# The Green Hydrogen Gap

## Conclusions on the analysis of the policy landscape of green hydrogen and carbon-dioxide derived from direct air capture in the UK and EU

**This paper is written by Opportunity Green on behalf of the SASHA Coalition, as the Coalition secretariat, but it in no way represents the views of the members of the SASHA Coalition - it is for informational purposes only.**

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## Executive Summary

- The SASHA coalition commissioned Arup to investigate the pathways and policies in place to decarbonise the aviation and shipping sectors.
- Existing drivers do not provide an adequate incentive to invest in the technologies that will aid the decarbonisation of these sectors, and policies should prioritise the use of hydrogen and carbon-dioxide from direct air capture (DAC) in applications where there is a lack of alternative decarbonisation interventions – such as the aviation and shipping sectors.
- Green hydrogen (i.e. hydrogen produced from renewables) is required for all pathways to truly sustainable fuels for both the shipping and aviation sectors, with DAC necessary where a sustainable source of $CO_2$ is required. Hydrogen, ammonia and methanol are the most promising options for shipping, and hydrogen and synthetic kerosene for aviation.
- Regulation stimulates innovation. If the price of green hydrogen is to reduce, regulation needs to require its availability. While recent legislation to decarbonise both sectors at the EU and UK levels is to be welcomed, it

does little to incentivise the production of green hydrogen or DAC over other alternative fuels. This is because it supports lower-carbon fuels but does nothing to incentivise the *lowest* carbon fuels over others. Instead, it is concentrated on scaling biofuels for aviation, and gas for shipping. Yet green hydrogen and DAC are the only long-term sustainable solutions. There is a "**Green Hydrogen Gap**" that will need to be fulfilled either by the voluntary action of first-mover ambitious companies or by regulation.

- Projections show that hydrogen production is behind where it needs to be for the Paris Agreement temperature goals to be met, mainly due to a lack of guaranteed demand. If the aviation and shipping sectors are to have the hydrogen they need, they will need to send clear, unambiguous demand signals to green hydrogen producers as soon as possible. But without legislation, industry will have to take on this cost voluntarily.
- Whatever fuel the aviation and shipping sectors use will also be sought after by other industries. If the aviation and shipping sectors don't make their case clearly and loudly now, they are unlikely to have access to fuels that will truly lead to sustainable decarbonisation. Other industries are already being prioritised by governments for hydrogen and without stronger interventions and stronger policy, the aviation and shipping sectors will be overlooked.

**Recommendations to policymakers:**

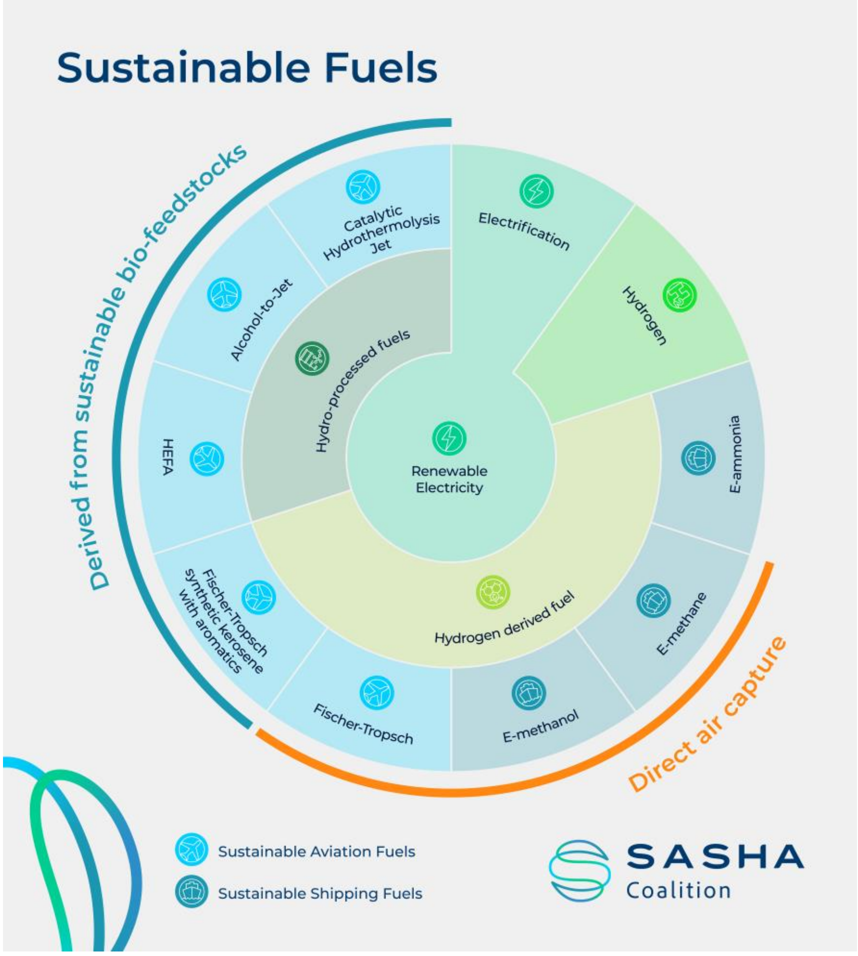
- Implement stringent sectoral emission reduction targets for both the aviation and shipping sectors that are aligned with a Paris Agreement-compatible trajectory.
- Recognise the long-term role that green hydrogen and DAC will play in sectors without other decarbonisation options, like aviation and shipping.
- Put in place mechanisms to incentivise the use of fuels with the greatest potential to reduce full lifecycle emissions over those with less emission reduction potential.
- Adopt ambitious mandates for the use of green hydrogen and green hydrogen-derived fuels to drive demand, and therefore supply.
- Strategies focussed on hydrogen demand must ensure it is used only in those sectors, like aviation and shipping, that don't have alternative options for decarbonisation.
- Adopt a cross-departmental approach to hydrogen policy, ensuring transport stakeholders are involved in decision-making on future uses of green hydrogen and DAC, and that hydrogen strategies recognise its importance in decarbonising the aviation and shipping sectors.

## Introduction: The aviation and shipping sectors' dilemma

In 2018 international aviation accounted for at least 3.5%[1] of global anthropogenic climate warming, while shipping emitted around 3%[2] of global anthropogenic greenhouse gases. However, the climate impact of these sectors could grow significantly if action is not taken.

Achieving a just transition to a net zero future in the aviation and shipping sectors is an ambitious goal, but it is one that is achievable with a properly supportive policy framework, resources, and collaboration between industry and decision makers. Action needs to be taken now, however, if we are to meet 2050 net zero goals, given that it will take time to develop and scale the technologies and supporting infrastructure needed to transition to these sustainable fuels.

With political attention increasingly being turned towards hydrogen, and the many opportunities its development provides, the SASHA Coalition is being formed to ensure that the aviation and shipping sectors are present in policy conversations and that their voice is heard at this important time. This briefing accompanies a policy analysis commissioned by the SASHA Coalition from Arup.




This graphic shows the different potential fuel production pathways for the aviation and shipping sectors. Other than where direct electrification can be used, hydrogen is required either as a key component of these fuels or as part of their processing.

[1] Lee et al., 2021, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, Atmospheric environment, 244, 117834.
[2] International Maritime Organisation, 2020, Fourth IMO GHG Study (2020)

## Why green hydrogen?

Green hydrogen is essential for all fuels that will prove truly sustainable for the aviation and shipping sectors in the long run. Currently both aviation and shipping use primarily oil[3], although there is also an increasing use of gas (LNG) in shipping. Both sectors will have to move away from fossil fuels if the temperature goals of the Paris Agreement are to be met, and both sectors have their own voluntary, national, regional and international decarbonisation goals. While there are many options in both sectors to improve technical efficiency, ultimately a new source of fuel will have to be found for both.

Both sectors essentially have two large categories of future fuels: those derived from green hydrogen, including green hydrogen itself, and biofuels. Within both categories are several different types of fuels. While our report specifically focuses on the pathway of green hydrogen and green hydrogen-derived fuels, we touch briefly on biofuels below.

### Biofuels

Biofuels are fuels produced from biomass (crops) or waste. There are a large variety of types of biofuels, but their main advantage is that they can generally be used in existing vessels and aircraft with little modification. Biofuels are critically limited in different ways[4], for reasons of land-use change, limited and declining waste production streams, production costs and competition, such that they will not be able to deliver full decarbonisation to the aviation and shipping sectors. Therefore, green hydrogen and green hydrogen-derived fuels will be required.

The SASHA Coalition takes no position on the use of biofuels other than to support the proposition that the full lifecycle impacts of all fuels must be considered so that false solutions are not prioritised.

### Hydrogen and hydrogen-derived fuels

The diagram on the next page demonstrates that hydrogen is required as a feedstock for all fuel pathways. For the ambitious actors in the aviation and shipping industries looking to invest now in decarbonisation options that they can know fully decarbonise their operations and are viable long term, fuels produced from green hydrogen are the clear winners. Synthetic fuels have the potential to allow both the aviation and shipping industries to get to zero or near zero (see aviation non-$CO_2$ impacts) emissions.

Like biofuels, there are many different feedstocks that can produce hydrogen. Green hydrogen is the only one that can provide zero emission or near zero emission fuels.[5] But there are constraints around

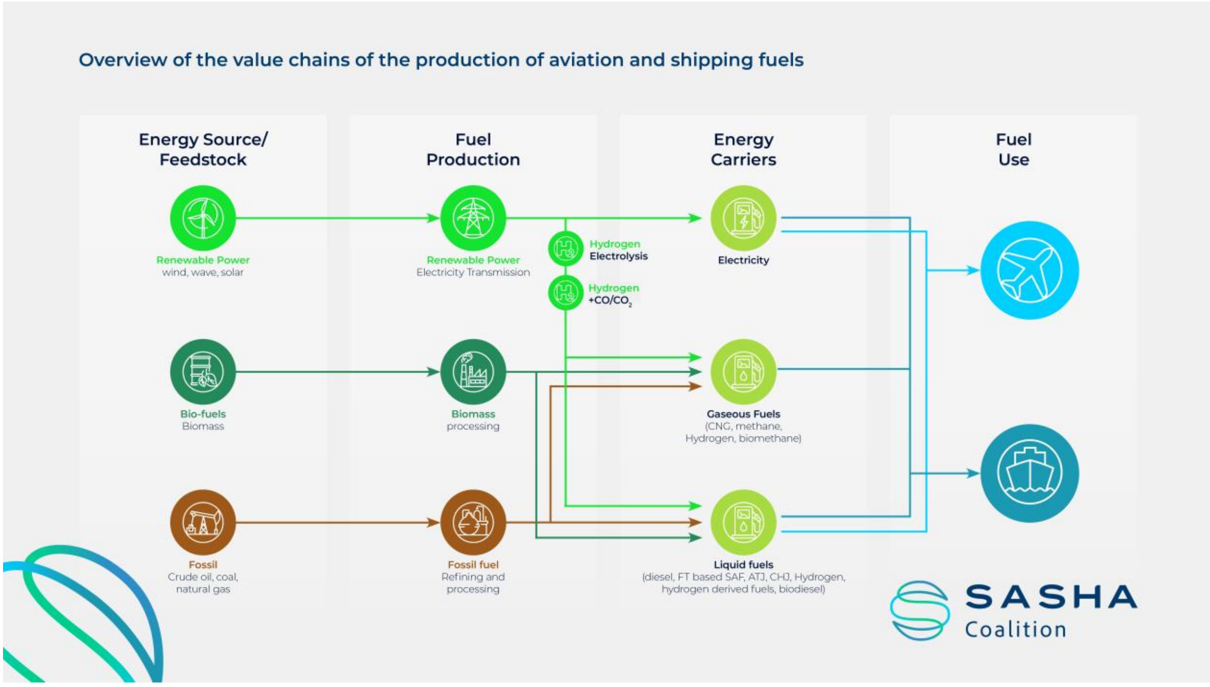
[3] The maritime sector alone accounts for 5% of all oil sales worldwide (see page 38 of the accompanying Arup report).

[4] Land-use issues mean that first generation biofuels are no longer considered viable. As well as land-use issues from an environmental perspective (deforestation, for example), repurposing land for crop production could impact negatively on food security (see page 17 of the accompanying Arup report). Biofuels-derived from waste are limited in scope and many of the waste streams from which those biofuels are produced will be wound down in a net zero world. Third-generation biofuels – derived from algal biomass – could have higher yields but require high temperatures and large volumes of water to grow, with associated high costs and issues around water scarcity (see page 17 of the accompanying Arup report). As electrolysis also requires large volumes of water, it is important that green hydrogen is limited in use to the sectors with no alternative decarbonisation options to limit water consumption. A number of sectors are already using biofuels to decarbonise, meaning there is competition for their limited supply, and the amount of land needed to replace just the UK's aviation fuel is over 50% of that available in the UK for agriculture (The Royal Society, Policy Briefing, '[Net zero aviation fuels: resource requirements and environmental impacts](),' p 22).

[5] IRENA says not all types of hydrogen are compatible with sustainable, climate-safe energy use or net-zero emissions. Only "green" hydrogen – produced with electricity from renewable sources – fulfils these criteria, which also entail avoiding "grey" and hybrid "blue" hydrogen. IRENA, 2021, 'Marking the breakthrough: Green hydrogen policies and technology costs', p 3.

green hydrogen, the most pressing of which is that the amount of renewable energy required will be huge. Therefore, the use of this green hydrogen needs to be minimised where possible.

One important way to minimise the amount of fuel is to ensure it is directed only at those sectors that have no other viable decarbonisation pathway, such as shipping, aviation, steel and fertilisers. We therefore need to focus all our effort on deploying zero-emission technologies in an effective way. The sooner industry starts to invest in the new capital stock of green hydrogen, the sooner its price will reduce. But that innovation will only happen if it is stimulated by regulation. However, existing regulation does little to incentivise the production of these fuels for either the aviation or shipping




sector.

## $CO_2$ from Direct Air Capture

Multiple industries currently use $CO_2$ and will need sustainable $CO_2$ to decarbonise. This means that again, both the aviation and shipping sectors (on the methanol fuel route) will be competing with other industries for the technology.

For aviation especially, if e-kerosene produced from green hydrogen and DAC there still could be adverse climate impacts from the non-$CO_2$ emissions. Contrails - which are clouds formed at high altitude when hot exhaust gases from aircraft mix with cold moist air and freeze into ice crystals – are one example of these non-$CO_2$ emissions.

The non-$CO_2$ impact of aviation has not to date received much regulatory attention.  While some hydrogen-derived fuels, depending on their final formulation, will not reduce contrail formation, research suggests that hydrogen-powered aircraft could reduce the effect of contrail radiative forcing by ~20-25%[6]. Although the study found that the global area covered by contrails could increase by up to 70% for liquid hydrogen combustion and fuel cell powered planes, it is likely that it would result in shorter-lived contrails and therefore a relative reduction in their impacts. However, more research still needs to be done in this area to understand the impact of alternative fuels on non-$CO_2$ effects. Last

[6] Clean Air Taskforce, 2023, Non-$CO_2$ climate impacts of aviation: Contrails.

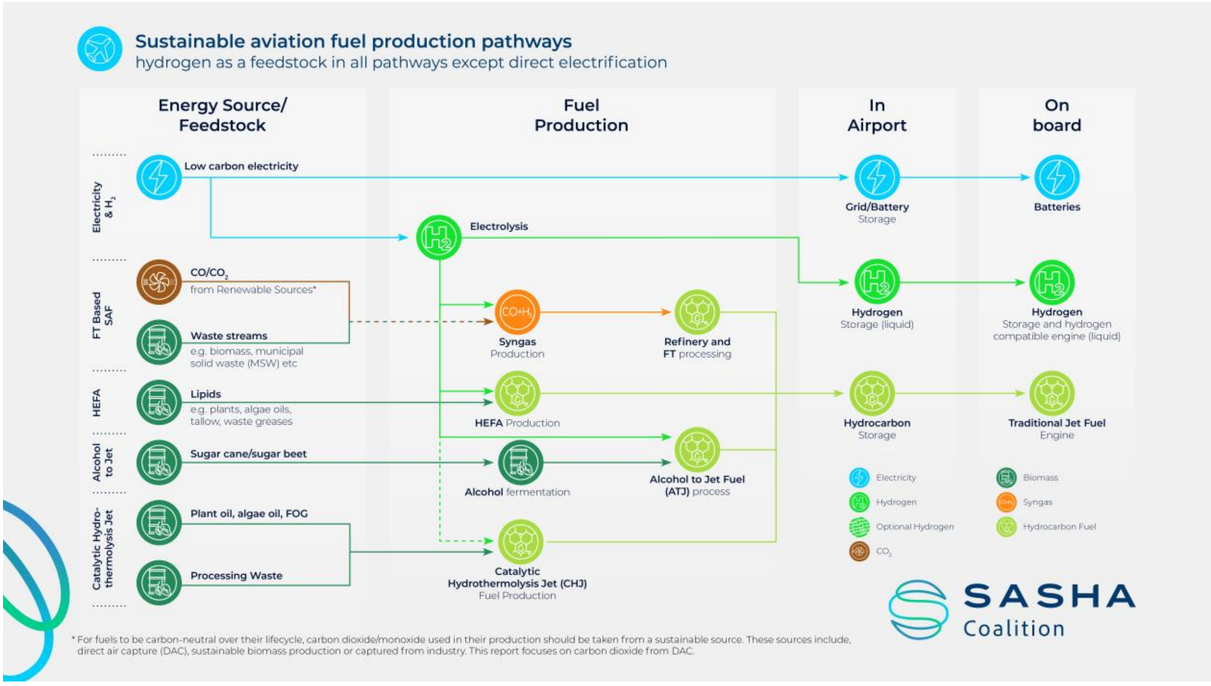
year, Airbus announced the "Blue Condor"[7] test programme, which will seek to better understand the non-$CO_2$ impacts of hydrogen powered aircraft.

## The Policy Gap

There is increasing regulation of the climate impact of the aviation and shipping sectors. In the European Union, this takes the form of several new regulations in both sectors as part of the Green Deal package, which aims to reduce the EU's emissions by at least 55% by 2030 compared to 1990 levels. And while that legislation is to be welcomed, it does little to drive the uptake of truly sustainable fuels - green hydrogen or green hydrogen-derived fuels, as outlined below.

# Aviation

- ReFuel EU Aviation includes a headline target of 6% Sustainable Aviation Fuel (SAF) in 2030, but only 1.2% of that is synthetic fuels (including green hydrogen-derived). This will rise to a target of 70% SAF by 2050, of which 35% must be synthetic fuels[8].
- Meanwhile, the UK government has committed to introducing a SAF mandate from 2025 onwards, with an equivalent of at least 10% of jet fuel to be made from sustainable sources by 2030[9], although it does not currently contain any targets for synthetic fuels. However, the government has recently consulted on introducing a Power-to-Liquid (PtL) mandate[10].
- These mandates will not be sufficient to meet the sector's net zero targets, and further, more ambitious regulation will be required to drive increased alternative fuels. With the overall goal of the EU's Fit for 55 Package being a reduction in emissions by 55% by 2030, heading towards net zero by 2050, aviation will only come under increasing regulatory scrutiny if it is to contribute meaningfully to the achievement of these targets.



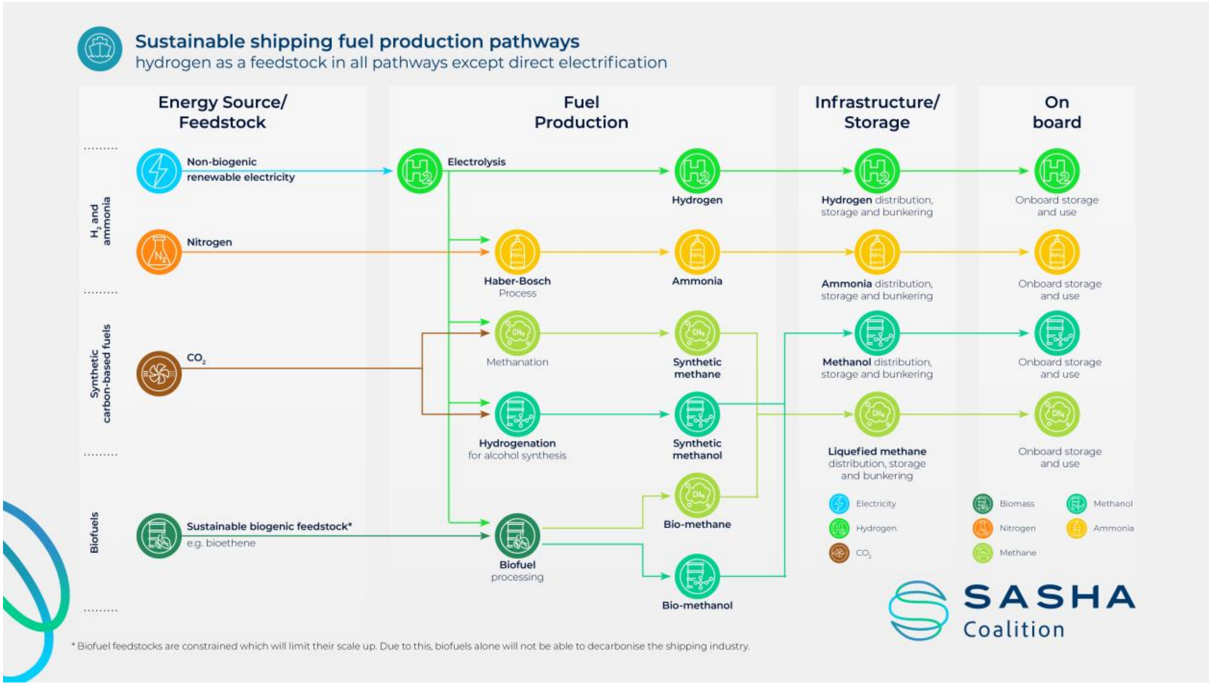

[7] The Blue Condor project will launch two modified Arcus gliders, one equipped with a hydrogen combustion engine and one equipped with a conventional kerosene-powered combustion engine, in order to compare contrails emitted at high altitudes.
[8] Reuters, 2023, EU agrees binding green fuel targets for aviation.
[9] Department for Transport, 2021, Mandating the use of sustainable aviation fuels in the UK.
[10] The consultation 'Pathway to net zero aviation: developing the UK sustainable aviation fuel mandate' ran from 30 March 2023 to 22 June 2023.

The graphic on the previous page shows the various fuel pathways for aviation. It is clear that hydrogen is required for all of them. To be truly sustainable and fully decarbonised in the long run, green hydrogen and DAC pathways will have to be favoured over others.

## Shipping

- The FuelEU Maritime initiative – which was adopted in July 2023 - calls for an 80% reduction in the greenhouse gas intensity of fuels used by the shipping sector by 2050. This is not in line with the Paris Agreement, and with the new strategy from the International Maritime Organization (IMO) striving for a 30% reduction in emissions by 2030, 80% by 2040 and net zero in 2050, the EU now lags behind the IMO and will need to increase its ambition quickly.
- The FuelEU Maritime regulation includes a 2% renewable fuels usage target by 2034 of synthetic fuels, including hydrogen-derived fuels[11], if synthetic fuels amount to less than 1% in the fuel mix in 2031.
- In the UK, there are no hard targets at all for shipping decarbonisation. The UK government is only looking to impose regulation on the domestic – not international – shipping sector. This is unlikely to lead to the support for green hydrogen and DAC that the sector needs.

The below graphic shows the various fuel pathways for shipping. As with aviation, hydrogen is required for all of them. To be truly sustainable and fully decarbonised in the long run, green hydrogen and DAC pathways will have to be favoured over others.




In summary, the EU and UK polices above are currently agnostic about the source of hydrogen or $CO_2$ production pathways. Existing legislation targets lower carbon emissions without doing anything to truly support or drive the investment in or development of the lowest carbon emissions technologies, namely green hydrogen or DAC. This policy gap must be filled if there is to be any hope of meeting the Paris Agreement temperature goals.

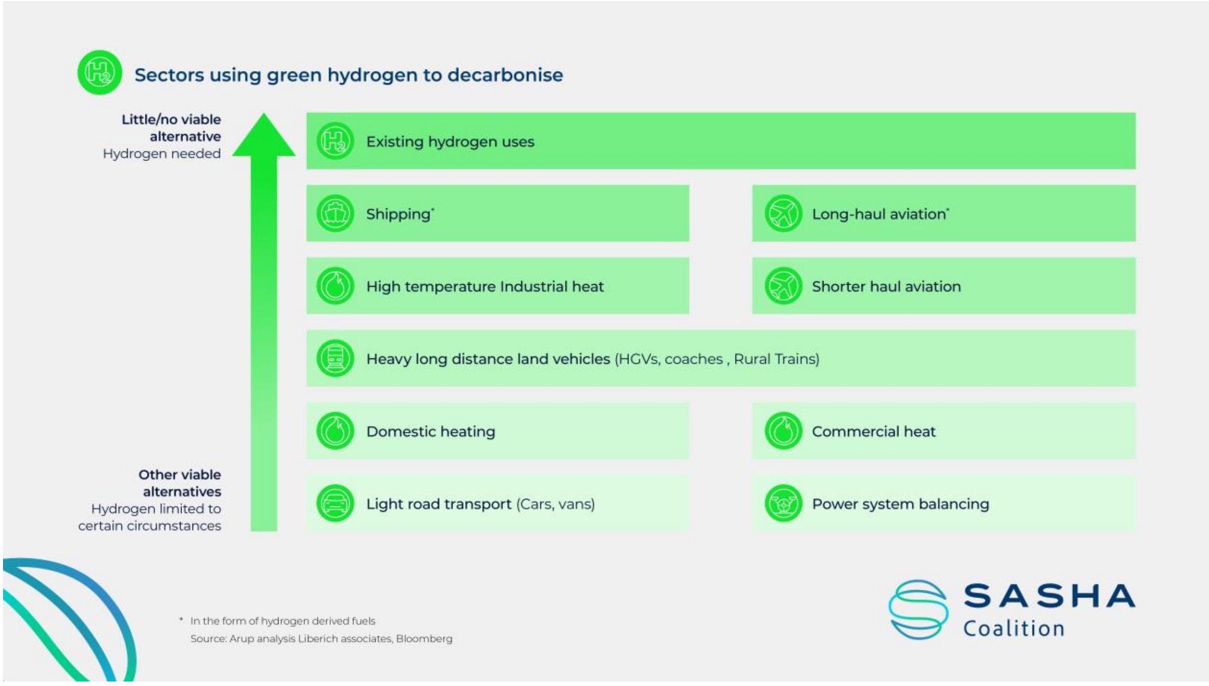
[11] The EU uses the term Renewable Fuels of a Non-Biological Origin or RFNBOs.

**Recommendations to address the shipping and aviation policy gap**

- Implement stringent sectoral emission reduction targets for both shipping and aviation that are aligned with a Paris Agreement-compatible trajectory.
- Recognise the long-term role that green hydrogen and DAC will play in sectors without other decarbonisation options, like shipping and aviation.
- Put in place mechanisms to incentivise the use of fuels with the greatest potential to reduce full lifecycle emissions over those with less emission reduction potential.
- Adopt ambitious mandates for the use of green hydrogen and green hydrogen-derived fuels to drive demand, and therefore supply.

## Green Hydrogen Policy Gap

In addition to the lack of coherent policy driving the decarbonisation of the aviation and shipping sectors, it is clear there is a wider policy gap on green hydrogen. The graphic below sets out some of the different sectors that also see hydrogen as a potential pathway to decarbonise. However, some of these sectors have other potential decarbonisation options, unlike aviation and shipping. Meanwhile, there is not enough green hydrogen available to meet the goals of the Paris Agreement across all of these sectors.[12] Agora-Energiewende has pointed out that unless hydrogen use is carefully prioritised, the EU will have to import much of its need. Proper consideration of the use of hydrogen is therefore key. [13]




[12] Odenweller et al., 2022, Probabilistic feasibility space of scaling up green hydrogen supply.
[13] Agora Energiewende, 2023, Breaking free from fossil gas: A new path to a climate neutral Europe.

A recent report found that aviation alone might need "9% of 224 Exajoules[14] global (renewable) electricity and 30% of available 50 Exajoules biomass, respectively."[15] If green hydrogen and biomass goes to sectors that have other potential decarbonisation pathways, the ultimate result will be that even more renewable electricity and biomass will be needed for the decarbonisation of the whole economy.

While it can seem as if there is a new hydrogen project being announced every day, collectively they do not add up to a future adequate hydrogen supply. While the theoretical production potential for green hydrogen is almost unlimited in terms of renewable energy (though availability of fresh water could prove the most limiting factor), to date there is not a pipeline of sufficient green hydrogen being produced.

The International Energy Agency (IEA) estimates that 70mn tonnes of clean hydrogen a year will need to be produced by 2030 under net zero goals. While analysis in the Financial Times demonstrates that currently announced projects take us to 30mn tonnes annually by 2030, those that have received a final investment decision make up only 2mn tonnes a year,[16] and indeed, the IEA published data showing that only 5% of global clean hydrogen projects by volume have received a final investment decision.[17] The IEA state that this is due to the lack of committed demand, without which it is very difficult to convince investors.[18] Indeed, there have been numerous reports that the EU will miss its green hydrogen targets due to a lack of regulatory clarity and resulting lack of clear demand.[19]

This stands in contrast to the fact that the decarbonisation of the shipping and aviation industries is set to be a billion-dollar industry, with hundreds of thousands of jobs being created in countries by 2050.[20] Globally, maritime decarbonisation alone is set to be a trillion-dollar opportunity, and investment in SAF will create or sustain an estimated 13.7 million jobs.[21]

### Recommendations to address the green hydrogen policy gap

- Strategies focussed on hydrogen demand must call for hydrogen to go only to those sectors, like shipping and aviation, that don't have alternative options for decarbonisation.
- Policymakers need to adopt a cross-departmental approach to hydrogen policy, ensuring transport stakeholders are involved in decision-making on future uses of green hydrogen and DAC, and that hydrogen strategies recognise its importance in decarbonising shipping and aviation.

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[14] An Exajoule is unit equal to $10^{18}$ joules used to measure energy.
[15] Becken et al., 2023, Implications of preferential access to land and clean energy for Sustainable Aviation Fuels.
[16] Financial Times Energy Source Newsletter, 2023, '"*Clean hydrogen projects need cash to list off',* Rachel Millars.
[17] Financial Times Energy Source Newsletter, 2023, '"*Clean hydrogen projects need cash to list off',* Rachel Millars.
[18] IEA, 2023, Tracking Clean Energy Progress 2023, Tracking Hydrogen.
[19] Financial Times, 2023, EU will miss its 'green' hydrogen targets, executives say.
[20] Business Up North, 2022, Sustainable Aviation Fuel Industry Could Bring Thousands Of Jobs To North West But Government Must Act Fast.
[21] ICF, 2021, Fuelling Net Zero: How the aviation industry can deploy sufficient sustainable aviation fuel to meet climate ambitions.

## Conclusion

This briefing has demonstrated the clear role that green hydrogen and DAC must play in decarbonising the shipping and aviation industries, and the associated risk of not putting in place the policies and regulations needed to ensure a secure supply of both for decarbonising those sectors.

Our research with Arup demonstrated that EU and UK policies and regulations should prioritise the use of hydrogen and carbon dioxide from DAC in applications where there is a lack of alternative routes to decarbonisation, including shipping and aviation. In considering the full lifecycle impacts, it is further clear that only green hydrogen – produced using renewable electricity – will produce truly sustainable fuels for these sectors, whether that be hydrogen, ammonia or methanol for shipping, or hydrogen and synthetic kerosene for aviation.

While we welcome the efforts made to date at the EU and UK level, legislation does not currently go far enough to incentivise the production of green hydrogen and DAC-derived fuels for shipping and aviation. Additionally, to overcome shipping and aviation's "Green Hydrogen Gap", there is a clear role for both stronger regulation and ambitious voluntary action from first-mover companies to ramp up demand for these fuels.

It is clear that green hydrogen production is lagging behind where it needs to be if the temperature goals of the Paris Agreement are to be met. There will also be significant demand from other industries for the fuels and feedstocks needed for shipping and aviation, with governments already starting to prioritise hydrogen for other sectors. If aviation and shipping are to have their required share of green hydrogen and carbon dioxide from DAC, both policymakers and industry leaders must act now to send a clear, unambiguous demand signal for the investment in and development of these fuels.

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