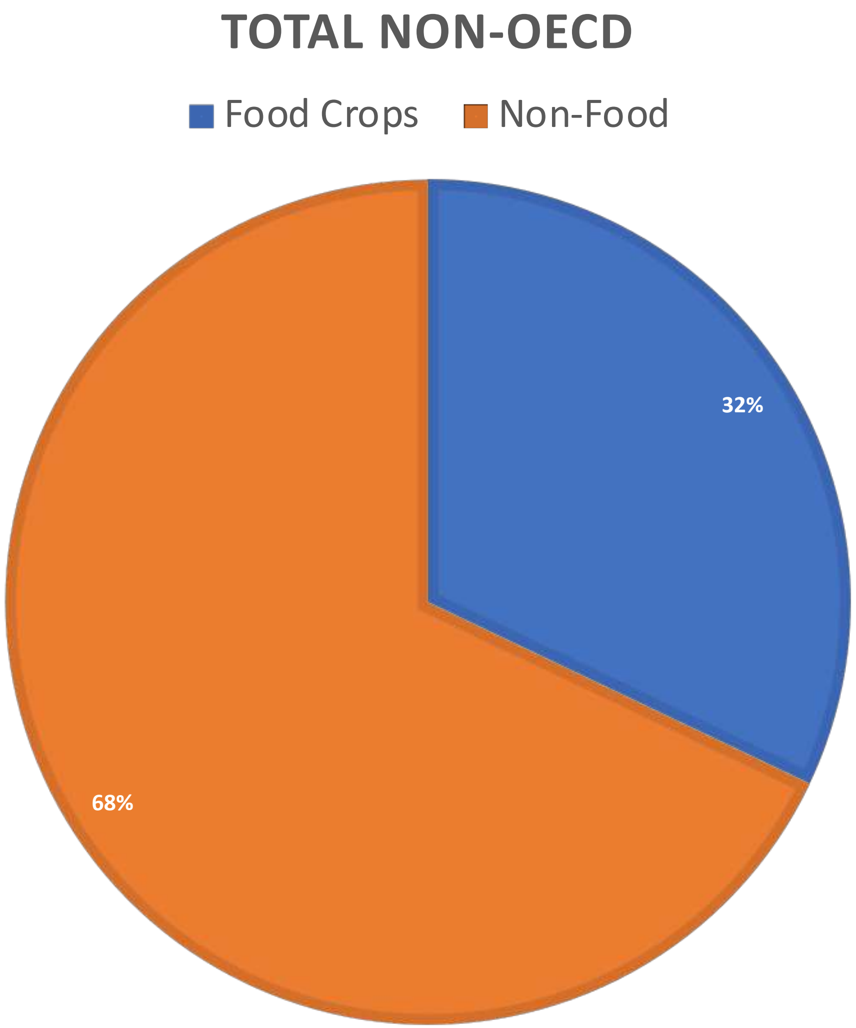
Feedstock type	Total non-OECD
Food crops **(starchy, sugary, vegetable oil crops)**	163,229
Food crop residues	57,557
Forestry residues	16,647
Lignocellulosic energy crops	166,370
MSW	89,281
Waste FOGs	15,853
Total for all feedstocks	508,937

Data derived from method published in Staples, Malina et al. Aviation CO_2 emissions reductions from the use of alternative jet fuels. Energy Policy. 2018 Mar 1;114:342-54.

"Missed" opportunity, as the production of SAF could not only generate new jobs and increase incomes, it could also improve environmental and health conditions due to SAF-induced improvements in waste management practices.

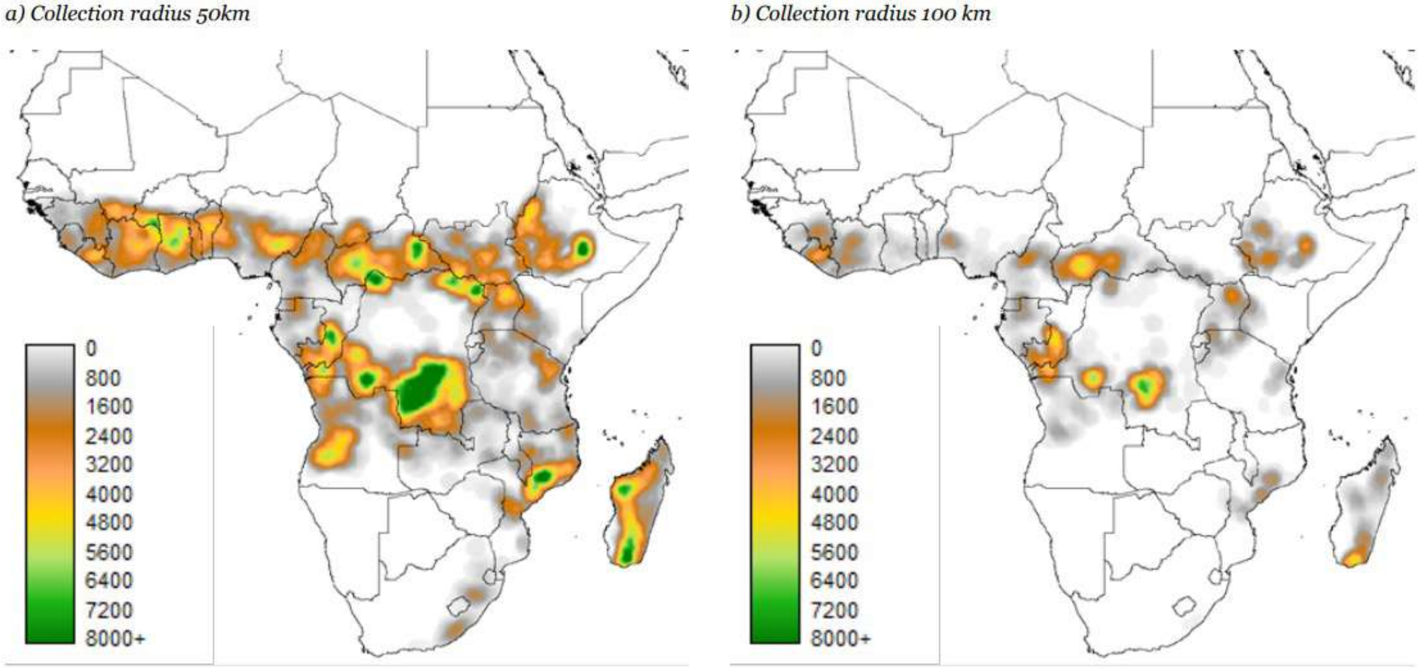
Feedstock Landscape in Non-OECD Countries





SAF Landscape in Africa

Figure 4.19. Cumulative biofuel feedstock potential from REMAIN land in a circle of 100 km, 2010


a) Collection radius 50km

b) Collection radius 100 km

Note: The map shows for each pixel the estimated cumulative potential production (in TJ biofuel equivalent) using all crop biomass of (a) sugarcane and miscanthus, and (b) sugarcane only, from prime, good and moderately suitable rain-fed REMAIN land subject to GHG Criterion 1 within a circle of 100 km. One million litres sugar/starch based biofuel is equivalent to 21.6 TJ (LHV).

3 minute read · April 14, 2021 3:52 AM EDT · Last Updated 2 years ago

South Africa's Sasol forms consortium to produce sustainable aviation fuel

Reuters

JOHANNESBURG, April 14 (Reuters) - South Africa's Sasol (SOLJ.J) has formed a consortium with companies including chemicals multinational Linde (LIN.N), to bid for production of sustainable aviation fuel under Germany's H2Global auction platform, it said on Wednesday.

The consortium, which also includes German renewables player Enertrag and South African construction and investment company Navitas Holdings, has notified the German government of its intention to bid via the double auction mechanism, Sasol said.

Barriers for SAF production in non OECD-countries

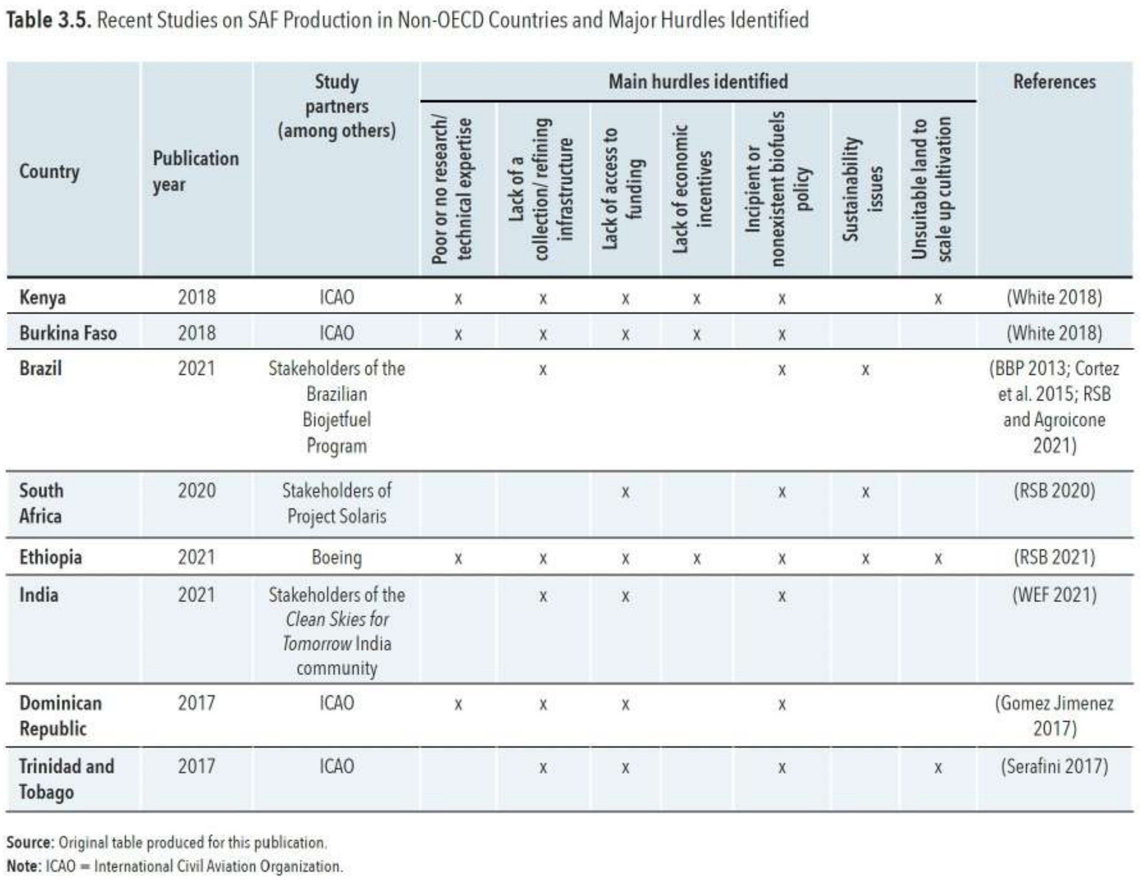


Table 3.5. Recent Studies on SAF Production in Non-OECD Countries and Major Hurdles Identified

Country	Publication year	Study partners (among others)	Main hurdles identified: Poor or no research/ technical expertise	Lack of a collection/ refining infrastructure	Lack of access to funding	Lack of economic incentives	Incipient or nonexistent biofuels policy	Sustainability issues	Unsuitable land to scale up cultivation	References
Kenya	2018	ICAO	x	x	x	x	x		x	(White 2018)
Burkina Faso	2018	ICAO	x	x	x	x	x			(White 2018)
Brazil	2021	Stakeholders of the Brazilian Biojetfuel Program		x			x	x		(BBP 2013; Cortez et al. 2015; RSB and Agroicone 2021)
South Africa	2020	Stakeholders of Project Solaris			x		x	x		(RSB 2020)
Ethiopia	2021	Boeing	x	x	x	x	x	x	x	(RSB 2021)
India	2021	Stakeholders of the *Clean Skies for Tomorrow* India community		x	x		x			(WEF 2021)
Dominican Republic	2017	ICAO	x	x	x		x			(Gomez Jimenez 2017)
Trinidad and Tobago	2017	ICAO		x	x		x		x	(Serafini 2017)

Source: Original table produced for this publication.
Note: ICAO = International Civil Aviation Organization.

> *"The challenge of the low-carbon transition starts with tackling the chronic lack of financing for productive investments that plagues most developing countries and the need to find new sources of financing and to leverage existing ones."*
> 2015 World Bank Report

One 2000 bpd MSW FT plant = 500 million USD = investment needs for Abidjan to Ouagadougou transport corridor, or the Ruzizi III Hydropower Project.

> *"The industry shares a broad agreement that the strong growth in announcements of SAF projects in OECD countries is largely driven by actual or expected policies implemented in those countries to speed up the decarbonization of the economy. However, very few non-OECD countries have introduced—or are actively pursuing the introduction of—SAF-incentivizing policies, and the lack of such incentives is regularly identified as a major barrier."*
> 2022 World Bank Report

World Bank's Effort to Decarbonize Transport

- Developing countries face a **transport financing gap of up to $944billion** annually through 2030 (WRI2016)

- The WB has set up **the Global Facility to Decarbonize Transport (GFDT)**

- The GFDT will support low carbon mobility and resilient transport solutions in three ways:

    - **Project design and implementation,**
    - **Research and data, and**
    - **Capacity building.**

- **Ambition is to raise $200 million overa10-year period** to invest in low-carbon transport solutions.

- Together with our partners **we have raised $9million for this initiative**.

- We're yet to raise aviation specific funding, but efforts are underway

Thank you for your attention !

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mabate@worldbank.org