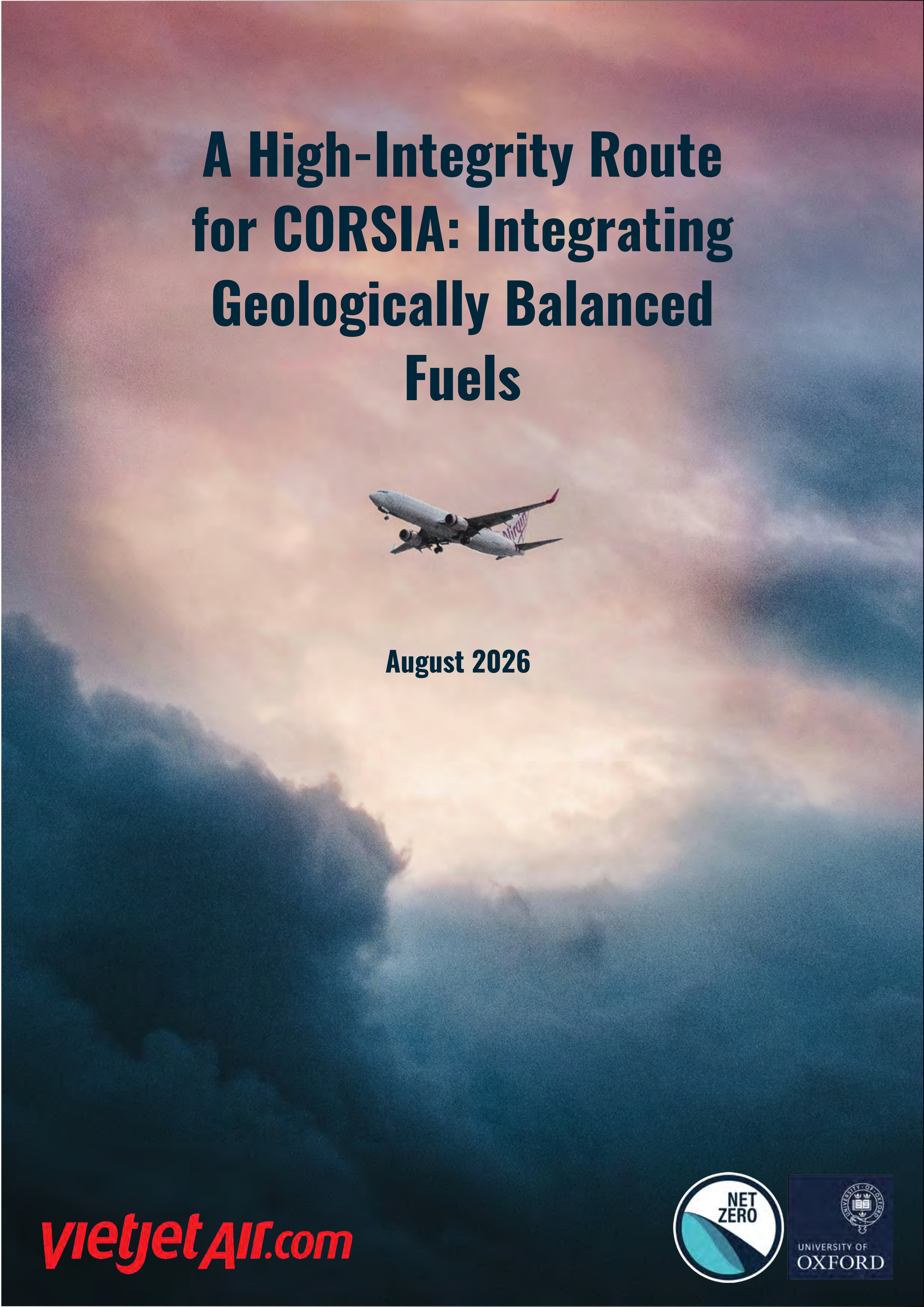

A High-Integrity Route for CORSIA: Integrating Geologically Balanced Fuels

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Summary

- Criticism of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) largely stems from its reliance on downstream offsetting markets that lie outside its direct oversight.
- Geologically Balanced Fuels (GBFs) – kerosene bundled with geological CO_2 storage units and accounted for at the point of fuel supply – could strengthen the integrity and effectiveness of CORSIA.
- GBFs can be treated as either a distinct CORSIA Eligible Fuel category, or as an offsetting instrument under the Eligible Emissions Units framework. We argue that the GBF product is most complementary and additional to existing approaches when treated as an eligible fuel.
- GBFs are intended to complement, rather than replace, Sustainable Aviation Fuels and Lower Carbon Aviation Fuels.
- Although the current CORSIA framework does not yet accommodate GBFs, it already contains important institutional building blocks, including recognition of fossil-derived eligible fuels and governance rules for carbon capture and storage projects, including a Reserve Inventory Account.
- Integrating GBFs into CORSIA would require three core amendments: legal recognition of GBFs, a methodology for accounting for GBFs, and GBF-specific sustainability criteria.
- The most important technical reform would fall within the CORSIA Methodology for Calculating Actual Life Cycle Emissions Values, through the addition of a GBF-specific chapter covering applicability and underlying fuel value, allocation of qualifying geological storage to a GBF batch, calculation of the GBF actual value, exclusivity and non-overlap, and Sustainability Certification Scheme verification of the GBF methodology.

1 Defining Geologically Balanced Fuels

International aviation is likely to remain dependent on kerosene, given the constrained supply of alternative fuels. The resulting fossil carbon dioxide (CO_2) emissions are long-lived in the atmosphere, and their mitigation requires an equivalent quantity of CO_2 to be permanently returned to geological storage, according to Geological Net Zero [1]. In this context, **Geologically Balanced Fuels (GBFs)** are proposed as a supply-side approach [2]. GBFs can be defined as kerosene supplied along with geological CO_2 storage units, with every unit matching the emissions from each tonne of kerosene, accounted for at the point of supply. That is, a GBF product comprises two components, as outlined in Jiang *et al.* (2026, in review) [3] and represented in Figure 1: (i) physical fuel delivery (black arrows), which follows the conventional supply chain, requiring no engineering modifications or additional certification processes that alternative drop-in fuels typically require; and (ii) corresponding climate attributes (green arrows) in the form of geological CO_2 storage units, unbundled from the physical delivery and tracked separately along the supply chain.

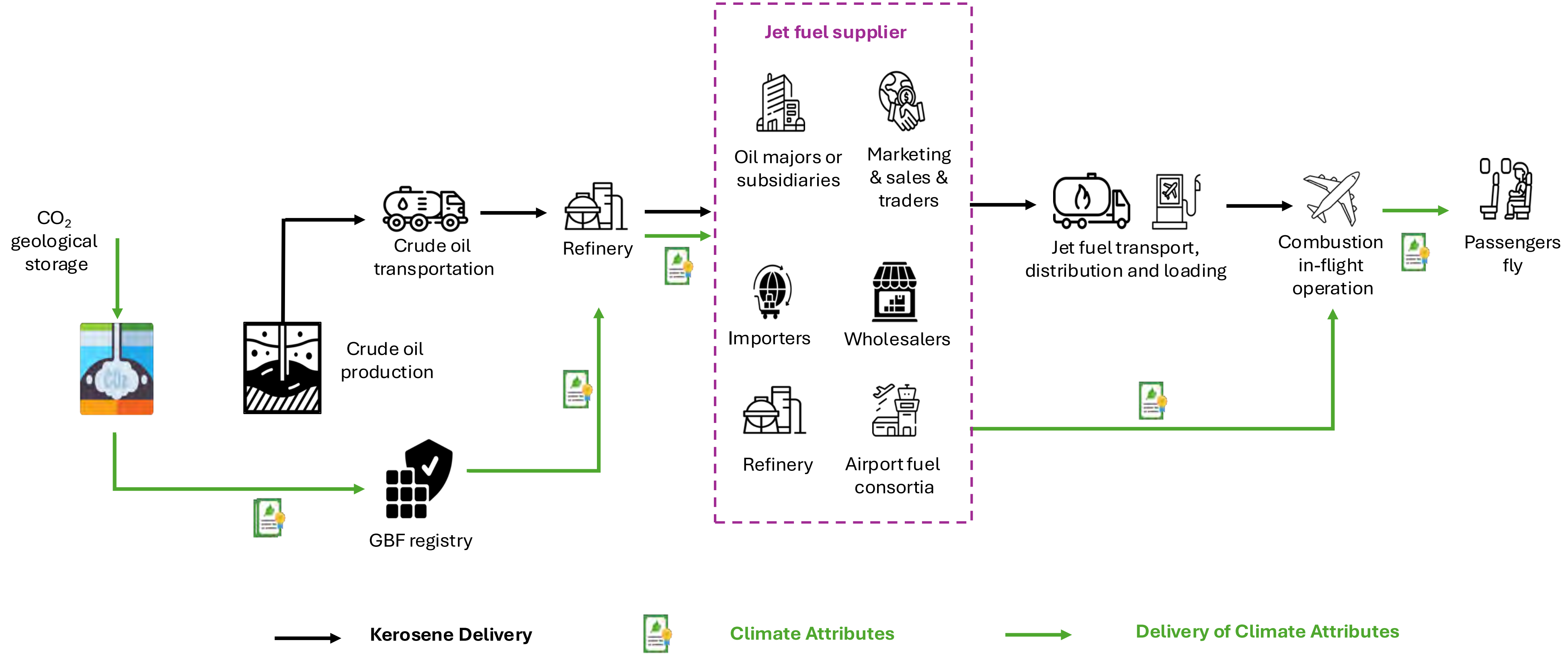


Figure 1: Schematic demonstration of the combining of kerosene and the climate attribute to produce a GBF product. In parallel, climate attributes are issued by geological CO_2 storage operators, verified through an accredited registry, and then bundled by upstream suppliers at the point of sale.When airlines procure GBFs, they receive both the physical fuel and the matched climate attributes. Figure by the authors.

The central design question for GBFs concerns this climate attribute: which emissions are covered, and how the climate attribute's certificate is generated. In Jiang *et al.* (2026, in review) the GBF's emissions scope is set through a series of linked design choices that align with the scientific evidence base while remaining adaptable to jurisdiction-specific policy requirements. Key parameters include [3]:

- Emission category: CO_2-only or including non-CO_2;
- Boundaries: tank-to-wake or well-to-wake emissions;
- Time dimension: a rising fraction of fuel emissions, current fuel emissions or current + legacy emissions; and
- Share of emissions offset: partial or 100% offset.

The mitigation potential of GBFs depends on two technological choices: the CO_2 source and sink used to generate the geological balance certificate (climate attributes in Figure 1). Eligible CO_2 sources include point source (PS) capture (from fossil fuel use or bioenergy) and Direct Air Capture (DAC). The sink should align with the like-for-like principle, whereby the durability of storage corresponds to the longevity of the climate impact being offset [4], including saline aquifers or disused oil and gas reservoirs.

The key differentiator between these options is the origin of the captured CO_2 and its implications for net emissions (Figure 2). With point source (PS) capture, one tonne of CO_2 is captured from an industrial facility and stored, offsetting one tonne released during fuel combustion, resulting in a 50% emissions reduction across the combined PS operator and airline system, rather than net-zero aviation in isolation. By contrast, both bioenergy with carbon capture and storage (BECCS) and DAC pathways remove CO_2 directly from the atmosphere, enabling the emissions from fuel combustion to be fully offset, and allowing aviation net zero to be achieved independent of other sectors. In all three cases, the precise claim available to the airline and/or PS operator depends on the design of the certification scheme and the market structure in which certificates are traded, with rules needed on the chain of ownership for claims in any cross-sector transactions.

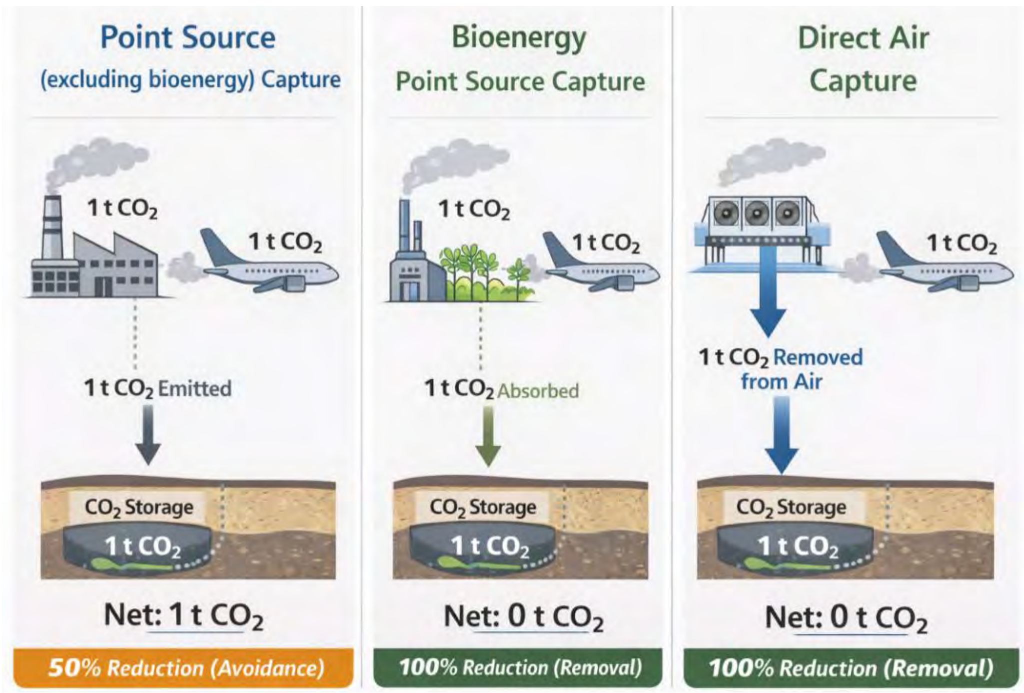


Figure 2: Climate implications of CO_2 origin for GBF-linked geological storage. PS capture provides a partial mitigation outcome because aviation combustion emissions remain in the atmosphere, whereas bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS) can deliver an

atmospheric-origin removal that can fully balance combustion emissions when stored permanently. Figure by the authors.

2 Constraints in the current CORSIA architecture

The international aviation sector was excluded from the initial Nationally Determined Contributions of the Paris Agreement due to its transboundary nature. To fill this gap, the International Civil Aviation Organization (ICAO) adopted the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016. Its implementation phases and current status are summarised in Figure 3. The scheme, in its current design, sets a limit for global aviation emissions to continue (2019 levels), and requires aircraft operators to compensate for emissions growth from 2020 onward beyond a defined baseline (currently set at 85% of the 2019 level, Figure 3).

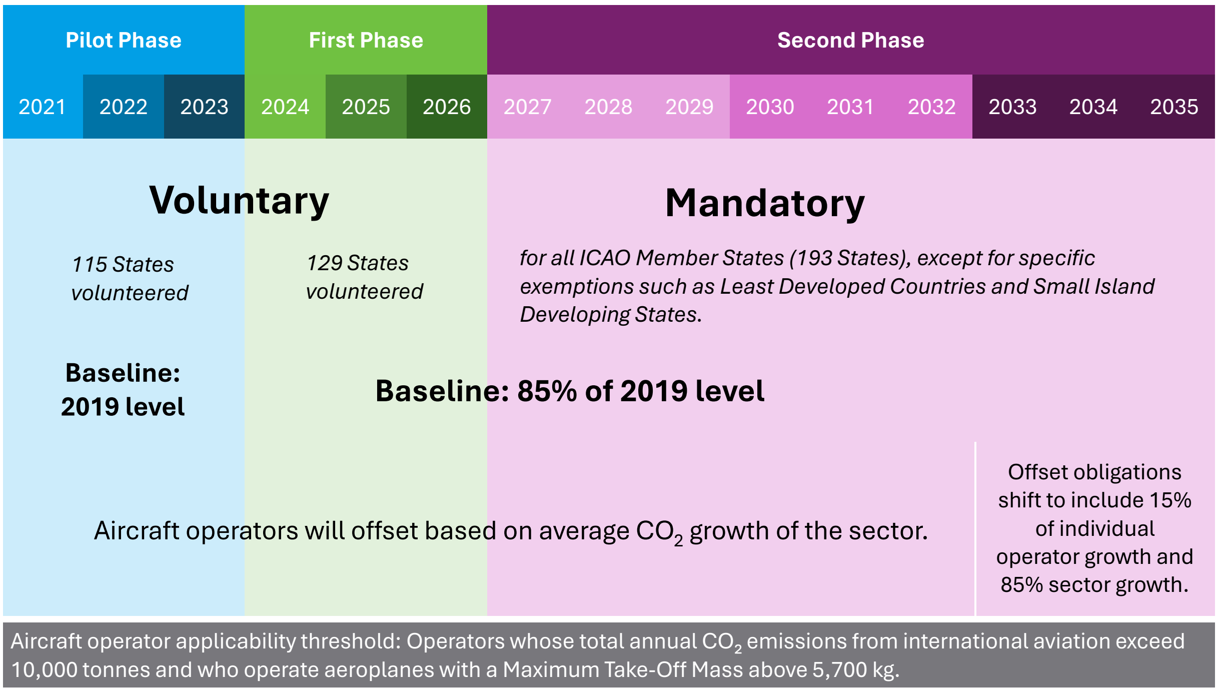


Figure 3: Implementation phases and requirements of CORSIA. CORSIA has evolved in three key respects: participation has shifted from voluntary to mandatory (with specified exemptions); the emissions baseline has tightened from 2019 levels to 85% of 2019 levels; and the offsetting allocation method will transition from a sectoral growth approach to a blended approach from 2033. Figure by the authors.

Under CORSIA, the point of compliance remains airline-centred and predominantly downstream. Aeroplane operators first incur *Offsetting Requirements*, which may then be reduced through claims for emissions reductions from the use of *CORSIA Eligible Fuels* (including Sustainable Aviation Fuels(SAF), and Lower Carbon Aviation Fuels (LCAF)) [5]. Any remaining final offsetting requirement must subsequently be met through the purchase and cancellation of an equivalent quantity of *CORSIA Eligible Emissions Units* [5].

CORSIA has been criticised on a number of grounds, including:

- **A lack of integrity.** Current eligible offsets, largely nature-based solutions alongside energy efficiency and renewable energy projects [6-8], have long been criticised for overstating emissions reductions [9-11], for their vulnerability to climate risks [12], and for their potential to generate serious social and environmental harms [13-15].
- **A shortage of Eligible Emissions Units.** ICAO has identified a shortfall of approximately 95–115 million eligible units during the first phase [16], driven largely by delays in host

country issuance of Letters of Authorization (LoAs) [17] – a bottleneck unlikely to ease given the unresolved governance challenges surrounding Article 6.2, including reporting inconsistencies [18].

- **A constrained supply of Eligible Fuels.** ICAO has indicated that eligible fuel use could deliver only up to 20 Mt CO_2 in emissions reductions, and no details have been announced regarding the availability of eligible LCAF for CORSIA purposes [19].
- **A risk of perverse incentives.** CORSIA structurally favours cheap emission unit compliance over investment in eligible fuels [19-21], creating a risk of temporary offset effects [19] and potentially incentivising emissions increases among participant countries [19, 20].

3 GBF as a complementary supply-side route

The foregoing weaknesses are not incidental. They follow directly from CORSIA's reliance on downstream offsetting markets that lie outside its direct oversight. This raises a key policy question: should offsetting responsibility be shared more broadly across the fuel supply chain, and if so, what instruments could support this effort?

Several jurisdictions show that upstream governance can work. For example, the New Zealand Emissions Trading Scheme (NZ ETS) places obligations on liquid fossil fuel importers and suppliers and allows eligible removal activities, including "storing carbon dioxide after capture"[22], to receive New Zealand Units (NZUs), which can be used for compliance, although this pathway does not appear to have been used in practice.

CORSIA could incorporate a supply-side offsetting model, and GBFs offer one way to do it. By linking continued kerosene supply to durable carbon offsets, GBFs are well aligned with the principle of Extended Producer Responsibility, under which many jurisdictions interpret "producer" to include the supplier that first places a product on the national market (whether domestically manufactured or imported) [23, 24].

The implementation characteristics of geological offsetting reinforce this. High capital intensity, strong regulatory dependence, long-term storage liability, and a small number of large-scale projects all point toward fuel suppliers as a more appropriate compliance actor than downstream actors (based on the Polluter Pays Principle). As subsidiaries of integrated oil and gas producers, suppliers have access to the capital, technical capacity and expertise to deliver geological storage at scale [25], and operate within established licensing, reporting and audit frameworks. They have the greatest single incentive to develop the long-term market for "net-zero-aligned fossil fuels", and they occupy a central commercial position in the jet fuel value chain, enabling them to transmit a clear demand signal upstream for storage services. Neither airlines nor passengers are well placed to negotiate and manage geological storage contracts themselves.

This model is already emerging in aviation. Shell Aviation [25], World Fuel Services [26], and AEG Fuels [27] have begun pairing fuel sales with carbon credits, though currently limited to less durable, nature-based offsets. GBFs extend this to geological offsetting, formalising them as a compliance-grade product attribute at the point of supply. The cost of permanent CO_2 storage is thereby internalised in the fuel price, so that the price reflects the environmental cost of the emissions. In doing so, GBFs combine the "producer pays" and "polluter pays" principles in a single instrument.

This also positions GBFs to address the weaknesses in CORSIA identified above. On integrity: geological storage is permanent, physically verifiable [26, 27] and governed by established MRV protocols including ISO 27914:2017 [30], which are more durable than biological offsets and less likely to generate the perverse incentives associated with temporary offsetting [21]. On supply: geological storage potential exists across many jurisdictions [28, 29], indicating compliance units can be generated and issued within the same national or regional framework, thereby reducing dependence on cross-border transfers, corresponding adjustments and the LoA process under Article 6.2.

4 Cost implications of GBFs with synthetic SAF

Whether GBFs can fulfil the decarbonisation role in practice depends in part on the cost competitiveness relative to alternative low-carbon fuel pathways. Conventional SAF pathways such as Hydroprocessed Esters and Fatty Acids (HEFA) and bio-SAF pathways remain important but limited in scale because of feedstock constraints, land-use risks and other sustainability risks [30]. This brief therefore compares GBFs with synthetic fuel (eSAF), as both can credibly be viewed as potentially scalable, net zero-aligned fuel products for long-term aviation decarbonisation, and are thus the most decision-relevant comparators for mid-century aviation.

Cost projections [31] suggest GBFs can reach within a factor of two of current kerosene prices (including PS- and DAC-based GBFs, and eSAF combining PS or DAC CO_2 with green or blue hydrogen, Figure 4). PS-based GBFs offer the nearest-term cost parity with fossil kerosene, though with more limited cost reduction over time, as the underlying technology is relatively mature. DAC-based routes, whether for GBFs or eSAF, start from a higher cost base, because the technology is less mature commercially, although the cost declines over time, bringing the ranges closer together by 2050 (purple range in Panel A). DAC-based products remain more expensive on average than PS-based products over the period assessed. However, they will be necessary for any legitimate claim that aviation has reached net zero.

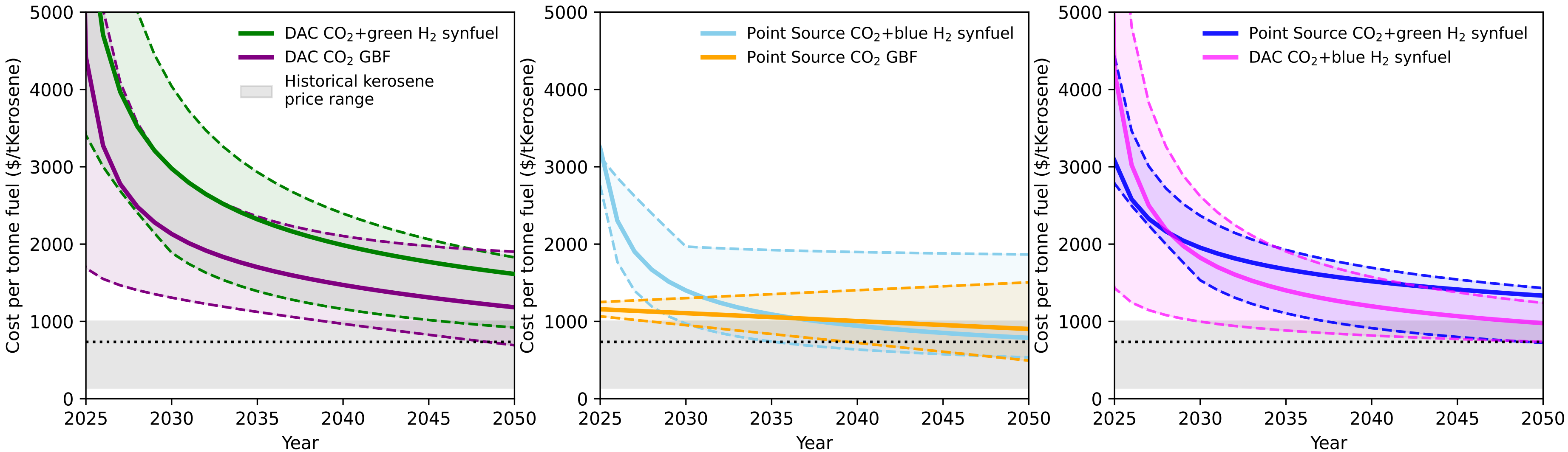


Figure 4: Cost projections for novel fuel types compared to conventional kerosene (grey, \$140–1,015/tonne; present-day value \$735/tonne, black dotted line). Panel A: DAC CO_2-GBF vs. DAC CO_2 + green H_2 eSAF. Panel B: PS CO_2-GBF vs. PS CO_2 + blue H_2 eSAF. Panel C: PS CO_2 + green H_2 eSAF vs. DAC CO_2 + blue H_2 eSAF. Figure by the authors.

By mid-century, GBFs and eSAF could be cost-comparable (Figure 4), yet the relative ranking is sensitive to fossil kerosene prices. At the upper end of historical kerosene price ranges, eSAF remains competitive; at average or lower prices, GBFs tend to be the lower-cost option. Several pathways could fall below the historical kerosene price ceiling by 2050, making the future price of conventional fuel itself a key variable in assessing competitiveness.

At net zero, both GBFs and eSAF converge on DAC, and the cost differences between them reflect their other components. For eSAF, hydrogen is the dominant cost driver. Blue hydrogen configurations could fall below the historical kerosene price peak by mid-century, yet green hydrogen carries a persistent cost premium. Where policy restricts blue hydrogen use, eSAF scale-up will be slower and costs higher in the near term. If policy does allow blue hydrogen for eSAF production (particularly if also allowing PS CO_2 feedstocks), careful policy consideration will be needed to maintain the legitimacy of claims of net decarbonisation for such e-fuels. eSAF produced with blue hydrogen and PS-captured CO_2 is substantially more energy intensive than direct FT-synthesised[1] kerosene from natural gas.

For GBFs, a gradual shift from PS CO_2 to DAC CO_2 could keep costs broadly stable through to net zero, remaining below eSAF throughout [31]. Figure 5 illustrates this transition for both fuel types over 2025–2050: a PS-to-DAC GBF pathway (red line), a blue-to-green hydrogen eSAF pathway using PS CO_2 (blue line), and a green hydrogen eSAF pathway using PS CO_2 throughout (green line).

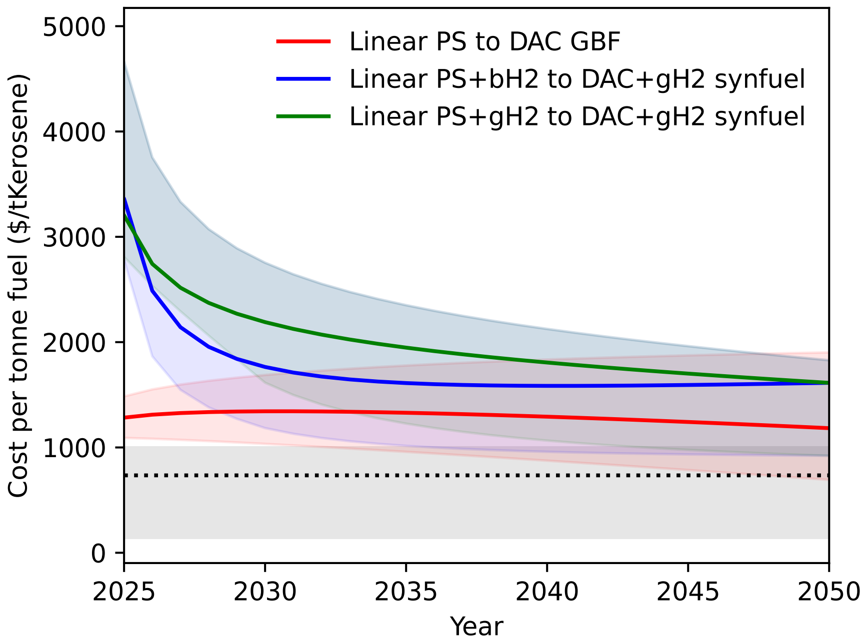


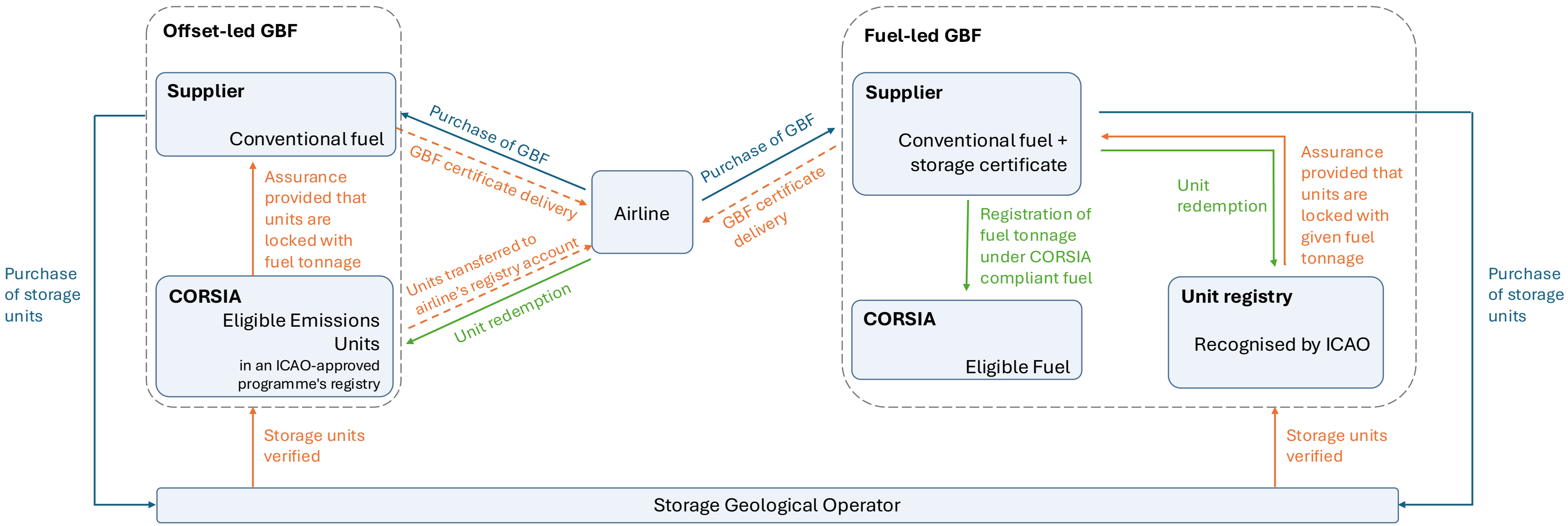
Figure 5: Blended fuel costs in comparison to historical conventional kerosene prices ($/tKerosene). Red: PS-to-DAC GBF, transitioning linearly by 2050. Blue: eSAF transitioning from PS CO_2 + blue H_2 to DAC CO_2 + green H_2 by 2050. Green: eSAF transitioning from PS CO_2 + green H_2 to DAC CO_2 + green H_2 by 2050. Figure by the authors.

1 Fischer-Tropsch-synthesised kerosene is produced by converting natural gas into a mixture of carbon monoxide and hydrogen (syngas). This gas mixture then undergoes the Fischer-Tropsch chemical process to build liquid hydrocarbon chains matching the properties of conventional aviation kerosene.

5 Pathways for Integrating GBFs into CORSIA

Consistent with current CORSIA requirements and drawing on the design choices introduced in Section 1, this brief frames GBFs as balancing current well-to-wake CO_2 associated with kerosene use. A key design choice is whether the GBF balances 100% of the fuel's embedded emissions, or partially balances them (to match equivalent partial reductions claims which are possible for SAFs under CORSIA-eligible fuels). Clearly, this offset fraction would have to scale up over time to cover 100% (or more) of emissions at net zero [2, 3]. Looking ahead, the definition of GBF could be tightened to incorporate non-CO_2 warming effects once they can be robustly quantified, or to address legacy emissions under more stringent climate objectives for international aviation.

Within CORSIA, GBFs could in principle be integrated through either of the scheme's two existing compliance channels: through Eligible Emissions Units (an offset-led route) – the climate benefit would be recognised as a separately governed compliance asset; or through the Eligible Fuel pathway (a fuel-led route) – GBFs would be recognised as part of a fuel-based compliance claim. The two routes are demonstrated in Figure 6.



Key Aspect	Offset-led GBF	Fuel-led GBF
Who holds live units	Supplier, airline	Supplier
Who completes final redemption action	Airline	Supplier
What the airline receives from the supplier	Physical fuel + live eligible units	Physical fuel + Proof of Redemption
Nature of airline obligation	Cancel units for CORSIA compliance	Uses Proof of Redemption for CORSIA compliance

Figure 6: Two routes for recognising GBF under CORSIA: offset-led versus fuel-led. In the offset-led route (left), the airline holds and redeems eligible units. In the fuel-led route (right), the supplier redeems the units, and the airline receives a finished compliant fuel with Proof of Redemption, without entering the registry. The table summarises the key differences between the two. Figure by the authors.

Route 1: GBFs as an offset-based product

Under this route, the supplier would purchase, from an ICAO-approved emissions-unit programme, units representing verified geological storage in a quantity matched to the emissions of the kerosene it supplies, and lock them in its registry account. At settlement, the physical fuel would be delivered to the airline under the fuel-supply agreement, while the locked units would be transferred through that programme's registry into the airline's registry account. The airline would then cancel the units for CORSIA compliance.

This route would create less friction for near-term implementation, because ICAO has recognised durable removal and storage within its eligible emissions-unit programmes. Credits issued under Isometric's DAC Protocol in combination with CO_2 storage in saline aquifers can be CORSIA-eligible for the 2024–2026 compliance period, subject to host-country authorisation and applicable CORSIA requirements [8].

However, this structure presents three main limitations. First, routing the storage benefit through a credit registry, separately from the physical kerosene, remains closer to a coordinated fuel-and-offset transaction, weakening the identity of GBF as a balanced fuel product. Second, because the approved registry holds credits of varying types and durability, the geological-storage benefit is exposed to their credibility problems and risks being conflated with lower-quality offsets. Third, the route creates ambiguity between CORSIA compliance and voluntary net-zero claims. CORSIA requires offsetting only of emissions growth above a baseline, whereas an airline pursuing full neutralisation would need to acquire additional units outside the scheme. It is unclear how those extra purchases would be kept distinct from units already retired for CORSIA.

Route 2: GBFs as a new fuel category

The fuel-led route offers an institutional classification for GBFs under CORSIA. GBFs should be recognised as a ***distinct category*** of compliant fuel – not a form of SAF, whose feedstock differs, nor an extension of LCAF, for two reasons:

- **Methodological boundary.** CORSIA's LCAF methodology credits geological carbon capture and storage (CCS) only where the CO_2 is captured within fuel production [32]. Point source CO_2 from other industrial facilities and DAC-based removal (Figure 1 and Figure 2) both fall outside this boundary and do not qualify.

- **Attribute accounting and linkage.** The compliance value of LCAF is incorporated directly into the certified life cycle emissions value of the fuel batch. GBFs, by contrast, rely on geological storage outcomes generated outside the fuel production life cycle, and hence their climate attributes cannot be carried in the fuel's emissions value. They must instead be verified and tracked independently, through unit-level registration, linkage and redemption provisions that go beyond the batch certification and chain-of-custody arrangements currently applied to LCAF.

This distinct treatment has a corresponding operational form. A supplier either obtains fuel and storage units together, where a kerosene producer also operates storage, or procures storage units from an independent storage operator and binds them to the kerosene. These units are issued, once the storage is verified, in a registry under CORSIA – either an existing approved programme whose scope covers eligible geological storage, or a registry approved specifically for GBF – and transferred from the unit provider's account into the supplier's. When an airline buys GBFs, the supplier redeems the matched units and records the airline as the purchaser in the registry. Then the registry issues a Proof of Redemption to the supplier, which passes it to the airline for CORSIA compliance. The airline reports against a finished fuel registered under CORSIA's compliant-fuel provisions and never holds a registry account or handles a unit; all registry actions are completed upstream.

This route presents several advantages:

- **A clearer fuel narrative.** Separating GBF from CORSIA offsetting enables suppliers to market it as a fuel product rather than as a credit.
- **Clear allocation of responsibility.** The supplier assembles the complete product; the airline buys a finished fuel and reports against it without operating in the credit market. Responsibility stays with the party best equipped to manage it.
- **Internalisation of aviation's emissions externality in the fuel price.** The Extended Producer Principle holds that for toxic or difficult-to-recycle products, the life cycle management costs should be embedded in the purchase price, such that the price tag reflects the environmental cost of use.
- **Fit with CORSIA's fuel architecture.** CORSIA's methodology already allows CCS within the eligible-fuel production life cycle to lower a fuel's carbon intensity, recognised as LCAF. Recognising GBF as an eligible fuel would extend this structure rather than create a parallel one.

The following sections therefore introduce what fuel-led GBF integration would require – the policy amendments and the implementation implications.

6 Recommended amendment package

ICAO could build on the existing CORSIA Eligible Fuels frameworks –Annex 16, Volume IV and the five associated supporting documents [33] – to integrate GBFs, particularly provisions for sustainability certification and life-cycle emissions accounting. They base operator claims not on molecular traceability but on the mass of eligible fuels supported by purchasing and blending records, accommodating co-mingled supply chains without requiring physical segregation. For CO_2 leakage management, the LCAF methodology introduces foundational CCS governance, requiring CCS processors to maintain a Reserve Inventory Account and compensate any verifiable reversal through a corresponding retirement of CO_2 from that account [32].

However, GBF integration would require formal recognition within CORSIA, followed by corresponding implementation in national regulatory systems, as well as the development of an appropriate accounting methodology and dedicated sustainability and eligibility criteria.

1) Establishing a legal definition for GBF

Annex 16, Volume IV is the sole legally binding instrument within the CORSIA framework. In its *Chapter 1 Definition* (Part I), three amendments should be made, indicated in blue italics below.

- **Amend:** CORSIA eligible fuel. A CORSIA sustainable aviation fuel, a CORSIA lower carbon aviation fuel, ***or*** *a CORSIA geologically balanced fuel* which an operator may use to reduce their offsetting requirements.
- **Amend:** CORSIA lower carbon aviation fuel. A fossil-based aviation fuel that meets the CORSIA Sustainability Criteria *through improvements to the conventional petroleum fuel supply chain*.

- **Add:** *CORSIA geologically balanced fuel. A fossil-based aviation fuel whose associated life cycle carbon dioxide emissions are matched by the verified capture and permanent geological storage of an equivalent quantity of carbon dioxide, and that meets the CORSIA Sustainability Criteria.*[2]

2) Establishing a GBF-specific actual-value methodology

Since GBF emissions reductions are storage-attribute-based, a dedicated GBF methodology is needed in the *CORSIA Methodology for Calculating Actual Life Cycle Emissions Values* to convert qualifying storage outcomes into an approved fuel-level life cycle emissions value.

The most significant amendment is to add a GBF-specific chapter, parallel to the existing SAF and LCAF chapters, including at least 5 clauses.

a. **Applicability and underlying fuel value**
For the purpose of determining the Actual Life Cycle Emissions Value of a CORSIA GBF, the calculation is batch-specific and begins with the underlying life cycle emissions value of the fuel absent any GBF storage allocation. The GBF storage term is applied as an adjustment to that underlying value and does not constitute an independent carbon credit separate from the fuel batch to which it is allocated.

b. **Allocation of qualifying geological storage to a GBF batch**
Only durable, verifiable geological storage outcomes that satisfy the eligibility requirements of Section 11 (Requirements for geological carbon capture and sequestration monitoring, mitigation and compensation of impermanence) of the methodology document may be allocated for the purposes of this Section. Allocation shall be made to a specific certified GBF batch, not to a producer, a production facility or a reporting period in general. The allocation shall be documented through the Technical Report and chain-of-custody system required under Section 3.1 (Reporting requirements) and Section 3.2 (Flow of information along the supply chain for actual LCA values), and shall record at minimum the storage project reference, the allocated quantity of CO_2, the point of allocation in the supply chain, and the batch identifier of the certified GBF batch.

c. **Calculation of the GBF actual value**
According to the equation for calculating the Life Cycle Emissions value of CORSIA Eligible Fuels (CEFs) provided in Section 2.1 (General provisions), the actual Life Cycle Emissions value for a certified GBF batch shall be calculated as follows:

$$\mathbf{L_{CEF\_GBF} = L_{CEF\_underlying} + ILUC_{CEF\_GBF} - (SA_{CEF\_GBF} \times \lambda_p)}$$

Where:

- $\mathbf{L_{CEF\_GBF}}$ is Actual Life Cycle Emissions Value of the certified GBF batch, expressed in gCO_2e/MJ.
- $\mathbf{L_{CEF\_underlying}}$ is underlying life cycle emissions value of the fuel absent the GBF storage allocation, expressed in gCO_2e/MJ.
- $\mathbf{ILUC_{CEF\_GBF}}$ is the emissions caused by induced land-use change, where it is 0 for fossil-derived fuels consistent with the treatment of LCAF.
- $\mathbf{SA_{CEF\_GBF}}$ denotes the net storage adjustment allocated to the certified GBF batch, expressed in gCO_2e/MJ of fuel.

2 The GBF Sustainability Criteria are set out, by way of example, in the Appendix.

- **λp** denotes the pathway recognition factor: for example, this could be 1.0 for removal pathways (BECCS-based GBF and DACCS-based GBF) and 0.5 for reduction pathways (PS-based GBF). The factor reflects the differing net effect of each source on atmospheric CO_2, as shown in Figure 2.

SA_{CEF_GBF} shall be derived by converting the qualifying quantity of geological storage, expressed in tonnes of CO_2, into a fuel-energy basis corresponding to the certified batch, and shall include only the net quantity eligible after applying all required adjustments, including expected leakage over the storage period, determined on the basis of a site-specific technical report; any CO_2 quantities excluded under the eligibility requirements of Section 11; a reversal-risk adjustment reflecting the reserve account coverage required under Section 11; and any other deductions prescribed by this methodology.

d. Exclusivity and non-overlap
The storage outcome counted in SA_{CEF_GBF} shall be uniquely allocated to the certified GBF batch to which it is assigned and shall not be simultaneously allocated to any other fuel batch, emissions unit, or compliance or crediting instrument under any other mechanism, unless ICAO rules expressly permit a specific form of concurrent use.

e. Sustainability Certification Scheme verification of GBF methodology
An approved Sustainability Certification Scheme shall verify, for each certified GBF batch claimed, at least the following:

- that the underlying fuel value has been correctly determined;
- that the storage allocation has been correctly calculated and documented;
- that the batch matching between the storage outcome and the certified fuel batch is verifiable through the chain-of-custody record;
- that the exclusivity and non-overlap requirements are satisfied; and
- that the relevant storage project remains within an active reserve-account framework.

Where a verifiable reversal occurs after the GBF batch has already been used for CORSIA compliance purposes, the Sustainability Certification Scheme shall notify the relevant competent authority, and the economic operator shall make good the shortfall through a corresponding retirement from the Reserve Inventory Account, or through such other remediation mechanisms as ICAO may prescribe.

3) Establishing GBF-specific sustainability criteria

In the *CORSIA Sustainability Criteria for CORSIA Eligible Fuels*, a new GBF-specific chapter should be added (Appendix), structured in parallel with the existing SAF and LCAF chapters across 14 sustainability themes.

7 Pathway forward

ICAO's long-term climate goal is net-zero international aviation by 2050. CORSIA, in its current form, runs to 2035. The priority today should rest on strengthening the existing scheme and building consensus on extending or maintaining a credible trajectory through the 15 years to net zero thereafter. This requires add-ons to CORSIA, such as recognising GBFs through the eligible fuel framework, to address current concerns with the reliance on downstream carbon markets outside CORSIA's oversight, and provide continuity for the long-term ambition under the ICAO.

Integrating GBF into CORSIA requires targeted amendments rather than institutional reinvention. The existing eligible fuels framework already provides the batch-based accounting foundation and the CCS governance elements needed to accommodate a fossil-based fuel category whose emissions reductions derive from geological storage.

Appendix: GBF-specific sustainability criteria

Of the 14 sustainability themes, three groups require different treatment. Social criteria independent of production method, such as human and labour rights and land-use rights, can be adopted unchanged from the SAF and LCAF narratives (black). Themes relating to production operations – waste and chemicals management – require only targeted rewording to reflect drilling, injection and storage activities (purple). Themes that are substantively central to GBF, notably carbon stock and seismic and vibrational impacts, require material reframing (blue).

Theme	Principle	Criteria
1. Greenhouse Gases (GHG)	Principle: CORSIA GBF should generate lower carbon emissions on a life cycle basis **through durable geological storage**.	Criterion 1.1: CORSIA GBF will achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
2. Carbon stock	Principle: **CORSIA GBF should not be produced using carbon dioxide that does not represent a genuine reduction in atmospheric or industrial greenhouse gas emissions.**	**Criterion 2.1: CO_2 counted toward GBF shall not include naturally occurring geological CO_2 extracted from underground reservoirs, including geological CO_2 extracted solely for reinjection, or CO_2 separated from natural gas during processing after extraction.**
		Criterion 2.2: CORSIA SAF will not be made from biomass that is either obtained/extracted from land or aquatic ecosystems converted after 1 January 2008 that was primary forest, wetlands, peat lands, coral reefs, kelp forests, seagrass meadows, estuaries, tidal salt marshes or mangrove forests or contributes to degradation of the carbon stock in primary forests, wetlands, peat lands, coral reefs, kelp forests, seagrass meadows, estuaries, tidal salt marshes or mangrove forests as these systems all have high carbon stocks.
		Criterion 2.3: In the event of land use conversion after 1 January 2008, as defined based on the Intergovernmental Panel on Climate Change (IPCC) land categories, direct land use change (DLUC) emissions will be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value will replace the default ILUC value.

3. Greenhouse Gas Emissions Reduction Permanence	Principle: Emissions reductions attributed to CORSIA GBF should be permanent.	Criterion 3.1: Operational practices will be implemented to monitor, mitigate and compensate any material incidence of non-permanence resulting from carbon capture and sequestration (CCS) activities.
		Criterion 3.2 Operational practices and financial measures will be implemented to monitor, mitigate and compensate any material incidence of greenhouse gas release resulting from closure and post-closure period of **storage-related facilities and infrastructure**.
		Criterion 3.3: Where geological storage is relied upon for GBF eligibility, the applicable storage arrangement shall include a mechanism to address verified reversal.
4. Water	Principle: Production of CORSIA GBF should maintain or enhance water quality and availability.	Criterion 4.1: Operational practices will be implemented to prevent contamination of surface water and groundwater resources from drilling, injection, and geological storage activities, including from CO_2 leakage and brine displacement. Criterion 4.2: Operational practices will be implemented to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities.
5. Soil	Principle: Production of CORSIA GBF should maintain or enhance soil health.	Criterion 5.1: Operational practices will be implemented to minimise surface disturbance from drilling, infrastructure installation, and associated activities, and to restore affected land to an equivalent or improved condition upon cessation of operations. Criterion 5.2: Operational practices shall be implemented to prevent soil contamination from leakage of CO_2, brine, or other substances associated with the geological storage process.
6. Air	Principle: Production of CORSIA GBF should minimize negative effects on air quality	Criterion 6.1: Air pollution emissions will be limited.
7. Conservation	Principle: Production of CORSIA GBF should maintain biodiversity, conservation value, and ecosystem services.	Criterion 7.1: CORSIA GBF production activities, including drilling, injection, and geological storage operations, will not be conducted in areas that, due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area, unless evidence is provided that the activity does not interfere with the protection purposes.
		Criterion 7.2: Operational practices will be implemented to avoid adverse effects on ecosystems, habitats and species in areas surrounding storage sites, including from induced seismicity, brine displacement, and surface infrastructure.

8. Waste and Chemicals	Principle: Production of CORSIA GBF should promote responsible management of waste and use of chemicals.	Criterion 8.1: Operational practices will be implemented to ensure that waste arising from production processes as well as chemicals used are stored, handled, and disposed of responsibly.
		Criterion 8.2: Responsible and science-based operational practices will be implemented to limit or reduce pesticide use.
		Criterion 8.3: Operational practices will be implemented to prevent, minimize and mitigate any damage from unintentional release of fossil resources, fuel products, and/or other chemicals.
9. Seismic and Vibrational Impacts	Principle: Production of CORSIA GBF should minimize seismic, acoustic, and vibrational impacts from CCS.	**Criterion 9.1: A site-specific seismic hazard assessment will be conducted prior to the commencement of CO_2 injection, and injection operations will be designed and managed to remain within approved pressure and volume limits that minimize the risk of induced seismicity.** **Criterion 9.2: A continuous seismic monitoring programme will be maintained throughout the injection and post-injection phases, with defined thresholds triggering operational review, injection rate reduction, or suspension.** Criterion 9.3: Operational practices will be implemented to minimize acoustic energy and vibrational impacts related to surface, subsurface, and underwater activities.
10. Human and labour rights	Principle: Production of CORSIA GBF should respect human and labour rights.	Criterion 10.1: CORSIA GBF production will respect human and labour rights.
11. Land use rights and land use	Principle: Production of CORSIA GBF should respect land rights and land use rights including indigenous and/or customary rights.	Criterion 11.1: CORSIA GBF production will respect existing land rights and land use rights including indigenous peoples' rights, both formal and informal.
12. Water use rights	Principle: Production of CORSIA GBF should respect prior formal or customary water use rights.	Criterion 12.1: CORSIA GBF production will respect the existing water use rights of local and indigenous communities.
13. Local and social development	Principle: Production of CORSIA GBF should contribute to social and economic development in regions of poverty.	Criterion 13.1: CORSIA GBF production will strive to, in regions of poverty, improve the socioeconomic conditions of the communities affected by the operation.

14. Food security	Principle: Production of CORSIA GBF should promote food security in food insecure regions.	Criterion 14.1: CORSIA GBF production will, in food insecure regions, strive to enhance the local food security of directly affected stakeholders.

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