Title

Low-Carbon Fuels for Aviation and Maritime Transport: Insights from Two Mirroring Workshops Held in the US and Europe

Authors

Cazzola, Pierpaolo
Murphy, Colin W

Publication Date

2023-05-01

DOI

10.7922/G2SB442Z

UCDAVIS
European Transport and Energy Research Centre
Institute of Transportation Studies

Supported by
Breakthrough Energy

Low-Carbon Fuels for Aviation and Maritime Transport

Insights from Two Mirroring Workshops Held in the US and Europe

May 2023

Pierpaolo Cazzola
Director, European Transport and Energy Research Centre,
Institute of Transportation Studies, University of California, Davis;
Global Research Fellow, Center on Global Energy Policy
School of International and Public Affairs, Columbia University

Colin Murphy
Deputy Director, Policy Institute for Energy, Environment, and the Economy,
University of California, Davis

Table of Contents

Cover photos: ship by Ian Taylor, airplane by Kevin Woblick, both on Unsplash

Reference No. UCD-ITS-RR-23-43
doi: 10.7922/G2SB442Z

List of Acronyms

CCS	carbon capture and sequestration
CCUS	carbon capture, utilisation, and storage
CGEP	Center on Global Energy Policy
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DAC	direct air capture
e-fuel	electrofuel
ETS	Emission Trading Scheme
FOGs	fats, oils, greases
GHG	greenhouse gas
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
IRA	Inflation Reduction Act
ITC	Institute of Transportation Studies
LCFS	Low Carbon Fuel Standard
MARAD	US Maritime Administration
MEPC	Marine Environment Protection Committee
MRV	monitoring, reporting, and verification
RD&D	research, development, and deployment
RFS	Renewable Fuel Standard
SAF	Sustainable Aviation Fuels

Introduction

On February 27 and March 16, 2023, Columbia University's Center on Global Energy Policy (CGEP) and University of California's Institute of Transportation Studies (ITS) convened roundtable discussions—the first in New York and the second in Brussels—to discuss options for the decarbonization of aviation and maritime transport (details on the agenda and the speakers are available in the Annex). These two sectors are likely to remain dependent on molecules, even in an electrifying world, but they will still require a shift to a decarbonized fuel mix, supplemented by improved energy and system efficiency.[1]

The workshops had the same agenda structure, with initial keynotes on framing conditions for policy action on climate and energy, targeted sessions covering aviation and maritime transport separately, and then a joint policy discussion. The events explored:

- The role of different energy options for the shipping and aviation sectors: common needs and key differences.
- Challenges and opportunities for the deployment of low-carbon fuels in these modes.
- Policy approaches currently in place to support low-carbon fuels, both domestically—with a focus on North America and Europe—and internationally—covering activities of the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO).
- Policy updates required to accelerate low-carbon fuel deployment, mitigate investment risks, and minimise trans-Atlantic frictions.

The workshops brought together representatives from international organizations, national administrations, aircraft manufacturers, aviation and shipping industry associations, ship owners and operators, engine manufacturers, energy companies and industry associations, classification societies, multilateral development banks, investor entities, think-tanks, non-governmental organizations, and academia. This summary focuses on the main topics covered during the lively discussions at both events.

Aviation: which fuels for a low-carbon future

Most aviation energy use and greenhouse gas (GHG) emissions originate in high-income countries. In Europe and North America (Canada and the United States), aviation accounts for roughly one eighth to one tenth of all domestic GHG emissions occurring in transportation. The majority of fuel burn takes place at cruise altitude (80% for domestic flights, 90% for international), and from aircraft with more than 100 seats (accounting for 96% of the total).

Traffic forecasts point consistently towards a continued rebound of activity (post COVID-19). Satisfying long-term demand for air travel while reducing emissions will require the decoupling of activity, energy use, and GHG emissions. There is consensus around the need for urgent decarbonization in the sector and, in the absence of contraction of activity, a combination of operational improvements, energy efficiency enhancements[2] (including through fleet renewal, especially from an aviation industry perspective), and a shift towards low-carbon fuels.

Jet fuel has a unique combination of properties that enable aircraft to safely operate.

[1] If a credible and verifiable measurement, reporting and verification framework is developed and if technology progresses, these developments would also complement carbon offsets.

[2] Aircraft manufacturers have a strong focus on aircraft that is significantly more fuel efficient (30%), which is also supported by publicly funded research (e.g., at NASA, the US National Aeronautics and Space Administration).

Sustainable Aviation Fuels (SAFs) are "drop-in" liquid hydrocarbons with similar performance and safety profiles as conventional jet fuel. SAFs are well suited for existing aircraft and already existing fuel supply/distribution infrastructure.[3] Due to these characteristics, there is consensus that SAFs are key technologies for the decarbonisation of aviation, especially for long distance flights. At the same time, it is difficult to see clear opportunities for a spontaneous transition, as SAFs are unlikely to be cheaper than the fossil fuel benchmark. Due to this significant challenge, policy is necessary to push solutions forward: waiting for their roll out without policy action is consensually seen as not sufficient to achieve critical climate and sustainability requirements over the next 2 to 3 decades.

Sales volumes of SAFs are still a very small of total fuel use in aviation—less than 1%. Despite this, expectations point clearly towards an increase. A key data point flagged in this context is the objective of the Clean Skies for Tomorrow Coalition of the World Economic Forum to reach 10% SAF share in global jet fuel supply by 2030. Other near-term signals pointing in this direction, both in Europe and North America, come from the growth of long-term offtake agreements for SAF supplies.

Currently, SAFs are mainly produced in developed economies.[4] Emerging economies are also underrepresented in short-term SAF production plans (10% by 2025). Supporting a shift in investment will be important for low- and medium-income countries (LMICs) not to miss significant economic, environmental, and social benefits of SAF production.

SAFs can be produced from both biogenic and non-biogenic feedstocks, though only biogenic were deployed at any significant scale to date. The development of feedstocks is one of the most pressing matters for a scale up in biogenic SAF supply. Most SAFs are currently produced via the hydrotreatment of fats, oils, and greases (FOGs).
Other certified pathways convert:
i) starches and sugars via fermentation to alcohol, which is then synthesized into jet hydrocarbons (Alcohol-to-Jet synthesis, or ATJ);
ii) lignocellulosic feedstocks (wood, energy crops, some forms of municipal solid waste and residues from agriculture and forestry) through gasification and Fischer Tropsch synthesis.[5]

Food crop-based feedstocks were indicated by some participants as relevant resources due to the capacity to scale them in the near-term. Others flagged that they yield only modest GHG benefits and, like other crop-based fuels, also come with significant land use requirements. Organic waste and purpose-grown energy crops[6] were flagged as relevant for the longer-term[7]. Novel feedstocks (in particular carinata, an oilseed feedstock that can be grown without competing against food crops[8]) were also

[3] SAF blends are currently only approved to 50%, for reasons related with technical compatibility, namely to allow seals to swell in older engines and prevent fuel leaks. Expectations of a progressive adaptation of these in new engines and the possibility to increase blending to 100% are consensual.

[4] For the United States, recent estimates point to almost 60 million litres procured in in 2022, 30 million of which are from imports.

[5] In Fischer Tropsch synthesis, carbon monoxide and hydrogen are converted into liquid hydrocarbons.

[6] Dedicated energy crops are grown specifically for their utilization in energy conversion processes.

[7] However, If introduced on a large scale, energy crops could affect other land uses, the prices of other crops, and trade in agricultural products.

[8] As cover crop (i.e. as a crop intended to preserve the soil, grown in addition to a primary crop), carinata is seen as an option that could support storing carbon in soil without competing for land with food production.

signalled by a participant as having a significant potential.[9]

Electrofuel (e-fuel) technologies combining hydrogen from low-carbon sources (primarily renewable electricity) and carbon from direct air capture (DAC) were also discussed in the workshop as part of the solution for SAF production, despite challenges related to large energy requirements and possible limitations in renewable energy availability.[10] Bio- and e-fuel technologies are also not mutually exclusive but can be complementary. Electricity and biogenic carbon streams can be part of power and biomass to liquids (PBtL) processes, also suitable for SAF production.[11]

The reliance on pathways based on abundant resources is consensually seen as a key characteristic for SAF to play a central role in the decarbonization of aviation. SAF made from used cooking oil, for example, is widely regarded as an extremely low-carbon form of SAF, however production of used cooking oil is far too limited to make a large contribution to global aviation fuel supplies.[12] It is crucial that SAF production has a demonstrated ability to reduce GHG emissions on a life-cycle basis: this is far from being achieved and remains unclear for a range of production pathways. In particular, some workshop participants pointed to a number of examples being questionable from a sustainability perspective (with specific reference to food-based pathways, including but not limited to FOG-based biofuels). Other challenges flagged during the discussion include investments and technologies that failed to succeed in the past (with reference to lignocellulosic production pathways).

There is consensus on the need to consider other technologies, adding to operational and efficiency improvements and competing with SAF to decarbonise aviation. Regarding these, batteries are seen as having a role in short distance and smaller aircraft (with options in this area being actively pursued in countries such as Norway). Hydrogen is seen as a relevant possibility, thanks to high gravimetric energy density. On hydrogen, participants referred to examples of aircraft manufacturers and start-ups actively developing dedicated technologies. On the other hand, the discussion also flagged consensual challenges due to leakage, metal embrittlement, the need for extremely low temperature for storage in liquid form, significantly lower (by a factor 4) volumetric density vs. hydrocarbon fuels and major changes for aircraft and land-based infrastructure for energy distribution, transport, and storage.

Which options for maritime transport

The combination of operational improvements, energy efficiency enhancements, and a shift towards low-carbon fuels is also critical in maritime transport. The case for enhanced energy efficiency improvements is especially strong in shipping, given the significant and cost-efficient potential readily available,

[9] Biofuels may also move from use in road vehicles towards aviation and maritime transport, as road-vehicles electrify.

[10] Limitations in renewable energy availability do not exclude significant renewable electricity potential, especially in specific global geographies: the example of Chile has been specifically flagged by some of the participants.

[11] Some participants also pointed to the fact that sustainably produced bio-based resources may be more available in specific geographies, while not in others, pointing towards the need to tap resources where they are available.

[12] Increased reliance on used cooking oil can also create perverse incentives, e.g. making used cooking oil more expensive than virgin oils, inducing demand increases for the latter (with indirect impacts on land use change).

including via retrofits.[13] This is an aspect that deserves greater attention and policy ambition.

Battery electric is seen as an option that is well suited for workboats and ferries, especially for relatively short distances. Beyond these cases and energy efficiency improvements (including the possibility of contributions from wind assistance), there is consensus that low-carbon fuels are necessary. Due to infrastructure-related constraints, these fuels need to be drop-in in the near-term. There is more potential to transition to novel alternative fuels in marine transport than in aviation, due to the less strict technical requirements they must satisfy.

For near-term options, it is important to look at what can be done today to reduce the carbon intensity of the fuels. As in the case of SAF, the transition is particularly challenging, as it is difficult to see—especially in the absence of changes in fuel quality requirements[14]—clear opportunities for making low-carbon shipping fuels cheaper than the fossil fuel benchmark.

Prospects for future developments point to a diversity of candidate fuels. Options presented in a review of different scenarios range from cases highly reliant on biofuels to cases with a major uptake of non-biological fuels, including methanol, ammonia, and synthetic hydrocarbons. As in aviation, biofuels are generally more technologically mature than other options and have achieved higher-scale production to date. Hydrogen is seen as less likely than its derivatives, due to the same challenges flagged for aviation (leakage risks, metal embrittlement, extremely low temperature storage, lower volumetric density, changes to ships and infrastructure).

As in the case of the SAF debate, bio- and e-fuel technologies are seen not as mutually exclusive but combinable, as fuel yields from biogenic carbon could be significantly increased by combining it with hydrogen in power and biomass to liquid processes. Despite near-term relevance, underlined by some participants, liquefied natural gas (LNG) is not featured in net-zero compliant scenarios, except for cases considering a switch to bio- or synthetic gas.[15]

Despite the diversity of options,[16] shipping fuels are expected to be primarily used in internal combustion engines, which have high energy efficiency ratings (notwithstanding improvements available, e.g., from waste heat recovery). Ship propulsion is therefore expected to be subject to an evolution. Engines have been or are being developed to work with different fuels.[17] New builds of maritime vessels are increasingly expected to be dual fuel ships, However, there will be a need to consider

[13] A unique feature of the marine industry is the long duration of the assets (30–40 or even 50 years): retrofits are important, in this context.

[14] Bunker fuels for maritime transport are well known to be "the bottom of the barrel," consisting of material that would require extensive and expensive additional processing to be used in other applications. Bunker fuels may also contain heavy metals and other contaminants that would otherwise have to be removed and disposed of. Tighter fuel quality requirements would necessitate some of these expenses and thereby make cleaner alternatives more economically viable.

[15] A key issue with liquefied natural gas is that it is not capable of delivering deep emission savings on a life cycle basis vs. an oil-based benchmark.

[16] One peculiarity underlined during the discussion for the shipping sector is the larger number and range of stakeholders with respect to aviation. This makes its ecosystem more diverse and can be an element adding more challenges to reach consensus.

[17] The flexibility offered by dual or multi-fuel engines, or engines ready for retrofits, is also seen as an important feature for long-lasting assets.

tradeoffs between multiple fuel tanks and cargo space availability.[18]

As shipping plays a significant role to carry energy needed in the rest of the economy, low-carbon energy carriers needed in other sectors of the economy may influence the choice of fuel also used in a decarbonizing maritime transport. One workshop participant argued that this is a reason why increased trade of ammonia—already seen as a viable low-carbon energy carrier by Germany (which developed two major ammonia import terminals) and Japan (which has a policy to co-fire ammonia in coal power plants)—will help making a case for it to also be used as a shipping fuel. Scenario analyses also point to sizable reliance on ammonia, which can be used in multi-fuel engines, with needs in shipping potentially comparable to current ammonia production.

Safety considerations are also critical when looking at alternatives to fossil fuels. A participant called for debunking issues about ammonia and safety, referring to the wide use of ammonia as a fertilizer and industrial chemical, to major amounts of ammonia already being traded, even in inland waterways. The International Energy Agency points to half of marine fuels in its net-zero scenario being low-carbon ammonia. Other participants agreed that ammonia will likely play a role in the decarbonisation of shipping, but they flagged that we are at an early phase of development, requiring further work on analyses of how ammonia impacts marine life and the need to improve capacity to address and handle ammonia spills.

Methanol was also discussed as a key alternative to ammonia for shipping, as a shipping fuel and also a feedstock for the production of fuels that could be used in aviation.[19] The discussion underlined that, as in the case of ammonia, the low-carbon production of methanol requires large amounts of renewable electricity. Unlike ammonia, producing methanol requires a source of carbon, either biomass or large-scale CO_2 capture (itself an energy-intensive process).

Both methanol and ammonia are commonly used industrial chemicals, produced at large scale already. While a shift in their production to low-carbon pathways would still be necessary, workshop participants mentioned that using one or both of them as shipping fuels would create a larger, more liquid, and more resilient market. This would help managing the risk for the shipping sector to be exposed to lack of fuel availability. On the other hand, both ammonia and methanol at scale still come with challenges to regulatory and legal frameworks regarding the way they are used on ships, as there is a need to develop and approve: engines running on these fuels; ship designs enabling their on-board storage; protocols, standards, and infrastructure to safely move and transfer them in ports, when they are used as fuels.

Regarding other e-fuels for maritime transport, a participant flagged the possibility of spillovers from aviation into shipping fuels, via drop-in hydrocarbons created as by-products of SAF production.[20]

In any case, as in the case of aviation, shipping fuels will need to rely on pathways based on abundant feedstocks and with a demonstrated

[18] An issue with fuel switching is the loss of carrying capacity due to multiple fuel tanks. This loss of carrying capacity is most relevant for gaseous fuels than for liquids, as liquid fuels have higher volumetric energy density.

[19] Some workshop participants argued that methanol is a relevant option to decarbonize shipping, seeing its use in shipping as a higher priority than in aviation. Others flagged the possibility of a greater willingness to pay for methanol (as a feedstock for SAF production) in aviation.

[20] Diesel and fats-oils fractions are always co-produced with lighter kerosene/SAF cuts: using them as drop-in fuels in shipping (rather than having to further process them to yield greater SAF shares) can improve the energy efficiency and project economics of SAF production.

ability to reduce GHG emissions on a life-cycle basis.

Stakeholders in the maritime transport sector flagged the lack of commercial availability of low-carbon maritime fuels as an important barrier for the decarbonization of the sector, pointing to a gap between pledges and final investment decisions on low-carbon shipping fuel supplies. Bringing together the shipping sector with other stakeholders is seen as a relevant strategy to facilitate a joint transition, as it would help, ay once, to aggregate demand and de-risk supply investments. In this respect, there is agreement also that better communication between the shipping and the energy sectors would be very beneficial. Related efforts are underway—e.g. in the context of the Clean Energy Ministerial.

Stakeholders in the maritime transport sector also underlined the importance of working with ports to enable trading and ensure the availability of clean fuels. The sector will need to balance the flexibility of having multiple clean marine fuel options against the economies of scale and predictability that come from a single ubiquitous solution. Flexibility is good for increased availability of fuels. Some ports are already handling different fuels/products, including methanol and/or ammonia. However, such flexibility raises challenges for the scaling-up of fuel production and the deployment of storage and distribution, as both will require mostly land-based, dedicated investments. Their materialization is higher with greater certainty of demand growth.

Ports are less homogeneous than airports and already reliant on different fuels: heterogeneity adds challenges for port modernization investment, but it may also come as an opportunity, at least in cases when each shipper has to organize its fuel supply. Ports are also less supported by public funding than airports. Bunker barges can be a transitional option in specific cases. However, the principal-agent problem (due to port authorities being landlords, and terminal operators being delegated to operate the facilities) is seen as a relevant obstacle to infrastructure-related investments, adding to other barriers due to their capital intensiveness and risk profile. The permitting process is also seen by stakeholders as an issue, mainly due to time delays (despite the fact that aviation has a much higher level of regulatory oversight).

Alternative technologies to low-carbon fuels are also being discussed in shipping. One of these is the case of carbon capture, transport, and storage. Both CO_2 transport to deal with carbon captured from stationary installations and on-board CO_2 emission storage arose in talks on decarbonisation strategies developed at the International Maritime Organisation (IMO). Workshop participants reported that Japan and Korea are looking into these options, including via demonstration projects based on concepts that move ammonia one way and CO_2 (aimed for geological storage) the other way. Selected ports are also looking at CO_2 capture technologies. In Europe, work on these subjects will be part of secondary legislation linked with the Emission Trading Scheme (ETS). Discussions suggested that CO_2 transport would be more relevant, in terms of volumes, than on-board CO_2 storage, but neither strategy has been fully detailed at the technical level. Important questions on how to verify that these technologies would actually be implemented internationally are also unresolved. The discussion concluded that, while on-board CO_2 transport and storage are being discussed, it is too early draw conclusions about the viability and relevance of these options.

Current policies supporting low-carbon fuels in aviation and shipping

United States

Speakers at the workshop held in New York on February 27, 2023 outlined that the Aviation Climate Action Plan, last updated in 2021 and to be revised every three years, is a key tool to

help coordinate actions by the US government aimed at decarbonizing the sector. The current version covers the ambition to achieve of net zero emissions by 2050. The SAF Grand Challenge, which set the objective of 11.4 billion liters/year (3 billion gallons) by 2030 and 133 billion liters/year (35 billion gallons) by 2050 for the US aviation sector, is part of this plan.

Aviation policy in the US is developed in a context that targets major developments across sectors, with a 2030 objective of economy-wide GHG emissions 40% below 2005 levels and pledges across all sectors. These include a transition to 100% decarbonized electricity by 2035; emission cuts in transport outlined in the Transport Decarbonization Strategy (looking at clean solutions for all transport modes and including a major role for liquid fuels in maritime and aviation); emission reductions in energy intensive industry and agriculture; and an overall focus on deployment.

Recent energy, climate, and innovation policy developments outlined at the workshop focus on three pillars: the Bipartisan Infrastructure Law (issued in November 2021 and allocating USD 63 billion for energy and climate investments); the CHIPS and Science Act (issued in July 2022 and having a budgetary allocation of USD 280 billion); and the Inflation Reduction Act (IRA; introduced in August 2022 and including around USD 400 billion for clean energy). These policy tools are largely focused on incentives and public spending and are not financed by revenues derived from carbon pricing.

For aviation, the IRA's primary support is a volumetric tax credit for SAF sold or used for blending in jet fuel, starting in early 2023 and lasting for two years. The tax credit starts from USD 1.25/gallon (USD 0.33/liter) for options that achieve at least 50% GHG reduction on a life-cycle basis and increases linearly for each additional percent, saving up to 1.75 USD/gallon (USD 0.45/liter). Subsequent 3-year incentives for SAF producers are available through the Clean Fuel Production Credit.[21] Additional policy support is also available via SAF technology grants that expand the Loan Programme of the US Department of Energy; this uses a USD 250 billion loan authority for the Energy Infrastructure Reinvestment Program that includes USD 10 billion for SAFs.

For maritime transport, the US Maritime Administration (MARAD) of the Department of Transport is also working closely with the Department of Energy to align programmes. A joint strategy to transform transportation, included in the US National Blueprint for Transportation Decarbonization, pairs MARAD and sister agencies in other parts of the administration (including the Department of Energy and the US Environmental Protection Agency) to develop a more detailed maritime decarbonization strategy. This is expected in the Autumn 2023. In the meantime, the Bipartisan Infrastructure Law and IRA provide nearly USD 6 billion for ports, but there are no federal vessel emissions reduction programmes at the moment. Mission Innovation—a global initiative catalysing a decade of action and investment in research, development, and demonstration to make clean energy affordable, attractive and accessible for all—includes one "Mission," co-led by the US (with Norway and Denmark), specifically targeted on shipping. Its goal is to demonstrate, by 2030, commercially-viable ships capable of running on well-to-wake zero-emissions fuels. The ambition is also that ships capable of running on hydrogen-based zero emission fuels and advanced biofuels make up at least 5% of the global deep-sea fleet measured by fuel consumption and that at least 200 of these ships primarily use these fuels across the main deep sea shipping routes.

[21] The IRA includes also 10-year tax credits for clean hydrogen (which can be used as an input for SAF production) and for carbon capture utilization and storage–including direct air capture (needed for the production of SAF from e-fuel pathways). The latter are not stackable with clean hydrogen credits, though.

The budgetary allocations and polices outlined above add to USD 25 billion by the Office of Clean Energy Demonstration across multiple technology areas, with relevance for low-carbon shipping and aviation fuels—including USD 8 billion for hydrogen hubs; USD 10 million for carbon capture and sequestration (CCS), DAC and industrial emissions reduction; and USD 2.5 billion for nuclear power.

Earlier policy instruments, first developed for road transport and later expanded to cover SAF, include the Renewable Fuel Standard (RFS) and California's Low Carbon Fuel Standard (LCFS). The former focused on road fuels, requiring a growing minimum share of renewable fuels on an annual basis (no longer increased), integrating an SAF "opt-in" approach to generate compliance units without a specific SAF mandate, and integrating advantages of SAF vs. renewable diesel. The LCFS is the combination of a carbon intensity reduction requirement with a carbon pricing mechanism, linked to a separate credit market for energy used in transport. It is in place in Oregon and Washington state, as well as California, and allows for an opt-in for aviation fuels, cross subsidizing SAF production from revenues raised from road transport.[22]

In discussions regarding the LCFS, participants voiced concerns that the its fragmentation—i.e., its existence only in in specific jurisdictions—is an issue, suggesting that a federal LCFS would be a better way forward.

European Union

Contributions from speakers to the Brussels event of March 16 outlined the policy framework adopted in Europe for aviation and shipping. The context is provided by an articulated set of policy developments, brought forward by the European Commission as part of the European Green Deal. In aviation and shipping, key features of these combine two pillars are:

- A carbon pricing mechanism—the Emission Trading Scheme (ETS)—allowing to raise the budget needed to support research and innovation in low-carbon fuels.
- EU-wide regulatory requirements (combined with significant non-compliance penalties and nested in the Renewable Energy Directive), requiring a ramp up SAF production in aviation (Refuel EU) and low-carbon fuels in maritime transport (Fuel EU Maritime).

The integration of maritime transport in ETS is a recent development (while intra-EU aviation was already part of it, since 2012), and so is the revision of some of the key aspects, in particular the phasing out of free allowances, as of 2026. The coverage for maritime transport includes all intra-EU voyages and 50% of all outgoing and incoming voyages. For aviation, the scope is limited to flights within the European Economic Area and departing flights to Switzerland and the United Kingdom, but it excludes flights from/to other airports[23] For the integration of maritime transport in the ETS, equal treatment on routes (flag neutrality) applies for ships of 5000 gross tonnes and above (a review clause allows the possibility of an extension to smaller vessels).

The Refuel EU regulation (focused on aviation fuels) integrates dedicated sub-targets for hydrogen and e-fuels (technically "renewable fuels of non-biological origin"), also paired with conditions that require additionality for

[22] Regarding the opt-in for aviation and whether it should be fully integrated in the LCFS, some participants argued that a full integration would be preferable, as SAF as opt-in does not align with the polluter-pays principle, while others argued that the opt-in may make more sense with greater low-carbon fuel availability in the market.

[23] This scope could be extended in 2027 - the deadline the EC gave itself to assess the effectiveness of international agreements—namely at the International Civil Aviation Organisation (ICAO) in reducing emissions.

renewable electricity used in their production, as it is scaled up.

The Fuel EU Maritime regulation establishes limits of GHG emission intensity, with a technology neutral approach based on life-cycle emissions, despite conditional requirements for renewable fuels of non-biological origin (RFNBOs), comprising hydrogen and e-fuels. Both the Refuel EU and Fuel EU Maritime regulations have a clear 2050 horizon.

Fuel EU Maritime also includes additional requirements for on-shore power supply of ships moored at the quayside.

Methane and N_2O emissions are important contributors to climate forcing due to their high global warming potential, and they are important in cases reliant on liquefied natural gas and ammonia as fuels. Monitoring of these emissions is required in the EU legislative framework beginning in 2024 and integrated in the well-to-wake mechanism accounting for Fuel EU Maritime beginning in 2026.[24] For aviation, two monitoring, reporting, and verification (MRV) systems, focusing on fuel quality (relevant for contrail formation) and non-CO_2 effects could be the basis of future regulatory developments.

An additional legislative proposal that is part of the Fit-for-55 policy package (but is less likely to be turned into law) includes a change in the energy taxation framework, removing exemptions for aviation and maritime transport fuels.

These policies are also accompanied by dedicated industry alliances (for the renewable and low-carbon fuels value chains) to help mobilize supplies. Another regulation sets minimum deployment requirements for alternative fuels infrastructure (including shore-side electricity in ports and electricity supply to stationary aircraft in airports).[25]

Canada

The workshop held in New York on February 27 also featured an overview of the Canadian policy framework for low-carbon aviation and shipping.

This covered the Clean Fuels Fund, an investment of CAD 1.5 billion over five years, reaffirmed in 2021 and aimed to de-risk the capital investment required to build new or expand existing clean fuel production facilities. While few projects have been funded to date (one on SAF and ten on hydrogen), the scope of the fund includes key elements of what is intended to underpin low-carbon aviation and shipping fuels: hydrogen, ammonia, SAF, and synthetic fuels.

---

[24] In maritime transport, the EU policy action builds on preparatory work that started with the regulation on MRV (monitoring, reporting and verification), covering 12000 ships above 5000 gross tonnes.

[25] Importantly, a proposal for a package of measures, included in the Green Deal Industrial Plan, also does the following: identifies goals for net-zero industrial capacity (the Net Zero Industry Act); provides a regulatory framework meant to drive its quick deployment; integrates a Critical Raw Materials Act (to ensure sufficient access to materials that are vital for manufacturing the technologies that will underpin the low-carbon economy); eases state aid rules to allow Member States to directly implement aid measures; and foresees the establishment of a European Sovereignty Fund to support investments in manufacturing of net-zero technologies (complementing in the mid-term the near-term availability of other funds linked to the ETS revenues) and of a Net-Zero Industry Academies to roll out up-skilling and re-skilling programmes in strategic industries. The technologies concerned in the Net Zero Industry Act include batteries, solar panels, wind turbines, heat pumps, electrolysers, and carbon capture, utilization, and storage (CCUS). Some of these are needed for the abundant and low-cost supplies of renewable electricity and heat that are necessary for advanced decarbonised fuels. This policy package was released on the day of the workshop held in Brussels, on March 16. While not extensively discussed at the event, it is described here for completeness, due to its relevance to the topics covered in the workshops.

Canada's Aviation Climate Action Plan set a net-zero by 2050 vision for the sector, but it does not include firm requirements. A voluntary target of 10% SAF by 2030 SAF opens up possibilities to start achieving emissions reductions while new zero-emission technologies are developed.

Research, development, and deployment (RD&D) activities are underway to support increased availability of low-carbon maritime fuels and related reporting requirements. Like the United States, Norway, selected EU Member States (including Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Spain, Sweden), and other major economies (including Australia, Chile, Japan, and the United Kingdom), Canada is also a signatory of the Clydebank Declaration, supporting the establishment of green shipping corridors by the middle of this decade, aiming to scale activity up in the following years.

Canada's 2023 budget includes CAD 17.7 billion funding for a new Clean Hydrogen Investment Tax Credit (ITC) between 2023 and 2035. This is largely in response to the IRA, seen as a game changer, with the risk of drawing investment away from Canada.

While carbon pricing mechanisms exist in Canada at the Provincial level (with a Federal backstop), aviation and maritime transport currently do not fall within their scope.

International aviation

The International Civil Aviation Organisation (ICAO) is the international organisation assisting its member governments as they collectively and diplomatically establish new international standards and recommended practices for civil aviation. Its Committee on Aviation Environmental Protection (CAEP) supports the formulation of new policies, including standards and recommended practices related to aviation environmental impact.

The ICAO Assembly adopted in 2022 a long-term net-zero emission goal by 2050, a key milestone in the international policymaking process on aviation but also only an aspirational target. It is important that this happened with agreement from all countries.

ICAO also adopted several measures to support the decarbonisation of aviation. They consist of reducing fuel consumption through more efficient aircraft technology and operations, a voluntary global market-based measure based on carbon offsetting—the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)—also integrating the option to achieve emission reductions through fuels with lower carbon content on a life-cycle (or well-to-wake) basis and specifically including several SAF pathways.

The workshops highlighted that ICAO decisions had, to date, limited impacts beyond what would have happened anyway for GHG emission reductions in aviation. However, ICAO's decisions are in a unique position to set a level playing field that moves aviation towards decarbonization, because they are the only global measures that address CO_2 emissions from international civil aviation and they are key enabling instruments for further international decisions.

The workshops also showed that ICAO's work on SAF—unlike the case of maritime transport—includes the development of life-cycle assessments for fuel production pathways and the establishment of sustainability criteria. This work has been followed by actions from regional organisations such as the European Civil Aviation Conference (ECAC), building on pioneering experiences on SAF supplies at specific airports and helping to map the SAF policy landscape.

Looking forward, discussions developed in the workshops underlined that the ICAO Council in November 2023 will offer an important opportunity to consider the establishment of global SAF adoption targets, complementing national action.

International shipping

The International Maritime Organisation (IMO) is the international organisation in charge of the development of international regulations for the international shipping. Its Marine Environment Protection Committee (MEPC) addresses environmental issues in the IMO framework, including the control of emissions—including GHG emissions—from ships.

The Initial IMO GHG Strategy on Reduction of GHG Emissions from Ships, adopted in 2018 and currently being reviewed, reflects the international agreement that outlines the ambition and the guiding principles for the decarbonisation of shipping, including a list of candidate measures to achieve them. Unlike in the case of aviation, the Initial Strategy sets out absolute GHG emission reduction requirements from international shipping: total annual GHG emissions must be reduced, by 2050, to levels that are at least 50% below those of 2008. The Strategy also outlines a timeline for short-term, mid-term and long-term policy measures to meet the GHG emission reduction requirement.

The Energy Efficiency Design Index (EEDI) consists of regulatory requirements aiming to improve the energy efficiency of new ships. The Ship Energy Efficiency Management Plan (SEEMP) complement the Energy Efficiency Design Index focusing on operational improvements. The Energy Efficiency Existing Ship Index (EEXI) aims to improve the energy efficiency for existing ships that are in service. The Carbon Intensity Indicator (CII) consists of a set of operational carbon intensity reduction requirements, entirely focused on direct emissions and—unlike the case of aviation—not taking a life-cycle approach for their assessment. There is broad agreement that these measures will likely be insufficient to reach the Initial IMO Strategy's ambition levels. There is also consensus that additional measures will be even more necessary if the International Maritime Organisation adopts, in July 2023, a revised and strengthened IMO GHG Strategy as recommended in 2022 by the MEPC.

The discussions developed at the workshops on the direction of IMO decisions going forward, further elaborated below, focused on the combined role of carbon pricing and regulatory requirements and ways to reallocate carbon pricing revenues.

Policy gaps

The workshop discussions pointed to a number of similarities between the aviation and maritime transport sectors.

- The longevity of the assets, underlining the importance of anticipation[26] and the need for solutions that are suitable for existing vessels/aircraft and infrastructure, alongside disruptive technologies.[27]
- The largely global/international nature of both modes. This implies stronger needs, compared to other sectors, for global harmonisation of policy developments.
- A carbon price alone, in these sectors and at prices likely to be politically and economically feasible, is unlikely to be sufficient to stimulate a fuel transition. This calls for complementary measures, including regulatory requirements.
- The presence of dedicated intergovernmental bodies: ICAO and IMO.

[26] Policies that target carbon emission reductions in fuels that can be used by existing powertrain options need to ensure that low-carbon options are available in sufficient supplies to replace high-carbon alternatives. Policies that require changes in the propulsion and fuel systems to reduce the use of high-carbon fuels need to match the pace of turnover in vehicle fleets.

[27] Indications from discussions developed in both workshops underlined that the scaling of low-carbon fuel options needs to be grounded on available feedstocks while remaining open to the market introduction of options that are not yet at high technology readiness levels.

These have the mandate to support governments for policy developments but can also constrain national-level action.

- Aviation and shipping are connected with national security and strategic aspects. Sparsely populated countries need aviation to ensure mobility, and shipping is a crucial enabler of trade. Environmental and innovation policies need to ensure that these crucial functions to continue to be effectively completed.

Importance of a supportive framework for increased decoupling between activity and environmental impacts

The workshops led to clear calls, by a range of stakeholders—including representatives from government, industry, financial institutions and non-governmental organizations—to develop supportive policies allowing to decouple aviation and maritime transport from environmental impacts. These instruments include pricing and regulatory requirements. There was agreement that regulations should be performance-based but also informed by technology analysis. That is: it is important to understand what technologies could deliver on regulatory requirements, to ensure resilient progress.

Predictability and regulatory certainty have been identified as important features to reduce investment risks in a context where the transition to low-carbon fuels is not likely to be driven by cost advantages, even with carbon pricing.

Importance of the adoption of a life-cycle approach

Stakeholders agreed that that taking a life-cycle approach to the assessment of fuels is crucial if policy decisions are to have meaningful outcomes. This consensus is important, as the use of a life-cycle approach to GHG emission accounting has been questioned recently in some of the proposals submitted for discussion in the context of IMO discussions. This is also striking, as life-cycle accounting is by now solidly established in the ICAO context.

Some workshop participants stressed the need to ensure that accounting frameworks embrace sound sustainability frameworks, minimizing the risk of regrets after policy implementation. In their view, this is essential for a durable climate change policy and reduced asset stranding risk. This is also necessary to ensure alignment between the urgency of action and the need to avoid rushing in the wrong direction, heading towards dead ends. Discussions emphasized that identifying durable climate change policy requires understanding and considering details, especially non-trivial ones. These include topics related with land use change, soil carbon sequestration, the implications of hydrogen emissions on the extension of the life of methane in the atmosphere, as well as the way to account for near- or long-term climate forcing impacts. In particular, the alignment of shipping with the life-cycle accounting approach used in the CORSIA framework (deemed as good practice) was flagged as a priority by some of the participants in both workshops. The discussion signalled the necessity to anticipate potential changes to life-cycle accounting.

Moving beyond default emission factors was also signalled as an aspect that will gain importance (therefore requiring policy responses) as the scale of low-carbon fuel production increases. In this context, one participant underlined that the blurred boundaries between bio- and e-fuels could also lead to additional complexity. Since power and biomass to liquids or e-fuels need hydrogen and may or may not need biogenic carbon, planning production facilities must be flexible in the type of feedstocks that they use. It will be important to make sure that this flexibility will not exclude pathways from qualifying as fit for purpose, as long as they are in line—for the different feedstocks—with sustainability requirements. Another comment pointed to the importance

for policies to incentivize carbon reduction while considering that different areas have different strengths and weaknesses (e.g., with respect to access to CCS and/or biogenic carbon).

The lack of harmonisation of the requirements to comply with similar policies set in different administrations was also mentioned as an issue requiring attention. Examples of this included differences in the way proofs of sustainability are granted to fuels allowed in road or aviation (with reference to the European context) and the risk of significant differences in the way low-carbon hydrogen (and its derivatives) are defined in Europe and North America.

Major differences between EU and US and need for convergence

There is consensus that the framing conditions for the discussion are defined by the so-called "energy trilemma," combining a need to address security, sustainability, and affordability. Yet, there are significant differences in the strategies elaborated in Europe and North America (in particular the US) to deal with it.

CORSIA, which was not first conceived as a SAF programme but became one, was flagged by a participant as an example of the difference between the EU and US policy approaches, with the former more focused on fuel switching and the latter on offsets.

Workshop participants signalled other important differences between the US and EU policy approaches:

- A greater focus on near-term policy instruments stimulating investments at the Federal level in the US (namely the IRA tax credits), predominantly centred on incentives rather than regulations or carbon pricing. The difference is even more striking given that US incentives are not paired with carbon pricing mechanisms to cover their cost,[28] due to political feasibility challenges. Long-term objectives exist in the US (they are clearer in aviation), but they are aspirational, not backed by hard policy requirements to achieve them.
- The EU focus on regulatory requirements offering long-term certainty (including specific subsets for technologies—such as e-fuels—that are at lower technology readiness), in combination with an increasing carbon price as a way to finance innovation funds.[29]

The discussions also flagged that the US approach is proving effective to attract intentions to invest in the near-term. This approach fueled fears (despite uncertainties in the duration of the incentives[30]) that other geographies would lose first mover advantage opportunities and remain negatively affected by lock-in effects. This induced the development of

[28] Carbon pricing mechanisms exist in specific States (California and the eleven Northeast states that make up the Regional Greenhouse Gas Initiative (RGGI): Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Virginia. Washington state also recently enacted new cap-and-invest legislation to take effect beginning in 2023. None of these frameworks covers shipping or aviation fuels. Transport-specific carbon pricing instruments are also in place in California, Oregon, and Washington state, based on the approach adopted with California's Low Carbon Fuel Standard. Aviation is covered only as an opt-in option in California, and therefore it is not subject to carbon pricing. Shipping is not covered.

[29] This is actually taking inspiration from polices first developed in California, with the Low Carbon Fuel Standard.

[30] The importance of a comparable duration of policy incentives with investment cycle was flagged by a participant as a critical requirement to unlock capital, especially in circumstances that do not see low-carbon fuels as options destined to have production costs comparable to fossil fuels, even after a production scale-up.

policy responses intended to prevent possible drawbacks.[31]

Discussions also pointed to a positive perception, by stakeholders from both industry and NGOs, of a combination of carbon pricing and mandates, with indications that the risks of investments moving across geographies are mainly due to policy signals that are inconsistent internationally. This resulted in a call for a better consensus between the US and EU policy approaches.

Despite the risks entailed in setting long-run regulatory requirements that require the deployment of novel technologies,[32] there was consensus on the opportunities offered by a policy framework that combines carbon pricing and the contextual establishment of funds to support innovation. Part of the reason for this was the need to design policy support mechanisms that ensure resilience, in particular in a case where low-carbon fuels will likely be more expensive (especially in the absence of carbon pricing) than fossil fuels. The relevance of an alignment on carbon pricing and the use of revenue to finance innovation is also a priority that emerged clearly in the debates for international policy frameworks, at ICAO and the IMO.

Another difference between EU and US policy that was signaled in the discussion was that biofuel policies in the US have been driven largely by a combination of agricultural and energy security policies, while the emphasis in the EU moved quickly towards GHG emission abatement and broader sustainability requirements.

Focus on infrastructure

Infrastructure policy was also mentioned during workshop discussions as something that deserves specific attention. Key examples include the use of hydrogen for aviation and the cases of methanol and/or ammonia as shipping fuels.

Long-term visibility was flagged as an important requirement for infrastructure investments, especially in a context that sees estimations pointing to large investment requirements needed in the maritime transport sector on the land side (ports, fuel production facilities) with respect to those needed on vessels.[33]

Especially in shipping, uncertainty regarding the fuel choice has been signalled as an element leading to risks of not meeting the targets. At the same time, a decarbonising shipping sector is currently expected to be based on multiple fuels. This suggests that addressing the shipping decarbonisation challenge requires plans that factor in the emergence of a diversity of options, mitigating risks related to it. The development of strategic partnerships between stakeholders in the maritime and energy sectors has been flagged as a key example in this context. Bilateral and multilateral exchanges, including across sectors and through international cooperation, are important to provide visibility and knowledge of what is going to happen elsewhere. Active engagement with front-line communities that bear the brunt of environmental consequences from shipping is also important. In this respect, initiatives developed via the Clean Energy Ministerial,

[31] Regarding this response, an important limitation signalled for the EU policymaking approach was the limitation of the European institutions to take decisions on fuel taxes (due to the need for unanimity and a track record that shows the alignment on energy and other taxation frameworks has proven hard to achieve).

[32] Referring to challenges that emerged in the context of the RFS obligations in the US, with lignocellulosic pathways struggling to deliver.

[33] Total investment needs are estimated by the World Bank at USD 1.8 trillion for maritime transport, mainly for facilities producing. hydrogen, for ammonia synthesis, tankage, bunker infrastructure etc. The same assessment points to ship-based investments (i.e., engines, on-board storage, new engine types etc.) that only take up 10% of the total.

bringing together shipping and energy sector stakeholders, were mentioned as an example of a much-needed development by some of the workshop participants.

Public funding is also something that can help address some of the challenges entailed in enabling infrastructure for low-carbon fuels. Regarding this, one participant recalled that, as capital availability is more constrained in emerging economies (as they do not have the balance sheets to deal with the transition on the infrastructure side), investment delays could lead to significant "collateral damage". Recycling funds raised with carbon pricing, as well as increased spending from multilateral development banks on climate finance, could help bridge inequalities and bring greater consensus. Engaging early with developing countries who have the potential to supply low-carbon and sustainable fuels at scale is important to make progress for increased engagement and greater collective buy-in; this would also help make progress in international negotiations. Workshop discussions signaled the need for an inclusive rather than exclusive approach, as this would facilitate more investments in all countries—including emerging and developing economies—that could exploit significant potential to become low-carbon shipping and/or aviation fuel producers.

Opportunities from action taken across private sector stakeholders

Ultimately, marine transportation represents a very small contribution to the final cost of most products that are shipped overseas. This means that while the cost of low-carbon fuels is higher, its relevance in the final product traded by ship is likely very small. The broader economic impact of a fuel transition in shipping is also likely to be small, since such small cost impact in final product demand will not be so disruptive for patterns of demand. This opens important opportunities for voluntary action by stakeholders requiring logistical services and actually already did result in significant mobilization of demand. Sustainable buyer alliances were flagged in the final policy panel of the New York workshop as a relevant example of effective private sector action. The case of aviation also points to successful examples, with almost as much voluntary SAF purchase in the next few years as there is in the mandates.

An effective integration of a book and claim system into regulatory mechanisms requiring increased adoption of low-carbon aviation and shipping fuels was flagged as essential by different stakeholders. Such a system would decouple the environmental benefits of lower-carbon fuels from their physical location, allowing regions with high capacity to produce such fuels to provide compliance credit elsewhere. Book and claim systems have been used in the trading of environmental attributes of electricity from natural gas substitutes, but their use in liquid fuels would be a novel expansion. A book and claim system would likely lead to lower GHG abatement costs at a global level. However, when an entity uses book-and-claim accounting to satisfy GHG abatement requirements, it foregoes opportunities to reduce local pollutant emissions by using cleaner fuels. Communities highly impacted by the environmental impacts of shipping should therefore have a role in developing and implementing book and claim systems.

Avoiding multiple claims on the same amount for emission reductions enabled by fuel switches and pairing this with international recognition could ease opportunities to leverage higher willingness to pay from richer areas of the world, facilitating an alignment between buyers and sellers, as long as sustainability criteria are also internationally aligned.

Workshop participants also pointed to long term offtake contracts as important instruments enabling investments to increase availability of low-carbon fuels, both in aviation and shipping.

Key milestones and developments needed at ICAO

CORSIA and the ICAO negotiations could ideally be a platform to enable the development of an international agreement, including a meaningful carbon price, carbon intensity reduction requirement, and revenue redistribution mechanism. However, discussions—in particular at the Brussels workshop—signaled that there is a lot that can be achieved from national and/or regional action.

The aspirational nature of the ICAO long-term target was also flagged as an important limiting factor. Other concerns were raised due to the significant role of offsets in the CORSIA framework, as they have often been ineffective in delivering emission savings. For this reason, combined with clear advantages to de-risking investments in SAF supplies, several workshop participants pointed towards SAF and/or carbon intensity mandates as better suited for the developments of policies developed in the ICAO framework. This aligns well with expectations that the ICAO Council in November 2023 will consider the establishment of global SAF adoption targets, complementing national/regional action.

Non-CO_2 impacts of aviation were also flagged as a crucial area requiring progress. Encouraging signals came from the perspectives of industry stakeholders, as these clearly pointed to a desire to enhance the collective understanding of the issue and the ability of all players to reduce these impacts. A key reason is the likely high return on investment from contrail avoidance technologies. Regarding SAF and non-CO_2 impacts, there was consensus that synthetic paraffinic kerosene (being a low-aromatic and low-sulfur fuel) could be part of the solution, as it is expected to lead to significant reductions of particulates and contrail formation, adding improved local air quality.[34]

Key milestones and developments needed at IMO

Expectations for the July 2023 MEPC meeting point towards a revision of the IMO GHG emission reduction strategy that increases ambition, including net-zero GHG emissions by 2050.[35]

As there is consensus that additional measures are necessary to fulfil this type of ambition, mid-term policies to be developed ay IMO represent an important opportunity to make progress.

Several policy options being proposed in the IMO framework complement each other: these include a carbon levy, feebates (i.e. a combination of fees and rebates, dependent on the environmental performance of ships), a fund and reward mechanism, and a green fuel standard. The last, submitted by the European Union to the IMO, would work on a well-to-wake basis, bringing it to zero gradually. Parallel proposals filed at the IMO and based only on direct carbon intensities were flagged as inadequate in the discussions.

Contribution to the workshop held in Brussels referred explicitly to this proposal and praised the fact that it combines regulatory requirements with carbon pricing, in line with mechanisms used in the Low Carbon Fuel Standard, first adopted in California and having had a demonstrated capacity to facilitate financial support, scale-up, and cost reductions for technologies with better GHG emission

[34]Avoiding flying through areas with a high potential of forming negative contrails is also crucial to address non-CO_2 effects.

[35] Recent support received for this objective in the context of the Major Economies Forum (White House, 2023) reinforces the indications that emerged at the workshops, on this.

profiles, despite costs of production that are initially well above the fossil fuel benchmark.

Carbon pricing proposals discussed in the New York workshop also touched upon the use of carbon revenues as an enabler of an equitable transition, arguing that there is a strong case can be made for developing countries as primary recipients of carbon revenues from international shipping, that there is merit in considering a combination of different levers to define their distribution, and that there are reasons not to re-use all revenues solely for maritime transport-related spending (even if this may remain a priority for developed economies).

Despite these proposals, discussions developed at the workshop suggested that a carbon levy tended to be favoured over a global trading scheme. The idea is that the levy would support increased availability of low-carbon fuels by funding RD&D activities. Expectations are that, if adopted, the carbon levy would be unlikely to send price signals that are high enough to induce changes aligning with the ambition of the Initial Strategy, nor with the enhanced GHG emission abatements being currently considered for its revision. Therefore, a carbon levy would require complementary action.

Other important topics being debated at the IMO, flagged in the workshop presentations and discussions, refer to the need to address "disproportionally negative" impacts on States and an equitable transition. Impacts are not limited to those directly related to decarbonizing shipping (e.g. due to fuel switching), but include increased competition at multiple levels in the economy. For example, increased electrification of end-uses may result in net reductions of volumes of fuels traded internationally. Competition could occur around access to renewable electricity, fresh water, hydrogen, availability of biogenic carbon, CCS capacity, or other inputs to production. The complexity of these transitional scenarios has not been fully analysed, and this is something that can influence the way the shipping sector will take decisions in the IMO meetings.

Pending increased ambition in international negotiations, regional action was flagged as something that could lead to sizable emission reduction, as in the case of aviation. A key indication of this is that covering shipments between the US, EU, and China would cover 85% of all maritime transport.

Role of credits and DAC investments, also for reliable offsets

As aviation and shipping are amongst the hardest sectors to decarbonize, a workshop participant also flagged the relevance of nature-based carbon credits, pointing to the fact that contributing to improvements in the stocks of carbon can go beyond what is achievable in decarbonizing the fuels. The same participant also flagged the need to increase investments to accelerate progress on DAC, as this is a technology that can lead to a significant contribution to the decarbonisation of aviation and shipping, either as a way to supply renewable carbon for e-fuels or, if paired with durable and reliable carbon sequestration technologies, as a way to enable effective offsets.

Workshop participants agreed that natural carbon dioxide removal, such as that often supported by carbon offsets and DAC, will have large roles to play if the world is to prevent the worst effects of climate change. However, they also recognized that neither natural carbon dioxide removal nor DAC could scale to anywhere near the magnitude needed to meet long-term climate goals.

Both carbon offsets and DAC will be subject to challenges in not only developing projects, but also in accurately assessing their contribution to global decarbonization. Additionality, assessing impacts of a project in comparison to a counterfactual world in which the project did not exist, is a particular challenge. Several studies have shown evidence that claimed GHG reductions from existing nature-based offsets

are overstated, largely due to overly optimistic assumptions about additionality. Questions regarding additionality also apply to DAC coupled with storage technologies, as they progress.

There is consensus that these technologies need to be viewed as complements to aggressive emissions reduction, not substitutes for it. Investments, both public and private, are needed to mature and scale both solutions, however the process of technological maturation may not provide, and should not substitute for, rapid emissions reductions.

Annex – Workshop agendas and speakers

Opening keynotes

Topics

- Common needs for shipping and aviation sectors, opportunities, and challenges for both sectors; key differences
- Overview of policy approaches: domestic and international, and implications for the decarbonization pathway of the sectors
- Role of different energy options and other approaches to decarbonization

Speakers

New York

Aaron Hoskin - Deputy Director, Decarbonization of Marine, Rail, and Aviation, Transport Canada

Jim Spaeth - Program Manager, Systems Development & Integration, Sustainable Aviation & International Engagement, Bioenergy Technologies Office, U.S. Department of Energy and Chair, Biofuture Platform

Brussels

Roland Roesch - Acting Director, Innovation and Technology Center, International Renewable Energy Agency

Jan Petter Steinland - Director Strategic Analysis & Transformation, Civil Aviation Authority Norway

Aviation session: which fuels for a low-carbon future

Topics

- Policy diversity in a global market: next steps after the recent US (IRA, SAF targets, LCFS) and EU (ReFuel EU, ETS, innovation & social fund) policies and the agreement on the ICAO long-term goal
- Role of bridge options and fuels: biofuels, offsetting and DAC; biofuels and RFNBOs: lock-ins and leapfrogs
- Role of consumers and corporate demand: initiatives for scope 3 abatement, including book & claim
- Local & global: implementation in EU, US and emerging markets

Speakers

New York

Kick-off presentations

Megersa Abate - Transport Economist, World Bank

Kevin Welsh - Executive Director, Office of Environment & Energy, Federal Aviation Administration

Industry/Civil society response panel

Lindsay Fitzgerald - VP of Government Relations, Gevo

Andreea Moyes - Aviation Global Sustainability Director, BP

Sean Newsum, Managing Director, Environmental Affairs, Airlines for America

Jane O'Malley - Researcher, International Council on Clean Transportation

Dale Smith - Regional Director, SAF Procurement & Policy Strategies, Boeing

Michael Wang - Director of the Systems Assessment Center, Argonne National Laboratory

Moderator

Colin Murphy

Brussels

Kick-off presentations
Ewa Oney - Team Leader for Sustainable Aviation, DG MOVE, European Commission
Cesar Velarde - Climate Change and Capacity Building Specialist, European Civil Aviation Conference

Industry/Civil society response panel
Laurent Donceel - Acting Managing Director at Airlines for Europe, A4E
Laurel Harmon - VP of Government Relations, LanzaTech
Sebastian Hirsz - Lead Advisor, Mobility Policy, BP
Lucas Kaestner - Co-founder, Sustainable Aero Lab
Steven Le Moing - Sustainable Aviation Fuels Manager, Environmental Affairs, Airbus

Moderator
Colin Murphy

Shipping session: which fuels for a low-carbon future

Topics

- Towards a global shipping decarbonization framework: complementarity and diversion between US (LCFS + IRA) and EU (Fuel EU Maritime + ETS, innovation & social fund) and international context in the IMO framework
- Role of bridge options and fuels: offsetting and DAC; biofuels and RFNBOs: lock-ins and leapfrogs
- Biofuels, e-methanol, e-ammonia, e-LNG, other e-fuels, on-board carbon capture: how to overcome uncertainties and move forward with infrastructure investments?
- Role of consumers and corporate demand: initiatives for scope 3 abatement including book & claim

Speakers

New York

Kick-off presentations
Rico Salgmann - Maritime transport specialist, World Bank
Daniel Yuska - Director, Office of Environment and Innovation, US Maritime Administration

Industry/Civil society response panel
Nelson Mojarro, Head of Innovation and Partnerships, International Chamber of Shipping (ICS)
Joel Moser - Chief Executive Officer, First Ammonia
Luisa Palacios - Senior Research Scholar, Center on Global Energy Policy, School of International Public Affairs, Columbia University
Melissa Peterson - Head of P2X Americas, Ørsted
David Walker - Vice President, American Bureau of Shipping
Christine Weydig - Executive Director, Coalition for Reimagined Mobility

Moderator
Pierpaolo Cazzola

Brussels

Kick-off presentations
Jasper Faber - Manager Mobility & Transport, CE Delft
Laura Lonza - Policy Officer, DG CLIMA, European Commission

Industry/Civil society response panel
Claudio Abbate - Group Vice President Maritime Policy and Government Affairs, MSC
Javier Ariztegui, Senior Manager Product Design, Repsol Technology Lab
Kaj Portin - General Manager, Research & Technology Programs; Engines Technology, Wärtsilä
Alison Shaw - Policy Lead, Energy Institute, University College of London/UMAS
Arne Strybos - Program Manager Fuel Transition, Corporate Affairs, Sustainable Transition, Port of Antwerp

Moderator
Pierpaolo Cazzola

Policy panel

Topics

- Policy discussion on how to accelerate the deployment of low-carbon fuels for shipping and aviation, with a focus on "no regret" choices allowing to meet both the imperative of rapid near term action and the requirement to enable deep emission cuts, to reach net zero by mid-century

Speakers

New York

Panelists
Mark Brownstein - Senior Vice President, Energy Transition, Environmental Defense Fund
Kim Carnahan - CEO, Neoteric Energy and Climate and Head of Secretariat, Sustainable Aviation Buyers Alliance (SABA)
Meg Gentile - Executive Director of the Board, HIF Global
Emily Kent - US Director, Zero-Carbon Fuels, Clean Air Task Force
Adam Klauber - Vice President Sustainability and ESG, World Energy
Christoph Wolff - Chief Executive Officer, Smart Freight Center

Moderator
Pierpaolo Cazzola

Brussels

Panelists
Tobias Block, Head of Strategy and Content, E-fuel Alliance
Jo Dardenne - Director, Aviation, T&E
Pedro Piris-Cabezas - Senior Director, Global Transportation & Lead Senior Economist at Environmental Defense, Environmental Defense Fund
Jack Saddler - Professor of Forest Products Biotechnology/Bioenergy and Dean Emeritus, Faculty of Forestry, University of British Columbia
Ashleigh McDoughall - General Manager Aviation Europe, Shell
Anne Sophie Vinther Hansen - Vice President Renewable Energy, Bornholm's Energy and Utility

Moderator
Lew Fulton - Director, Sustainable Transportation Energy Pathways Program, University of California, Davis