# Geologically Balanced Fuels: a net zero goal for Low-Carbon Aviation Fuels?

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**Geologically Balanced Fuels (GBFs) offer the aviation sector a flightpath to net zero. They complement existing strategies centred around efficiency improvements and technology switching, offset credits, and Sustainable Aviation Fuel (SAF) blending. A GBF is a conventional aviation fuel whose carbon dioxide emissions are compensated for by an equivalent quantity of carbon dioxide ($CO_2$) being captured and permanently stored in geological formations. The portion of the fuel's emissions which are geologically sequestered is the 'stored fraction' – this fraction increases gradually over time as the market matures, reaching 100% (i.e. net zero) in mid-century. The details of this definition, feasibility of the approach and potential impact of a GBF market remain underexplored, despite offering a potential alternative to reliance on synthetic or biological SAFs, or on nature-based offset credits, which currently dominate most airlines' decarbonisation strategies. There is an urgent need to develop the policies, reporting standards, and first-mover collaborations to support airlines and fuel suppliers to achieve durable net zero.**

### *GBFs: a practical, scalable, and durable decarbonisation strategy*

A geologically balanced fuel (GBF) is a conventionally refined jet fuel whose $CO_2$ emissions are compensated for by an equivalent quantity of $CO_2$ being captured and permanently stored in geological formations. Delivering a portion of aviation's net zero strategy via GBFs encourages durable decarbonisation at source, whilst allowing the continued operation of existing aircraft fleets and fuel supply networks. It is a logical "net zero extension" of the concept of Low-Carbon Aviation Fuels (LCAF),[0] and also allows the industry to benefit from the increased efficiency of scale, established workforce expertise, and access to capital found in their fuel supply network.

Fuel suppliers could begin by classifying fuels as partially decarbonised GBFs once an agreed fraction of the $CO_2$ emissions associated with fuel combustion are offset with geological $CO_2$ storage. This fraction of $CO_2$ content which is returned to geological storage would need to rise over time, such that at the date of net zero a GBF sold on the market represents a net zero jet fuel. This approach is similar to that advocated for in other fuel supplier regulatory policies, such $CO_2$ storage obligations (e.g. Carbon Takeback Obligation[1], Carbon Removal Obligation[2]) and low-carbon fuel standards[3], but applied specifically to balancing $CO_2$ emissions from aviation fuel with geological $CO_2$ storage.

Delivering an airline's decarbonisation strategy with GBFs places the *responsibility* for fuel decarbonisation at the point of supply, where:

a) there are a significantly smaller set of responsible actors (i.e. global aviation fuel suppliers), streamlining market management and regulation;
b) there is substantially more experience and agency in self-managing $CO_2$ capture and geological storage operations, facilitating a more rapid scaling of durable offsetting approaches, and enabling skills retention and workforce transition in the sector and in fossil-dependent locations[4]; and
c) CCUS and CDR projects are already somewhat established, with upstream organisations invested (or planning investments) in $CO_2$ transport and storage infrastructure in many jurisdictions, and with existing relationships with external investors and regulators.

GBFs avoid many of the logistical and operational challenges present for other net zero aviation strategies. From the perspective of the airline, GBFs are identical to the conventional jet fuel which is supplied to them today. Hence, GBF adoption would not require a retooling of aircraft fleets, or the global fuel supply network, to facilitate widespread adoption. In comparison to synthetic SAF, GBFs have substantially lower energy demand per tonne of fuel produced, avoiding the high energy intensity processes of hydrogen production and jet fuel synthesis[5]. GBFs also avoid many of the land-use change issues associated with SAF produced from biomass (bioSAF), and with nature-based offsetting approaches[6]. Nature-based Solutions are unlikely to be a viable option for the offsetting of jet fuel emissions on any significant scale in the long term[7]. Conversely, GBFs would not provide any potential benefits for local air pollution or reduced contrail formation that have been claimed for SAFs.

### *Issues to be considered in developing the concept of GBFs: allowable sources and sinks of $CO_2$*

A classification system is needed to categorize fuels as partially or fully geologically balanced, based on physical criteria defining standards for geological $CO_2$ offsetting. This categorisation needs support from both national aviation fuel regulators and international aviation organisations. Consultation with a broad range of stakeholders (governments, environmental NGOs and those in the aviation industry) is advisable to ensure appropriate and workable standards are set which maintain a level playing field across the sector.

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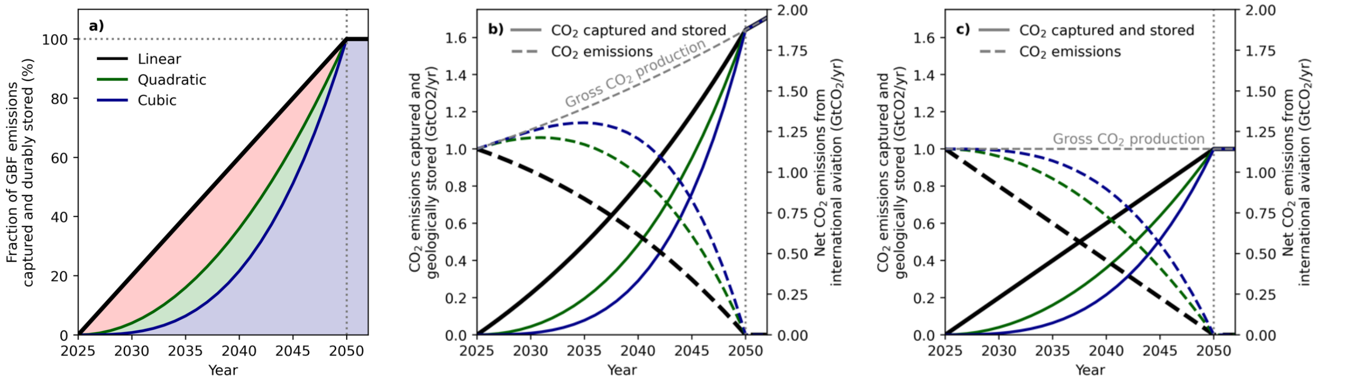


**Figure 1 – Global $CO_2$ flows if net zero aviation is delivered with GBFs.** Schematic of GBF design (panel a) and impact on net $CO_2$ emissions, $CO_2$ storage requirements, and gross $CO_2$ production from fuel use in the aviation sector (panels b and c). The fraction of $CO_2$ produced from the burning of a unit of jet fuel which are recaptured and geologically stored at each year in the GBF product are shown in panel a, with the black line showing a linearly increasing, green line a quadratically increasing, and blue line a cubically increasing stored fraction. Panels b and c show annual jet-fuel-burn $CO_2$ production (grey dashed line), net $CO_2$ emissions (dashed lines), and required $CO_2$ capture and storage rates (solid lines) to deliver the GBF product across the global aviation market, reaching net zero in 2050. Panel b assumes 2024 jet-fuel-burn $CO_2$ production is ~1Gt$CO_2$ per year and grows at 2% per year thereafter (consistent with ICAO's environmental report 2022[8]); panel c assumes no growth in jet-fuel burn $CO_2$ production after 2024.

Central to this classification system is the concept of 'like-for-like' $CO_2$ offsetting, where sources of anthropogenic $CO_2$ emissions are balanced with durable $CO_2$ storage[6]. For aviation fuels, this requires a clear definition of which $CO_2$ capture sources may be considered as 'adequate compensation' for $CO_2$ released through the production, distribution and combustion of jet fuel. Key decisions include:

i. How will the stored fraction that defines the GBF product rise over time (see panel a) in Figure 1)?
ii. Which $CO_2$ sources (e.g. point-source Carbon Capture and Storage vs. Direct Air Capture) are deemed appropriate for the offsetting of jet-type fuel emissions, and will the permitted fractions for $CO_2$ sources and sinks change over time?
iii. Who is responsible for regulating the market, defining MRV structures, and what are the penalties for non-compliance or $CO_2$ leakage?
iv. Are the emissions associated with the production and distribution of the GBF, as well as its use, included in the $CO_2$ capture and storage quantity needed to define the product?

At one extreme, $CO_2$ recaptured from the atmosphere is clearly adequate for establishing a GBF standard globally, but DAC is both costly and energy-intensive to deliver at scale, suggesting better outcomes at lower cost might be achieved by allowing other sources of $CO_2$ to be used. At the other extreme, $CO_2$ extracted from natural reservoirs in the Earth's crust for the explicit purpose of reinjection for enhanced oil recovery would not be suitable for establishing a GBF, because it was never in nor likely to enter the atmosphere in the first place. There is a broad spectrum of options between these two extremes, including BECCS, point-source CCS, and Biochar.

One option to facilitate the GBF product's development today is to define the GBF product's stored fraction to include sub-portions delivered via $CO_2$ purchased from point-sources, or stored via impermanent storage mechanisms, with these portions then phased out over time[9]. This leaves a 100% DAC-based GBF product at the time of net zero, as required by the aviation sector's net zero trajectory, but facilitates an interim GBF market to develop before DAC has fully matured. As an example, panel a) in Figure 1 shows a cubic DAC-based GBF product reaching 100% stored fraction in 2050 (blue line). This could be topped up with $CO_2$ purchased from point-source CCS operators (green shading) and from temporary $CO_2$ storage mechanisms, such as Nature-based Solutions (red shading), so that the overall GBF product exhibits a linearly rising stored fraction (black line). Increasing the ambition of the GBF product via the purchasing of $CO_2$ from industrial point-sources in this way would require point source operators to pay any carbon price associated with their sold $CO_2$ in their operating jurisdiction, since they would no longer have 'avoided their emission', having sold the right to the captured and stored $CO_2$ to the GBF owner. This could remain profitable for the $CO_2$ capturing entity if the carbon price associated with the emission were less than the cost of DAC (as would occur in cost-optimal policymaking).

Rules would be needed to govern when a partial decarbonisation claim could be made using GBFs, including but not limited to: defining the trajectory for the progressively rising stored fraction, setting the initial stored fraction at an ambitious but practical level in the context of available $CO_2$ capture and storage opportunities in the near term, guaranteeing that purchased $CO_2$ for packaging into GBF products comes from appropriate sources and is effectively 'owned by the GBF product owner', and ensuring high durability $CO_2$ storage is used throughout.

## *Addressing an urgent need for the aviation sector*

There is an urgent need to develop the policy suite, reporting standards, and first-mover collaborations necessary to support the aviation sector and their fuel suppliers to achieve durable net zero. A new project between IATA and the University of Oxford, funded by Vietjet, looks to explore many of these questions, including:

*Costs and potential*

Exploring the costs of conventional decarbonisation approaches in comparison to approaches including GBFs, using mixed CCS and DAC $CO_2$ sources as in Figure 1. Key to this is an exploration of the potential for the GBF market to support a net zero transition for aviation, considering the scaling rate for DAC-based and CCS-based $CO_2$ capture and storage opportunities, costs of GBFs incorporating these different strategies, and synthesis of this analysis towards an assessment of the potential for GBFs to contribute to aviation's net zero future.

*Interactions with existing standards and policies*

A GBF market will not exist in isolation of other decarbonisation policies. Any future GBF product must therefore be able to interact with the existing policy and standard landscape. For example, as described above, protocols must exist to ensure the ownership of stored $CO_2$ used to define the GBF product. If a GBF is created using $CO_2$ purchased from point sources operating within the EU and UK ETS, rules would be required to avoid double-counting of claims.

SAF production and fuel blending mandates are being discussed in many jurisdictions. The UK's new SAF mandate requires 2% SAF blending into jet-A1 fuel by 2025, rising to 22% by 2040[10]. Since GBFs are chemically identical to conventional Jet-A1 fuel, GBFs can be blended with SAF to produce a net zero jet fuel blend, regardless of the blending limit imposed on SAFs. Existing jet-A1 fuel blends are governed by international standards ASTM D7566[11] and ASTM D1655[12] – any future GBF fuel, or GBF fuel blend, would also need to demonstrate compliance.

Demand control measures, such as incorporating a carbon tax in airfares, frequent flyer levies, or placing jurisdictional limits on business travel have all been described as potential methods to reduce demand for aviation. GBFs act similarly to a carbon price airfare adjustment, assuming the additional cost realised by the airline was packaged into airfares at the point of sale. The impact of price-based demand control measures is variable[13], and region-/sector-specific (for example, resilience to airfare price variations is typically higher in business traveller pools). The use of demand control measures therefore depends on national context, and must consider the passenger pool being targeted, how revenues and costs from a price-based control would be hypothecated, and the wider societal benefits of avoiding additional climate change[14].

Since the adoption of GBFs would increase the outlay on fuel for airlines, there is a risk that restrictive policies adopted unilaterally in one jurisdiction could create perverse incentives, for example encouraging refuelling in neighbouring jurisdictions, impacting the competitiveness of that jurisdiction's airport infrastructure. Suitable border adjustments may be considered necessary, as well as international cooperation as part of first-mover coalitions, to reduce the negative impacts and maintain international competitiveness.

*Perceptions of stakeholders*

The success of operationalising GBFs will also depend on the perceptions and acceptance of a wide range of stakeholders, including those involved directly in working towards net zero aviation, as well as broader communities of policy, regulation, civil society, and general publics. We will explore the possibilities and challenges of achieving a 'social license to operate' for GBFs, as well as the implications of GBFs for climate justice globally.

***Geologically Balanced Fuels could become an important component of the aviation sector's net zero strategy. They promise many benefits including: limiting the need for replacing fleets and fuel supply networks; operating legacy aircraft at net zero where pure SAF is not permitted; limiting the need for alternative offsetting schemes; and diversifying and derisking net zero strategies. The success of GBFs relies on a collaboration between standards setters, policymakers and practitioners to drive the market forward from nascence to maturity.***

***To keep up to date on the project, get in touch, or to collaborate go to www.netzeroclimate.org/netzeroaviation.***