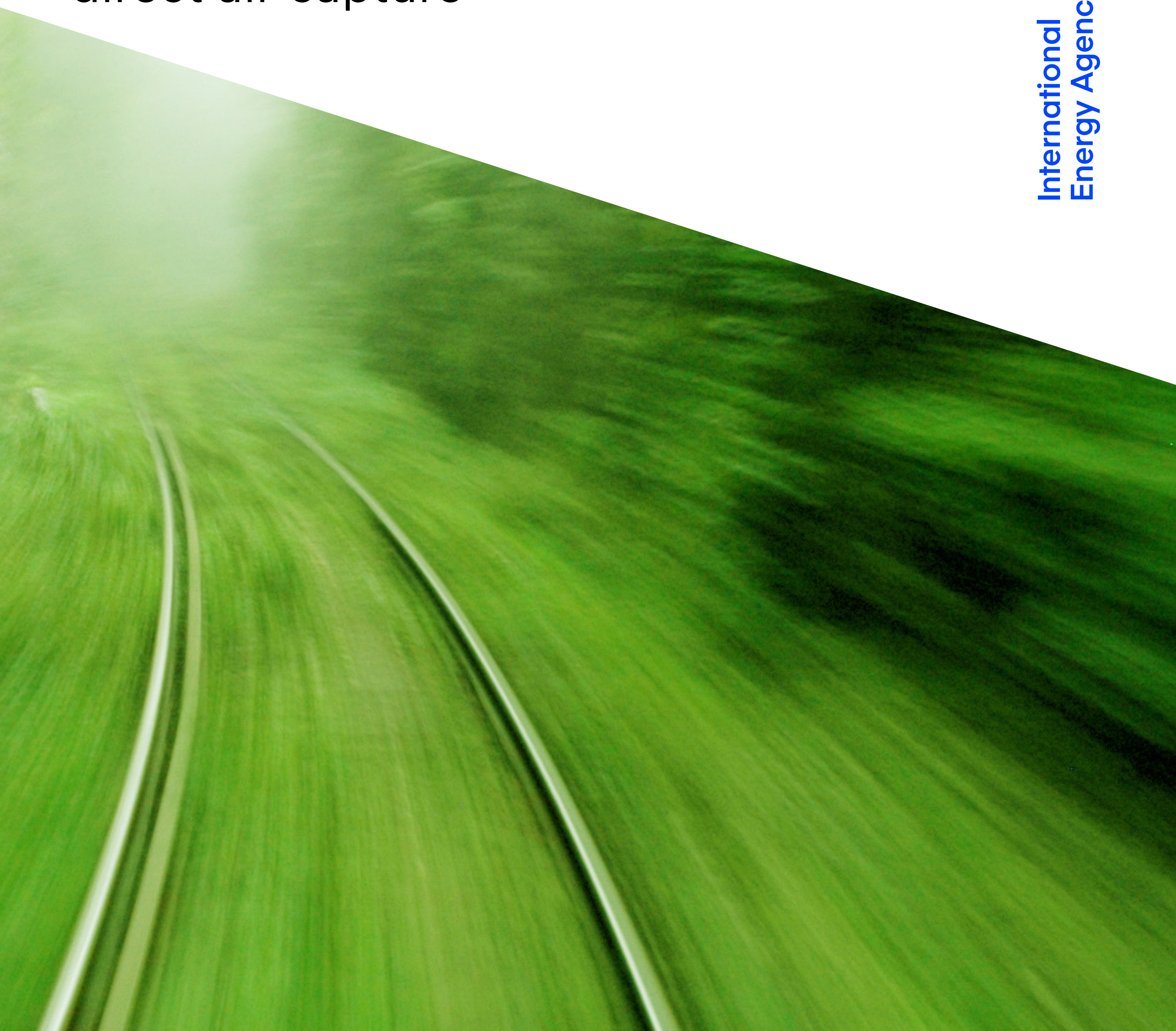
The Role of Carbon Credits in Scaling Up Innovative Clean Energy Technologies

How high-quality carbon credits could accelerate the adoption of low-emissions hydrogen, sustainable aviation fuels and direct air capture

International Energy Agency



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Abstract

Achieving net zero requires rapid development of technologies such as low-emissions hydrogen, sustainable aviation fuels (SAF), and direct air capture and storage (DACS). The IEA and GenZero report explores how carbon credits can incentivise their deployment.

Massive scaling-up is needed: low-emissions hydrogen production needs to jump from almost zero today to 70 million tonnes by 2030; SAF's share of final energy consumption in aviation needs to rise from close to zero today to around 11% by 2030; and annual removals of CO_2 via DACS need to reach almost 70 Mt CO_2 in 2030, from almost zero today.

Investment must also increase dramatically. Governments can unlock investment through a mix of policies and financing instruments. Carbon credits can play an important role, especially in attracting private capital and accelerating technology adoption.

Carbon credits cannot bridge the investment gap on their own, and governments and the private sector need to develop strategies to create the right enabling environment for investments. Moreover, the current low availability of crediting methodologies hinders the generation of carbon credits from low-emissions hydrogen, SAF and DACS, but the landscape is shifting. A coalition of stakeholders should develop clear guidance on emissions accounting, and efforts to get better data on emissions are necessary to provide the foundation for such guidance.

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Executive summary

The transition to global net zero emissions requires the rapid development and deployment of innovative technologies that are critical for decarbonising hard-to-abate sectors, such as industry, aviation and long-haul transportation. This report, prepared jointly by the IEA and GenZero, explores how carbon credits could help scale up low-emissions hydrogen, sustainable aviation fuels (SAF) and direct air capture and storage (DACS).

To align with the IEA Net Zero Emissions by 2050 (NZE) pathway that limits the rise in global average temperatures to 1.5°C, all these technologies need a massive and urgent scale-up in deployment. Low-emissions hydrogen production reaches 70 million tonnes (Mt) of hydrogen (H_2) by 2030 in this pathway, from less than 1 Mt H_2 in 2022. SAF's share of final energy consumption in aviation rises from close to zero today to around 11% by 2030. Annual removals of CO_2 via DACS reach almost 70 Mt CO_2 in 2030, and some 700 Mt CO_2 by 2050, again from almost zero today.

Achieving the necessary scale-up of these technologies will depend on early deployment and investment. In 2023, the level of investment in low-emissions hydrogen, SAF and DACS was USD 9 billion. In the NZE Scenario, this needs to increase to nearly USD 300 billion annually by the early 2030s and reaches around USD 700 billion yearly by mid-century. Around 75% of these investments in 2050 would be required for low-emissions hydrogen and hydrogen-based fuels.

To mobilise this level of investment, governments need to deploy a mix of complementary policies and innovative financing instruments. A blended approach of public, private and philanthropic funds could help manage different risks and lower the overall cost of capital. Limited public funds could contribute to manage regulatory and country risks to help bring in private capital in early projects. In developing economies, blended finance can use grants or guarantees to support market entry and project feasibility. Governments could help to bridge the investment gap by providing clear regulations and enabling policies. High-quality carbon credits are a potentially important tool to further incentivise investment and increase project revenues.

High-quality carbon credits can be helpful in attracting private capital to fund low-emissions hydrogen, SAF and DACS, especially in jurisdictions where no compliance carbon pricing instruments are in place. Carbon pricing instruments, which include "compliance" instruments (i.e. carbon taxes, emissions trading systems or hybrids of the two) and carbon credits, could help in different ways. In jurisdictions where compliance carbon pricing instruments are well established, governments could use the revenues to fund low-emissions technologies, especially for early-stage technologies facing the “valley of death”, which is the high-risk phase where many emerging technologies falter before reaching widespread adoption. High-quality carbon credits used towards a compliance obligation or in the voluntary carbon market could also accelerate the deployment of these technologies.

Carbon credit markets have faced serious concerns on both the supply and demand sides, but several initiatives have been set up to tackle these issues. On the supply side, concerns often revolve around over-crediting, a lack of additionality or human rights abuses. On the demand side, some corporations have used carbon credits to make misleading claims about reaching carbon neutrality without making genuine efforts to reduce their own emissions. In response, initiatives such as the Integrity Council for the Voluntary Carbon Market (ICVCM) and the Voluntary Carbon Markets Integrity Initiative (VCMI) have set stricter quality standards on the supply side and created guidance to help buyers navigate these complex markets and perform due diligence.

Generating high-quality carbon credits from low-emissions hydrogen, SAF and DACS is possible with appropriate safeguards. Project developers and carbon credit programmes should prioritise addressing potential risks of an inaccurate quantification of emissions reductions from low-emissions hydrogen and SAF, and potential risks of double counting of the emissions reductions from SAF carbon credits. DACS developers should be ready to justify why they need carbon credits to cover the green premium even when other incentives are in place.

Barriers and recommendations on the role of carbon credits in scaling up low-emissions hydrogen, SAF and DACS

Carbon credits cannot bridge the investment gap on their own, and governments and the private sector need to develop strategies to create the right enabling environment for investments. Low-emissions hydrogen, SAF and DACS require more than just carbon credits for large-scale adoption. Carbon markets struggle to incentivise early-stage technologies due to high upfront costs, volatile credit prices and market uncertainties. Governments should adopt a mix of complementary policies to bridge the investment gap. Roadmaps providing investment clarity, research and development (R&D) programmes, grants, and targeted public procurement (including using carbon credits) are some of the options available. Additionally, private sector coalitions could help lower technology costs through advance purchase commitments.

The current low availability of crediting methodologies hinders the generation of carbon credits from low-emissions hydrogen, SAF and DACS, but the landscape is shifting. There are currently no crediting methodologies to generate SAF carbon credits, and only a few methodologies for low-emissions hydrogen, which are limited in scope. Some DACS methodologies have been developed recently, but their applications have yet to scale. Carbon crediting programmes, project developers and experts are accelerating efforts to develop new methodologies to credit from these technologies, and they should also pay attention to potential quality issues.

A coalition of stakeholders should develop clear guidance on emissions accounting, and efforts to get better data on emissions are necessary to provide the foundation for such guidance. This is particularly important for emissions from the supply chain of low-emissions hydrogen and SAF carbon credits, which are complex as the emissions accounting often spans across several countries, across compliance regimes and voluntary markets, and across different types of carbon pricing instruments. Greater co-ordination and transparency are needed to ensure that countries and non-state actors account accurately for emissions from the supply chain of low-emissions hydrogen and SAF carbon credits.

1. Introduction

To shift onto a 1.5°C trajectory, the world must accelerate global clean energy investments, especially on key technologies

Reaching global net zero emissions will require a profound transformation of energy systems, necessitating an acceleration of the deployment of existing clean energy technologies, and the urgent deployment of innovative technologies that can address the most challenging sectors and remove residual emissions. Rapid progress has been made in the last few years on both fronts. For instance, innovation is already delivering new tools and lowering their costs: in the IEA's 2021 Net Zero Emissions by 2050 Scenario (NZE Scenario), technologies not available on the market at the time were set to deliver nearly half of the emissions reductions needed in 2050 to reach net zero; in just two years, that number has fallen to around 35%.

However, for the energy sector to achieve net zero CO_2 emissions by 2050, further near-term progress is nonetheless essential to scale up new and emerging technologies. Among these, low-emissions hydrogen and hydrogen-based fuels,[1] sustainable aviation fuels (SAF),[2] and direct air capture and storage (DACS) would need to grow substantially in the next few years. Low-emissions hydrogen produced from renewables, nuclear energy or fossil fuels with carbon capture and storage can help integrate variable renewable electricity into the grid and decarbonise hard-to-abate sectors, such as long-haul transport, chemical manufacturing, and iron and steel production.

In the NZE Scenario, low-emissions hydrogen production increases from less than 1 million tonnes (Mt) of hydrogen (H_2) in 2022 to around 70 Mt H_2 in 2030. SAF is critical to decarbonise the aviation sector, alongside a combination of other decarbonisation measures, and its share in final energy consumption in the aviation sector rises from close to zero today to around 11% in 2030. DACS is also a crucial technology for removing CO_2 from the atmosphere and for addressing residual emissions from hard-to-abate sectors. In the NZE Scenario, the CO_2 removed by DACS increases from virtually zero in 2022 to almost 70 Mt CO_2 in 2030. By 2050, DACS removes around 700 Mt CO_2 per year from

[1] Hydrogen-based fuels come under class of synthetic fuels which are also known as electrofuels or e-fuels, and ammonia produced from natural gas with carbon capture and storage.
[2] In this report, SAF refers to both bio-based aviation fuels and hydrogen-based SAF.

the atmosphere in the NZE Scenario, becoming a key technology for the achievement of global net zero emissions.

Without widespread adoption of these technologies, the world will fall short of its climate goals. Achieving the necessary scale-up depends on early deployment and investment. Across all clean energy technologies and infrastructure, the IEA estimates that an annual investment of USD 4.5 trillion per year by the early 2030s is needed to accelerate deployment, up from USD 1.8 trillion in 2023. While public finance plays an important role, most of this investment needs to come from the private sector.

Investment and deployment of low-emissions hydrogen, SAF and DACS are starting to pick up, but from a very low base, and need substantive public and private support to accelerate to the levels needed in the NZE Scenario. A variety of public and private financing mechanisms can help to scale up support for nascent technologies. High-quality carbon credits could play a role as a complementary instrument to other policies to accelerate the adoption of these technologies by crowding in private capital, but some important barriers impede progress.

This report explores how carbon credits can accelerate the adoption of low-emissions hydrogen, SAF and DACS globally. Chapter 2 presents the state of play for low-emissions hydrogen, SAF and DACS. Chapter 3 provides an overview of investment needs and sources of finance for the three technologies and highlights financing mechanisms that could help scale investments, and includes specific considerations for emerging market and developing economies (EMDE). Chapter 4 delves into the potential role of carbon credits in supporting the adoption of nascent technologies, providing insights into the latest developments in carbon crediting from low-emissions hydrogen, SAF and DACS. Chapter 5 provides an overview of current barriers to the adoption of carbon credits from these technologies and discusses how to overcome them.

Carbon credits can help to catalyse investment in innovative low-emissions technologies

Accelerating the deployment of these technologies will require a combination of complementary policies, including mandates, tax credits, incentives and public procurement initiatives. Carbon pricing instruments, which include "compliance" instruments (i.e. carbon taxes, emissions trading systems or hybrids of the two) and carbon credits, can also further contribute in different ways, depending on the specific local contexts. For instance, in jurisdictions where compliance instruments are well established, revenues can be redirected towards scaling up the adoption of low-emissions technologies. One notable example is the Innovation Fund in the European Union (EU) Emissions Trading System (ETS), which reinvests part of the revenues raised by the ETS into funding programmes for innovative low-carbon technologies. By their design, carbon pricing instruments make carbon-intensive technologies more costly, thereby increasing the economic attractiveness of low-emissions technologies and incentivising actors to implement mitigation activities. Compliance instruments, or, in other jurisdictions, high-quality carbon credits – which refer to reductions or removals of CO_2 or GHG emissions from the atmosphere generated by projects verified by third parties – could help increase mitigation ambition while bridging the investment and operational gap and channelling funding to low-emissions technologies.

Compliance carbon pricing instruments and carbon credits can also act in a complementary manner, for instance in their scope and coverage. For instance, voluntary carbon markets typically incentivise mitigation activities to reduce or remove emissions in sectors that are not covered by compliance carbon pricing instruments or other regulatory mechanisms. Moreover, while compliance carbon pricing instruments drive mitigation that is usually confined within a jurisdiction's geographical borders, carbon credits also incentivise cross-border mitigation.

Certain compliance carbon pricing instruments also allow covered entities to use eligible carbon credits to cover parts of their compliance obligations. For example, Singapore allows companies covered by its carbon tax to use eligible carbon credits to cover up to 5% of their compliance obligations. Similarly, Canada also allows companies to use credits from its Greenhouse Gas Offset Credit System as a compliance option in its federal output-based pricing system.

What are carbon credits, and how do carbon credit markets function?

One carbon credit *should* represent one tonne of CO_2 equivalent reduced or removed, although that is not always the case due to imperfections of the crediting methodologies or their implementation, or to a lack of additionality. Carbon credits can be generated by projects that do one of two things:

- Reduce GHG emissions against the likeliest forward-looking counterfactual scenario, which forecasts emissions in the absence of the mitigation project. For instance, when a new emissions reduction project (e.g. a flight uses SAF, replacing traditional jet kerosene) is implemented instead of the baseline project (e.g. the plane uses traditional jet kerosene), the difference in emissions between the counterfactual baseline scenario and the project scenario provides the volume of associated carbon credits (one credit is issued per tonne of GHG reduced). These projects are often referred to as "emissions reduction projects" and prevent additional future GHG emissions from being emitted.

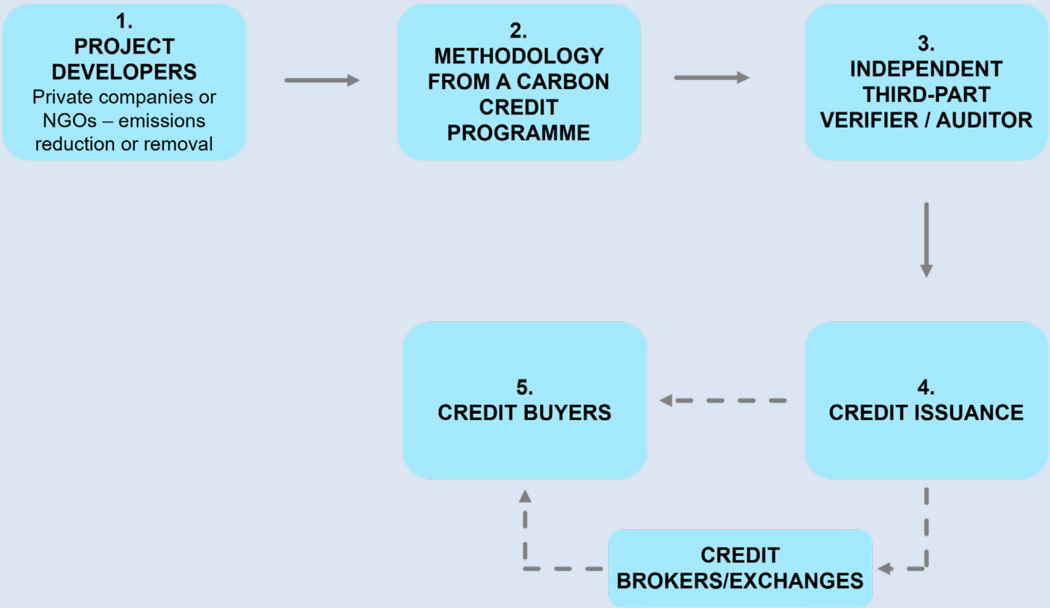
- Remove previously emitted CO_2 from the atmosphere. Removal projects use nature-based solutions (e.g. afforestation or reforestation) or technologies (e.g. DACS) to remove CO_2. The volume of human-induced, additional, removed CO_2 is used to calculate the volume of carbon credits that can be issued (one credit is issued per tonne of CO_2 removed). These projects are often referred to as "removal projects".

In both cases, project developers often use revenues from the sale of carbon credits to partially fund the operation of their projects, and they should justify – before carbon credits are issued – that these revenues are essential for the project to come to fruition.

To receive carbon credits, as a standard procedure project developers must register their reduction or removal projects to a carbon crediting programme, such as Gold Standard or Verra, in the voluntary carbon market (VCM), to the upcoming Article 6.4 mechanism under the United Nations Framework Convention on Climate Change (UNFCCC) (when it becomes operational), or to offset protocols or programmes under certain compliance carbon pricing systems. While a centralised governmental body defines the guidance and rules and oversees their application of the Article 6.4 mechanism and programmes under compliance carbon pricing systems, VCM programmes – which in certain cases are for-profit institutions – are free to define their own rules. These programmes provide project developers access to several types of crediting methodologies that allow project developers to estimate how many carbon credits they could issue from a specific project. These methodologies, and their parameters thereof, vary across different programmes, with some being more stringent than others. For instance, choosing one programme over another can impact the number of carbon credits issued for the same project.

As a standard procedure, independent third-party auditors must verify that the project developers have correctly applied the chosen programme methodology, which also includes an obligation to monitor and report the project emissions. Only once the verification process is complete can the programme allow the issuance of carbon credits, usually for a fee.

Simplified flow chart of how carbon credits are issued and bought



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Notes: NGOs = non-governmental organisations. The flow chart does not reflect all steps involved in more complex scenarios, such as trading of internationally transferred mitigation outcomes (ITMOs), where further steps such as authorisation, or the application of a corresponding adjustment, are needed.

Once carbon credits are issued, project developers can in theory directly sell the credits to the credit buyers, which can be governments or corporations (or even individuals). However, in practice, this transaction does not always occur directly between the project developers and the credit buyers. Instead, credit brokers or carbon exchanges usually aggregate the demand by purchasing carbon credits in bulk from the project developers and resell them to buyers.

While recognising the importance of compliance carbon pricing instruments, this report analyses the potential role of carbon credits in accelerating the scale-up of low-emissions technologies. All actors should always prioritise reducing their own emissions first. In the last few years, loopholes and imperfections in the design of carbon credit markets have led to justified scepticism on the real effectiveness of these markets to drive emissions mitigation. However, in over 20 years of existence, carbon credit markets have also established a quite unique, robust and reliable cross-border financing infrastructure, which has proven efficient in channelling pay-for-performance funding to developing countries in particular.

Non-state actors (e.g. corporations) and governments also use carbon credits for other purposes. For instance, non-state actors use carbon credits – mostly from the VCMs – to offset their residual emissions to claim carbon neutrality or the achievement of net zero emissions as part of their voluntary climate targets. Airlines also use carbon credits to comply with part of their obligations under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Until 2020, some governments also used carbon credits from the Kyoto Protocol flexibility mechanisms to comply with their emissions mitigation obligations under the protocol. Since 2020, some governments have started or are considering using a form of carbon credits – the internationally transferred mitigation outcomes (or ITMOs) – to voluntarily co-operate under Article 6 of the Paris Agreement to reach and go beyond their nationally determined contributions (NDCs).

Article 6 of the Paris Agreement

Article 6 of the Paris Agreement allows countries to voluntarily co-operate with one another to achieve and go beyond their NDC ambition. Article 6.2 and Article 6.4 are market-based approaches, while Article 6.8 sets out guidelines for non-market co-operation.

Article 6.2 sets the rules of bilateral and multilateral voluntary co-operation through Article 6 credits (ITMOs) across countries. Several countries have already begun to trade ITMOs under Article 6.2. Article 6.4 builds on the rules of Article 6.2, and develops a centralised mechanism, intended to replace the Kyoto Protocol's Clean Development Mechanism (CDM). The Article 6.4 mechanism will operate as a carbon crediting programme, issuing credits when projects, programmes and policies are developed based on approved methodologies, and it will record in a registry the credits issued and transacted. The Article 6.4 Supervisory Body will oversee the mechanism. As of 2024, Article 6.4 is not yet operational because countries could not reach an agreement at the 28th Conference of the Parties (COP28).

A key accounting rule set out in Article 6 co-operation is the mandatory application of corresponding adjustments on ITMO transactions, whereby the seller country is not able to use the emissions reduction or removal associated with the ITMO towards its NDC. This is critical to prevent double counting or double claiming, i.e. a situation where both the seller and buyer countries count or claim the same emissions reductions towards their respective NDCs.

Countries can use ITMOs towards their NDCs, and – alongside other actors – for other international mitigation purposes, such as for complying with sectoral compliance schemes. For instance, CORSIA's first phase (2024-2026) requires airlines to purchase credits with corresponding adjustments, necessitating ITMOs.

Initiatives to strengthen environmental integrity and restore trust and transparency in carbon markets

Carbon credit markets have come under scrutiny in recent years. On the supply side, there have been doubts over the "quality" of certain types of carbon credits – which is a multifaceted concept. Some projects have been accused of over-crediting, i.e. issuing more credits than emissions reduced or removed, because of lenient quantification of the mitigated emissions. Other projects have been accused of a lack of additionality, in cases, for instance, where projects would have succeeded even in the absence of the price signal from carbon credits. Other projects have been accused of human rights abuses. On the buyer side, some companies have suffered from greenwashing accusations because of misleading claims on the use of carbon credits, particularly those who retired carbon credits to claim carbon or climate neutrality without making genuine efforts to reduce their own emissions; or those who bought carbon credits from low-quality projects without performing due diligence.

In the last few years, there have been efforts to improve the environmental integrity of carbon markets addressing both the supply and demand sides. For instance, on the supply side, the Integrity Council for the Voluntary Carbon Market (ICVCM) was set up as an independent governance body to set minimum thresholds for high-quality carbon credits, the criteria of which are detailed in the ICVCM's Core Carbon Principles (CCPs). Similarly, the International Civil Aviation Organization's (ICAO's) CORSIA sets out criteria for eligible carbon credits that can be used by airlines towards the international aviation decarbonisation goal. Progressive strengthening of baseline methodologies under the CDM also contributed to continuous improvement. Many actors also hope that if the Article 6.4 mechanism manages to develop strict quality criteria, especially in terms of methodologies and additionality, these could serve as benchmarks for the carbon crediting programmes under the VCM.

On the demand side, it is usually difficult for corporations or governments without specific expertise to navigate the multifaceted carbon credit markets. A number of initiatives have been set up to provide guidance for buyers. For instance, the Claims Code of Practice of the Voluntary Carbon Markets Integrity initiative (VCMI) provides guidance on how carbon credits can be used with integrity, safeguarding against greenwashing practices. Similarly, the Nordic Code of Best Practice for the Voluntary Use of Carbon Credits aims to promote a coherent and transparent use and claim of high-integrity voluntary carbon credits. The Finnish government also issued a guide in 2023 to support voluntary mitigation actions with carbon credits, which include a comprehensive overview of existing demand-side integrity initiatives.

The past years have also seen the emergence of carbon credit rating companies such as Sylvera, Calyx and BeZero. These companies rate carbon credit projects against independent, self-defined quality criteria, and some stakeholders see them as an additional layer of due diligence in the market, though there is still some degree of variance in their ratings of similar projects.

Non-exhaustive examples of initiatives and organisations seeking to improve environmental integrity and transparency in carbon credit markets

Role	Organisation	Description
Supply side	Integrity Council for the Voluntary Carbon Market	The ICVCM is an independent governance body that seeks to set minimum thresholds for high-quality carbon credits. The ICVCM's CCPs set out detailed criteria for carbon crediting programmes and methodologies.
	Carbon Credit Quality Initiative (CCQI)	The CCQI provides assessments on the different types of carbon credits based on characteristics such as project type, carbon crediting programme, sustainable development safeguards and host country.
	CORSIA Eligible Emissions Units	The ICAO's CORSIA allows airlines to use carbon credits towards achieving the target of carbon-neutral growth. Similar to the ICVCM's CCPs, CORSIA sets out eligibility criteria.
	International Carbon Reduction and Offset Alliance (ICROA)	ICROA's Code of Best Practice sets out best practices for carbon credits and is used to assess carbon crediting that seeks its endorsement.
	Carbon crediting programmes (e.g. American Carbon Registry, Article 6.4, ART-TREES, Cercarbono, Climate Action Reserve, Global Carbon Council, Gold Standard, Puro.earth, Verified Carbon Standard)	Carbon crediting programmes are responsible for developing methodologies that specify how to develop projects and how to estimate emissions reductions or removals to generate carbon credits. Programmes also specify how independent validation/verification bodies should audit projects and manage registries.
	Rating agencies (e.g. BeZero, Calyx Global, MSCI Carbon Markets, Renoster, Sylvera)	The recent years have also seen the emergence of carbon credit rating companies. These companies rate projects for quality and provide an additional layer of checks.
Demand side	Voluntary Carbon Markets Integrity Initiative	VCMI's Claims Code of Practice, designed for building integrity in voluntary carbon markets, sets out guidance for companies and other non-state actors on how they could credibly make voluntary use of carbon credits as part of their climate commitments and what they could communicate regarding the use of those credits. The Claims Code of Practice requires that companies use carbon credits in addition to prioritising internal emissions reductions, and to make credible claims

Role	Organisation	Description
Demand side (continued)	Science-Based Targets Initiative (SBTi)	The SBTi sets out guidance and principles to set and achieve climate targets. Its guidance covers the use of carbon credits in relation to a corporation's targets.
	Government regulations on green claims or reporting (e.g. European Union [EU] Green Claims Directive, United States [US] Commodity Futures Trading Commission Proposed Guidance on voluntary carbon credit derivatives)	Governments are also increasingly weighing in on carbon credit use, in particular where it pertains to the use of carbon credits in relation to corporate claims and public communications.
Supply and demand side	UNFCCC (i.e. Article 6 of the Paris Agreement)	Article 6 of the Paris Agreement sets out the rules that enable countries to generate, trade and use carbon credits towards their climate targets.
	International Organization for Standardization (ISO)	The ISO develops standards pertaining to a number of sectors, including on climate change. Some of these standards such as the "net zero guidelines" and the "carbon neutrality standard" set out guidelines on carbon credit quality and use.

2. State of play for low-emissions hydrogen, sustainable aviation fuels and direct air capture and storage

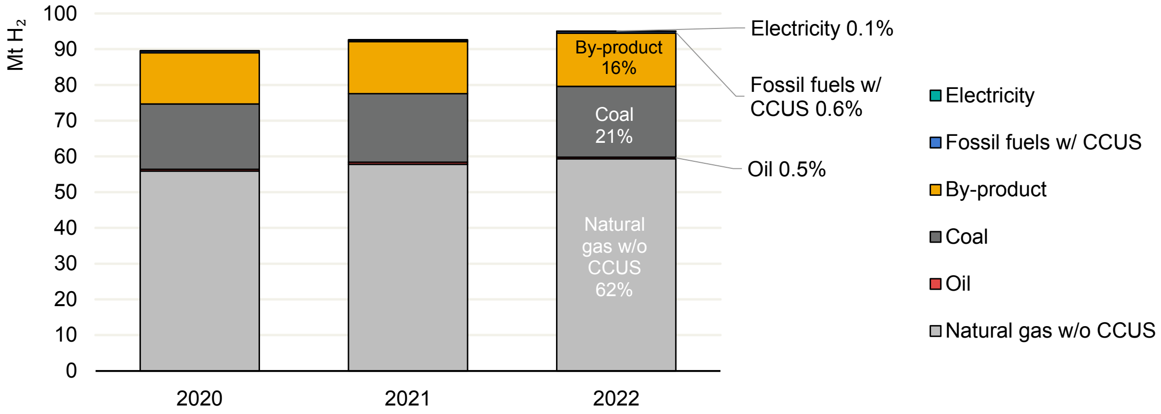
State of play for low-emissions hydrogen

Hydrogen is a versatile energy carrier that has the potential to address various clean energy challenges. Today hydrogen is primarily employed in the refining and chemical industries, and its production is largely reliant on coal and natural gas, contributing to substantial CO_2 emissions. However, producing hydrogen through renewable or nuclear energy, or fossil fuels with carbon capture, holds the potential to decarbonise a diverse range of sectors. These include some hard-to-abate sectors, such as long-haul transport, chemical manufacturing, and iron and steel production. Moreover, electricity generated by hydrogen can help in integrating variable renewable energy sources into the electricity grid, with hydrogen being an option for storing energy over extended periods.

Boosted by climate goals and, in some countries, by energy security considerations, policy momentum behind low-emissions hydrogen remains strong. The adoption of new industrial strategies by several major economies sees low-emissions hydrogen playing a key part. However, this momentum has yet to turn into large-scale deployment.

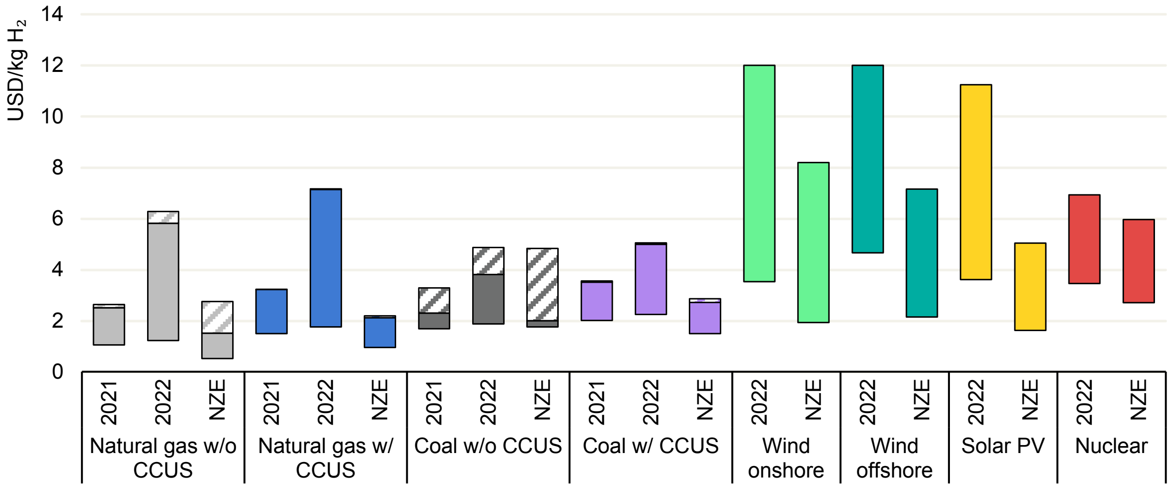
Global hydrogen production reached almost 95 million tonnes (Mt) of hydrogen (H_2) in 2022, with a slow but steady increase since 2020. Hydrogen production was dominated by unabated fossil fuels: 62% of global production came from unabated natural gas, 21% from unabated coal, 16% produced as a by-product from different operations such as naphtha crackers, and with low-emissions hydrogen making up only 0.7% of global production, almost entirely from fossil fuels with carbon capture utilisation and storage (CCUS). Production from water electrolysis continued to be relatively small, still below 100 kilotonnes of H_2 in 2022, which represents 35% growth compared with the previous year.

Global hydrogen production by technology, 2020-2022



Source: IEA (2023), Global Hydrogen Review 2023.

Levelised cost of hydrogen production by technology in 2021, 2022 and in the Net Zero Emissions by 2050 Scenario in 2030



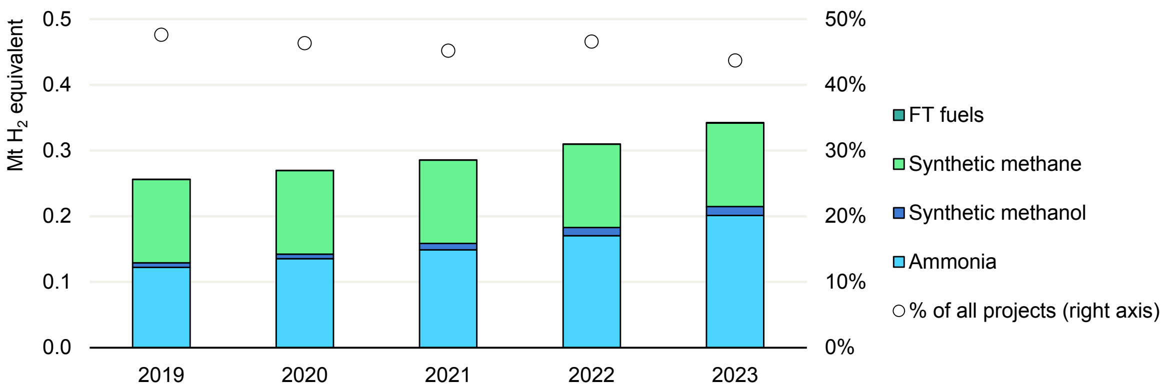
Notes: kg = kilogramme; PV = photovoltaic; NZE = Net Zero Emissions by 2050 Scenario in 2030. Solar PV, wind and nuclear refer to the electricity supply to power the electrolysis process. NZE Scenario values refer to 2030. The dashed area represents the CO_2 price impact, based on USD 15 per tonne (t) of CO_2 to USD 140/t CO_2 for the NZE Scenario. The Global Hydrogen Review 2023 provides the techno-economic assumptions on energy and capital costs.
Source: IEA (2023), Global Hydrogen Review 2023.

If all planned projects from electrolysers and fossil fuels with carbon capture are realised, these will lead to annual production of low-emissions hydrogen of 38 Mt H_2 in 2030. Of these, around 27 Mt H_2 is based on electrolysis and low-emissions electricity, and around 10 Mt will come from projects using fossil fuel with CCUS. Electrolysis projects have a wider geographical diversity, with Europe, Australia, New Zealand and Latin America leading announcements of planned projects; conversely, announcements for low-emissions hydrogen production projects from fossil fuels with carbon capture are mostly concentrated in North

America (50%) and Europe (40%). However, only 4% of potential low-emissions hydrogen production in 2030 has taken final investment decision, and the slow implementation of policy or regulatory support is delaying investment decisions.

Hydrogen-based fuels, such as ammonia, methanol and synthetic hydrocarbons, are more convenient to store and transport compared with pure hydrogen. They can also utilise existing infrastructure, offering potential advantages – such as the production of synthetic kerosene that can fit existing end-use technology in aviation. In 2022, there were around 80 hydrogen-based fuels production projects in operation, corresponding to approx. 0.3 Mt H_2 of annual production. Ammonia, which is used as fertiliser or long-distance carrier for hydrogen, and synthetic methane were the largest and second-largest hydrogen-based fuels produced respectively.

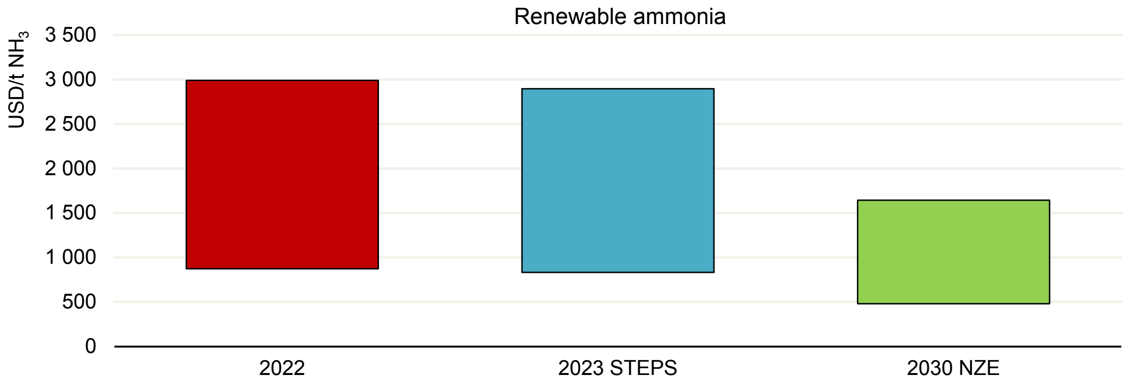
Global hydrogen-based fuel production by fuel, 2019-2023



Notes: FT = Fischer-Tropsch; % of projects based on total number of low-emissions hydrogen projects. 2023 values are estimated from October 2023 data release.
Source: IEA (2023), Global Hydrogen Review 2023.

Currently announced projects in 2023 project hydrogen-based fuels production to grow to an annual production of 17 Mt H_2 equivalent (H_2-eq) by 2030, for a total of 325 projects. This capacity in 2030 is mostly concentrated in Australia and North America (4.7 Mt H_2-eq from 75 projects combined), followed by Central and South America (2.6 Mt H_2-eq) and Europe (1.8 Mt H_2-eq). However, converting hydrogen into these fuels requires additional energy and feedstocks, which could result in higher costs.

Levelised costs of ammonia in 2022 and 2030 in the Net Zero Emissions by 2050 Scenario



Note: NH_3 = ammonia.
Source: IEA (2023), Global Hydrogen Review 2023.

As of February 2024, 46 countries and the European Union (EU) have implemented hydrogen strategies. Targets for the adoption of hydrogen production technologies are expanding, especially for electrolysis, with national targets reaching a combined 160 gigawatts (GW) to 210 GW. However, there has been minimal progress in setting targets to increase demand for low-emissions hydrogen, with the notable exception of the European Union, which established targets in March 2023 to stimulate demand in industry and transport. The majority of existing policies focus on supporting demand creation in transportation applications, primarily through purchase subsidies and grants, while only a few policies target industrial applications, despite these applications accounting for the majority of current demand. Governments are also considering adopting quotas and mandates to support demand creation for low-emissions hydrogen in industry, aviation and shipping, although none of the announced quotas have yet been implemented. A few countries and regions, including the European Union (EU), the United States (US) and the United Kingdom (UK), have also stepped up efforts to support research and development (R&D) and innovation in low-emissions hydrogen. Several governments have also begun to implement policies to support project developers and mitigate investment risk in low-emissions hydrogen, in the form of grants, loans, tax breaks and carbon contracts for difference. Several countries and regions, including Canada, the European Union, India, Japan and the United States and have incorporated e-fuels, fuels made from low-emissions hydrogen, into their hydrogen strategies and roadmaps to bolster R&D. Brazil is also formulating a regulatory framework for low-emissions e-fuels. Globally, however, low-emissions hydrogen-based fuels are not expanding at a rate consistent with NZE Scenario ambitions.

Selected examples of policy support mechanisms to support low-emissions hydrogen production

Government/ Jurisdiction	Description
Brazil	Brazil adopted the National Hydrogen Programme (PNH2) in 2022, establishing a series of guidelines in developing hydrogen production. The Triennial Work Plan (2023-2025) aims to increase investments in research, development and innovation in low-emissions hydrogen to BRL 200 million (Brazilian reals)[3] per year in 2025.
Canada	Canada published its Hydrogen Strategy in 2020 with the goal to deliver up to 30% of its end-use energy in the form of hydrogen by 2050.
Chile	Chile published a National Green Hydrogen Strategy in 2020 with three main objectives: • have 5 GW of electrolysis capacity operating and under development by 2025 • produce the cheapest green hydrogen in the world by 2030 • be among the world's three largest exporters by 2040. In 2021, Chile presented a comprehensive document outlining its investment opportunities and selected private projects under development. It has also have defined a Roadmap for 2023-2030 which is currently in public consultation.
European Union	The European Commission approved two rounds of funding for major hydrogen-related initiatives in 2023: • Hy2Tech, focused on developing innovative hydrogen technologies • Hy2Use, focused on industrial applications. Additionally, the European Hydrogen Bank launched a pilot auction to support domestic production of renewable hydrogen which closed in February 2024. The European Hydrogen Bank plans a new tender for imports in 2024.
Germany	The H2Global initiative's bidding process commenced in December 2022, with hydrogen deliveries anticipated for the end of 2024. Moreover, Germany has recently become the first European Union (EU) member state participating in the European Hydrogen Bank.
India	India approved the National Green Hydrogen Mission in 2023 with the aim to develop hydrogen production capacity of at least 5 Mt per year by 2030.
Japan	Japan's New Energy and Industrial Technology Development Organization (NEDO) has allocated JPY 220 billion (Japanese Yen – approx. USD 1.45 billion) from its Green Innovation Fund Project to support the development of a liquefied hydrogen supply chain between Australia and Japan. Moreover, the bill passed in February 2024 on the Promotion of the Supply and Utilization of Low-Emissions Hydrogen intends to cover the difference between the cost of low-emissions hydrogen (including its derivative products) and the reference price of the fossil fuel counterpart.

[3] Exchange rate (2022): 1 Brazilian Real (BRL) = USD 0.19.

Government/ Jurisdiction	Description
Singapore	Singapore introduced its National Hydrogen Strategy in 2022, with efforts to experiment with the use of advanced hydrogen technologies, invest in R&D, pursue international collaborations, undertake long-term land and infrastructure planning, and support workforce training and development of the broader hydrogen economy.
United Kingdom	The government launched the first Electrolytic Allocation Round between July 2022 and January 2023, identifying promising projects with the goal of supporting at least 250 megawatts (MW) of capacity. A second allocation round with an aim to support up to 875 MW of capacity by the end of 2025 commenced in December 2023.
United States	The government introduced a tax credit, an investment credit and grant funding to support the development of low-emissions hydrogen production projects. In September 2022, the Department of Energy (DOE) announced a USD 7 billion call for the establishment of regional clean hydrogen hubs. Seven hubs were selected in October 2023.

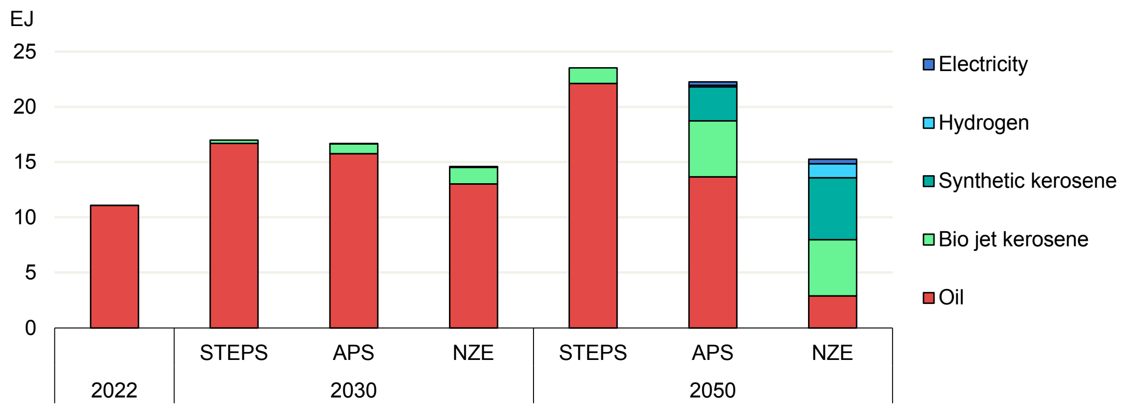
A number of barriers are holding back low-emissions hydrogen development. These include uncertainties about demand, high costs of production, lack of clarity in regulations and a lack of infrastructure to deliver hydrogen to end users. Without robust demand, producers of low-emissions hydrogen will not secure sufficient off-takers to underpin large-scale investments, jeopardising the viability of the entire low-emissions hydrogen industry. Rising inflation exacerbated these barriers. As a consequence, public funds have become scarcer as financing needs for individual projects become larger. Moreover, long lead times for low-emissions hydrogen infrastructure projects mean that early and coherent planning is needed to get on track. This is particularly acute for storage, which may have an important role to play to ensure security of supply.

State of play for sustainable aviation fuels

Jet fuel from fossil fuels still dominates the aviation sector, which is responsible for over 2% of global energy-related CO_2 emissions. To decarbonise this sector, various parallel approaches are essential. Efficiency improvements will play a crucial role in aviation decarbonisation, but they can offer only a partial answer to the problem. Modern airplanes, employing enhanced aerodynamics and lightweight materials, offer nearly 20% greater fuel efficiency compared with their decade-old counterparts. While further advancements are anticipated, these will take time, mostly due to the long implementation cycles of technological, material and design modifications in aviation. The reduction in emissions coming from efficiency improvements cannot fully counterbalance the rising demand for air travel, which is projected to increase by approximately 4% annually until 2050.

This points to the need to develop a further array of possible complementary solutions to tackle the remaining emissions in the aviation sector. One of them is the development and deployment of low-emissions fuels. Sustainable aviation fuels (SAF) provide an alternative to traditional jet fuel (i.e. kerosene), offering the potential to reduce emissions. SAF are drop-in fuels that are blended with conventional oil products at rates of up to 50%, but they have the potential to be used on their own – some aircraft manufacturers and airlines are piloting SAF-only run flights. SAF, which can take the form of biojet kerosene and synthetic fuels (e.g. made from low-emissions hydrogen and CO_2), play an increasingly important role in the energy demand in aviation in the IEA NZE Scenario, in both 2030 and 2050.

Energy demand in aviation by fuel and scenario, 2022-2050

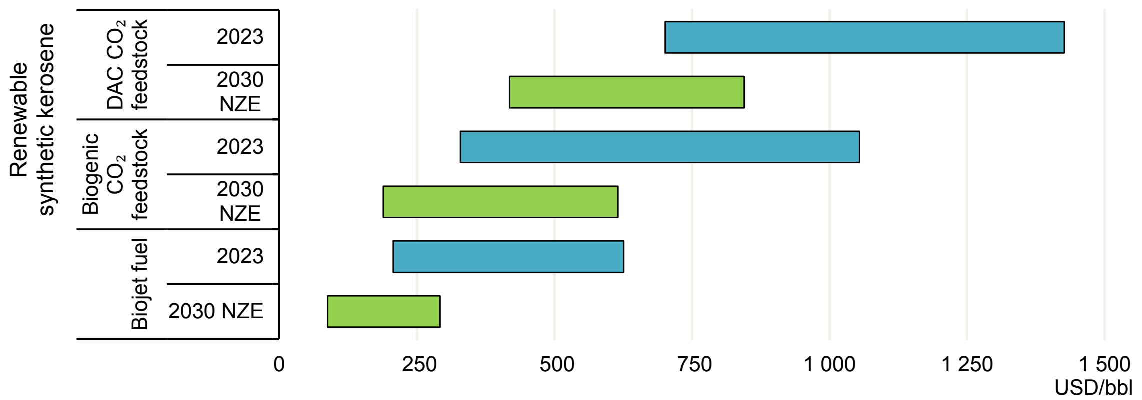


Notes: EJ = exajoules; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. SAF are categorised in this chart as “Synthetic kerosene” and “Biojet kerosene”.
Source: IEA (2023), World Energy Outlook 2023.

SAF are still very expensive and today meet less than 0.1% of energy demand in aviation. Despite a substantial increase in SAF offtake agreements in the last three years, indicating rising demand, high costs and limited SAF availability continue to hinder widespread adoption. The announced pipeline of SAF projects accounts for only approximately 1-3.5% of global aviation demand by 2028. Moreover, while existing policies under the IEA Stated Policies Scenario (STEPS) will bring biojet fuel’s share to 1% by 2028, the NZE Scenario requires 8% of fuel supply coming from biojet fuel by 2030. This highlights the need for further expansion of SAF production.

Barriers to widespread adoption of SAF are its high production costs and the limited supply of resources to produce biojet fuel. The price of biojet kerosene is currently around 3-4 times the price of conventional kerosene, while the cost of producing synthetic kerosene is 5-6.5 times the price of conventional kerosene. Increasing production capacity can help bring down costs due to economies of scale, but the STEPS projects the average price of SAF to be roughly twice that of conventional kerosene in 2030. Synthetic kerosene is produced in only negligible quantities today, and is expected to contribute only over the longer term due to its low technology readiness and high cost. In 2021, Atmosfair, a German non-profit organisation, inaugurated the first project for the production of synthetic fuels using hydrogen produced from renewable electricity, which included an offtake agreement for 25 000 litres of synthetic kerosene annually with the airline Lufthansa. Production costs for synthetic kerosene from electrolytic hydrogen vary greatly depending on the cost of electricity and the source of the CO_2 used for the production, e.g. they can range from USD 30/t CO_2 for biogenic CO_2 from ethanol production to USD 600/t CO_2 to USD 1 000/t CO_2 for CO_2 from direct air capture (DAC). Private sector investment is also essential for the advancement and commercialisation of synthetic kerosene, which has low technology readiness and high costs today.

Levelised costs of renewable synthetic kerosene and biojet fuel in 2023 and 2030 in the Net Zero by 2050 Scenario



Note: bbl= barrel.
Source: IEA (2023), Global Hydrogen Review 2023.

Various policies are already in place to promote SAF development. The US Inflation Reduction Act offers tax credits for SAF production, with aims to achieve a production capacity of 3 billion gallons (0.2 million barrels per day) by 2030 and 35 billion gallons (2.3 million barrels per day) by 2050, sufficient to fuel all US flights by 2050. Moreover, the United States has also developed the SAF Grand Challenge Roadmap to outline measures to meet its 2030 and 2050 targets. The Inflation Reduction Act provides USD 3.3 billion in tax credits and a competitive grant programme for SAF support over the period 2023-2031. The EU Innovation Fund also provides grants for SAF development, and ReFuelEU Aviation's mandate provides for SAF to make up 70% of aviation fuel in the European Union by 2050. Japan also has a planned mandate for SAF to account for 10% of aviation fuel usage by 2030. In the People's Republic of China (hereafter "China"), the Civil

Aviation Administration of China targets an increase in SAF use and a lower GHG emissions intensity by 2025. The UK Jet Zero strategy to decarbonise aviation by 2050 also supports further SAF development. Singapore is introducing a 1% SAF target for flights departing Singapore from 2026, with the aim to raise it to 3%-5% by 2030, subject to global developments and the wider availability and adoption of SAF. Finally, India intends to mandate the use of SAF to make up 1% of aviation fuel from 2027 and increasing to 2% in 2028.

The limited supply of resources to produce biojet fuel is another potential barrier to SAF uptake. Certain feedstocks, such as used cooking oil and waste animal fats currently used for biojet kerosene production, have finite supply that can hinder growth in the medium to long term. SAF manufacturing up to 2027 will mostly depend on waste and residue oils, fats, and vegetable oils. The demand for these products for the production of all biofuels is anticipated to rise by 50% between 2023 and 2028, which is likely to keep raw material costs high. To overcome this potential feedstock scarcity and meet future biofuel demand, alternative production routes using materials such as municipal solid waste, agricultural residues and forestry residues are being further developed and brought to market.

State of play for direct air capture and storage

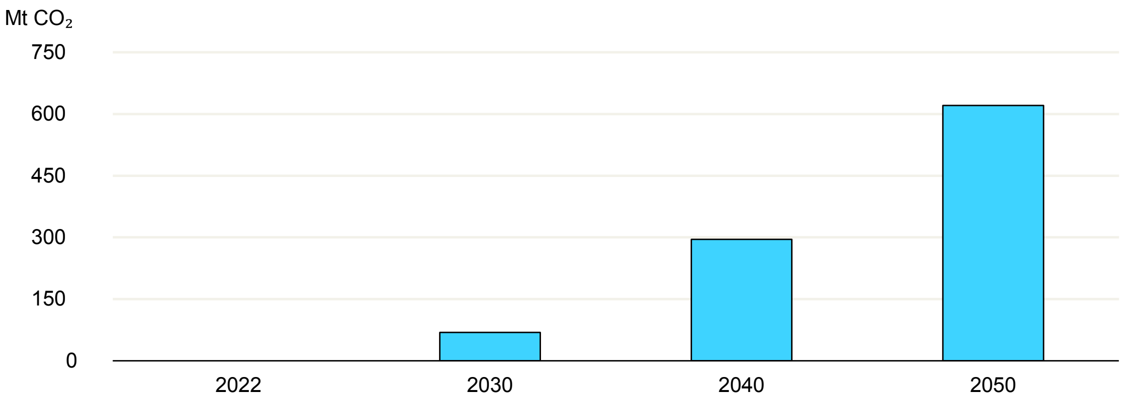
DACS can play an important role in net zero emissions pathways. DACS is a key CO_2 removal approach for balancing residual emissions mainly in hard-to-abate sectors; however, it should not substitute for immediate and substantial GHG emissions reductions. The captured CO_2 from direct air capture can also be converted into feedstock for low-emissions fuels, such as synthetic kerosene (see the related section above) or other synthetic fuels. Using air-captured CO_2 offers the possibility for these fuels to be close to carbon-neutral over their life cycle. In this respect, DACS can also be one of very few solutions available to reduce emissions in aviation, which remains one of the most challenging energy sectors to decarbonise.

DACS is a relatively new technology: the first pilot plant was commissioned in 2010, and the first kilotonne-scale plant was commissioned in 2021. Two main technological approaches are currently employed to capture CO_2 from the atmosphere: solid direct air capture (S-DAC) and liquid direct air capture (L-DAC). S-DAC technologies, which are currently at a demonstration stage, operate at ambient to low pressure and medium temperature (80° C to 120° C). L-DAC technologies operate at high temperatures (300° C to 900° C) but are currently at a prototype stage. Both are characterised by high energy requirements, and need to be scaled up dramatically to align with the IEA NZE Scenario. New promising technologies are also emerging, such as electro-swing adsorption, zeolites and passive DAC. While they can offer several advantages, including lower costs, lower energy intensities and higher availability of sorbents, they are all still at early stages of development.

In DACS applications with geological sequestration, the timescale of the storage for the captured CO_2 is usually very long, with a high probability that most of the CO_2 will remain trapped for at least 1 000 to 10 000 years. In certain cases, DACS developers need to compress the captured CO_2 at a very high pressure to inject it into geological formations. This step increases capital costs, due to the requirement for additional equipment such as a compressor, and also operating costs, due to higher energy demand.

To date, 27 DAC plants have been commissioned worldwide and the installed capture capacity of DACS today is less than 0.01 Mt CO_2/year, installed in the United States and Iceland. Some DACS projects are also planned in Kenya. To align with the IEA NZE Scenario, this capacity needs to increase to 69 Mt CO_2/year in 2030, to 162 Mt CO_2/year in 2035 and to 621 Mt CO_2/year in 2050.

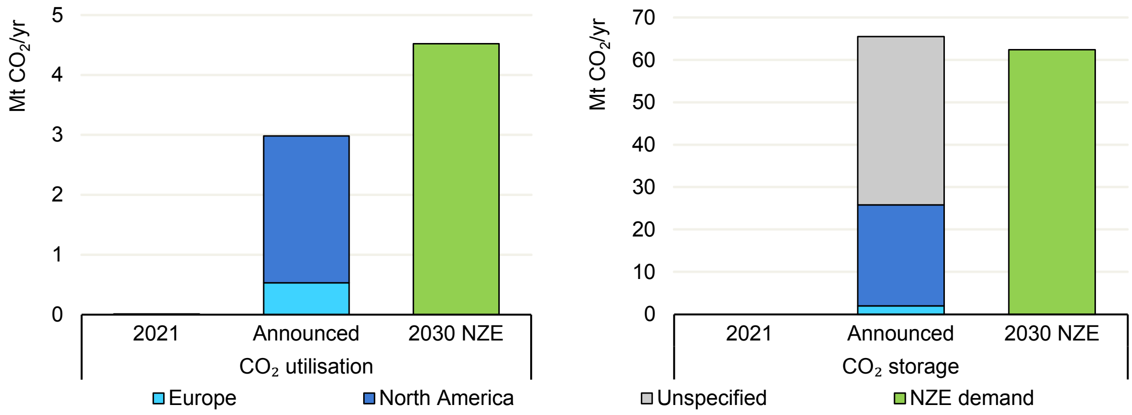
Global direct air capture and storage capacity in the Net Zero by 2050 Scenario



Note: Direct air capture capacity refers to the CO_2 captured via DAC and permanently stored in geological storage.
Source: IEA (2023), World Energy Outlook 2023.

DACS is currently associated with high costs and energy needs. Broadly, these vary depending on the capital cost of the plant (e.g. air contactors, compressors, vacuum pumps), type of technology (S-DAC, L-DAC or other novel methods), source of energy, and proximity to relevant storage or utilisation sites. At the project level, additional factors that influence the cost of CO_2 capture include the scale of the DACS plant and its level of utilisation, as well as capture efficiencies, The cost of removal through DACS technologies ranges today between USD 300/t CO_2 for L-DAC and USD 730/t CO_2 for S-DAC. This includes an average transport and storage cost of USD 30/t CO_2, but transport and storage costs can vary significantly depending on transport distance and type of storage. Project developers can optimise the siting of DACS facilities to minimise these costs by targeting locations characterised by high penetration of renewable energy and CO_2 storage potential. Moreover, there is further considerable potential for cost reduction in the future, with e.g. the US DOE intending to bring the cost of DACS below USD 100/t CO_2 within a decade through its Carbon Negative Shot. Moreover, in the short to medium term, the expected cost reduction for L-DAC from the first large prototype to the nth of a kind is 27%, while for S-DAC technology providers are expecting a threefold to sixfold cost reduction. Cost reductions will be driven by performance improvement, and also by further research, economies of scale and technology spillover.

Direct air capture capacity by country/region for use and storage according to announced projects and in the Net Zero by 2050 Scenario



Notes: RoW = rest of world. Announcements included as of July 2023. Dedicated storage only. Announced capacity includes existing capacity. “Unspecified” refers to 69 to 100 facilities recently announced by 1PointFive and Occidental (Carbon Engineering), for which locations have not yet been finalised. The fate of the captured CO_2 (storage or use) for these unspecified projects has not been disclosed.
Source: IEA (2024), IEA CCUS Projects Database, accessed 8 April 2024.

A few countries have taken an early lead in supporting DACS research, development, demonstration and deployment. However, policy support mechanisms are concentrated in the advanced economies, and there is no DACS-specific support policy in emerging market and developing economies. Several corporations, including JPMorgan Chase & Co., BlackRock and Microsoft, have also announced major investments in the DACS sector in various forms.

Selected examples of policy support mechanisms to support DACS research, development, demonstration and deployment

Government/ Jurisdiction	Policy instrument	Description
Canada	Climate Action and Awareness Fund	The fund is investing CAD 206 million (Canadian dollars)[4] (USD 164 million) to support projects that will reduce Canada's GHG emissions, including efforts to understand the potential for, and implications of, carbon removal technologies including DAC.
	Net Zero Accelerator	Canada announced this initiative as part of the Strategic Innovation Fund in December 2020 and further enhanced it with the Budget 2021 to provide a total of CAD 8 billion (approx. USD 6 billion) over seven years to support the decarbonisation of the industrial sector. DAC with CO_2 use is eligible as a climate-neutral CO_2 feedstock to produce low-carbon products.
	Canada's Greenhouse Gas Offset Credit System	Canada's GHG Offset Credit System Regulations include a protocol for direct air carbon dioxide capture and sequestration that is under development to further incentivise permanent storage opportunities.
	Clean Fuel Standard	The standard will require liquid fuel suppliers to gradually reduce the carbon intensity of the fuels they produce and sell. Low-carbon-intensity fuels include those made from sustainably sourced biomass and DAC. Moreover, the third reading of the Low Carbon Fuels Act of British Columbia indicates they are considering making eligible removals from the atmosphere at a site in British Columbia to generate compliance credits.
	Investment tax credit for carbon capture	Canada's 2021 federal budget included the announcement of a planned investment tax credit for CCUS projects. In the 2022 federal budget, the government outlined details of the tax credit, which will apply to CCUS projects that permanently stored captured CO_2 via dedicated geological storage or storage of CO_2 in concrete. From 2022 through 2030, the tax credit rates will be set at 60% for investment in equipment to capture CO_2 in DAC projects.

[4] Exchange rate (2022): 1 Canadian dollar (CAD) = USD 0.77.

Government/ Jurisdiction	Policy instrument	Description
Denmark	NECCS Fund	The DKK 2.5 billion (Danish kroner – approx. USD 0.4 billion)[5] NECCS Fund aims to achieve negative emissions of an additional 0.5 Mt per year from 2025 onwards through CO_2 capture. The fund will support the achievement of negative emissions from CO_2 capture of biogenic sources and subsequent geological storage. Biogenic sources refers to CO_2 capture from biogas upgrading, biomass-based power and heat production, the biogenic share of CO_2 captured in waste incineration plants, and carbon captured directly from the atmosphere (DACS).
European Union	Horizon Europe	DACS projects are eligible for support under Horizon Europe, the main European Union funding programme for research and innovation, with a total budget across all areas of EUR 95.5 billion (around USD 104 billion).
	Innovation Fund	The European Union launched in 2020 this EUR 10 billion (approx. USD 10.9 billion) fund to support innovation in low-emissions technologies and processes, including CCUS and DAC.
	Communication on Sustainable Carbon Cycles	The communication, released in December 2021, sets out a strategy to increase removals of carbon from the atmosphere. It suggests that 5 Mt of CO_2 should be removed annually by 2030. As part of its next steps, the European Union has agreed on a regulation that establishes a voluntary framework to certify carbon removals, farming and storage.
	Industrial Carbon Management Communication	The communication includes preparatory work in setting up a regulatory framework for CO_2 transport and storage, assessing the potential for industrial carbon removals, and creating a carbon accounting system for CO_2 utilisation. The strategy links to the recent recommendations formulated under the 2040 Climate Target Plan. The 2040 recommendation indicates that approximately 280 Mt would need to be captured by 2040, rising to around 450 Mt annually by 2050.
	Connecting Europe Facility (CEF)	The CEF promotes the development of cross-border energy and transport infrastructure projects. So far, the CEF has granted around EUR 680 million to CO_2 projects of common interest such as pipelines connecting capture initiatives, and export terminals to storage sites.
Japan	Moonshot Goal 4	The Moonshot Goal 4 (a subset of the Moonshot R&D Program, launched in 2019 with a total budget

[5] Exchange rate (2022): 1 Danish kroner (DKK) = USD 0.14.

Government/ Jurisdiction	Policy instrument	Description
Japan (continued)		of JPY 100 billion [approx. USD 0.7 billion]) focuses on "the realisation of a sustainable resource circulation to recover the global environment by 2050". In order to reach this goal, the Moonshot Goal 4 includes R&D funding of JPY 20 billion (approx. USD 130 million) for multiple innovative technologies, including DAC. Furthermore, the government has established a DAC working group that aims to discuss the creation of a market for DAC and development of a calculation methodology.
United Kingdom	DAC and GHG Removal Competition	This competition, announced in 2020, will provide funding for technologies that enable the removal of GHGs from the atmosphere. Total budget is up to GBP 100 million (approx. USD 127 million).
	Net Zero Innovation Portfolio	The Net Zero Innovation Portfolio provides funding for low-emissions technologies and systems. It focuses on ten priority areas: future offshore wind, nuclear advanced modular reactors, energy storage and flexibility, bioenergy, hydrogen, homes, DAC and GHG removal, advanced CCUS, industrial fuel switching, and disruptive technologies.
	CCUS Vision	The CCUS Vision lays out a comprehensive strategy in developing a competitive market for CCUS through three different phases while detailing the evolving role of governments and the private sector.
	Greenhouse gas removals (GGR) business models	The UK government designed the proposed commercial framework for GGR to address the gap between the cost of removal and the achieved sales price of negative emissions credits on carbon markets. The UK government will publish further details on the policy and its measurement, reporting and verification methodology in 2024.
United States	Inflation Reduction Act	The 45Q tax credit (introduced in 2008 and expanded in 2022) provides up to USD 85/t CO_2 permanently stored and USD 60/t CO_2 used for enhanced oil recovery or other industrial uses of CO_2. The credit amount significantly increases for DAC projects to USD 180/t CO_2 permanently stored and USD 130/t for used CO_2.
	California Low Carbon Fuel Standard (LCFS)	DAC projects anywhere in the world are eligible to receive LCFS credits, provided the projects meet the requirements of the Carbon Capture and Sequestration Protocol (including 100 years of storage monitoring). The LCFS credits traded at an average of around USD 200/t CO_2 in 2020.

Government/ Jurisdiction	Policy instrument	Description
United States (continued)	Infrastructure Investment and Jobs Act	This act, enacted in November 2021, includes almost USD 12 billion in CCUS support. This includes USD 3.5 billion in funding to establish four DAC hubs (1 Mt CO_2 per year and above) and related transport and storage infrastructure. DAC projects are also eligible for additional CCUS funding support included in the act of around USD 0.5 billion. The infrastructure package also fully funded the DAC Prize programme, with USD 100 million for commercial-scale projects and USD 15 million for pre-commercial projects.
	Carbon Negative Shot	The United States announced this initiative at the 26th Conference of the Parties (COP26) in November 2021 as a call for innovation in technologies and approaches that will remove CO_2 from the atmosphere and durably store it at meaningful scales for less than USD 100/t CO_2-eq, including DAC.
	DOE funding programmes	The DOE announced multiple funding programmes specifically for DAC in March 2020 (USD 22 million), January 2021 (USD 15 million), March 2021 (USD 24 million) and October 2021 (USD 14.5 million).
	Voluntary Carbon Dioxide Removal Purchase Challenge	In March 2024, the US DOE launched the proposed Voluntary Carbon Dioxide Removal Purchase Challenge, which features a leader board for voluntary carbon removal purchases. The DOE will also evaluate carbon removal credit suppliers.
	California Carbon Removal Innovation Support Program	The California Carbon Removal Innovation Support Program aims to develop DAC technologies that use mechanical and chemical processes. Eligible projects include, but are not limited to technology research, development and demonstrations and implementation of prototype and pilot research test centres.

Source: IEA (2024), expanded from Direct Air Capture 2022.

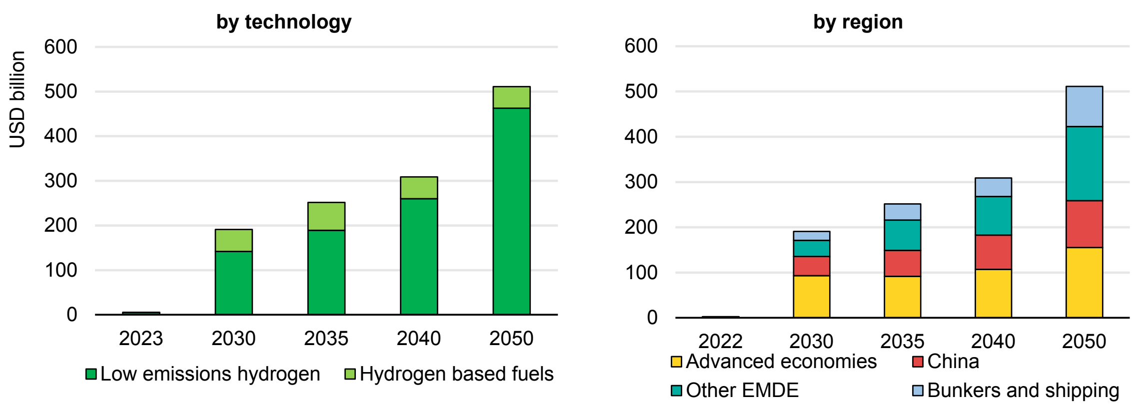
High capital costs are a major barrier to deployment of DACS at scale. Other barriers to scale up adoption include the high energy consumption needed to separate CO_2 through emerging separation technologies; the lack of identification and development of CO_2 storage resources that are subject to permitting timelines; the lack of clarity on internationally agreed approaches for DACS certification and accounting; the speed at which safe and permanent dedicated CO_2 storage can be developed; and the lack of a clear assessment of the role of DACS in national net zero strategies.

3. Financing needs and mechanisms for nascent technologies

Investment needs and sources of finance

Although the overall share of investment needs for low-emissions hydrogen, SAF and direct air capture (DAC) in the IEA's Net Zero Emissions by 2050 Scenario (NZE Scenario) is only about 5% of total annual investments by the early 2030s, the growth compared to with current levels is enormous. The annual estimated investment across these three technologies in 2023 was just USD 9 billion. This needs to increase to nearly USD 300 billion annually by the early 2030s under the NZE Scenario, and nearly USD 700 billion by 2050. In 2050, nearly three-quarters of the investments will be required for low-emissions hydrogen and hydrogen-based fuels, with DACS making up about 20% and SAF just over 6%. In the early 2030s, the share of SAF investments is higher at 18%, while DACS is slightly lower at 14%.

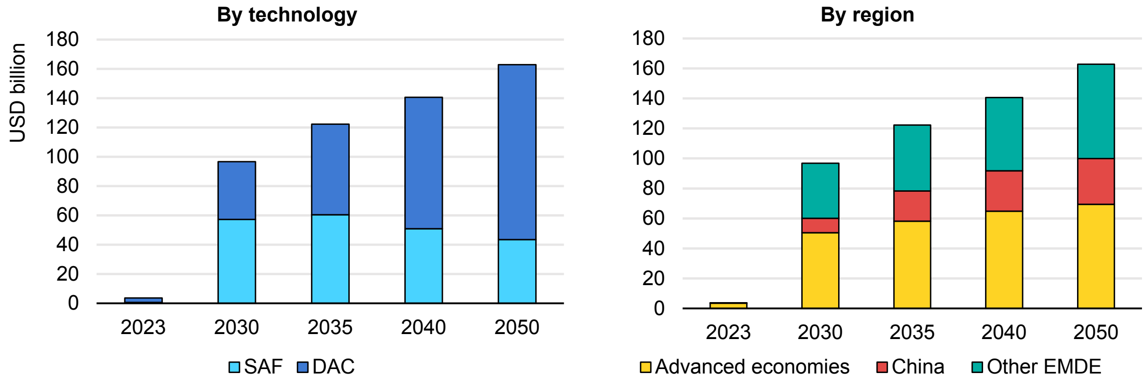
Annual investment needs for hydrogen by technology and region in the Net Zero by 2050 Scenario, 2022-2050



Notes: Other EMDE = other emerging market and developing economies. Investments in hydrogen-based fuels include investments in hydrogen-based SAF and ammonia and also investments in electrolysers. The values in this set of figures and the one following should not be added together as it would lead to double counting.

Regionally, in the NZE Scenario, advanced economies lead investments for hydrogen and hydrogen-based fuels over the next decade, with emerging market and developing economies (EMDE) accounting for a growing share of investment needs to 2050 and hence the focus later in this chapter on solutions to mobilise investment and finance to EMDE. In addition, the People's Republic of China (hereafter, "China") also sees a steady increase in investments for hydrogen and hydrogen-based fuels to decarbonise the hard-to-abate sectors of heavy industry, aviation and shipping. EMDE currently account for the largest share of investments in biofuels and have the potential to play a leading role in developing SAF, where investments are expected to continue outpacing those of advanced economies. Overall investment needs in DAC continue to grow substantially to 2050, while investment needs for SAF peak around 2035 with investment needs in EMDE growing over time.

Annual investment needs for DAC and SAF in the Net Zero by 2050 Scenario, 2022-2050

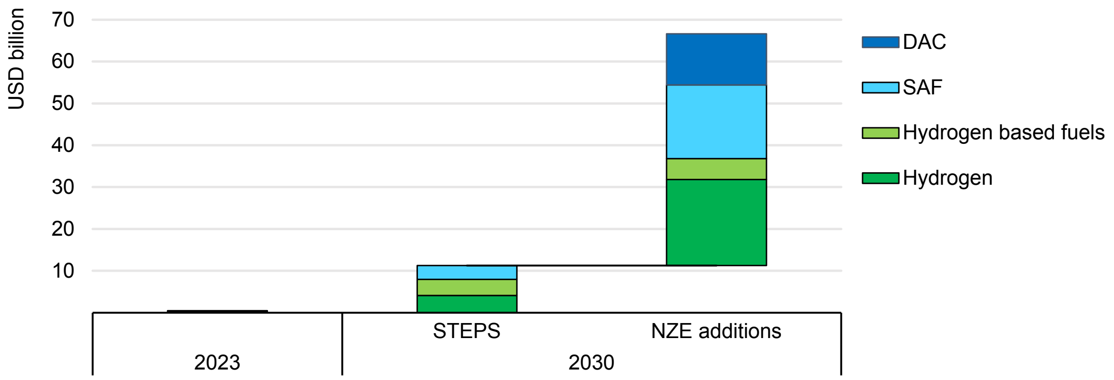


Notes: Investments in SAF and DAC do not include the cost of low-emissions power as projects may purchase electricity from the grid or invest in dedicated low-emissions power capacity. Including the investment needs for the electricity to power the plants would increase capex needs by about 20% for DAC and can lead to as high as a doubling in the investment cost for hydrogen-based SAF. Investments in electrolysers for hydrogen-based SAF are not included here but captured in the previous chart under investments for hydrogen-based fuels. The investment values for hydrogen-based SAF are also included in the previous chart and these two figures should not be added together as it would represent double counting.

Investment needs for low-emissions hydrogen, SAF and DACS in EMDE (excluding China) reach nearly USD 90 billion annually in the NZE Scenario by 2030, up from just USD 0.14 billion in 2023. Under the Stated Policies Scenario (STEPS), which reflects today's policy settings, investments in these technologies reach just under USD 9 billion in EMDE in 2030, split between investments in low-emissions hydrogen and in SAF, and a negligible amount towards DACS.

The high cost of these emerging technologies, combined with higher financing costs, points to an important investment gap in EMDE between the STEPS and the NZE Scenario of just under USD 60 billion annually – more than a sixfold increase in investment levels between the two scenarios. With other competing demands for limited public funding within and outside the energy sector, alternative mechanisms will be required to help fill the investment gap for these more expensive technologies that are critical to achieve net zero emissions in the hard-to-abate industry and transport sectors. Carbon credits could offer an attractive option to help fill or narrow this gap by providing additional revenues that can help bring down the high cost of project development and shift more capital to EMDE for financing net zero transitions.

Investment gap in EMDE (excluding China) in the Net Zero by 2050 Scenario versus the Stated Policies Scenario, 2030



Note: STEPS investments include investment needs under the IEA Stated Policy Scenario for SAF, hydrogen, hydrogen-based fuels and DACS. Investments in hydrogen-based SAF is included only under SAF to avoid double counting.

Establishing markets and suitable business models for these technologies over the next decade is critical if their contributions to meeting decarbonisation needs in the hard-to-abate sectors are to be scaled to the levels necessary by 2050. Governments and industry will need to work closely together to design targeted financing mechanisms that can spur early development and encourage rapid adoption globally. Delaying investments could lead to higher costs in the long term.

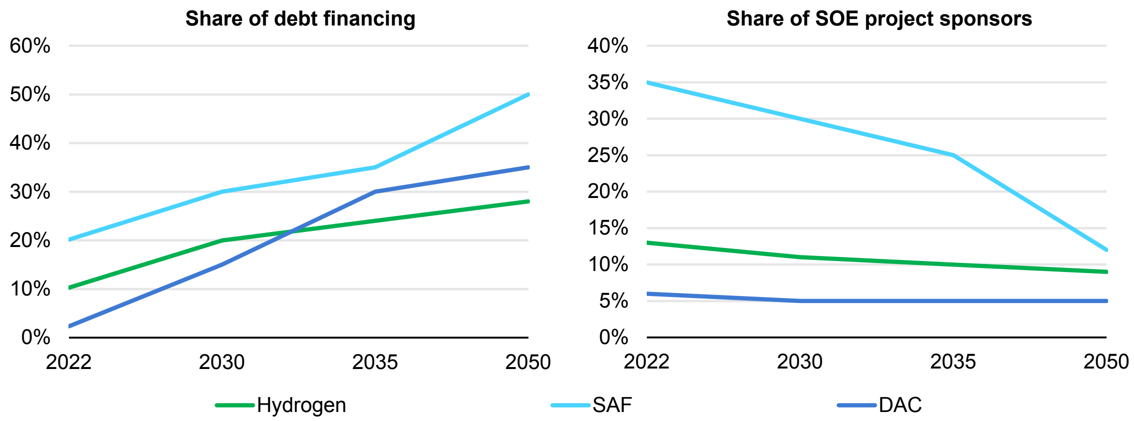
Equity dominates early financing, while debt financing grows in later years

The early development phase of new technologies tends to rely heavily on equity financing, with the share of debt financing rising as technology reaches maturity and revenue streams can be secured through long-term purchase agreements. With a single low-emissions hydrogen project requiring upwards of USD 1 billion in capital, financing needs to be backed by long-term offtake contracts. Funding sources are expected to follow a similar path to financing of wind projects, with project finance and debt financing assumed to reach around 30% by 2050.

Financing sources for SAF are expected to follow that of biofuels in their early development, shifting towards that of the refinery sector as demand for SAF becomes more established. Corporate finance is expected to dominate with a high share of equity financing in the development period, followed by rising shares of debt financing reaching levels of about 50% once the technology matures.

State-owned enterprises (SOEs) currently play an important role in biofuels development in EMDE and are also expected to be significant producers of SAF. Public sources of finance today account for over 30% of all financing for SAF and about 6% for hydrogen. The role of SOEs is expected to decline over time for SAF as the technology matures and demand rises with private developers playing a growing role. For hydrogen, production is expected to shift over time towards EMDE with cheap solar and wind resources, in part through exports of hydrogen-based fuels. In these markets, SOE utilities dominate the power sector, and these players are expected to remain influential in the NZE Scenario. The role of SOEs in DAC remains limited given the very high cost of the technology and limited applications focused on achieving net zero emissions for heavy industry and the oil and gas sectors, where the private sector is assumed to continue leading developments. This, however, may change in the future if major oil and gas companies in large producing countries get involved in deployment.

Sources of finance and project sponsors for hydrogen, hydrogen-based fuels, SAF and DAC, 2022, 2030, 2035 and 2050



While first-of-a-kind (FOAK) projects are expected to rely heavily on public sources of finance, limited public funding can be most effectively used to leverage higher multiples of private capital. This can be achieved by focusing on project de-risking through first-loss tranches and revenues or off-taker guarantees to help establish new business models. Financing from development finance institutions (DFIs) will be needed to support projects in EMDE where local capital markets tend to be shallow and insufficient to finance investments of this scale. These limited funds could provide targeted support for project preparation and project structuring to meet the requirements of international funders. In addition, DFI financing could also provide guarantees to help manage country and project risks such as delays in securing land access, permitting, currency and regulatory risks.

Role of domestic and international public finance

Strong government incentives including grants, subsidised loans and loan guarantees have played a major role in the financing and development of low-emissions hydrogen projects around the world, mainly in advanced economies and China that accounted for over 90% of these investments in 2023. The combination of high capital costs and technology risk for these FOAK commercial-scale projects may require substantial public financing for projects to help pass the economic hurdle to enable a final investment decision.

However, economic development in EMDE outside China will drive much of the growth in emissions in hard-to-abate industry and transport sectors. These countries often do not have the same fiscal capacity to provide public funding for the uptake of emerging low-emissions technologies and will need to rely more on international public funding to help deploy and scale these technologies to the level required in the NZE Scenario.

In the United States (US), the implementation of the US Inflation Reduction Act is likely to increase the share of funding via tax credits. This policy is particularly targeted at incentivising local manufacturing for low-emissions technologies and is expected to have a major impact on the development of low-emissions hydrogen and DACS with targeted elements of the programme covering DACS and hydrogen. In addition to this programme, the US Department of Energy announced up to USD 1.2 billion in funding for the development of two commercial-scale DACS projects that are intended to support the development of regional DACS hubs in Texas and Louisiana, in an effort to help these regions transition their industry from fossil fuels towards clean energy. In the European Union (EU), policies such as the EU Emissions Trading System and the carbon border adjustment mechanism also help to support the investment case and close the green premium. Japan's climate transition bond framework also helps to raise additional public funds for financing low-emissions technologies as well as to help leverage private capital.

DFI financing for technology uptake in EMDE

For SAF, the International Civil Aviation Organization (ICAO), an intergovernmental organisation under the United Nations, has been actively engaging with leading public and private financial institutions to raise awareness and explore potential financing solutions. ICAO has estimated that the aviation sector will need USD 3.2 trillion in cumulative investments between now and 2050 to replace fossil fuels. Decarbonising the aviation sector will require all regions to transition to SAF, requiring an internationally co-ordinated approach that takes into consideration affordability among consumers in advanced, emerging and developing economies. Governments and industry will need to work together to develop clear criteria and harmonised frameworks to facilitate SAF financing, providing private investors with confidence on the sustainability of projects and lowering risks. Public financing can be used to manage risks related to off-takers, revenue predictability and lower financing costs for FOAK projects and to improve the risk-adjusted returns to raise private capital in early projects.

With the world's lowest cost solar and wind potential, EMDE such as Chile, Namibia and South Africa, among others, are also actively developing and funding low-emissions hydrogen projects with technical and financial support from multilateral development banks. DFI financing to these countries in the form of grants, concessional loans and guarantees are needed to help develop markets and lower the cost of financing for these nascent technologies, as the cost of capital for clean energy can be more than two times higher than in advanced economies. Chapter 2 provides a comprehensive overview of various government-backed incentives and programmes for low-emissions hydrogen, SAF and DACS.

Private sector initiatives

A number of industry-led initiatives also exist to accelerate investment and finance of SAF, low-emissions hydrogen and DACS projects. For example, a consortium of growth investors, including Carbon Direct Capital, Lightrock, GenZero and Kibo Investments, have invested USD 40 million in Velocys, a leading SAF technology company, to accelerate the deployment of its technology to customer projects and to scale its production. The International Airlines Group (IAG) also announced a USD 400 million investment over the next 20 years in SAF development with British Airways, partnering with SAF developers. SAF fuel consumption commitment levels, such as those made by IAG to reach 10% SAF consumption by 2030, are essential to establish a reliable demand outlook for SAFs. All Nippon Airways has also entered into a three-year purchase agreement for CO_2 removals from DAC to begin in 2025. Offtake agreements from the airlines need to back these commitments for project developers to be able to secure financing. Such corporate targets and early adoption coalitions have been critical in the early adoption and wide deployment of renewable energy. For example, the RE100 initiative has helped to establish and quickly grow demand for renewable power globally.

For DACS projects, private-led initiatives supported by philanthropic foundations such as X-Prize and Breakthrough Energy's Catalyst programme have been active in financing DACS start-ups, while the oil and gas company Occidental acquired Carbon Engineering last year and is using its technology to build the world's largest DACS project in Texas. These projects may also be eligible for tax incentives and grants under the US Inflation Reduction Act.

Financial sector initiatives for SAF and other low-emissions technologies

Recognising the key role that the financial sector will need to play in supporting new clean energy technologies, a number of different financial institutions around the world are developing targeted financing vehicles for SAF technologies. For example, the Bank of America plans to mobilise USD 2 billion in sustainable finance by 2030 for the production of SAF and other lower-carbon aviation solutions. The First Abu Dhabi Bank also announced plans to finance more than USD 75 billion in low-emissions aviation (including SAF) by 2030. Finally, Banque de Montreal has a sustainable finance guarantee programme that covers 50% of the risk of the loan up to USD 60 million with bioenergy, carbon capture and storage, and hydrogen as eligible sectors.

Financing partnerships led by philanthropic foundations targeting nascent technologies

Philanthropic foundations have been instrumental in mobilising both philanthropic and private capital to finance investments in new technologies critical to meeting net zero transition goals. With patient capital and a high-risk threshold, philanthropic foundations prioritise high social gains while aiming to support emerging technologies that have the potential to reach wide-scale commercialisation. The world's leading business leaders and investors, who have created some of the world's largest corporations and investment funds and play an important role in mobilising private capital for the energy transition, lead these foundations.

In 2015, Bill Gates, together with other foundations and private investors, created Breakthrough Energy Ventures to pool capital together to finance the clean energy transition. Breakthrough Energy Ventures currently manages three funds with total capital of USD 2.35 billion. The Breakthrough Energy Catalyst programme manages USD 1 billion of these funds targeting large demonstration and FOAK commercial-scale projects that can displace fossil-intensive industries. In Europe, the Breakthrough Energy Catalyst Partnership funded by the Breakthrough Energy Catalyst, European Investment Bank and European Commission provides venture debt to small demonstration projects (EUR 30 million to EUR 100 million) and equity and quasi-equity finance for FOAK commercial-scale projects (EUR 100 million to EUR 1 billion). The partnership targets SAF, low-emissions hydrogen, DACS, and long duration energy storage projects. It seeks to mobilise EUR 820 million in investments between 2023 and 2027.

The Bezos Earth Foundation funded in 2020 the Mission Possible Partnership coalition to agree and act on decarbonising industry and transport. The World

Economic Forum, We Mean Business, the Energy Transition Commission and the Rocky Mountain Institute lead the coalition of climate leaders and companies. The coalition has developed industry-backed net zero strategies in seven heavy industry and transport sectors. The partnership is engaging with financial institutions to decarbonise the hard-to-abate sectors, adopt collective lending and investment policies that are in line with net zero sector roadmaps, and develop transition finance mechanisms to finance near-term pilot projects, and working with public and private financial institutions on innovative deal structures to support projects in hard-to-abate sectors.

Innovative financing mechanisms

Targeted and innovative financing mechanisms that can allocate or manage various risks such as technology, off-taker, revenue, currency and regulatory risks to stakeholders most able to manage these risks are needed in the development of SAF, low-emissions hydrogen and DACS. Funding platforms that combine public, private and philanthropic funds can help manage different risks by pooling funds and targeting limited public and philanthropic funds to take risks that private investors are unwilling to bear such as regulatory, off-taker and revenue risks. Domestic and international partnerships will be needed to accelerate development of these technologies, with national and regional partnerships focused on supporting domestic industrial development and international partnerships aimed at mobilising funding in EMDE where much of the future growth of carbon-intensive industries will take place.

Public and philanthropic funds can be used to provide early-stage development grants for pilot projects, as well as concessional funding in the form of convertible equity, subsidised loans or first-loss guarantees for FOAK commercial-scale projects, where demand and, hence, revenues may be uncertain for new technologies. They can also be used to provide various de-risking mechanisms in the form of guarantees for currency, technology, off-taker and/or regulatory risks. Blending public, philanthropic and private capital in structures has potential to allocate risks efficiently to those stakeholders most able to manage these risks, leading to lowering the cost of capital for these technologies. For example, public funding may be best placed to manage regulatory risks while philanthropic funds may be suited to manage technology risks.

Blended finance for private capital mobilisation in EMDE

Blended finance structures that target private capital mobilisation through the use of official development assistance funding should focus on commercial technologies and are not suited to managing technology risks.[6] The use of concessional funding (e.g. grants for project development and structuring or concessional loans and guarantees) can help commercial technologies expand into new markets and near-commercial technologies establish market viability. Blended finance vehicles could help expand the production of SAF, low-emissions hydrogen and hydrogen-based fuels in EMDE by providing revenue and off-taker guarantees for FOAK commercial-scale projects. Careful consideration will be needed to ensure such vehicles do not take undue technology risks and focus on proven advanced biofuel technologies and proven electrolyser technologies in commercial operations.

Blended finance structures could also include the integration of high-quality carbon credits to provide additional revenues for projects in emerging and developing economies to reach commercial viability or enhance returns to levels needed to meet risk-adjusted return requirements. With the cost of capital for clean energy technologies in EMDE more than twice that of advanced economies, carbon credits for low-emissions hydrogen, SAF and DACS can push projects past the necessary return requirement to achieve project bankability.

[6] The Organisation for Economic Co-operation and Development (OECD) defines official development assistance as government aid that promotes and specifically targets the economic development and welfare of developing countries. The OECD defines blended finance as the strategic use of development finance for the mobilisation of additional finance towards sustainable development in developing countries. Concessional finance covers grants or concessional loans and equity that is priced below market rates or subordinated in liquidation and/or payment to senior lenders or preferential equity holders.

4. Role of carbon credits in supporting adoption of nascent technologies

This chapter provides a qualitative overview of how carbon credits can accelerate a scaled-up adoption of low-emissions hydrogen, SAF and DACS. First, it provides a description of the latest developments in carbon credit methodologies for these technologies. It then elaborates an assessment of the quality of these credits. While the assessment of the quality of credits considers different project archetypes, each project's specific characteristics and local context will influence the final evaluation. This report does not consider these factors, while recognising that these are crucial and relevant in real-world applications. The criteria used to assess credit quality in this report are partly based on the Integrity Council for the Voluntary Carbon Market (ICVCM) Core Carbon Principles (CCPs). They aim to highlight key considerations specific to the project archetypes, without referencing specific crediting methodologies, and do not substitute for any upcoming ICVCM CCP labelling system which might differ from the assessment of this report. This report assesses the following criteria for each project archetype to elaborate key considerations: additionality, permanence, robust quantification of emissions reductions and removals, avoidance of double counting, leakage, and sustainable development benefits.

Low-emissions hydrogen carbon credits

State of play of low-emissions hydrogen carbon credit methodologies

As of April 2024, there is only one crediting methodology allowing the issuance of carbon credits from the production and use of low-emissions hydrogen, although many are under development. The Clean Development Mechanism (CDM) AM0124 methodology calculates emissions reductions from the production of hydrogen using renewable energy. Verra, Gold Standard and the China Certified Emissions Reduction standard are in the process of developing further methodologies that may involve low-emissions hydrogen applications.

The most comprehensive attempt to develop low-emissions hydrogen crediting methodologies to date is the Hydrogen for Net Zero (H2NZ) initiative. H2NZ aims to develop methodologies that cover the hydrogen supply chain, encompassing production, transportation, storage and utilisation of low-emissions hydrogen and associated products (e.g. heating, clean steel production). The H2NZ initiative is in the process of developing its first methodologies, which can be used by Verra and Gold Standard.

Key low-emissions hydrogen carbon credit methodologies

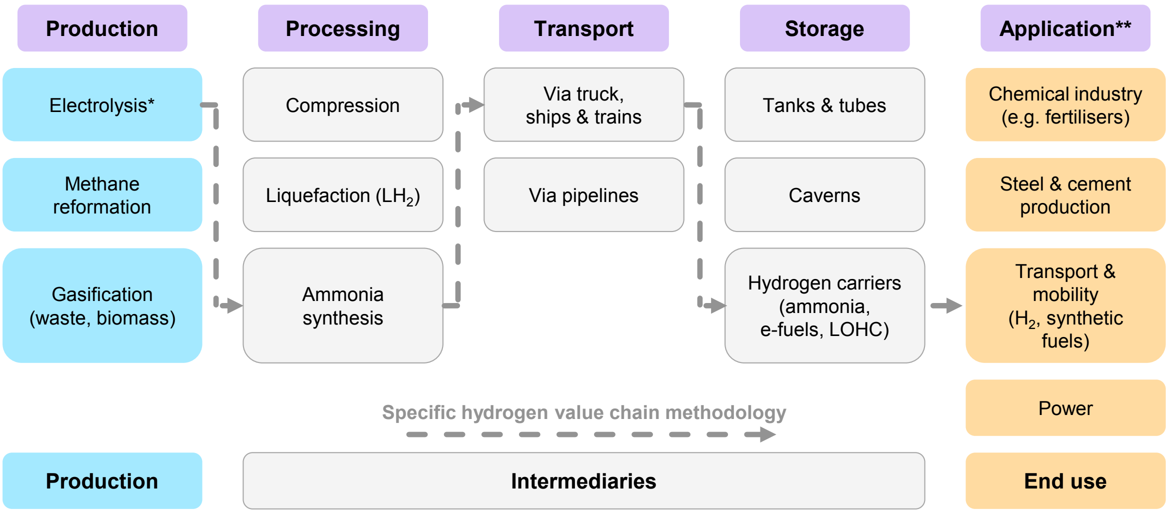
Standard	Methodology/ Initiative	Status	Remarks
Clean Development Mechanism (CDM)	AM0124: Hydrogen production from electrolysis of water	The methodology is active.	AM0124 calculates emissions reduction by producing hydrogen using renewables compared with a baseline scenario where hydrogen is produced using fossil fuels (e.g. coal).
Verra, Gold Standard, China Certified Emissions Reduction	Fuel switch methodologies E.g. Alternative Low-Carbon Fuels in Shipping, Hydrogen in Transport	Methodologies are under development.	These methodologies focus on the utilisation of hydrogen to replace fossil fuels.
Verra, Gold Standard	Hydrogen for Net Zero (H2NZ) initiative	Methodologies are under development.	The H2NZ initiative will develop methodologies for applications and consider the emissions reductions from the life cycle of producing low-emissions hydrogen.

Carbon credit methodologies that account for the life-cycle emissions of low-emissions hydrogen across the entire value chain are complex because of the various possible combinations of the technologies and methods involved in production, transportation, storage and utilisation of hydrogen. Due to a different level of baseline emissions, the utilisation of hydrogen in the chemical industry leads to different final emissions from its utilisation in steel and cement production. This results in differing volumes of emissions reductions. Further, the emissions profile of low-emissions hydrogen projects varies significantly depending on whether the hydrogen was produced from renewable energy, nuclear energy or fossil fuels with carbon capture.

To quantify the emissions reductions achieved by low-emissions hydrogen, carbon credit methodologies can compare two distinct scenarios:

- Baseline Scenario: this represents a scenario in the absence of low-emissions hydrogen, potentially involving:
  - Hydrogen production using unabated fossil fuels (e.g. in chemical production).
  - Unabated fossil fuel use in various sectors (e.g. steel production, transportation, heating).
- Project Scenario: this scenario considers the use of low-emissions hydrogen displacing unabated fossil fuel use from the baseline scenario.

Illustration of permutations within the hydrogen value chain, and possible pathways for low-emissions hydrogen carbon credit methodologies development

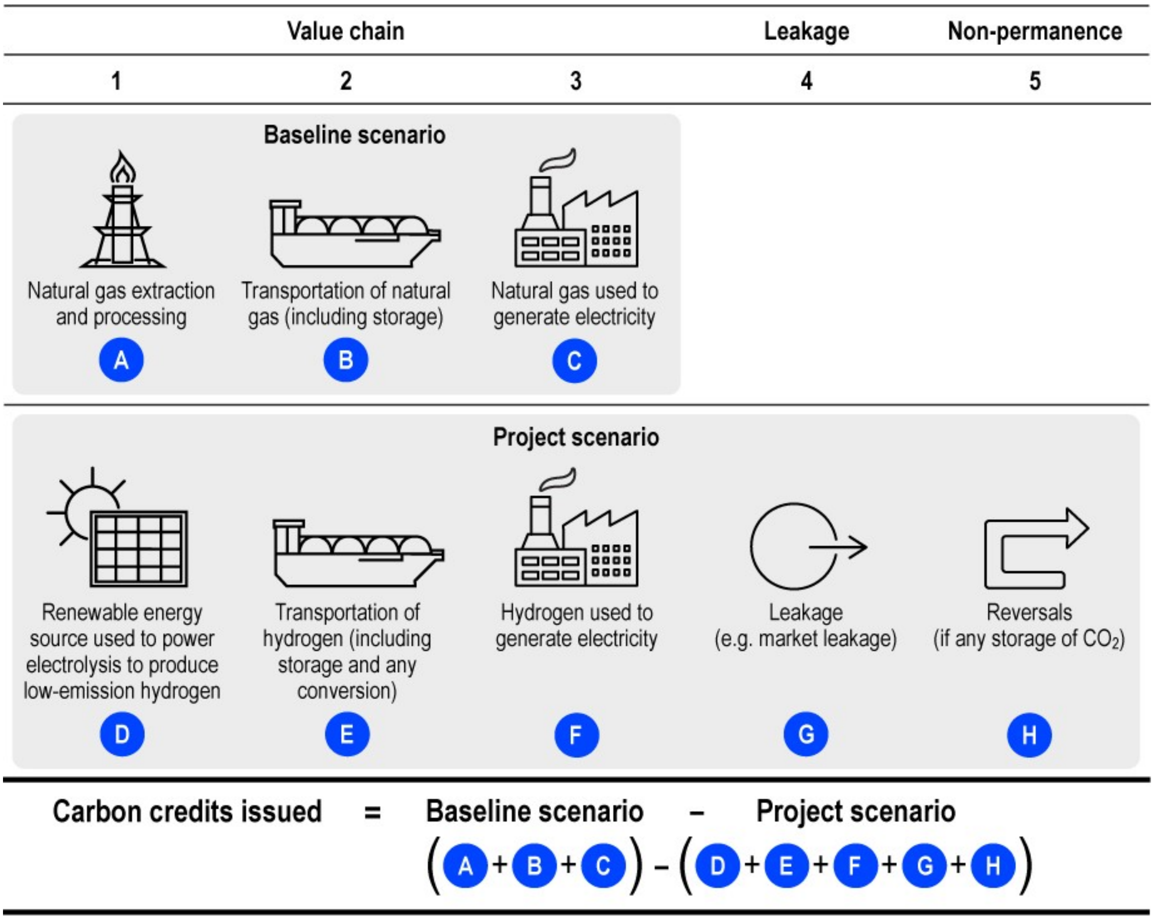


IEA. CC BY 4.0.

* Different electricity sources will be considered in the modules and tools (renewable/non-renewable/grid).
** For the substitution of fossil fuels and carbon-intensive hydrogen.
Note: LH_2 = liquid hydrogen; LOHC = liquid organic hydrogen carriers; H_2 = hydrogen.
Source: GenZero analysis; adapted from H2NZ proposals.

The example below assumes that hydrogen produced from renewable energy is used to produce electricity for meeting seasonal demand when renewable electricity might not be available in sufficient quantities, displacing electricity produced from natural gas. The methodology should also account for possible market leakage, which may occur if the reduced use of natural gas in the baseline plant leads to increased consumption of natural gas in other parts of the economy. Reversals (the release of stored emissions) are not relevant in this project scenario but could be a concern in a case where CO_2 is captured and stored as part of the hydrogen production process.

Illustration of how a low-emissions hydrogen carbon credit methodology would work when hydrogen is used to generate electricity



Source: GenZero analysis.

Considerations on the quality of carbon credits from low-emissions hydrogen

Quality marker	Hydrogen carbon credits
Additionality	**Low risk**
Permanence	**Low risk**
Robust quantification of emissions reductions and removals	**Medium risk**
Double counting	**Low risk**, but depends on other safeguards
Leakage	**Low risk** with appropriate safeguards
Sustainable development benefits	**Limited**

Additionality: Low risk. Due to the high costs and low adoption rates of low-emissions hydrogen, there is generally a strong case for additionality. Where there are incentives in place for hydrogen production or consumption, the project should demonstrate that the received incentives are insufficient to bridge the green premium, and that carbon credits are necessary. If there are any future governmental mandates to produce or use low-emissions hydrogen, then future low-emissions hydrogen projects would not pass a regulatory additionality test in most circumstances.

Permanence: **Low risk**. Low-emissions hydrogen carbon credits are generated from emissions reductions that occur from the difference between a traditional fossil fuel use scenario and low-emissions hydrogen use. This already accounts for the emissions from low-emissions hydrogen production, transport, storage and use. In these cases, emissions reductions cannot be reversed and hence permanence risk is low.

Robust quantification of emissions reductions and removals: **Medium risk**. Quantification of emissions reductions is dependent on a comparison against a baseline where fossil fuels are used. This case is frequent, especially in hard-to-abate sectors. However, there are potential scenarios where fossil fuel use may not be the most likely scenario for the future. For instance, the use of low-emissions hydrogen for fuelling passenger cars for short distances is less likely than an electric vehicle, given strong electric vehicle adoption rates. The trajectory of fossil fuel consumption can also affect the emissions reductions estimated. This trajectory needs to be a credible and persuasive projection, and can be compared against an industry average, or other similar applications. Where there are options among various projections, project developers should pick the most conservative option: the option that would generate the fewest carbon credits. Finally, the quantification of emissions should encompass all material emissions, including any process or energy emissions, and fugitive emissions within the value chain. Where there is uncertainty, project developers should adopt conservative approaches.

Double counting, issuance and claiming: **Low risk.** Carbon crediting programmes should have requirements and robust registries to ensure that no double counting, double issuance or double claiming occurs. If the buyer uses carbon credits towards nationally determined contributions or the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a corresponding adjustment will be required, following the accounting rules of Article 6.2 of the Paris Agreement. Emissions reductions from low-emissions hydrogen production can occur across its value chain. This poses the risk of double counting if the producer of the low-emissions hydrogen claims the emissions reductions generated in the supply chain while the buyer of a resulting carbon credit claims the same emissions reductions. Double counting may also occur where there are overlapping claims between the producer and consumer of low-emissions hydrogen.

Leakage: Low risk. Safeguards need to be in place to ensure that leakage from low-emissions hydrogen production is minimal. For instance, hydrogen produced with renewable energy needs to ensure that it does not displace renewable energy from the grid in ways that would lead to emissions increases from fossil fuel use. In countries or grids where there is no close monitoring of the source of electricity used for hydrogen production, this risk is higher.

Sustainable development benefits: **Limited**. Low-emissions hydrogen projects generate limited co-benefits beyond creating employment through the implementation of the project.

SAF carbon credits

State of play of SAF carbon credit methodologies

As of April 2024, there are no methodologies developed specifically to allow issuing carbon credits from SAF projects. However, Gold Standard has plans for developing a crediting methodology for fuel switching in aviation.

SAF certificates and SAF carbon credits

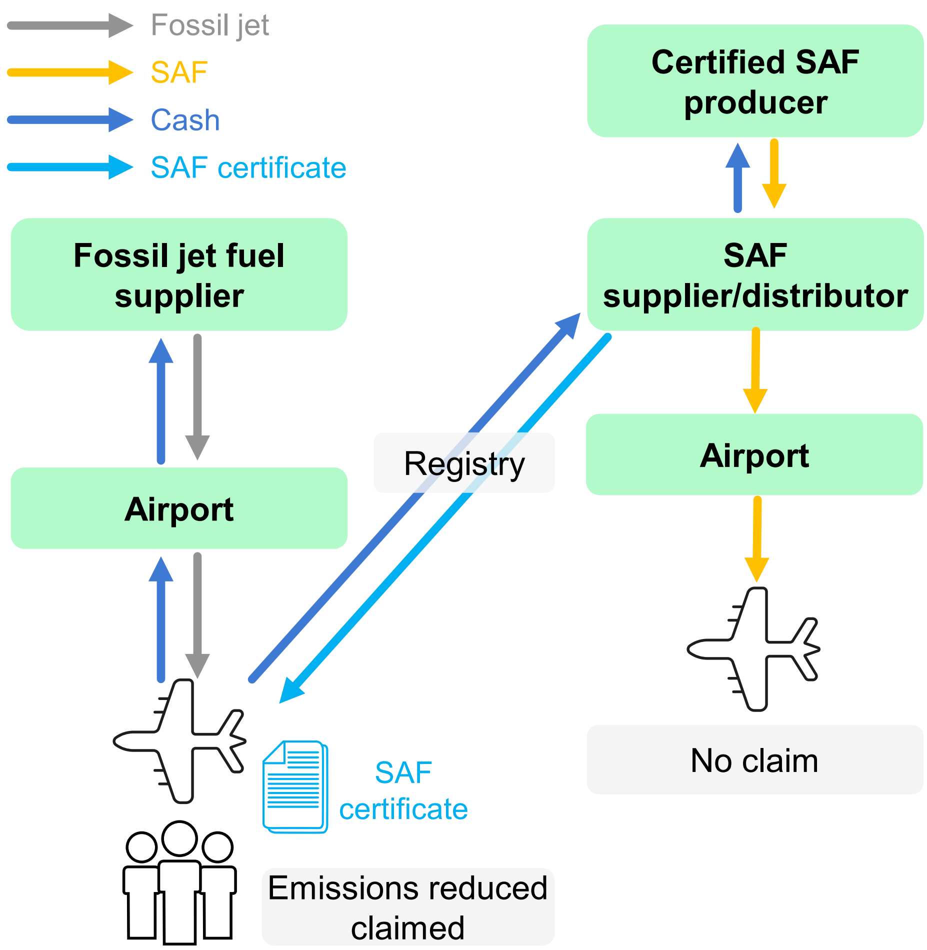
While SAF carbon credits have not been issued yet, interested stakeholders can purchase on the market so-called SAF certificates.[7] Even if the two products may seem similar, they have some fundamental differences. SAF certificates describe environmental attributes and are used to certify the fuel's production from sustainable feedstocks, such as waste oil or renewable energy e-fuels. They are measured in tonnes of SAF, and one SAF certificate corresponds to about 0.32 tonnes (t) of carbon dioxide equivalent (CO_2-eq) reduced to 2.97 t CO_2-eq reduced,[8] depending on the type of feedstock used. Conversely, SAF carbon credits are measured in tonnes of CO_2-eq, and one SAF carbon credit corresponds to 1 t CO_2-eq reduced. Moreover, the buyers of SAF certificates can use them to claim emissions reductions only within the aviation sector, whereas the buyers of SAF carbon credits can use them to claim emissions reductions in

[7] In the market, there is a lack of consistency around the terminology used to describe "SAF certificates". Depending on the registry where SAF are recorded, SAF certificates can also be referred to by other terminologies, including "SAF credits" (a term which can be easily confused with "SAF carbon credits"), "book and claim units", "SAF environmental attributes", and "SAF end-user reduction claim" (specifically for Scope 3 users). This report uses the terminology "SAF certificates".
[8] According to the International Civil Aviation Organization (ICAO), traditional jet fuel produces 3.16 t CO_2-eq per tonne of fuel, while SAF have life-cycle reductions ranging from 10-94%. Hence, this corresponds to a reduction range of 0.32 t CO_2-eq to 2.97 t CO_2-eq reduced per tonne of SAF.

GHG inventories across all emissions scopes and sectors. Furthermore, any future methodology for issuing carbon credits from SAF would include requirements to test the additionality of the projects and potential leakage effects, which are not a requirement for issuing SAF certificates.

Even if they are distinct products, there are a few lessons from SAF certificates that can be helpful for generating SAF carbon credits in the future. The first lesson is the importance of tracking the unique SAF use. Once SAF is injected into the fuel system, it is practically indistinguishable from traditional aviation fuel. SAF certificate registries, such as the Roundtable on Sustainable Biomaterial (RSB), Avelia, or the SAFc (sustainable aviation fuel certificates) registry, use "book and claim" systems to trace the ownership and use of SAF associated with specific SAF certificates. These systems prevent double counting and double claiming from unique SAF certificates, and enable the purchase and claim of SAF certificates in locations where physical SAF are not yet available for use, thus unlocking more finance to fund the adoption of SAF globally.

Illustration of a book and claim system



Source: GenZero analysis; adapted from RSB.

Singapore SAF pilot

The Civil Aviation Authority of Singapore (CAAS), GenZero and Singapore Airlines (SIA) undertook a SAF pilot project in Singapore between February 2022 and September 2023. The pilot project was used to validate the operational readiness of supplying SAF to Singapore's Changi Airport. This includes the procurement, blending of neat SAF (i.e. SAF that has not been blended) with traditional jet fuel in Singapore, safety certification, and delivery of blended SAF to the airport for uplift onto aircraft using existing infrastructure.

Importantly, the pilot project was used to trial the generation and sale of SAF certificates to test voluntary market demand. SAF certificates were sold to corporations and air cargo companies looking to decarbonise their footprint, as a way to crowd in financing to share SAF's higher costs. Under the pilot, SIA purchased 1 000 t of neat SAF which generated 1 000 SAF certificates, corresponding to approximately 2 500 t of CO_2 reductions. These SAF certificates were generated through a trusted industry standard, the RSB Book & Claim System.

About two-thirds of the 1 000 certificates generated were sold during the pilot project, which validated market demand for SAF certificates but also showed that more education, outreach, and corporate and government policy support is needed for wide-scale SAF adoption.

Following the pilot, Singapore has announced a 1% SAF target for flights departing Singapore from 2026, with the aim to raise it to 3%-5% by 2030, subject to global developments and the wider availability and adoption of SAF.

Approaches used for the so-called "co-claiming" of SAF certificates can also serve as a learning model for SAF carbon credits. Co-claiming is a concept that allows flight passengers and freight forwarders to share the green premium of the purchase of SAF certificates with airlines. This allows to channel more private funding to incentivise wider adoption of SAF. Direct aviation fuel-related GHG emissions for airlines (falling under Scope 1 as defined by the GHG Protocol) are simultaneously the indirect emissions of passengers and freight forwarders (categorised as Scope 3).[9] Therefore, a reduction of airlines' Scope 1 aviation emissions also simultaneously reduces the Scope 3 aviation emissions of passengers and freight forwarders. As of April 2024, co-claiming is still a nascent concept, and it has raised questions about potential concerns of double claiming

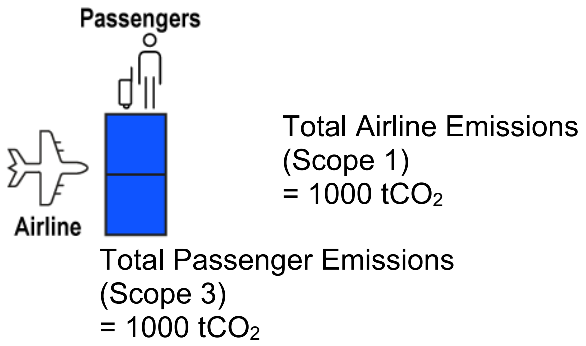
[9] The GHG Protocol clarifies that Scope 3 emissions of a company are by definition the direct emissions of another entity. Further, "two or more companies may account for the same emission within scope 3". "By allowing for GHG accounting of direct and indirect emissions by multiple companies in a value chain, scope 1, scope 2, and scope 3 accounting facilitates the simultaneous action of multiple entities to reduce emissions throughout society".

or double counting of environmental attributes related to individual SAF certificates, including their emissions reductions. For example, if one airline that physically used SAF in a flight sells a SAF certificate to another airline, the airline that used the physical SAF should not be allowed to claim its environmental attributes. Double counting could also happen if airlines use SAF certificates to comply with CORSIA obligations or other regulations. Bodies such as the International Air Transport Association (IATA) and book-and-claim registries have begun developing guidelines to enable the practice of co-claiming in an environmentally sound way, in order to allow different actors to collectively reduce the green premium of SAF. If the concept of co-claiming is also adopted for SAF carbon credits, carbon credit programmes should also adopt such safeguards to prevent double claiming and double counting.

Example of co-claiming

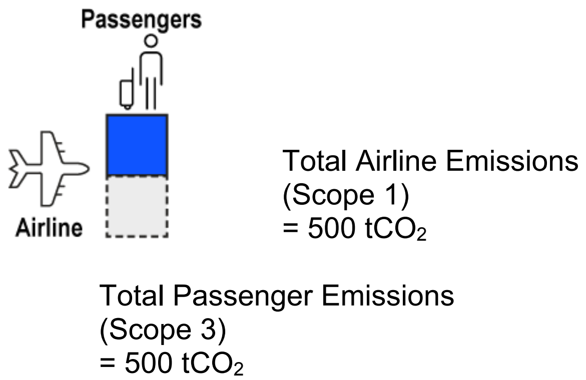
Baseline Scenario

Airline uses traditional jet fuel. Total emissions from flight are **1000 tCO_2**.



SAF scenario

Airline uses SAF to reduce its emissions. Total emissions from flight are now **500 tCO_2**. **Both the airline and passengers** can **claim the reductions for their Scope 1 and 3 emissions** respectively, assuming the airlines and passengers own the rights to the respective Scope 1 and 3 claims.



Emissions from traditional jet fuel

Emissions reductions from SAF

Source: GenZero Analysis

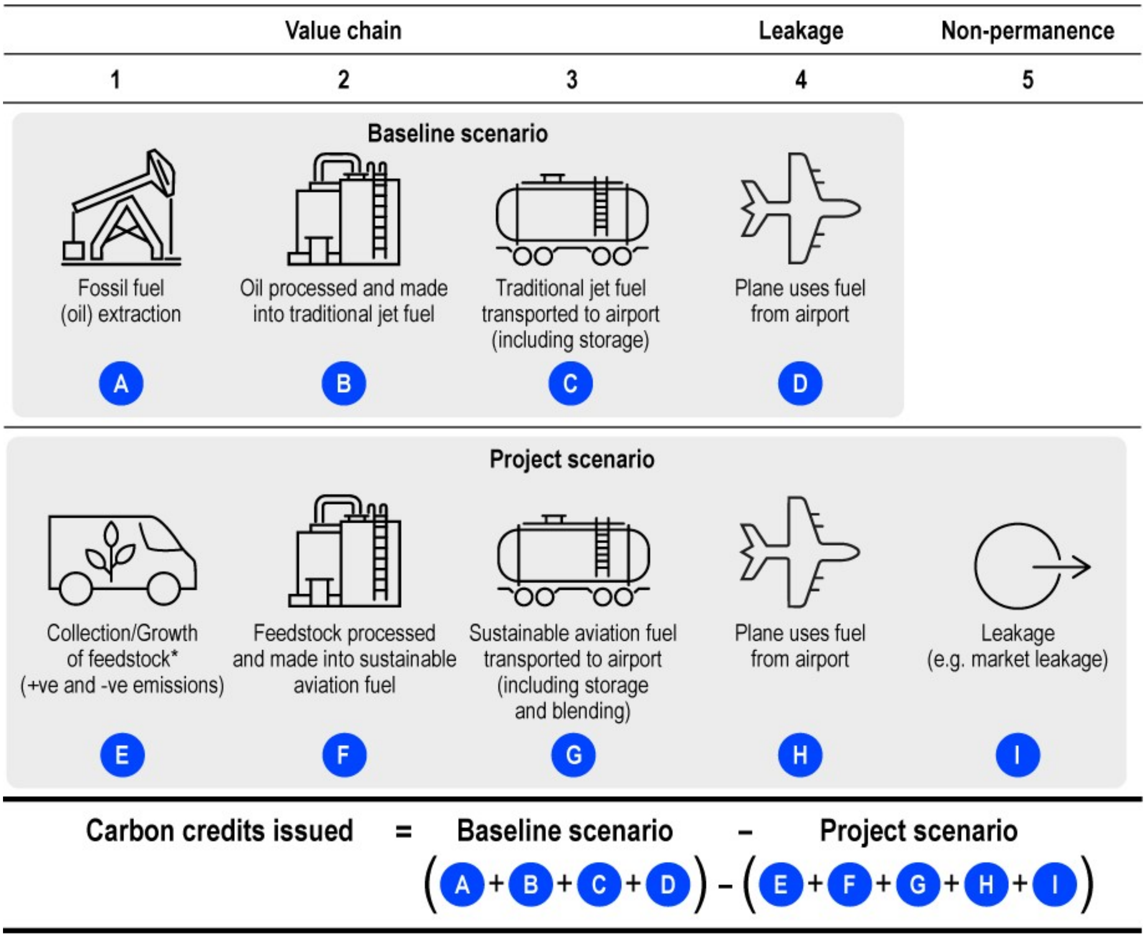
SAF carbon credit methodology

A SAF carbon credit methodology would need to quantify the emissions reductions (and therefore carbon credits) from the use of SAF. The methodology would compare two scenarios:

- a Baseline Scenario, where the airline continues using traditional jet fuel.
- a Project Scenario, where the airline replaces a certain percentage of jet fuel with SAF, leading to lower GHG emissions on flights using SAF blend.

The methodology would calculate the difference in emissions between these two scenarios, representing the actual GHG emissions reductions achieved by using SAF. This difference forms the basis for issuing carbon credits. The example below assumes a project scenario where SAF used on a flight is produced by collecting and processing feedstock displaces traditional jet fuel (produced using fossil fuels). The methodology in the example below accounts for leakage, such as when reduced use of traditional jet fuel in the baseline scenario leads to an increase of traditional jet fuel on other flights.

Illustration of how a SAF carbon credit methodology could work



Source: GenZero analysis.

Considerations on the quality of SAF carbon credits

Quality marker	SAF carbon credits
Additionality	**Low risk**
Permanence	**Low risk**
Robust quantification of emissions reductions and removals	**Medium risk**
Double counting	**Medium risk**, but depends on other safeguards
Leakage	**Low risk** with appropriate safeguards
Sustainable development benefits	**Moderate**

Additionality: Low risk. Generally, there is a strong case for additionality of SAF carbon credits due to the high costs of SAF relative to traditional jet fuel and presently low adoption rates of SAF. SAF carbon credits are not additional where there are existing regulatory mandates for minimum SAF use (e.g. European Union [EU]) or regulations that affect SAF use (e.g. EU Emissions Trading System). SAF carbon credits would need to demonstrate that SAF consumption is above and beyond regulatory requirements. Where there are incentives for SAF production or consumption (e.g. United States [US] Inflation Reduction Act), the onus is on the project to demonstrate that the incentives were insufficient to bridge the green premium and that carbon finance is necessary.

Permanence: Low risk. In the various SAF pathways, emissions reductions occur as a result of the difference in emissions between traditional jet fuel and SAF use, and the emissions emitted from SAF production and use have already been accounted for. For instance, SAF made from municipal solid waste accounts for the avoided methane emissions, and also reduces emissions from the combustion of SAF compared to traditional jet fuel when used. In such situations, the emissions savings cannot be reversed and hence the permanence risk is low.

Robust quantification of emissions reductions and removals: Medium risk. Quantification of emissions reductions is dependent on a comparison against a baseline where traditional jet fuel is used. While this is likely to be the case in most situations today, the projected trajectory of SAF consumption can affect the emissions reductions estimated and hence the credibility of the baseline. For instance, if SAF demand for the specific country is projected to increase (e.g. due to eco-conscious travellers), the use of SAF carbon credits would increasingly be less additional. This trajectory needs to be a credible counterfactual, and can perhaps be derived from an industry average, or other airlines' consumption. Where there are options among various projections, the more conservative option should be picked (i.e. it would generate fewer carbon credits). With SAF, emissions reductions are also calculated based on life-cycle emissions, necessitating a robust life-cycle emissions calculation, and transparency and traceability through the value chain. Finally, the quantification of emissions should encompass all material emissions, including any process or energy emissions, and fugitive emissions within the value chain, and where there is uncertainty, a conservative approach should be adopted.

Double counting, issuance, and claiming: **Medium risk.** The carbon crediting programme should have requirements and a robust registry to ensure no double counting, issuance or claiming. With SAF, further double counting considerations come into play. Firstly, because eligible SAF used on international flights can be counted towards CORSIA obligations and are already reported as emissions reductions, further generation of carbon credits used towards NDCs or CORSIA would result in double counting. Given this, the use of SAF carbon credits may need to be limited (e.g. to domestic flights, or voluntary purposes) in order to prevent double counting of the emissions reductions. If the buyer used carbon credits towards NDCs or CORSIA, the transfer should apply a corresponding adjustment, following the rules of Article 6 of the Paris Agreement. Further, with an active SAF certificate market, double counting can occur with the generation of SAF certificates and carbon credits from the same unit of SAF used and subsequently, where different parties claim emissions reductions. Safeguards are necessary to ensure that there is no duplicate generation from the same unit of SAF. Finally, because emissions reductions from SAF occur across its value chain, there may be double counting risks if emissions reductions from parts of the chain are claimed (e.g. methane avoided from municipal solid waste) and SAF carbon credits also claim similar emissions reductions.

Leakage: **Low risk**. Safeguards need to be in place to ensure that leakage (i.e. where the project leads to an increase in emissions outside the project boundary) from SAF production is minimal. For instance, should SAF be made from agricultural feedstock (e.g. plant oils), the agriculture product should be grown on verifiably degraded land that does not displace food production or encourage further deforestation. Should waste products (e.g. used cooking oil) be the feedstock, it needs to be verified that the feedstock is indeed waste by-products. A failure to do so can lead to perverse incentives (e.g. where unused oil is used to produce SAF, which inadvertently leads to increased cooking oil production and increased emissions). Many of these safeguards are not dissimilar to those needed to ensure that the SAF has been produced from feedstock with environmental benefits.

Sustainable development benefits: Moderate. SAF production can create employment for local communities, particularly in the feedstock production or collection process. Depending on the feedstock, it could also create other sustainable development co-benefits. For instance, the use of municipal solid waste for feedstock can alleviate waste management problems and improve health outcomes.

DACS carbon credits

Unlike other technologies, DACS projects lack marketable by-products besides the captured CO_2. Generating revenue through carbon credits and other policy mechanisms that value the environmental attributes of DACS is therefore crucial for their survival, making it a cornerstone of most DACS business models. Despite the high costs of removing CO_2 from the atmosphere, the demand for carbon credits issued from DACS projects is already high. Many corporations have signed forward contracts to purchase DACS credits that will be generated in the future. Corporations and coalitions that have made advance market commitments to accelerate DACS development include Frontier, which was founded by Stripe, Alphabet, Shopify, Meta, McKinsey Sustainability and Airbus; and NextGen, which is a jointly managed carbon removal credit facility by South Pole and Mitsubishi Corporation, and which received advance market commitments by Boston Consulting Group, LGT Private Banking, Mitsui O.S.K. Lines, Swiss Re and UBS.

State of play of DACS carbon credit methodologies

There are already methodologies available to issue carbon credits from DACS. Puro.earth's Geologically Stored Carbon Methodology and the Global Carbon Council's Methodology for project activities involving the capture, transport and geological storage of carbon dioxide have provisions for crediting from DACS projects. Moreover, the CCS+ initiative (through Verra), the American Carbon Registry, Isometric and Canada's Greenhouse Gas Offset Credit System are in the process of developing methodologies for DACS crediting. Climeworks, one of early developers of DACS projects, developed its own methodology, which was validated by DNV. Gold Standard has also approved a methodology for issuing credits from accelerated carbonation of concrete aggregate, where the use of CO_2 captured from DAC is one of the possible sources.

Overview of methodologies for issuing carbon credits from DACS projects

Programme	Methodology	Status	Number of projects using the methodology	Comment
Puro.earth	Geologically Stored Carbon Methodology	Active	1	The methodology scope allows for DACS projects and biogenic CO_2 capture (i.e. from plants) projects. CO_2 needs to be stored in geological structures (i.e. subsurface rock formations).

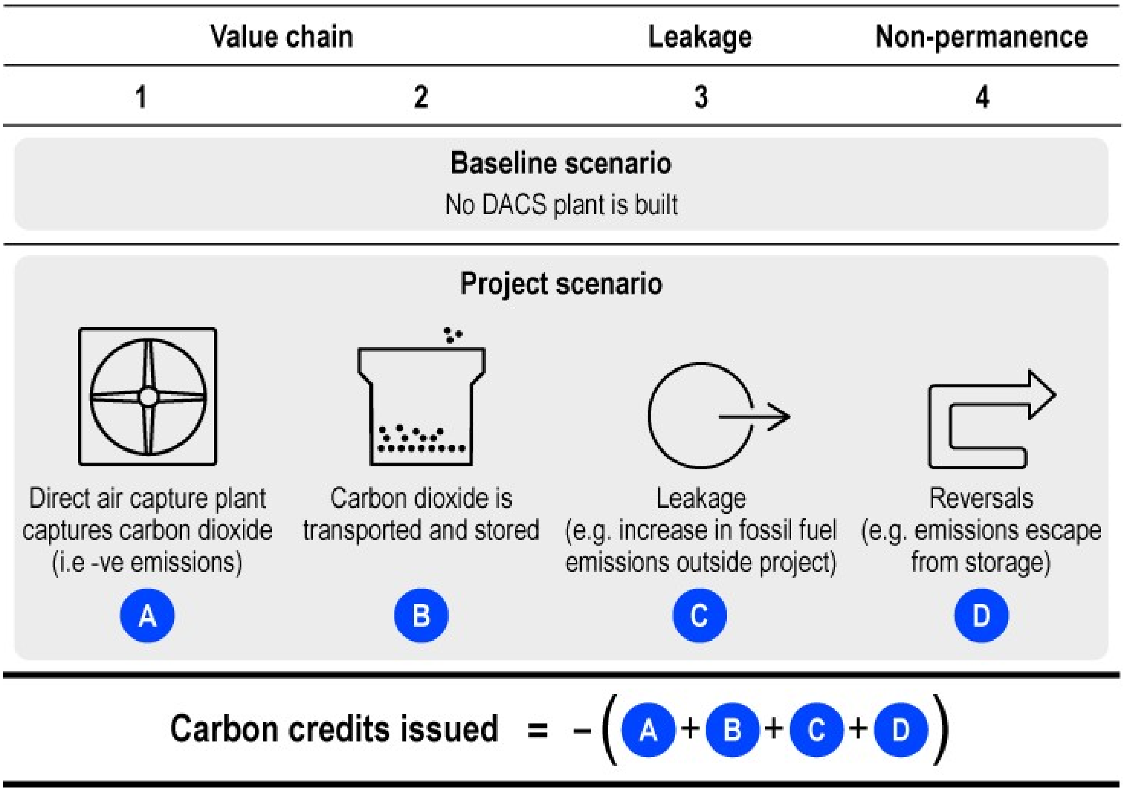
Programme	Methodology	Status	Number of projects using the methodology	Comment
Global Carbon Council	Methodology for project activities involving the capture, transport and geological storage of carbon dioxide	Active	0	Methodology scope allows for DACS projects, carbon capture and storage (CCS) (i.e. point source capture) and bioenergy with CCS. CO_2 needs to be stored in the country where it is captured (i.e. no transboundary movement is allowed).
American Carbon Registry	CCS projects	Active	0	Methodology scope allows for DACS projects, CCS (i.e. point source capture), a enhanced oil recovery in the United States and Canada.
Isometric	Direct air capture	Active	0	Methodology for DACS projects using various capture processes.
Climeworks and DNV	Proprietary methodology	Active	1	Climeworks developed its own methodology for its direct air capture plant, Orca, and sought third-party validation from DNV. The methodology was based on ISO 14064-2, a standard used to quantify, monitor and report on GHG emissions reductions and removals. The credits are not issued by an independent carbon crediting programme.

Programme	Methodology	Status	Number of projects using the methodology	Comment
Gold Standard	Carbon sequestration through accelerated carbonation of concrete aggregate	Active	0	Compared with other methodologies where CO_2 is stored in geological formations, CO_2 is stored in concrete aggregate. One of the eligible sources of CO_2 is direct air capture.
Verra	Direct air capture module to be used as a part of a methodology for carbon capture and storage	Under development	0	Perspectives Climate Group and South Pole are developing the methodology and the direct air capture module, along with other modules for transportation and storage.
Canada's Greenhouse Gas Offset Credit System	Direct Air Carbon Dioxide Capture and Sequestration	Under development	0	-
EU Carbon Removal Certification Framework	No methodology yet	Could be developed	0	The EU Carbon Removal Certification Framework is expected to set requirements for removal activities and may eventually result in an EU DACS methodology.

Note: Information as of April 2024.

Since DACS is a carbon removal technology, in most of the existing and forthcoming methodologies, carbon credits are issued by subtracting the project emissions (such as emissions associated with the electricity used for plant operation or with the transportation of captured CO_2, or potential leakages of the stored CO_2) from the volume of CO_2 captured and permanently stored.

Illustration of how DACS carbon credit methodologies usually work



Source: GenZero Analysis

With DACS methodologies, the baseline scenario would be a scenario in which the DACS plant is not built. Hence, the only relevant emissions that project developers need to estimate and monitor is the volume of the carbon emissions removed and stored in the project scenario. Project developers should also account for any reversals in the case that captured emissions escape into the atmosphere.

Considerations on the quality of DACS carbon credits

Quality marker	DACS carbon credits
Additionality	**Very low risk**
Permanence	**Low risk**
Robust quantification of emissions reductions and removals	**Very low risk**
Double counting	**Very low risk,** but depends on other safeguards
Leakage	**Low risk**
Sustainable development benefits	**Limited**

Additionality: Very low risk. Due to the current high costs of DACS, there is a strong case for additionality. This is especially true when CO_2 is captured and stored, because storing CO_2 generally creates no other additional economic benefits. Where governmental incentives are in place to develop DACS projects, the project developers should demonstrate that the incentives were insufficient to bridge the green premium and that carbon finance is necessary. Further, as costs fall over time, or if DACS projects become part of compliance targets, the additionality case for DACS credits may weaken, and should be assessed regularly over time.

Permanence: **Low risk**. DACS typically involves storing captured CO_2 in a geological reservoir, where it can be stored for over a thousand years. However, this is dependent on appropriate site selection and measures to monitor, mitigate and compensate for reversals where necessary. Where project developers poorly choose storage sites, risks may be higher. Further, with different storage options, the technology readiness levels vary and choosing a more nascent storage option can also increase risks.

Robust quantification of emissions reductions and removals: **Very low risk**. The amount of CO_2 that is removed from the atmosphere should be robustly quantified. CO_2 that is released into the atmosphere during the capture and storage process should be deducted, as should any emissions required to power the plant.

Double counting, issuance and claiming: **Very low risk.** Carbon crediting programmes should have requirements and robust registries to ensure that no double counting, double issuance or double claiming occurs. If the buyer uses carbon credits towards NDCs or CORSIA, a corresponding adjustment will be required following the accounting rules of Article 6.2 of the Paris Agreement.

Leakage: Low risk. Safeguards need to be in place to ensure that if renewable energy is used to power the DACS plant, its use does not displace renewable energy from the grid, leading to emissions increases from fossil fuel use.

Sustainable development benefits: DACS projects generate limited co-benefits beyond creating employment through the implementation of the project.

5. Barriers and recommendations on the role of carbon credits in scaling up low-emissions hydrogen, SAF and DACS

This chapter provides an overview of non-comprehensive barriers and recommendations to overcome them that are specific to low-emissions hydrogen, SAF and DACS scale-up and carbon credits adoption.

Summary of barriers and recommendations

#	Barrier	Recommendation
1	Carbon credits cannot bridge the investment gap on their own.	Governments should adopt a mix of complementary policies, and private sector coalitions should help channel funds through advance market commitments.
2	A lack of methodologies and concerns about additionality are a major obstacle to issuing carbon credits.	Carbon crediting programmes and project developers should accelerate efforts to develop methodologies and clarify additionality.
3	It is challenging to account accurately for emissions and emissions reductions in the supply chains of low-emissions hydrogen and SAF carbon credits.	A coalition of stakeholders should develop clear guidance on emissions accounting.

Barrier 1: Carbon credits cannot bridge the investment gap on their own

While high-quality carbon credits may offer valuable tools for emissions mitigation and channel funds, they are not likely to be sufficient on their own to incentivise the large-scale deployment of costly technologies such as low-emissions hydrogen, SAF and DACS. Carbon markets alone struggle to incentivise the early-stage technology adoption that is needed to overcome the "valley of death" – which is the high-risk phase where many technologies fail before reaching widespread adoption. The high costs of these technologies, alongside the price volatility of carbon credits and the uncertainties in carbon markets, make it difficult today for project developers to rely solely on carbon credits as a steady and reliable revenue source to scale up their businesses.

Recommendation 1: Governments should adopt a mix of complementary policies

Governments can play a significant role in addressing regulatory certainty and improving the investment conditions for such technologies through a mix of complementary policy instruments that can help bridge the current profitability gap between these high-cost options and other less costly, more established mitigation solutions.

An important first step is the development of a roadmap which could provide clarity for investments to take place. For instance, as mentioned above, 46 countries and the European Union (EU) have launched national low-emissions hydrogen strategies. These provide clarity by setting out a vision for low-emissions hydrogen production within the country, and often include targets for production or consumption and a plan for how these targets might be achieved.

Depending on the specific national circumstances, governments can leverage a range of policy instruments to provide incentives in investing and scaling up these technologies. For example, for early-stage technologies, support in the form of research and development programmes or subsidies could be helpful. For the latter, a notable example is the EU Innovation Fund, which provides funds for low-emissions hydrogen projects, among others.

Governments can also use other policy tools to bring technology deployment at scale. For example, governments could decide to directly incentivise a specific technology or range of technologies through well-targeted public procurement, or to leverage markets through carbon contracts for difference. These could create earlier bankability for the projects. Public procurement could also incentivise the scale-up of targeted technologies using carbon credits. For instance, in September 2023 the United States (US) Department of Energy launched the Carbon Dioxide Removal (CDR) Purchase Pilot Prize, which will award USD 35 million to companies that directly sell CDR credits to the US government in the form of offtake agreements across four removal pathways including DACS. Other policies complement the CDR Purchase Pilot Prize, such as the Regional Direct Air Capture Hubs programme, which provides USD 3.5 billion to help accelerate the demonstration and deployment of DAC. However, given the limited public budgets available, public procurement might not be a sustainable, long-term solution. Compliance carbon markets (e.g. emissions trading system [ETS] or carbon tax) could also create firm demand signals if these policies allow for the use of carbon credits within the system (e.g. to reduce the carbon tax paid or as a substitute for surrendering an emissions permit in an ETS). The carbon price in the compliance carbon market needs to be sufficiently high to stimulate demand for such early-stage technologies.

Non-state actors can also support cost reductions of these technologies through buyer coalitions, such as the First Movers Coalition, NextGen or Frontier which create demand for nascent technologies including DACS. These coalitions provide an advance commitment to purchase future carbon credits or other environmental attribute certificates. This helps to lower the costs of borrowing and enables project developers to scale up deployment of the technology with enhanced financial predictability. While the share of removal carbon credits needs to increase in carbon markets in order to align with a net zero pathway, it is also important to fund low-emissions hydrogen and SAF to reduce emissions in hard-to-abate sectors (as shown in Chapters 2 and 3 of this report) in the short to medium term, including through high-quality carbon credits. Therefore, there is also potential for more buyer coalitions to increase adoption of low-emissions hydrogen and SAF through high-quality carbon credits, alongside existing advance market commitment coalitions for DACS.

Barrier 2: A lack of methodologies and concerns about additionality are a major obstacle to issuing carbon credits

A fundamental barrier to the issuance of low-emissions hydrogen, SAF and DACS carbon credits is the lack of available methodologies. There are no methodologies to generate SAF carbon credits at present, and a limited range of methodologies for low-emissions hydrogen. Existing hydrogen methodologies are limited in scope, and the Hydrogen for Net Zero (H2NZ) initiative is developing methodologies that cover the hydrogen value chain. Several DACS credit methodologies have just been developed or are under development in carbon crediting programmes including Puro.earth, Global Carbon Council, Verra, and the American Carbon Registry. Such low availability of methodologies means that carbon finance cannot be used to enhance the deployment of these technologies. However, there is promise that carbon crediting programmes and practitioners can tackle this challenge in the near future as several new methodologies are currently under development.

Another possible methodological shortcoming relates to the impact of low-emissions hydrogen on climate change. Project developers should systematically monitor any possible leakage of hydrogen, and experts should study its impact further. While hydrogen is not a GHG, the chemical reactions of leaked hydrogen can reduce the concentration of molecules that destroy other GHGs such as methane, ozone and water vapour. Studies estimate that the global warming potential of hydrogen can be as high as 12 times that of CO_2. If untamed, it could affect the viability of low-emissions hydrogen carbon credits.

Moreover, in cases where technologies receive subsidies or other incentives, it might be challenging to justify the financial additionality of individual projects. Usually, a project is considered additional under the financial additionality criterion if it would not be profitable enough without the price signal from carbon credits. This can be determined either by evaluating the level of profitability of the project compared with the business-as-usual scenario, or by evaluating the internal rate of return or payback period and comparing it with a predefined benchmark. However, where complementary policies provide financial support or incentives to these technologies, and if these policies governments are also included under the unconditional measures of the nationally determined contribution, it might be more challenging for low-emissions hydrogen, SAF and DACS to pass the "traditional" additionality test.

Recommendation 2: Carbon crediting programmes and project developers should accelerate efforts to develop methodologies and clarify additionality

Carbon crediting programmes and project developers should accelerate efforts to develop methodologies that channel carbon financing towards these technologies. The methodologies should contain robust quality criteria (e.g. robust quantification of the emissions reductions or removals, and additionality). Regarding crediting from SAF, crediting methodologies should also avoid double issuance for the same emissions reduction. Moreover, where there are leakage risks, a default crediting discount factor could be applied if no better quantified estimation is available.

For low-emissions hydrogen, to ensure robust quantification of emissions, methodologies would need to account for factors such as the global warming potential of hydrogen, even though it is not a GHG. Better data can enable more robust quantification, and the quality of data could improve if there was strict monitoring across all projects (e.g. driven by reporting and disclosure requirements).

Moreover, while governments may put in place subsides or incentives to develop specific technologies, there may be the need to adapt existing additionality tests or to develop new ones if the subsidies or incentives are insufficient on their own to enable the full development of the projects. Some experts have already proposed a tool for the demonstration and assessment of additionality that can be adapted for such purposes.

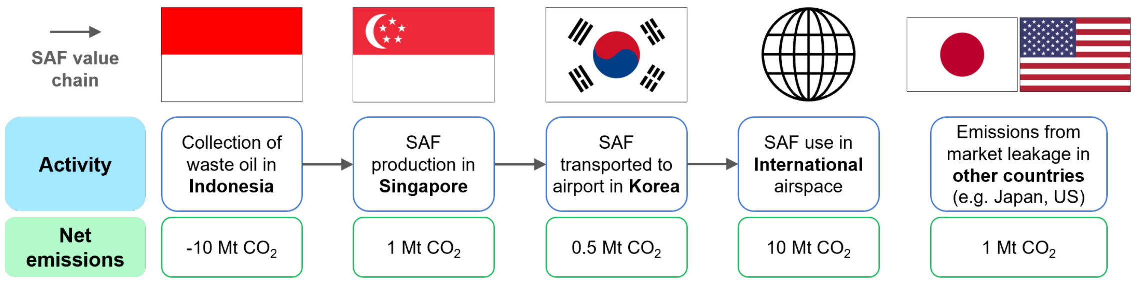
Furthermore, to help manage risks associated with the non-delivery of the expected mitigation and associated carbon credits, insurance providers could consider offering related services or products. For instance, the Multilateral Investment Guarantee Agency (MIGA) of the World Bank Group has developed tools to de-risk carbon markets through the management of non-commercial risks. A well-developed financial market can also help to manage some of these risks.

Barrier 3: It is challenging to account accurately for emissions and emissions reductions in the supply chains of low-emissions hydrogen and SAF carbon credits

Accounting for the emissions from low-emissions hydrogen and SAF carbon credits is complex because the emissions reductions are accounted for across supply chains, and these tend to span across several countries.

In a voluntary carbon market context, there are minimal implications as the accounting for voluntary carbon credit projects operates independently from national emissions accounting. However, if buyers were to use SAF or low-emissions hydrogen carbon credits towards NDCs (as part of Article 6 co-operation) or the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), corresponding adjustments would be required. This necessitates the application of a corresponding adjustment to national emissions inventory, and the transboundary nature of the emissions would make accounting complex. For instance, SAF can be produced using feedstock from Indonesia, refined in Singapore, and eventually used in a plane in Korea.

Example of the complexity of SAF carbon accounting



Note: Mt = million tonnes.

In such cases, the application of a corresponding adjustment can be a complex accounting and administrative exercise. Moreover, should the concept of co-claiming be brought forward in the context of carbon credit markets, there are a few issues that would need to be clarified to avoid double claiming or double counting of emissions.

Co-claiming emissions reductions from SAF needs clear guidance to prevent potential double counting

When an airline uses SAF, it lowers its own Scope 1 emissions while also reducing the Scope 3 emissions of its passengers. This creates a question of who can claim the reduction: the airline, the passenger who bought a SAF certificate or a SAF carbon credit, or both? Clear guidance is essential to ensure that any SAF co-claiming is done with the highest environmental integrity. Traditionally, carbon credits were generated from lower-cost mitigation options, making co-claiming less of an issue. However, achieving net zero emissions will increasingly require the deployment of more expensive solutions such as SAF, and co-claiming could be one avenue to allow multiple stakeholders to share the cost. Clear guidance on co-claiming for SAF carbon credits can allow different actors to share the financial burden of the SAF "green premium", ultimately accelerating the adoption of critical low-emissions technologies such as SAF.

Without clear guidance and adequate safeguards, co-claiming applied to SAF carbon credits could risk double claiming of emissions reductions. Managing the risks around co-claiming is relatively common with SAF certificates through the book-and-claim system, with recognition that the reduction of Scope 1 emissions for a party (e.g. airline) would entail the Scope 3 emissions reduction for other parties (e.g. passengers). However, co-claiming is a new concept for carbon credit markets and it is still being widely debated in the industry. There is also a lack of clarity on the distinction between co-claiming and double claiming, of which the latter is a form of double counting. If a passenger purchased a SAF carbon credit to offset their Scope 3 emissions from a flight, and if the airline promoted publicly that that flight has reduced its Scope 1 emissions without adjusting for passengers who bought the SAF carbon credit, this situation could lead to double claiming of emissions reductions. Indeed, the total claimed emissions reductions from SAF usage would exceed the actual SAF volume that the plane used.

For technologies that can generate carbon credits alongside environmental attribute certificates, such as SAF certificates or hydrogen guarantees of origin,* there could be a problem of double issuance, i.e. more than one unit/certificate is issued for the same emissions reduction. This could happen, for instance, when an airline uses SAF on a flight, and it generates SAF carbon credits and SAF certificates. Guidance is needed to clarify which actors (i.e. airline, carbon credit owner, freight forwarders) can claim the associated emissions reductions.

Double counting also becomes a concern when using SAF on international flights. If an airline accounts for and reports emissions reductions from eligible SAF towards its CORSIA obligations, generating carbon credits from the use of that SAF and using them towards an NDC or CORSIA would result in double claiming of the same emissions reduction. To prevent this, the issuance and use of SAF carbon credits might need to be limited to specific cases, such as domestic flights (which are outside CORSIA's obligations) where other domestic flight obligations are not in place, or for voluntary climate contributions (whereby the buyer of the credits cancels them without claiming the associated emissions reductions).

Work on developing guidance for SAF co-claiming is nascent and further dialogue is needed to build consensus around the associated principles, in particular for SAF carbon credits. Early efforts by the International Air Transport Association (IATA) and registries such as the SAFc Registry show promise for co-claiming of SAF certificates, allowing airlines and passengers to share claims for Scope 1 and Scope 3 emissions respectively. International collaboration among different actors, such as carbon crediting programmes, as well as book-and-claim registries, would be crucial to establish robust principles around co-claiming for SAF carbon credits.

* Another notable example are renewable energy certificates and credits issued by renewable energy projects, a case that is not dealt with in this report.

Moreover, the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories do not include an explicit accounting methodology for removals from DACS or geological storage, making it difficult for countries to have consistent guidance of how to do so. Some countries have nonetheless already accounted for removals in their national inventories. For example, Norway has regularly reported in its national inventory reports on geological storage starting from a 1996 carbon capture and storage project, Sleipner. The IPCC has committed to deliver a "Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage" as part of the work programme of its Seventh Assessment Report. Its release at the end of 2027 should provide the needed clarity to address this issue.

To add complexity, there is still a disconnect in the way countries and non-state actors account for their emissions. Countries follow the accounting method of the IPCC Guidelines for National Greenhouse Gas Inventories, while corporations usually follow the GHG Protocol Corporate Accounting and Reporting Standard. The latter categorises emissions by scope, which facilitates planning and accounting for GHGs at a corporate level. However, this also creates complexity when overlaid with national GHG inventories, especially for complex cases where value-chain emissions occur across countries.

Recommendation 3: A coalition of stakeholders should develop clear guidance on emissions accounting

With new forms of carbon credits generated from projects that span across several countries (e.g. low-emissions hydrogen and SAF), and that could be used in compliance regimes or voluntary markets (e.g. SAF use could count towards

CORSIA and SAF carbon credits may interact with other carbon markets), greater co-ordination and transparency are needed to ensure that carbon accounting is done accurately. A coalition of actors, including carbon credit programmes, project developers, academia, governments and carbon accounting experts should develop clear guidance on emissions accounting to ensure that the use of carbon credits does not lead to an overall increase in global emissions. Clear guidance on emissions accounting would also be the foundation for further thinking and guidance on important issues relating to emissions accounting in carbon markets, such as corresponding adjustments under Article 6.

To create effective accounting guidance, international collaboration is crucial for developing clear standards. Building confidence in accounting guidance ultimately hinges on the availability of good data, for which robust emissions tracking across international borders and across international supply chains is essential. Increased adoption of standardised emissions reporting, alongside advancements in monitoring technology, are key to achieving this. The long-term vision should aim at a shared data ecosystem where organisations, governments and regulators can all contribute and access these data and information, ultimately reducing overall costs.

Annex

Abbreviations and acronyms

APS	Announced Pledges Scenario
BRL	Brazilian real
CAAS	Civil Aviation Authority of Singapore
CAD	Canadian dollar
CCP	Core Carbon Principle
CCQI	Carbon Credit Quality Initiative
CCS	carbon capture and storage
CCUS	carbon capture, utilisation and storage
CDM	Kyoto Protocol's Clean Development Mechanism
CDR	carbon dioxide removal
CEF	Connecting Europe Facility
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
COP	Conference of the Parties
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DAC	direct air capture
DACS	direct air capture and storage
DFI	development finance institution
DKK	Danish kroner
DOE	US Department of Energy
EMDE	emerging market and developing economies
ETS	Emissions Trading System
EU	European Union
FOAK	first-of-a-kind
FT	Fischer-Tropsch
GGR	greenhouse gas removal
GHG	greenhouse gas
H_2	hydrogen
H_2-eq	hydrogen equivalent
H_2NZ	Hydrogen for Net Zero initiative
IAG	International Airlines Group
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICROA	International Carbon Reduction and Offset Alliance
ICVCM	Integrity Council for the Voluntary Carbon Market
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ITMO	Internationally Transferred Mitigation Outcome

JPY	Japanese yen
L-DAC	liquid direct air capture
LCFS	Low Carbon Fuel Standard
LH_2	liquid hydrogen
LOHC	liquid organic hydrogen carrier
MIGA	Multilateral Investment Guarantee Agency
NDC	nationally determined contribution
NEDO	Japan’s New Energy and industrial Development Organisation
NH_3	ammonia
NZE	Net Zero Emissions by 2050 Scenario
OECD	Organisation for Economic Co-operation and Development
PNH 2	Brazil’s National Hydrogen Programme
PV	photovoltaic
R&D	research and development
RSB	Roundtable on Sustainable Biomaterial
S-DAC	solid direct air capture
SAF	sustainable aviation fuels
SBTi	Science Based Targets initiative
SIA	Singapore Airlines
SOE	state-owned enterprise
STEPS	IEA’s Stated Policies Scenario
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USD	US dollar
VCM	Voluntary Carbon Market
VCMI	Voluntary Carbon Markets Integrity initiative

Units of measurement

Bbl	barrel
EJ	exajoule
GW	gigawatt
kg	kilogramme
Mt	million tonnes
MW	megawatt
t	tonne

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