Written evidence from Carbon Engineering

Background on Carbon Engineering

Carbon Engineering is a Canadian clean energy company with global plans to capture CO_2 directly out of the atmosphere by deploying our technology at megatonne scale, working with a network of international partners. We capture excess CO_2 which can then be safely and securely stored deep underground offshore to accomplish Greenhouse Gas Removal (GGR). Alternatively, facilities can utilise clean hydrogen to convert our atmospheric CO_2 into sustainable aviation fuels. We're commercialising our proven technology. In North America we're building the world's largest Direct Air Capture with Carbon Storage (DACS) facility in partnership with 1pointFive, due online by 2025. In the UK we are working in partnership with Storegga, lead developers of the Acorn project, to develop a DACS facility in North East Scotland capable of capturing and removing 0.5-1 million tonnes of CO_2 per annum.

The IPCC *Global Warming of 1.5°C* report showed that every single 1.5°C scenario requires large-scale GGR and the UK *Sustainable Aviation Decarbonisation Roadmap: A Path to Net Zero* 2050 requires ultra low carbon synthetic fuels, at scale, to be rapidly deployed. It's time for the UK to take a leadership role in this growth sector by accelerating domestic deployment of DAC. However, to bring technology costs down and kick-start these industries in early markets like the UK, a mixture of policy levers will be required to provide a financeable market for permanent carbon removals and sustainable aviation fuels, and we welcome the opportunity to respond to this consultation.

For more information, please contact:

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1. **What contribution can operational efficiencies make to reduce emissions from aircraft / shipping vessels and over what timescale could these have an effect on emissions?**

Not answered

2. **How close are zero carbon fuels to commercialisation for aviation / shipping? How effective will the Jet Zero Council be in catalysing zero emissions technologies? What role should transitional fuels such as alternative hydrocarbon fuels play?**

General:

Carbon Engineering believes that "zero carbon fuels" should be interpreted to encompass any dense energy carrier which has very low or zero life-cycle carbon intensity. This definition would include the types of synthetic hydrocarbons which can be manufactured from captured atmospheric CO2 and renewable hydrogen, such as those produced from CE's own Air to Fuels™ process. Such a definition allows for a more flexible and rapid scale-up of clean fuels than what could be accomplished by confining the definition solely to energy carriers - such as hydrogen or ammonia - without carbon, as such fuels will require complete infrastructure turn-over at multiple points along the down-stream fuel supply and combustion chain which will require decades.

Fuels from air and permanent greenhouse gas removals (GGR), such as DACS, offer a feasible, available and drop-in compatible solution whilst enabling the energy transition. One unit of GGR from DACS is equivalent in Global Warming Potential (GWP) impact to one unit of *GHG emissions avoided* by switching from fossil fuels to sustainable fuels with lower carbon intensity.

When considering sustainable fuels, it is essential they are measured on their GHG reduction potential on a full well-to-wing/ship basis.

Please note that we consider the commercial-readiness of zero carbon fuels in our answer to Question 3.

Aviation: additional notes

DAC is a critical component of two key aviation decarbonisation pathways: carbon removals and synthetic fuels, the Climate Change Committee stated in their 6th Budget Carbon Report for aviation that DAC will be a key component in *enabling synthetic fuels to displace fossil fuels*.

Whilst we fully support the work of the Jet Zero Council to date, indeed we sit on a handful of sub-groups, we believe it is important to see synthetic fuels and carbon removals represented on the main Council too, otherwise it is not representative of the critical pathways to decarbonisation identified by the industry.

Shipping: additional notes

It is important to note that transitional fuels proposed by the industry such as LNG, ammonia, or methanol remain problematic with engines and auxiliary equipment requiring retrofitting, also they potentially cause significant health hazards and environmental risks if non-planned release events occur. Further, such fuels only lower the overall GHG emissions of the shipping sector if their manufacture, transport, and use results in low life-cycle carbon intensities. IE. Methanol derived from natural gas reforming will offer minimal GHG reduction potential as its production and combustion still result in the release of fossil carbon to the atmosphere.

As no synthetic fuel can completely decarbonise shipping, GGR will be necessary to remove the residual emissions from the sector. DACS is an essential part of the GGR toolkit as it is essentially unlimited from a feedstock perspective and does not compete with food and agriculture frameworks. It is cost competitive (even before the expected innovation gains) versus fuels being considered for decarbonisation on a levelised cost basis. For example, blue ammonia, one of the most affordable shipping fuels being considered for decarbonisation, we understand from conversations with experts, has a levelised abatement cost ranging from \$200/tCO_2 to \$400/tCO_2. Costs for DACS fall well within this range, with the technology being proven and in commercialisation with critically no feedstock limitations.

3. What new technologies are there to reduce emissions from aircraft / shipping vessels and how close to commercialisation are they?

General:

In Question 2 we have outlined that DAC is an essential part of the decarbonisation toolkit. Carbon Engineering is deploying large-scale DAC which will be a critical driver of both carbon removals and synthetic fuels.

The current status of development of CE DAC technology is:

- CE has been operating a prototype demonstration plant in British Columbia since 2015 that is capable of extracting approximately 350 tonnes per annum of CO_2 from the atmosphere.
- CE has now commissioned a 1,000 tonnes per annum validation plant also in British Columbia, which will be used for advanced development of DAC.
- In the United States, CE has entered into a license agreement with development company 1PointFive. The agreement is to develop up-to-1 million tonnes per annum commercial DACS plants in the Permian basin, with the target of 27 such plants within the next decade.
- Front end-engineering design of the first such plant is underway and construction is expected to start in 2022, with the plant becoming fully operational in late 2024.
- Over 65,000 engineering hours have been invested in the technology to date by our partners and main engineering partner, Worley. Also, an independent engineering report by new technology experts Leidos has been supplied to investors detailing the progress.
- All equipment and process materials have industrial precedents, and existing supply chains are fully established with capacity for DAC. CE's focus is now on advanced development for deployment at scale within different environments and geological locations.
- In the UK, CE is in partnership with Storegga, lead developers of the Acorn site in North East Scotland. The team is developing a plant to remove 0.5-1 million tonnes of CO_2 p.a. This will

be the first industrial DACS plant in the UK with a slated start date targeting 2026 for full operation. The project is currently in pre-FEED.

And CE's DAC for synthetic fuels:
- Since 2017 CE has had the capability of producing synthetic fuels from its pilot plant in British Columbia, Canada. As a finalist in Natural Resources Canada's (NRCan's) Sky's the limit competition, CE carried out a project to prove the AIR TO FUELS™ SAF technology and progress CE's SAF business. CE successfully completed the project in 2021, including producing and testing a SAF sample through test methods under ASTM D7566 and ASTM D1655. CE has submitted the final project deliverables to NRCan, and we are waiting for the announcement on the final competition winner in Q1 2022.
- In the UK, Carbon Engineering has partnered with LanzaTech UK in the DfT's Green Fuels Green Skies competition (GFGS) to investigate the feasibility of combining CE's DAC technology of capturing atmospheric CO2 and feeding it into LanzaTech's gas fermentation process to produce ultra low carbon jet fuel. This first of kind project will investigate the feasibility of a large scale commercial air-to-jet fuel production facility that will produce more than 100 million litres of Sustainable Air Fuel (SAF) per annum, here in the UK.

4. How should the Government's net zero aviation strategy support UK industry in the development and uptake of technologies, fuels and infrastructure to deliver net zero shipping and aviation?

General:

Creating and implementing the correct market leading strategy and subsequent policies early on is vitally important, as failure to do so would significantly endanger the industry's ability to invest, implement and improve the latest and emerging technologies that will empower and support the UK government's decarbonisation objectives and ambition.

Incentivising GGR for both aviation and shipping: In order to scale-up GGR, and particularly DACS solutions, at the rate required to deliver on the net zero targets for aviation and shipping, CE believes the following action is needed from the UK Government:

Publish a comprehensive GGR strategy ahead of COP26: This document should set specific science-based targets for GGR in addition to reductions, which will serve to increase investor long term confidence in the first plants to be developed in the UK.

Accelerate GGR business models: Government policy on incentivising point-source carbon capture and storage (CCS) technology and business models is progressing at pace, but discussions on incentivising GGR technologies and business models is still only at the early consultation phase. GGR incentivisation policy needs to run in parallel, rather than lag behind CCS policy development, so we call for a coherent GGR strategy setting out policy incentive proposals to commercialise the technology before the COP26 Conference in November.

Add DACS into the upcoming SAF mandate mechanism: Permanent carbon removals from DACS should be eligible for SAF mandate compliance and treated as equivalent to net reductions from fossil fuel switching to SAF. A comprehensive precedent has been set by California's LCFS, which includes DACS, whereby projects can directly generate credits so long as they comply with the quantification methodology and permanent removal protocols. This is a global policy blueprint that has effectively reduced lifecycle emissions from transport fuels, whilst also incentivising strategic technologies like DACS. It allows for flexibility to meet targets as fuels made from all feedstocks and via all conversion methods are eligible, but participate on the basis of stringent life-cycle assessment which accurately measures their net contribution of emissions to/from the atmosphere.

Incentivising sustainable aviation fuels

We believe the following critical measures would assist the UK in being a globally competitive supplier of SAF, with SAF availability and subsequent pricing supporting the uptake in SAF usage in with this consultation:

1. A SAF price support mechanism (e.g. CfD) that supports the financing of SAF plants, due to investor confidence. The key elements of this are:
   - Fixed contract length and strike price (the price which the producer receives). This mechanism removes supply uncertainty in the market for UK produced SAF, and provides plant investment confidence in terms of revenue generation.
   - Carbon or other tradable credits for SAF customers – this could be construed as one of the biggest risks facing investment into SAF projects.
   - Price setting through administrative action / negotiation in the first round of SAF contracts (since the market is not mature enough to support an auction) – auctions will be appropriate later for a maturing SAF market that grows in line with consultation up-take scenarios.
   - Incentivisation based on well-to-wing carbon intensity (see further detail below). This would ensure a balanced perspective and outcome on feedstock/technology combinations that will quickly become of strategic importance to the UK.
   - A funding mechanism that is consistent with the SAF mandate and designed so as to minimise carbon leakage throughout the supply chain and production of SAF.

2. Finance made available for first-of-a-kind projects through the UK Infrastructure Bank. Support in the form of e.g. equity, debt or loan guarantees has been demonstrated to stimulate private sector investment, most notably in the US.

3. Continued international engagement through ICAO and with the EU, to maximise policy alignment, minimise the risk of carbon leakage and disadvantage to UK industry, and help to achieve a global plan for aviation in line with science-based targets and emerging technology / operational efficiency.

4. A mandate for SAF based on GHG reduction; this should ensure that the long-term market is aligned with the ultimate objective. It is essential GHG reduction is based on the full picture of climate impact, i.e. a well-to-wing basis (please see below).

5. Representation of synthetic fuel players on the Jet Zero Council to ensure attention is both on the near term (waste-based) and the long term (synthetic fuels)

CE encourages the UK government to look at proven examples from other countries who have proactively supported and progressed SAF development to help accelerate their countries decarbonisation progress. Specifically, the USA has taken and is considering multiple fundamental significant steps to reduce the cost of SAF to airlines, bringing it closer to the cost of fossil jet fuel, and significantly boosting the US SAF market position. For example, several features of the US policy landscape make it an attractive market environment for SAF investment and this has led to the construction of early commercial SAF projects. The US SAF policy features include:

- A robust traded market in GHG reductions within the California Low Carbon Fuel Standard. This precipitates predictable volume demand, several years' of trading history, and a realistic pricing structure several times that of UK ETS ($185/T CO_{2e}, as of 2-8 August 2021). Note that a similar program exists in Oregon, and that state-level LCFS programs are subject of active legislation in Washington, New Mexico, and New York, among others.
- Loan guarantees that provide investment security are provided through the Department of Energy (DoE), these loans do not require equal risk from commercial lenders, thus early de-risking of projects has stimulated the market.
- Substantial federal grants up to $70M per project, have been provided.
- The potential eligibility of carbon capture projects for tax exempt bonds with favourable interest rates. are provided to developers of industry leading SAF production projects.
- 45Q tax credits for Carbon Capture, Utilization, and Storage projects.
- The proposed SAF Blender's Tax Credit of an additional $1.50-$2.00 per gallon (30-40p per litre) of produced SAF.
- Direct financial support indicated in the August 2021 U.S. Senate Infrastructure Bill included authorization of $3.5 B USD for "regional DAC hubs", and $7 B USD for "clean hydrogen hubs", both of which are anticipated to impact the US market for synthetic SAF.

Well-t0-wing accounting

The intention of the UK government is to reduce greenhouse gas (GHG) emissions from transportation. To achieve that goal, fuels made from all feedstocks and via all conversion methodologies should be eligible, but should participate on the basis of stringent life-cycle assessment which accurately measures their net physical contribution of GHGs to/from the atmosphere.

All fuel production pathways and feedstocks should be eligible for participation in the SAF mandate and any future mechanism designed to decarbonise transportation. But since not all feedstocks have the same potential to deliver GHG savings, a performance-based framework should be used to implement them under the mandate RTFO. This framework should be based on the full lifecycle accounting of GHG emissions generated during the production and usage of fuels - importantly - including emissions incurred during the production and acquisition of feedstocks.

It is crucial that the accounting method chosen reflects the physical mass flow of GHG emissions to/from the atmosphere for the entire pathway, i.e. beginning with carbon feedstock production to carbon release upon fuel combustion. Pathways that yield co-product(s) to fuels should use an allocation method to aggregate total emissions to air, and attribute them to the fuel and other product(s). For example, if waste gas is recovered from a facility that manufactures steel, and is then supplied for CO_2-to-fuel conversion, the life-cycle accounting methodology should aggregate all emissions associated with the production of steel (including upstream and downstream) and the emissions associated with conversion into fuel, refining and transport, and in-vehicle combustion, from mine to foundry, then onto SAF production.

The methodology chosen should then allocate the total-pool of GHG emissions to the steel product and the SAF fuel produced, either by mass, energy content (only applicable in use cases where the co-product is electricity rather than steel), or financial value. If this full-scope aggregation of emissions and co-product allocation is not performed, it can allow fuel producers to incorrectly claim that "avoided emissions" (measured with respect to a counterfactual scenario) from the flue stack lower their fuel carbon intensity, which is equivalent to leaving all GHG emissions in the un-regulated product (steel) with the lower carbon pricing regime, and claiming all the benefit in the more tightly regulated product (SAF). This is equivalent to "carbon leakage", which the UK and many other nations are working to avoid, where benefits are claimed in high-value regulated markets and emissions are "shuffled away" into unregulated sectors. Put simply, counting 'avoided emissions' in calculating fuel carbon intensity can be gamed, whereas allocation of full life-cycle emissions cannot. CE strongly encourages reviewers to be cognizant of this distinction, as newer regulated markets are expected to incorporate "attributional" instead of "displacement" life-cycle carbon accounting, and pre-existing markets are expected to transition accordingly, at the recommendation of the academic LCA community. Support for fuels that only achieve low carbon intensities on a "displacement" basis could leave such fuels, and the systems they thrive within, open to criticism and/or financial risk if regulated markets transition to "attribution" LCA accounting as expected.

Another important consideration is to evaluate the counterfactual analysis of the UKs CO_2 feedstock. Is there an alternate use case for the CO_2 that enables higher GHG savings than the fuels pathway? With the UK committing to two CCUS clusters by the mid-2020s and four by 2030, the leading edge to curtail industrial CO_2 emissions will soon become carbon capture and storage. Permanent storage of these "non regulated" emissions would allow for higher GHG savings by returning these fossil fuel derived CO_2 emissions to geologic formations, whereas the fuel route would instead lead to a net addition of these fossil derived CO_2 industrial emissions to the atmosphere.

5. What is the most equitable way to reduce aircraft passenger numbers (e.g. reforming air passenger duty and taxes, frequent flyer levies, bans on domestic flights where trains are available, restrictions on airport capacity)? Are there any policy mechanisms that could reduce our reliance on shipping?

Government's desire to reduce the reliance on shipping and aircraft passenger numbers is commendable. Naturally, this direction has to have the balance of measuring the risk to the UK's economy and the public acceptance of potential travel restrictions. Market forces operating within a strong government framework that underpins the net zero aims of government would be the logical direction to undertake.

It is important that potential government levies operate on a level playing field. With levy generation scaled upon the lifecycle of GHG emissions collected, by organisations and individual end users of transport. Also, recipients of GHG levies should have the ability to offset their account via certifiable carbon removal credits. To ensure organisations or individuals don't usurp the process, the ability to use carbon removal credits should be limited per annum, and scaled to ensure an equitable outcome based on circumstantial factors of both organisations and individuals.

The above direction would encourage a circular economy, with levies obtained then being deployed via incentivisation policy to expedite the green fuel economy that the government requires to obtain the net zero targets set out.

6. What further action is needed by the International Civil Aviation Organization and International Maritime Organization to drive emissions reductions? What can the UK Government do to drive international action on emissions?

Aviation:

The International Civil Aviation Organisation should continue to push for a global agreement on a sympathetic global market based measure (GMBM) that encompasses technology deployment, operational effectiveness, infrastructural impact and places annual carbon emissions limits on aviation companies. This approach enables a platform of encouragement to the industry to innovate, invest and adopt low carbon fuels. The current ICAO targets and policies are lacking on two fronts

- There is no net zero by 2050 target
- CORSIA in its current form will not be sufficient to drive demand for carbon removals - the implied carbon price is circa.$5-30 per tonne of CO2 and the quality threshold is not sufficient to drive buyers towards high quality carbon removals. As members of Sustainable Aviation, we find the group broadly aligned to the Oxford net zero principles, i.e. 100% of offsetting by 2050 must be through permanent removals, as shown by diagram 1 below:

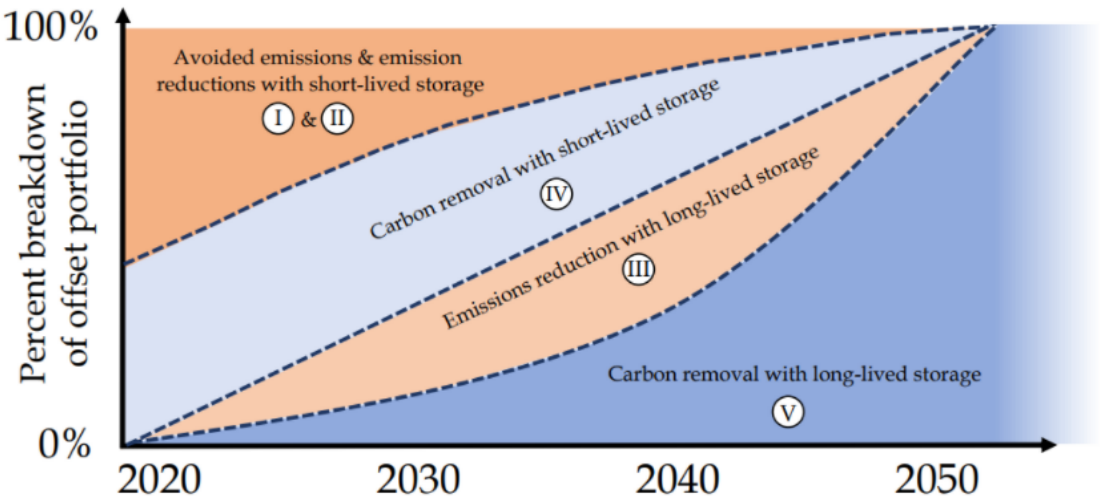

Diagram 1: Emissions Offsetting Portfolio 2020 to 2050 (Reference: Oxford Principles for Net Zero Aligned Carbon Offsetting 2020).

We believe that there is a *significant role for the DfT* in mandating this trajectory and influencing ICAO to adopt similar policy through CORSIA. We believe a pragmatic target could be 10% of offsets from permanent removals by 2030, 40% by 2040 and 100% by 2050.

Shipping:

The IMO must create a framework to account for emissions in the shipping industry. The lack of jurisdiction and accountability for ownership of vessels hinders the sector's ability to decarbonise. Energy efficiency requirements, set by the IMO under its 2018 initial strategy, have a minimal impact on CO_2 reduction, with our estimates envisaging an 1% reduction by 2050. The IMO should push for obligations, such as the LCFS, to include shipping emissions and formulate a CORSIA equivalent for the industry. Emission reductions should focus on supporting the uptake of clean and scalable fuels from non-biological origins to meet reduction targets.

The UK Government set out its maritime decarbonisation strategy in 2019 under the Clean Maritime Plan. The strategy could act as a standard that the industry could take a national, rather than an international, approach to decarbonisation.

7. How effective will the global offsetting scheme for international airlines (ICAO's CORSIA) and the UK and EU ETS be at stimulating technology improvement and/ or behaviour change to reduce emissions from aviation / shipping?

CE believes that, due to the high reliance on dense energy carriers and the high costs of infrastructure turn-over unique to the aviation and shipping sectors, permanent physical carbon removal will be critical to achieving decarbonization targets at viable costs. Today's pathways to achieve permanent physical carbon removal with high integrity (BECCS, DACCS, and some forms of engineered weathering) typically have costs far in excess of forecast credit prices within ICAO CORSIA and the UK-ETS.

The aviation and shipping sectors cannot afford to wait for greater stringency in CORSIA and UK-ETS to develop over coming years in order to create a sufficient market price to enable large-scale investment in carbon removal projects. They must instead pursue and accomplish two goals at once:

1. Encourage emissions reductions at lowest cost through market-based mechanisms (such as ICAO CORSIA and UK-ETS), and;
2. Enable the deployment and scale-up of carbon removal facilities - in the 2020's - to develop a sufficient industrial base such that carbon removal can tackle the "residual emissions" which will persist in aviation and shipping.

Achieving both goals 1 and 2 will require committed policy support beyond what exists in today's landscape and what will exist in ICAO CORSIA and the UK-ETS in coming years.
Such augmented support could take the form of:

- Targeted Government action to support early deployment (e.g. Direct procurement).
- "Enhanced" incorporation in existing policies and markets (e.g. Inclusion in high-value RTFO development fuel category, inclusion in UK ETS with a temporary CfD mechanism).
- Implementation of new policy to promote GGR in addition to measures and markets targeted at reduction (e.g. Carbon take-back).

The primary goal of these Targeted and Enhanced measures is to provide sufficient value and revenue certainty to early plants so developers can raise capital to deploy at scale
It is then expected that as GGR scales and costs come down, and as the broader economy moves to addressing more difficult sources of emissions, that "enhanced" measures for GGR will no longer be needed. (i.e. the shadow price of carbon exceeds the cost of GGR.)

Further to these dedicated support mechanisms, we also address shortcomings with ICAO CORSIA and UK-ETS from the perspective of a carbon removal provider.

Aviation - CORSIA:

The current ICAO targets and policies are lacking on two fronts

- There is no net zero by 2050 target.
- CORSIA in its current form will not be sufficient to drive demand for carbon removals - the implied carbon price is circa.$5-30 per tonne of CO2 and the quality threshold is not sufficient to drive buyers towards high quality carbon removals. As members of Sustainable Aviation, we find the group broadly aligned to the Oxford net zero principles, i.e. 100% of offsetting by 2050 must be through permanent removals (see diagram 1). We believe that there is a role for the DfT in mandating this trajectory and influencing ICAO to adopt similar policy through CORSIA. We believe a pragmatic target could be 10% of offsets from permanent removals by 2025, 25% by 2035 and 100% by 2050.

ETS:

Broad 'schemes such as the UK ETS which include easier to decarbonise industries such as power will generate credits from cheaper removal and avoidance products. Prices in the ETS *will not be high enough* in the near-term to support permanent GGR without intervention (see diagram 2).

It should be noted that the EU ETS (and the similar California Cap & Trade) to date has not been successful in incentivising GGR. These are broad schemes which rightly include easier to decarbonise sectors such as power where credits can be generated by reduction and avoidance at source with mature and cost-effective substitutes. As a result, credit prices are typically lower than what is required to motivate most types of GGR today.

The ETS could be used with specific carve outs for removals, targeted as specific hard to decarbonise sectors such as aviation and shipping, or with a CfD in place until the shadow carbon price meets with the cost of permanent removals. The ETS is not suitable for land-based removals which do not offer the permanence nor MRV credentials of engineered solutions, and are generally lower cost today than reductions and could therefore disincentivise highly effective reduction pathways. However, the higher cost of permanent removals means ETS is well aligned to this principle.

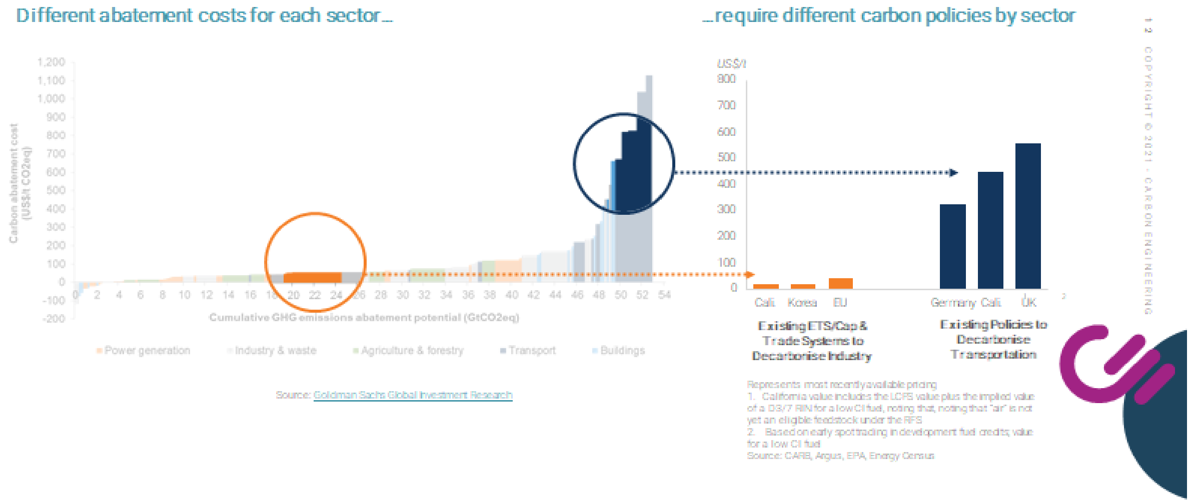

Diagram 2: DACS can cap the cost of decarbonisation in hard to abate sectors such as aviation (Source: Goldman Sachs Carbonomics, reproduced and commentary provided by Carbon Engineering)

8. How should the UK define its ownership of international aviation and shipping emissions (i.e. arrivals, departures or both) in order to include them in legislative targets?

Not answered

September 2021