# MISSION POSSIBLE

## REACHING NET-ZERO CARBON EMISSIONS FROM HARDER-TO-ABATE SECTORS BY MID-CENTURY

ENERGY TRANSITIONS COMMISSION

SECTORAL FOCUS

## AVIATION

The **Energy Transitions Commission (ETC)** brings together a diverse group of leaders from across the energy landscape: energy producers, energy users, equipment suppliers, investors, non-profit organizations and academics from the developed and developing world. Our aim is to accelerate change towards low-carbon energy systems that enable robust economic development and limit the rise in global temperature to well below 2˚C and as close as possible to 1.5˚C.

In November 2018, the ETC published ***Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century***. This flagship report is available on our website. This report describes in turn:

- Why reaching net-zero $CO_2$ emissions across heavy industry and heavy-duty transport sectors is technically and economically feasible;
- How to manage the transition to net-zero $CO_2$ emissions in those harder-to-abate sectors of the economy;
- What the implications of a full decarbonization of the economy are for the energy system as a whole, in particular in terms of demand for electricity, hydrogen, bioenergy/bio-feedstock, and fossil fuels, as well as carbon storage requirements;
- What policymakers, investors, businesses and consumers must do to accelerate change.

**This Sectoral Focus presents in more details the underlying analysis on aviation decarbonization that fed into the ETC's integrated report *Mission Possible*.** It constitutes an updated version of the consultation paper with the same title published by the ETC in July 2018.

**We warmly thank all experts** from companies, industry initiatives, international organizations, non-governmental organizations and academia, who have provided feedback on this consultation paper. Their insights were instrumental in shaping the *Mission Possible* report and this updated Sectoral Focus.

The *Mission Possible* report and the related Sectoral Focuses constitute **a collective view of the Energy Transitions Commission**. Members of the ETC endorse the general thrust of the arguments made in this report but should not be taken as agreeing with every finding or recommendation. The institutions with which the Commissioners are affiliated have not been asked to formally endorse the report. The list of our Commissioners at the time of publication can be found in the *Mission Possible* report.

**In 2019, the Energy Transitions Commission will continue to engage actively and work with key policymakers, investors and business leaders around the world**, using our analysis and the unique voice of the ETC to inform decision-making and encourage rapid progress on the decarbonization of the harder-to-abate sectors. We are keen to exchange and partner with those organizations who would like to progress this agenda. Please contact us at info@energy-transitions.org.

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# TABLE OF CONTENTS

# REACHING NET-ZERO CARBON EMISSIONS FROM AVIATION

Emissions from aviation currently amount to circa 1Gt $CO_2$ per annum accounting for almost **3% of total global emissions**, but, under a business-as-usual scenario, they would grow to almost 1.8Gt by 2050 representing above 4% of global emissions and 14% of the transport sector emissions[1].

In 2009, the aviation industry, through the International Air Transport Association (IATA) and the Air Transport Action Group (ATAG) committed to keep total aviation emissions flat at the 2005 level from 2020 onwards, and to achieve a 50% reduction by 2050[2]. The schematic diagram which IATA then released assumed that **improvements in energy efficiency of engines and airframes, combined with greater efficiency of aviation operations, could reduce the growth of emissions by 30-45% below business-as-usual**, but that further reduction would require alternative aviation engines or fuels[3] [Exhibit 12].

Our analysis confirms this conclusion. Improvements in engine and airframe efficiency, along with air traffic and other operational improvements, can significantly reduce the rate of growth in carbon emissions from aviation, and must be pursued aggressively. But it will not be possible to keep emissions flat, let alone to **achieve net-zero carbon emissions by mid-century**, as required to meet the targets of the Paris Agreement, without a shift to alternative low-carbon fuels or to electric engines.

**Battery electric and hydrogen planes could play a role over short distances**, but without a dramatic and currently unforeseeable improvement in battery energy density, these technologies will not be able to power long-haul aviation. The path to net-zero-carbon aviation therefore relies on some **combination of biofuels and synthetic fuels** ("power-to-liquids"). The use of "drop-in" low-carbon fuels can considerably facilitate the transition to net-zero-carbon aviation, as it will not require any significant equipment or infrastructure investment. But internationally coordinated regulation and/or carbon pricing is essential to ensure their large-scale deployment, which will in turn drive cost reductions. Certification will also be needed to guarantee the safety of new fuels as well as their true sustainability.

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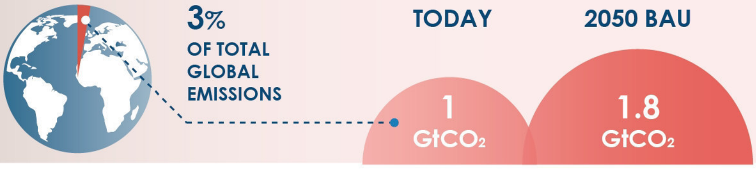
[1] IEA (2017), *Energy Technology Perspectives*

[2] IATA (n.d.), *A Global Approach to Reducing Aviation Emissions*

[3] ATAG (2010), *The Right Flightpath to Reduce Aviation Emissions*

ENERGY TRANSITIONS COMMISSION

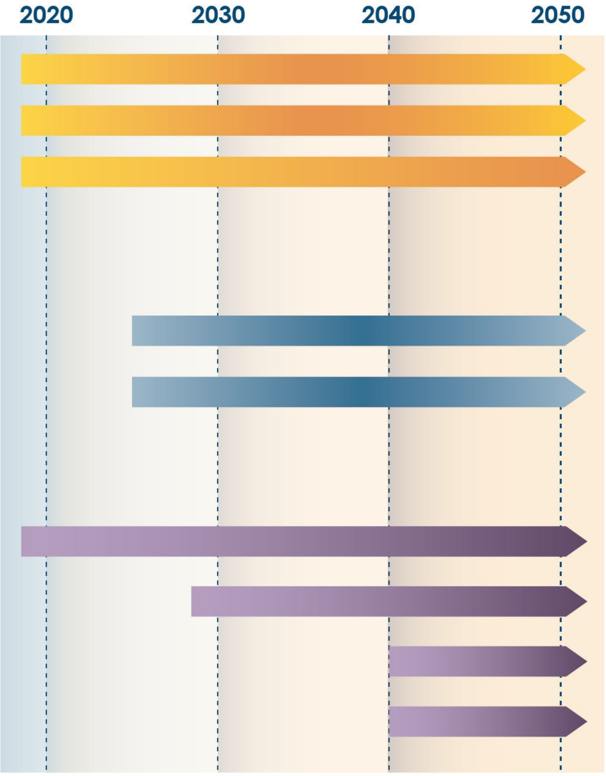
# HOW TO REACH NET-ZERO $CO_2$ EMISSIONS FROM AVIATION



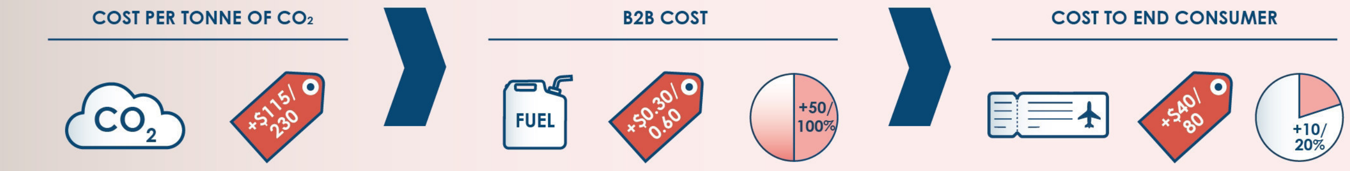
## REACHING NET-ZERO $CO_2$ EMISSIONS FROM AVIATION IS POSSIBLE BY COMBINING 3 MAJOR DECARBONIZATION ROUTES:

| | | MAXIMUM $CO_2$ EMISSIONS REDUCTION POTENTIAL |
|---|---|---|
| 1 DEMAND MANAGEMENT | Better Air Traffic Management (ATM)<br>Load factors improvement<br>Modal shift to high-speed rail | -15% |
| 2 ENERGY EFFICIENCY | Thermodynamic efficiency of new engines<br>Aircraft design | -30/45% |
| 3 DECARBONIZATION TECHNOLOGIES | Biofuels | -100% |
| | Synfuels | -100% |
| | Hydrogen (short-distance transport) | -100% |
| | Electric battery (short-distance transport) | -100% |

TECHNOLOGY APPLICABILITY / AVAILIBILITY OVER TIME



MAXIMUM DECARBONIZATION COST



COST PER TONNE OF $CO_2$

$CO_2$ +$115/230

B2B COST

FUEL +$0.30/0.60 +50/100%

ON A LITRE OF JET FUEL

COST TO END CONSUMER

+$40/80 +10/20%

FOR A LONG-DISTANCE ECONOMY FLIGHT

## TOP 3 ACTIONS TO ACCELERATE THE TRANSITION FOR…

### INNOVATION

- Improve airframe and engine efficiency
- Drive down the cost of sustainable biofuels
- Drive down the cost of synthetic fuels

### POLICY

- Create a “green fuel” mandate imposing an increasing percentage of zero-carbon fuels reaching 100% by 2050
- Create fuel taxes of about US$100 per tonne of CO2 applied at full rate to domestic flights and with reduced rates to international flights
- Tighten sustainability standards on biofuels, based on lifecycle carbon analyses and assessments of other environmental impacts

### INDUSTRY/BUSINESSES

- IATA: increase ambitions of IATA roadmap to aim for zero emissions by mid-century
- Airport and airlines: create a coalition to secure a large-scale supply of cost-competitive sustainable biofuels
- Airlines: develop a “green flight” offer at a premium price in coordination with major travel agencies and corporate consumers of air travel

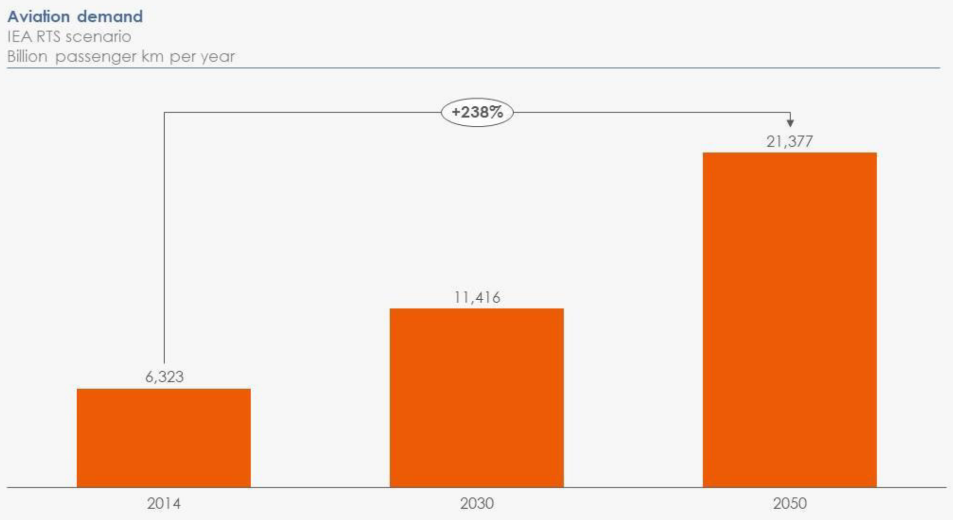
# 1. OVERVIEW OF THE CHALLANGE

## A. DEMAND TRENDS BY MID-CENTURY

Air travel has grown very rapidly over the last decades and will continue to grow in the future, with both freight and passenger traffic strongly correlated with growing global income[4].

- Passenger traffic represents the lion's share of the aviation sector, accounting for nearly 90% of global carbon emissions from aviation worldwide. Passenger kilometers have been multiplied by 12 since 1970[5] and are forecasted to grow another 238% between now and 2050 in a business-as-usual scenario[6] [Exhibit 1], with tourism demand in particular displaying strong income elasticity.
- Domestic flights currently account for the majority of passenger kilometers, but this is expected to change in the 2020s as international travel grows faster than domestic travel and international flights are expected to represent 1.5 times the passenger kilometers of domestic flights by 2040. Biggest increases in passenger air travel will be concentrated in parts of the world experiencing rapid income growth, with the Asia-Pacific region accounting more than half the new passengers by 2036[7] [Exhibit 2].
- In comparison, freight traffic represents a small portion of the aviation sector, with dedicated freight representing less than half of freight tonne kilometers today – a proportion that is forecasted to decrease against belly freight. However, freight tonne kilometers have also grown rapidly and are forecasted to double by 2036, with both belly and dedicated freight volumes rising significantly[8] [Exhibit 3].

**Aviation demand is expected to increase significantly by mid-century**



Source: IEA (2017), *Energy Technology Perspectives*; OECD (2017), *IFT Transport Outlook 2017*

**Exhibit 1**

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[4] World Bank (2017), *Aviation Data*

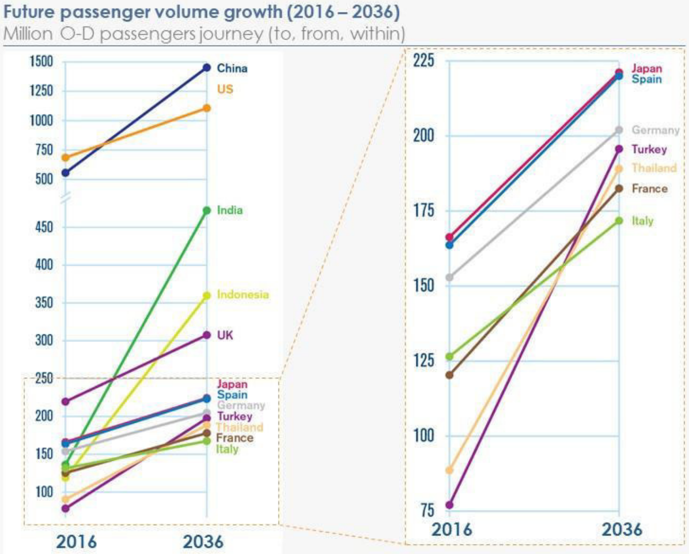
[5] Airbus (2017), *Global Market Forecast*

[6] IEA (2017), *Energy Technology Perspectives*

[7] IATA (2017), *2036 Forecast Reveals Air Passenger Will Nearly Double to 7.8 Billion*

[8] ITF (2017), *Transport Outlook*

**Future passenger volume growth will primarily come from emerging countries**



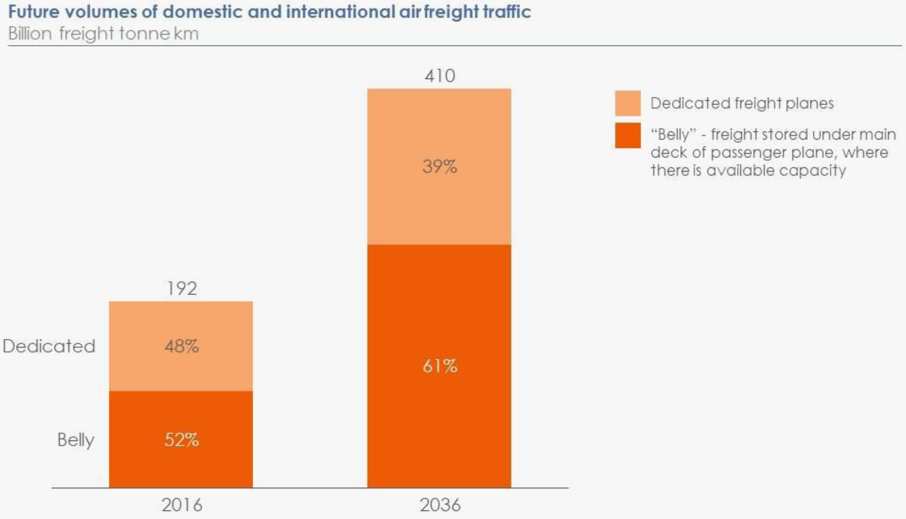
Future passenger volume growth (2016 – 2036)

Million O-D passengers journey (to, from, within)

Source: IATA (2017), *2036 Forecast Reveals Air Passenger Will Nearly double to 7.8 Billion*

**Exhibit 2**

**Both belly and dedicated freight volumes are expected to rise significantly in the next 20 years**



Future volumes of domestic and international air freight traffic

Billion freight tonne km

Source: Airbus Global Market Forecast (2017)

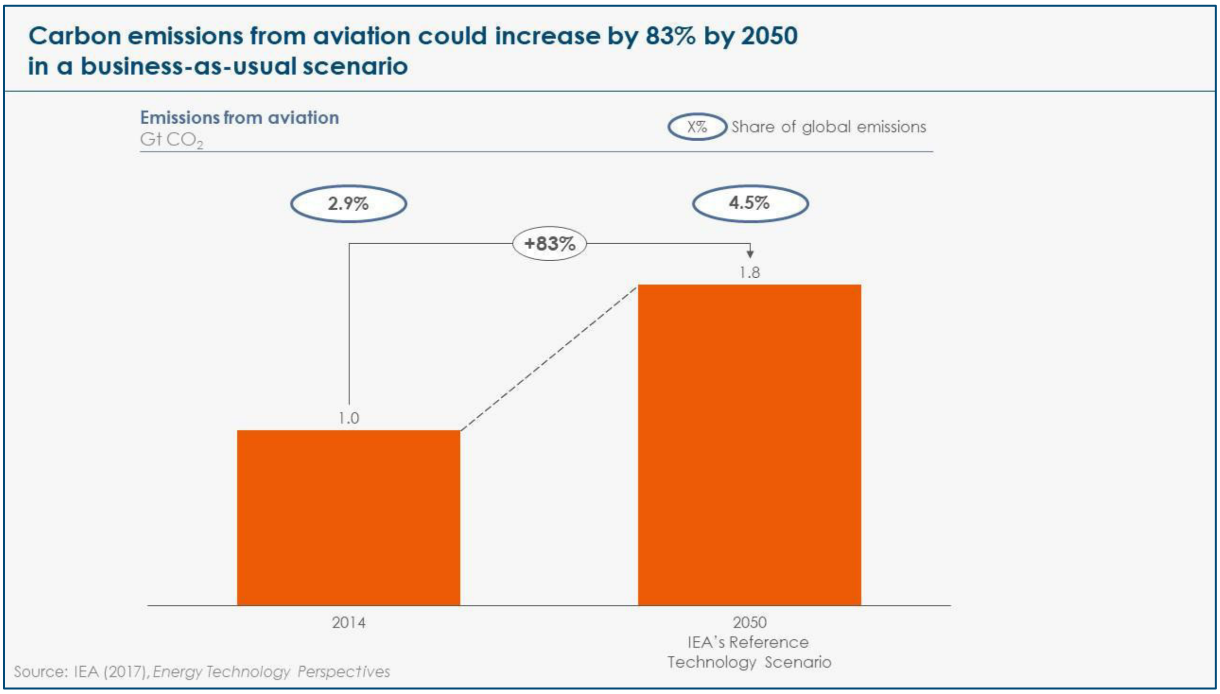
**Exhibit 3**

# B. CARBON EMISSIONS – AND OTHER ENVIRONMENTAL IMPACTS

$CO_2$ emissions from aviation currently amount to 1Gt per annum, which represents currently about 3% of total global emissions from the energy systems, but they could grow to 1.8Gt per annum by 2050 in a business-as-usual scenario, rising to 4.5% of global emissions[9] [Exhibit 4]. The main challenge lies in passenger travel, which represents 95% of carbon emissions from the sector today, and in particular, international passenger travel, which accounts for about 60% of emissions from passenger flights[10] [Exhibit 5].

Since energy-intensive takeoff and climb create an element of fixed emissions per flight, international/long-distance flights have somewhat lower emissions per passenger kilometer travelled, but the effect of great distances still dominates due to total volumes, so that international flights account for over half of all today's emissions from aviation[11].

On international passenger flights, emissions per passenger kilometer also vary significantly based on class seats, from 80 grams per passenger-km for economy class to 325 grams per passenger-km for first class[12]. [Exhibit 4]



**Carbon emissions from aviation could increase by 83% by 2050 in a business-as-usual scenario**

Source: IEA (2017), *Energy Technology Perspectives*

**Exhibit 4**

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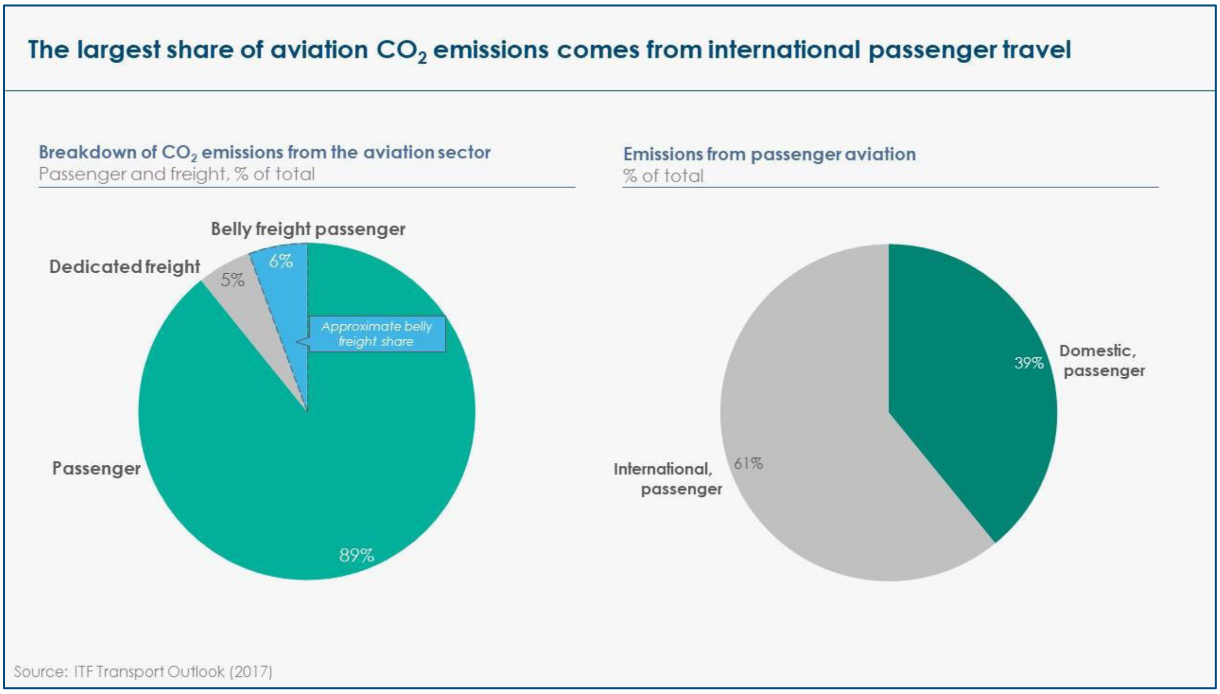
[9] IEA (2017), *Energy Technology Perspectives*

[10] ITF (2017), *Transport Outlook*

[11] ITF (2017), *Transport Outlook*

[12] Committee on Climate Change (2009), *Meeting the UK aviation target – options for reducing emissions to 2050*



The largest share of aviation $CO_2$ emissions comes from international passenger travel

Breakdown of $CO_2$ emissions from the aviation sector
Passenger and freight, % of total

Emissions from passenger aviation
% of total

Source: ITF Transport Outlook (2017)

**Exhibit 5**

Beside carbon emissions from fuel combustion, aviation yields other non-$CO_2$ greenhouse gases with global warming effects. These include: $NO_X$, water vapor, sulphate particles, soot particles and formation depending on atmospheric conditions[13]. Soot particles, formation and water vapor all have a positive radiative forcing effects which, alongside $NO_X$, result in additional global warming impact. Attempts have been made to estimate other aviation effects, in particular the wider aviation cloudiness effects (AIC). While findings are uncertain, studies of the AIC effect find greatest potential warming impact when combined with a high $NO_X$ concentration.

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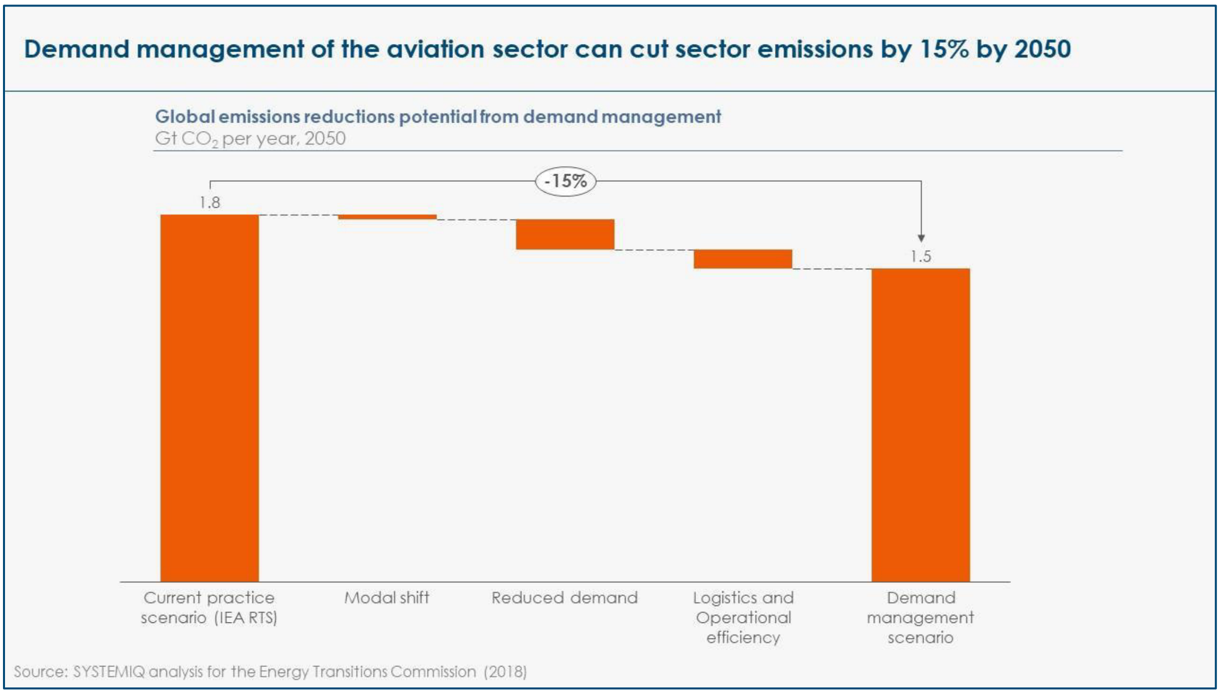
[13] Committee on Climate Change (2009), *Meeting the UK aviation target – options for reducing emissions to 2050*

# 2. REDUCING $CO_2$ EMISSIONS BY CURBING TRAFFIC VOLUMES

Opportunities to curb demand growth are more limited in the transport sector compared to the industrial sector. Economic development drives higher demand for services which sustain good standards of living: freight transport is driven by global economic growth and passenger transport by higher mobility demand in emerging economies. This is also true in heavy industry, but demand for raw materials can be mitigated by reducing the amount of materials required to offer the same level of services – e.g. reducing the amount of virgin steel required to build a house – whereas it is more difficult to apply that same logic to cut demand for mobility services. Nonetheless, a combination of modal shifts, greater logistics and operational efficiency, and reduced demand for passenger flights might still deliver up to **15% emissions reduction in aviation by 2050.**



Demand management of the aviation sector can cut sector emissions by 15% by 2050

Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

**Exhibit 6**

**With regards to modal shift, there is a significant potential to shift from short-haul domestic and intra-regional air travel to high speed rail**, which would yield an average of 80% reduction in energy per kilometer travelled. Successful examples of modal shift between aviation and high-speed rail include the Eurostar between the UK and the continent, or the Shinkansen in Japan. These examples show, however, that significant investment in the rail infrastructure is required for such shift to occur. Even if a third of all short-haul passenger traffic was shifted to rail by mid-century, only about 10% of total emissions from aviation would be eliminated, reflecting the dominance of long-haul flights where such modal shift is impossible[14].

**Significantly higher prices for air travel may also somewhat moderate the growth of leisure traffic – and probably to a lesser extent of business traffic.** It is likely that low-carbon biofuels and synthetic fuels will, at least for several decades, be more expensive than fossil-based jet fuel, but the price differential – adding between US$40 and US$80 in fuel costs per economy passenger on a long-haul flight – is unlikely to drive massive behavioral change.

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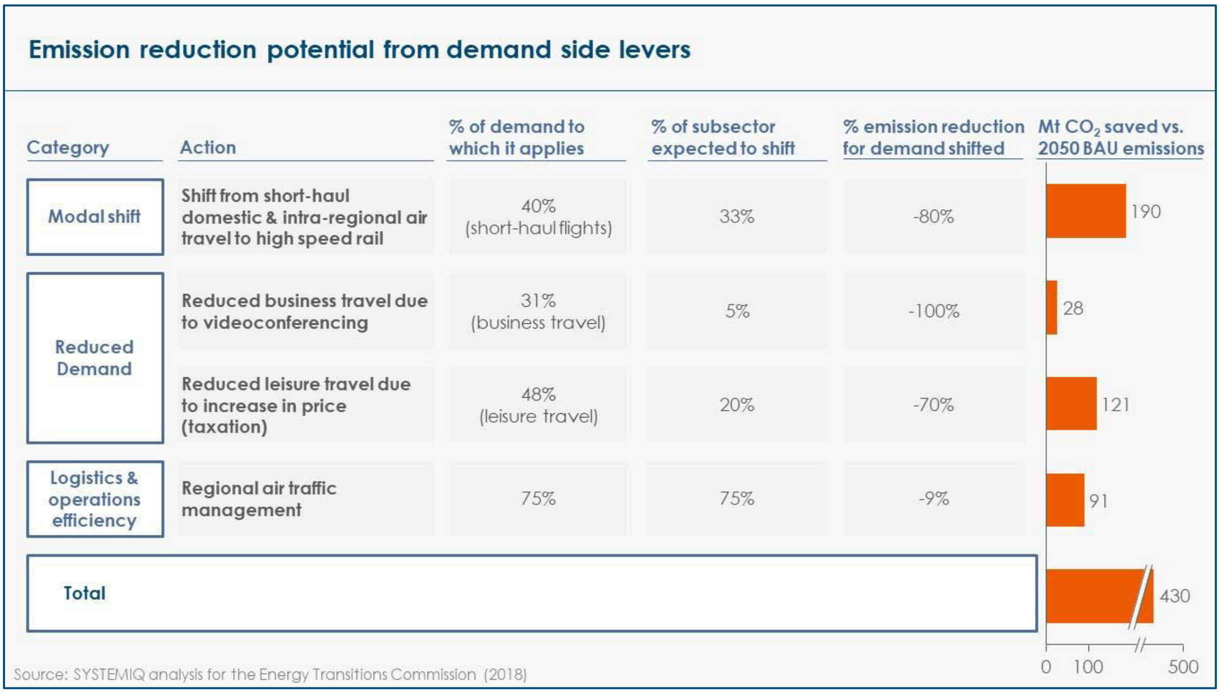
[14] SYSTEMIQ analysis for the Energy Commissions Transition (2018)

With consumers placing high value on the ability to fly as their income increases, the combination of high income-elasticity and relatively low price-elasticity of demand makes it probable that the primary response to any price increase will be to accept the higher price rather than to significantly reduce demand, with the possible exception of short-haul flights as rail could become cost-competitive as a result of higher flight prices. Much higher levels of forceful taxation of air travel would be required to discourage long-haul leisure travel, and these are unlikely to gather enough political support to be implemented. Our illustrative scenario for price-induced demand reduction therefore suggests **no more than a 10% reduction in demand for leisure travel**, leading to a 7% potential reduction in total emissions from aviation[15].

**Videoconferencing could, in principle, also reduce the need for business travel**, especially as previously modest adoption of videoconferencing accelerates, quality improves and cost declines. Business travel, however, and the perceived importance of face-to-face contact may well limit the impact on air travel demand, and might not induce more than a 2% cut in total aviation emissions.

**Finally, research shows that improved logistics and operations, through better air traffic management (ATM), could deliver approximately 52Mt of $CO_2$ savings by 2030** (compared to 2010 levels) if applied in Europe (via the Single European Sky ATM Research Program, SESAR) and in the United States (via the Next Generation Air Transportation System) only[16]. Practically, ATM entails measures such as optimizing routing, air traffic flow management, minimizing flight distances, cutting aircraft waiting times and more flexible routing. In our scenario (based on a 9% emission reduction factor due to operation optimization and load factor improvement[17] applied to a limited share of the aviation demand), regional air traffic management allows a 5% reduction in total aviation emissions.



Emission reduction potential from demand side levers

| Category | Action | % of demand to which it applies | % of subsector expected to shift | % emission reduction for demand shifted | Mt $CO_2$ saved vs. 2050 BAU emissions |
|---|---|---|---|---|---|
| Modal shift | Shift from short-haul domestic & intra-regional air travel to high speed rail | 40% (short-haul flights) | 33% | -80% | 190 |
| Reduced Demand | Reduced business travel due to videoconferencing | 31% (business travel) | 5% | -100% | 28 |
| | Reduced leisure travel due to increase in price (taxation) | 48% (leisure travel) | 20% | -70% | 121 |
| Logistics & operations efficiency | Regional air traffic management | 75% | 75% | -9% | 91 |
| Total | | | | | 430 |

Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

**Exhibit 7**

Therefore, the demand reduction scenario above, while simply illustrative, provides robust enough orders of magnitude to make it clear that progress towards significant emissions reductions will have to rely primarily on supply-side rather than demand-side measures.

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[15] SYSTEMIQ analysis for the Energy Transitions Commission (2018)

[16] Air Transport Action Group (2010), *Beginner's Guide to Aviation Efficiency*

[17] RMI (2011), *Reinventing Fire Transportation*, *Transportation Sector Methodology*

# 3. IMPROVING ENERGY EFFICIENCY

**Historically, improved airplane efficiency has been achieved through a combination of better engine efficiency and improved airframe design**. Commercial aircrafts engines, while varying with aircraft, have an overall efficiency of about 50% today. Further improvements are possible but limited by thermodynamics to a maximum of circa 65-70%[18]. New aircraft design could reduce carbon impact of air travel by 10-20% in the early 2020s (using engine updates and composite structure components) and by 30-40% by 2030 (using laminator flow control, open rotor, fuel cell for on-board energy)[19]. Beyond 2030, achieving even greater carbon mitigation would involve technologies such as blended wing bodies, radical changes in the positioning of fuel tanks to enable hydrogen-fueled planes, revolutionary engines and new materials. Importantly, however, **the longevity of a passenger aircraft is between 25-28 years[20], which is likely to create a legacy issue and slow down the pace of deployment of new technologies**. Retrofitting could only yield a 6-9% emissions reduction[21].

**Improved infrastructure** could bring additional benefits, for instance through the deployment of fixed electrical ground power units, i.e. equipping airport gates with power and pre-conditioned air, which the aircrafts can use while on the ground instead of running those functions on jet fuel. This would save an average of 5.6kg $CO_2$ per minute while on the ground[22].

Even if all possible technological, operational and infrastructural efficiencies are achieved over the next 20 years, emissions from aviation would still grow significantly in absolute terms and as a percentage of total global carbon emissions, due to booming demand. Decarbonization of the aviation sector will therefore require the development of alternative low-carbon engines or fuels.

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[18] National Academies of Sciences, Engineering, and Medicine (2016), *Commercial Aircraft Propulsion and Energy Systems Research Reducing Global Carbon Emissions*

[19] IATA (2013), *Technology Roadmap*

[20] The Boeing Company (2015), *Trends in fleet and aircraft retirement*

[21] IATA (2013), *Technology Roadmap*

[22] ICAO (2016), *On Board a Sustainable Future*

# 4. DECARBONIZING AIR TRAVEL

## A. TECHNICAL FEASIBILITY OF ALTERNATIVE ENGINES OR FUELS

The ETC analysis on heavy-duty road transport[23] suggests that the future is electric, with either battery or hydrogen powered electric engines almost certain eventually to dominate. Multiple initiatives have now been announced to develop airplanes powered either by batteries or by hydrogen (which could, in turn, either be converted to electricity via fuel cells or directly burnt). Theoretically, **the range of technological solutions available today consequently include:** (i) electricity to power an electric motor, (ii) liquid hydrogen used to power fuel cells and an electric motor, (iii) liquid hydrogen used in a turbine engine, (iv) biofuels or synthetic fuels (synfuels) for use in a turbine engine.

Our analysis suggests, however, that **until and unless there is a major breakthrough in battery gravitational density, battery-powered planes will not be a feasible alternative for long-haul/international flights**. At current state, battery's density would need to improve five-fold (from 300Wh/kg to 1,500Wh/kg) for electric intercontinental flights to become technically feasible [Exhibit 8].

While hydrogen comparably carries a relative storage weight advantage, the required volume outweighs this gain. **Until and unless there is a major redesign of aircrafts** that significantly increases the available volume for energy storage, **use of hydrogen, either as combustible and or in fuel cells, will not be feasible for long-haul/international flights** [Exhibit 9]**.**

Meanwhile, **electric or hydrogen planes could play an increasing role in short-haul and perhaps medium-haul flights.** Both major aircraft constructors and start-ups are indeed exploring these options, for instance:

- Airbus has produced an electric aircraft, Vahana, designed to move a passenger or small cargo within the confines of a city, which completed its first first full-scale flight test in 2018.
- Lilium, an all-electric taxi jet service, tested its first flight in 2017, is planning for first manned flight in 2019 and full commercial roll-out in 2025, primarily for intra-city travel.
- Zunum Aero, with investment from Boeing and JetBlue Technology Ventures, are planning to deliver a 12-passenger electric aircraft to travel 700 miles imminently.
- Eviation Aircraft, an Israeli start-up, is similarly focused on the short-range market and working to deliver a 9-passenger plane operating primarily in the 100-600-miles range.

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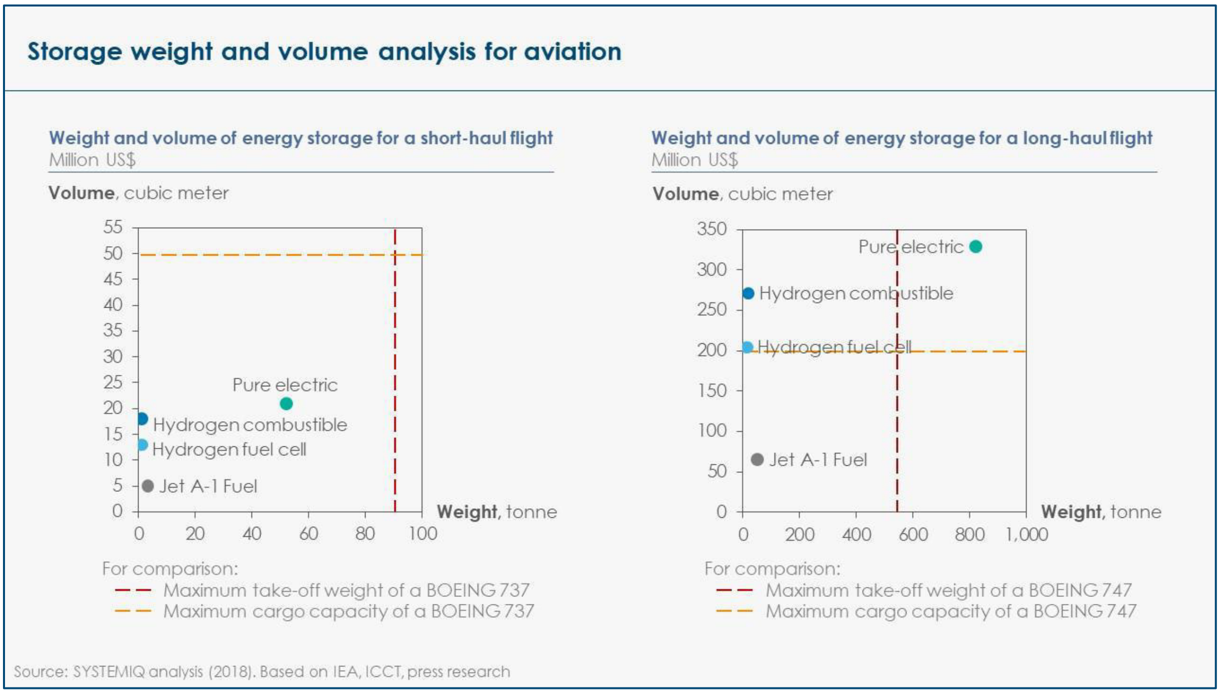
[23] Energy Transitions Commission (2019), *Reaching net-zero carbon emissions from heavy-duty road transport*



Storage weight and volume analysis for aviation

Weight and volume of energy storage for a short-haul flight
Million US$

Weight and volume of energy storage for a long-haul flight
Million US$

Source: SYSTEMIQ analysis (2018). Based on IEA, ICCT, press research

**Exhibit 8**

In that context, it is almost certain that **the only route to radical decarbonization of long-haul aviation will require the development of a non-fossil-fuel-based liquid hydrocarbon fuel**. It is technically possible to produce the chemical equivalent of jet-fuel either from a bioenergy source, or via a "power-to-liquid" synthesis, combining $CO_2$ (extracted from the air or captured on the back of an industrial plant) with hydrogen. These fuels would obviously release $CO_2$ at the point of use, but could, in theory, be net-zero carbon emissions throughout their lifecycle.

This decarbonization route brings with it a major advantage: these fuels are easier to deploy than new aircraft technologies, as **they can technically be used almost immediately as "drop-in" fuels** in existing engines and existing refueling infrastructure, and can even, in the short term, be blended with existing jet fuel with the aim of increasing proportions through time. The only barriers to deployment would therefore be the **price differential** with current jet fuels and the capacity of the supply chain to **scale up production**.

Compared with other harder-to-abate sectors in heavy-duty transport and industry, there are fewer complex transition challenges in decarbonizing the aviation sector – such as arise in other sectors from the need to replace existing capital assets or from complex interdependencies between different items of capital equipment in an industrial complex.

A rapid scale-up of these "net-zero hydrocarbons" in long-haul aviation could position these as a readily available decarbonization option for short-haul aviation too, reducing the scope for breakthrough electric and hydrogen planes, unless these can demonstrate greater efficiency and air pollution advantages.

# B. ALTERNATIVE LIQUID FUELS: COST COMPARISON

The crucial issue for the decarbonization of aviation is therefore the cost at which biofuels or synfuels can be produced, and the implications for the total cost of aviation and thus ticket prices.

- Estimates of today's production costs suggest that **bio-based jet fuels might cost 2 to 3 times fossil-based jet fuel**, but these costs will likely reduce if and when large-scale use drives economy of scale and learning curves effects. By mid-century, a cost penalty of less than 100% (and perhaps much less) can almost certainly be attained.
- For synthetic fuels, if renewable electricity were available at US$20 per MWh[24], **synfuels could be delivered for about US$1.10 per liter**, which represents a ~80% cost penalty. These costs would also be likely to reduce over time if large-scale production was achieved[25].

For many decades at least, however, it is likely that there will be a cost penalty in using either biofuels and synfuels. Exhibit 9 sets out an illustrative scenario to estimate the size of this cost penalty and concludes that it would translate into a **US$115-230 abatement cost per tonne of $CO_2$**, which makes aviation one of the most expensive sectors to decarbonize in the global economy.

Given that biofuels and synfuels are the only undoubtedly technically feasible way to decarbonize aviation, reaching net-zero carbon emissions from aviation by mid-century, in line with what is required to respect the Paris Agreement, will necessarily entail **accepting this cost penalty**. As argued in the section on demand above, it is highly likely that price increases of this magnitude would not produce a dramatic reduction in demand for air travel, given the high-income elasticity and low-price elasticity of consumer behavior.

The key policy questions, considered later in this sectoral focus, are therefore:

- How to ensure as low a cost penalty as possible?
- How to use internationally-coordinated regulation and carbon pricing to drive a shift away from fossil-fuel-based jet fuel and over what timeframe?

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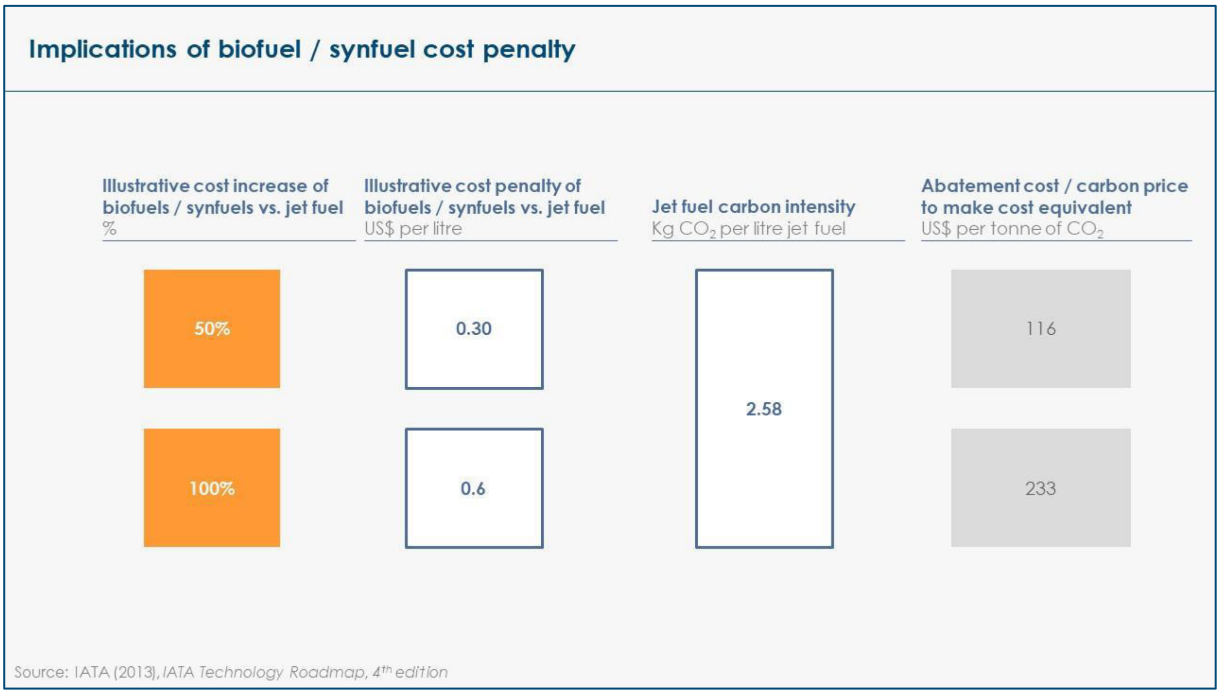
[24] See Energy Transitions Commission (2018), *Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century* – Chapter 6 for explanation of why this is a believable scenario for mass production of synfuels in favorable locations

[25] SYSTEMIQ analysis for the Energy Transitions Commission (2018), based on interviews with experts.



Implications of biofuel / synfuel cost penalty

| Illustrative cost increase of biofuels / synfuels vs. jet fuel % | Illustrative cost penalty of biofuels / synfuels vs. jet fuel US$ per litre | Jet fuel carbon intensity Kg $CO_2$ per litre jet fuel | Abatement cost / carbon price to make cost equivalent US$ per tonne of $CO_2$ |
|---|---|---|---|
| 50% | 0.30 | 2.58 | 116 |
| 100% | 0.6 | | 233 |

Source: IATA (2013), *IATA Technology Roadmap, 4th edition*

**Exhibit 9**

## C. ALTERNATIVE LIQUID FUELS: SUSTAINABILITY ISSUES

Even if biofuels can be produced at a lower price premium to conventional jet fuel than synthetic fuels, it may be preferable to use synthetic fuels to meet at least part of the aviation sector demand if (i) there are limits to the amount of truly sustainable bioenergy that can be produced and/or (ii) if total lifecycle emissions in sustainable biofuels production are greater than those for synthetic fuels.

**The carbon footprint of the "power-to-liquid" synfuel route** depends on the process for capturing $CO_2$ and producing hydrogen:

- If the $CO_2$ is obtained via direct air capture and hydrogen produced from electrolysis, the carbon intensity of the synfuel over its lifecycle is solely determined by the carbon intensity of the electricity input and can potentially reach net-zero. However, the carbon intensity of the electricity input to synfuels needs to be below 115 grams per kWh – much lower than today's power grids carbon intensity – for synfuels to produce less emissions than fossil-fuel-based jet fuels[26].
- If, in turn, the hydrogen is produced through steam methane reforming (SMR), hydrogen production will need to be abated through carbon capture to tend towards zero lifecycle emissions, and could not fully reach net-zero lifecycle emissions given that carbon capture installations typically only capture up to 80-90% of the $CO_2$ stream. Methane leakages throughout the gas production value chain would also have to be brought to zero.
- Finally, synfuels using $CO_2$ captured on the back of industrial plants could not reach net-zero lifecycle emissions at it would only displace emissions from other sectors.

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[26] SYSTEMIQ analysis for the Energy Transitions Commission (2018)

**The environmental impact of the biofuel route** depends on both the total lifecycle $CO_2$ emissions involved in production and on the sustainability of bioenergy resources used, in a context of competition for land use. It is therefore essential to assess total potential sustainable bioenergy resources in light of the total amount of "claims" on bioenergy to decarbonize different sectors of the economy – and the specific position of aviation in this context. The ETC report *Mission Possible* analyzes those issues in chapters 6 and 7.

The relevant conclusions for aviation are that:

- Aviation is almost the only sector of the economy where (absent a major breakthrough in battery density and/or a sharp reduction in the carbon-intensity and price of power for hydrogen production) there appears to be no feasible alternative to a bio-based route to achieve net-zero carbon emissions. There is therefore a strong case for **treating aviation as the priority sector** claimant on a constrained supply of sustainable bioenergy.
- In the road transport sector, for light-duty as well as heavy-duty vehicles, it is highly likely that a non-biofuel decarbonization route will dominate, with electric drive trains (whether driven by batteries or hydrogen fuel cells) likely to be more cost-competitive. This implies that **aviation cannot rely on developments in the road transport sector to drive biofuels development and production volumes** sufficient to produce economies of scale and learning curve effects. If biofuels are to play a major cost-effective role in aviation, specific aviation-focused policies and industry initiatives will be required.
- The ETC suggests that a sustainable biomass supply of 70EJ could be produced each year, possibly going up to 100EJ thanks to tightly-regulated reforestation efforts[27]. The ICAO estimates that circa 600Mt of jet fuel will be necessary to cover all needs from aviation in 2050[28]. This equates to about 26EJ of final energy demand, which could require up to 45EJ of biomass input to biofuels production, given the relatively low efficiency of the transformation process. This would imply that, **in principle, all aviation demand could be met by sustainable biofuels production.**
- It is essential, however, that **biofuels are sourced in a truly sustainable way**, which should ideally not involve the significant use of plants which compete with food production, but be based primarily or entirely on waste streams (municipal, agricultural or forestry waste) or lignocellulosic sources. This implies that a tight definition of what constitutes a "sustainable biofuel" must be embedded in any policy aiming to increase biofuels uptake in aviation.

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[27] Energy Transitions Commission (2018), *Mission Possible*

[28] ICAO (2016), *Environmental Report*

# 5. COST OF FULL DECARBONIZATION OF AVIATION

As section 2 through 4 argued, although it is technically possible in the long-term to achieve a full decarbonization of the aviation sector "within itself" through alternative liquid fuels (producing zero carbon emissions over their lifecycle) and without purchasing offsets from other sectors, the cost associated with this decarbonization constitutes the single most important obstacle to progress. This chapter considers in turn:

- The cost to the economy derived from the abatement cost per tonne of $CO_2$ saved,
- The implications for the cost of fuel and of flight tickets purchased by consumers.

## A. COST TO THE ECONOMY

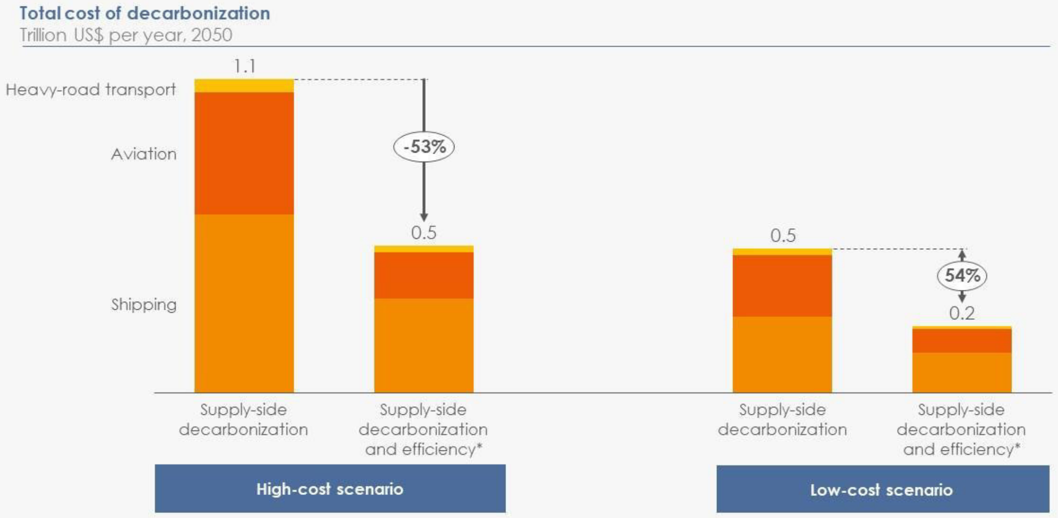
Actual abatement costs – and the least-cost route to decarbonization – will depend on future technological developments and cost trends. The ETC estimated that using biofuels or synfuels should **add a 50-100% cost penalty** to the cost of a liter of fuel, which corresponds to an abatement cost of US$115-230/tonne of $CO_2$.

An initial estimate of the maximum annual cost to the global economy of achieving net-zero $CO_2$ emissions within the aviation sector (with no use of offsets) can be generated by multiplying these abatement costs with the volume of $CO_2$ emissions projected by mid-century in a business-as-usual scenario. This indicative "cost to the economy" is still very low compared with an indicative 2050 global GDP: running a fully decarbonized aviation industry could amount to less than 0.13% of global GDP in 2050, or less than US$500 billion per annum [Exhibit 10 and 11].

This could be significantly reduced by three factors:

- **Lower renewable energy costs**: if zero-carbon electricity was available at US$20/MWh or below, the cost of the synthetic fuel route would be drastically reduced, bringing the cost penalty down to 100%.
- **Demand management**: energy efficiency improvements, a slower growth in demand for passenger flights, a modal shift to rail, and better air traffic management could reduce the total decarbonization cost by 60%, bringing the total cost of decarbonizing aviation to lower than 0.06% of global GDP.
- **Future technological development**: the cost of decarbonization could be dramatically reduced or even eliminated if technological improvements increase the efficiency in biomass-to-biofuel transformation, make bioenergy from lignocellulosic sources or algae cost-competitive, or bring to market cheaper synfuels.

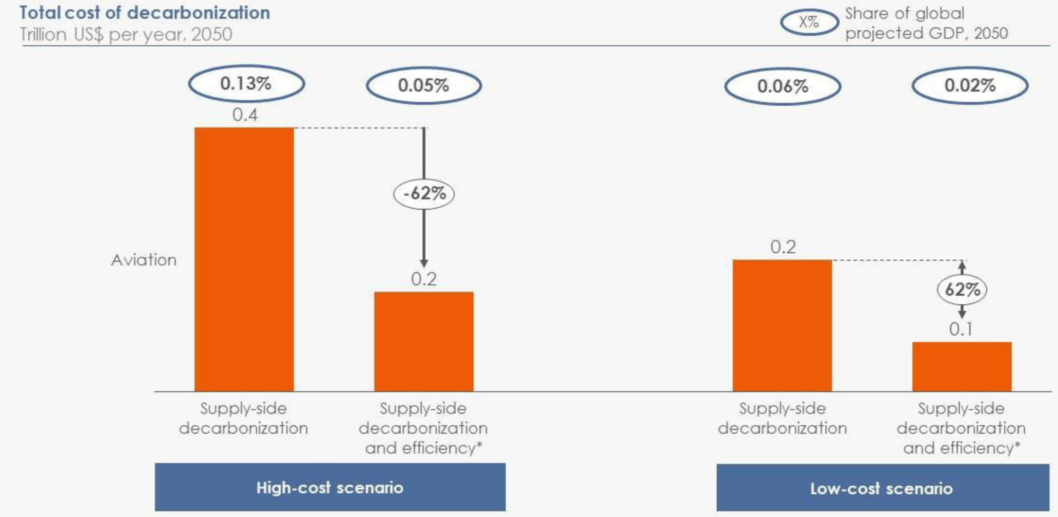
**Aviation is the second most expensive harder-to-abate transport sector to decarbonize**



Note: The term "efficiency" covers demand management
Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

**Exhibit 10**

**Decarbonizing aviation would cost less than 0.15% of global GDP, and significantly less if pursuing energy efficiency improvement and demand management opportunities**



Note: The term "efficiency" covers demand management
Source: SYSTEMIQ analysis for the Energy Transitions Commission (2018)

**Exhibit 11**

# B. B2B COST AND END-CONSUMER COST OF DECARBONIZATION

Unlike in other sectors of the economy, decarbonizing aviation will have a significant impact not only on the cost of the intermediary product (in this case the fuel), but also on the cost for end consumers:

- At the **intermediate product** level, the increase of the price of a liter of jet fuel could be as much as +100% when using zero-carbon fuels compared with conventional jet fuel. This high cost penalty advocates for putting in place strong policy incentives as market forces only are unlikely to drive decarbonization in that context.
- This could trigger up to **a 20% increase in the ticket price** for a typical long-haul flight (using an assumption of 2.57kg$CO_2$ per liter of jet fuel, the high-range abatement cost of supply-side decarbonization of US$230/tonne of $CO_2$, and an initial ticket price of US$400). This represents a significant price increase and the greatest price increase for any specific item of consumer expenditure that could arise from the full decarbonization of the economy. Indeed, cost penalties in other harder-to-abate sectors, such as steel or shipping, tend to be diluted in the final price of the end product, such as a car or an imported piece of clothing, which includes many other sources of cost. Despite this high impact on consumer prices, the decarbonization of aviation is **unlikely to alter overall living standards**, since international aviation accounts for less than 3% of global household consumption.

The implications of this cost penalty for appropriate policy are considered in Sections 6 and 7.

# 6. CONCLUSIONS AND POLICY IMPLICATIONS

The analysis set out above implies that aviation decarbonization will need to be primarily driven by energy efficiency and fuel switch rather than demand moderation measures, and that, in terms of supply-side decarbonization, the following will be the primary levers:

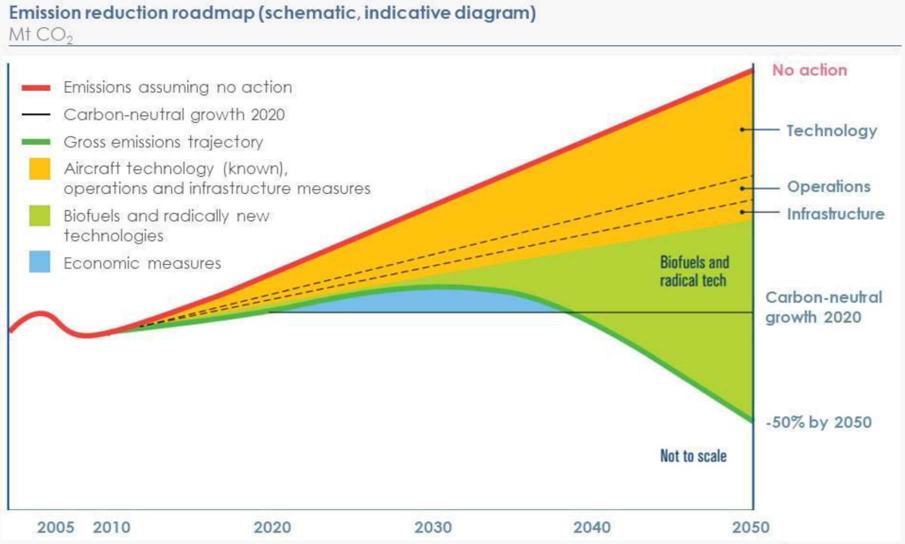
- **Continued significant improvement in energy efficiency** in engines and airframes, which will be driven primarily by already existing market incentives (given the competitive drive for fuel cost savings);
- **Improvements in Air Traffic Management (ATM) efficiency** which would require coordinated action by the industry and public authorities;
- **The gradual replacement of fossil-based jet fuel with either biofuels or synfuels,** even if, as is likely, this will impose, at least initially, significant additional fuel costs and thus imply higher ticket prices;
- **The development of electric battery and hydrogen-based planes for short- and medium-haul**, which would also be fostered by expectations of future higher jet fuel costs, and which would benefit from the public R&D support for battery and hydrogen fuel cell development, which is also required to support decarbonization in many other sectors of the economy.

Given the likely cost penalty of decarbonization, **the shift to biofuels and synfuels will only occur if governments impose either a carbon tax on fossil-fuel-based jet fuel, or regulatory mandates** requiring that a gradually increasing percentage of jet fuel is derived from bio or synthetic sources. However, given the international nature of aviation, there are limits (not absolute, but significant) to how far carbon pricing or regulation can be effective on a national or regional (e.g. European Union) basis.

# 7. EXISTING INDUSTRY INITIATIVES

2018 marked the 10th anniversary of the adoption of short and long-term climate goals by the aviation industry. In its first decarbonization roadmap, the International Air Transport Association (IATA) – representing 280 airlines – has set three main targets: 1.5% per year improvement in fuel efficiency from 2009 to 2020, carbon-neutral growth starting 2020, and 50% reduction in $CO_2$ emissions by 2050 relative to 2005 levels[29]. These objectives, although insufficient to enable a net-zero-carbon economy by mid-century, remain an essential first step and great example of industry commitment. To achieve them, the aviation industry has committed to improvements in the following areas [Exhibit 12][30]:

**The International Air Transport Association (IATA) has set global goals for the reduction of aviation's emissions**



Source: IATA (2013), *IATA Technology Roadmap, 4th edition*

**Exhibit 12**

- **Operations**: More than a third of the planned emissions reductions could come from efficiency improvements, in planes themselves and in operations (including via better air traffic management).
- **Sustainable Aviation Fuels**: The Sustainable Alternative Aviation Fuels Strategy is the framework by which the IATA hopes to meet its emission reduction target. Most of the emissions reduction will have to come from a switch to Sustainable Aviation Fuels (SAF), sourced from a variety of renewable and recycled feedstocks. In order for aviation fuels to be considered sustainable and not need to be offset, the fuels will need to meet ICAO's sustainability criteria, or Standards and Recommended Practices (SARPs), first-ever $CO_2$ emission standards for aircraft, adopted in June 2018. These low-carbon alternatives are significantly more expensive than traditional jet fuels, including a significant pricing factor for distribution, blending and fuel quality testing, putting industry adoption and SAF production capacity development at risk. However, many airlines have concluded long-term offtake agreements with SAF suppliers and different airports have agreed to supply SAFs through hydrant systems.

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[29] Hassan M., Pfaender H., Mavris D. (2018), *Probabilistic assessment of aviation $CO_2$ emissions targets*
[30] Sources: IATA (2018), *Countdown to CORSIA*; IATA (2013), *IATA Annual Review*; ICAO (2017), *Sustainable Aviation Fuels Guide*

For instance, British Airways announced in 2017 a new partnership with renewable fuels company Velocys, investing massively in a large-scale waste-to-fuel plant.

- **Market-based measures**: Unlike other solutions, these measures do not aim to reduce emissions in the aviation sector itself, but to offset them. Under CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation), aircraft operators of ICAO[31] member states will be required to offset $CO_2$ emission units based on their annual fuel consumption. This scheme is detailed in the box below. This initial use of offsets can be justified given that the aviation industry faces **high mitigation costs per tonne of $CO_2$** (US$1150-US$230 depending on premium cost of alternative hydrocarbons) compared with other sectors of the economy. However, it should only be transitional if the world is to reach the target of net-zero carbon emissions from the energy and industrial systems by mid-century.

The latest ICAO analysis suggests that **current policies and likely developments would not drive rapid enough alternative fuel growth to achieve even flat emissions between now and 2050 let alone a 50% reduction**[32]. It is therefore essential to put in place policies and industry actions which can ensure the rapid development of either sustainable biofuels or synfuels to make the IATA target of a 50% reduction in carbon emissions credible, and then to raise that target to net-zero carbon emissions by 2060 at the latest.

### Box 1 – CORSIA: a carbon offsetting and reduction scheme in aviation

Agreed by the International Civil Aviation Organization Assembly (ICAO, a specialized agency of the United Nations) in October 2018, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is the world's first global, sector-wide market-based climate measurement. A total of 73 ICAO members, representing more than 87% of the international aviation activity, have volunteered to take part in CORSIA. During the initial pilot phase (2021-2023) and first voluntary phase (2024-2026), operators that use air routes between voluntary states will have to offset their $CO_2$ emissions (which will be calculated by applying the annual sectoral increase in carbon emissions to the 2018 baseline emissions of each individual company). This will create a powerful incentive for emissions reduction within the aviation sector, while also creating space for a transitional solution through the use of offsets, most probably from the land use sector. Moreover, to establish a reference scenario for later offsetting requirements, a global baseline of $CO_2$ emissions from international aviation activity is to be established and finalized by 2020. This baseline will then be used to measure progress over the following decades. As part of this program, all airlines operating international flights will have to monitor and report fuel consumption and emissions from January 2019. These measurements will be key to provide a reliable dataset to calculate the sectoral 2020 emissions baseline. To kickstart this, the ICAO launched a successful training program (ACT-CORSIA) in July 2018, which had over 500 participants across 250 airline companies. Company-level baselines will then be used to set detailed targets that airlines will need to comply with from January 2021.

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[31] ICAO: International Civil Aviation Organization, specialized agency of the United Nations

[32] ICAO (2016), *Environmental Report*

# 8. RECOMMENDATIONS

To some extent, **the transition to net-zero-carbon aviation is more straightforward than in other sectors**. Whereas in trucking public policy needs to play a role in supporting electric charging or overhead wiring infrastructure, and whereas in industry sectors there are often complex transition challenges for closely integrated industrial clusters with long-lived assets, in aviation, the fact that the transition will almost certainly be driven by increasing use of a "drop-in" biofuel or synthetic fuel, utilizing existing engines and fuel distribution infrastructure, greatly simplifies the transition. But strong public policies, together with industry action, will still be essential to accelerate the pace of change.

## A. RESEARCH AND DEVELOPMENT

Public R&D support, aviation industry collaborative research projects, and individual company R&D investments should focus in particular on:

- Improvements in **airframe and engine efficiency**;
- Driving down the **cost of producing biofuels** from clearly sustainable waste, lignocellulosic or algae-based biomass resources;
- Driving down the cost of Direct Air Capture of $CO_2$ and of hydrogen electrolysis, to make possible **cheaper production of synthetic fuels** from low-carbon electricity.

In addition, it is possible that future improvements in battery density and/or in hydrogen tanks and fuel cells will increase the range of flights for which battery or hydrogen power is feasible and economic. Further R&D investment in these technologies is therefore also vital, though likely to be driven primarily by other sectors of the economy, such as trucking.

## B. PUBLIC POLICY

The most important public policy priority in the aviation sector is to **ensure clear incentives for the gradual replacement of fossil-fuel-based jet fuel by sustainable biofuels or synthetic fuels**, even if these are significantly more expensive. Given the international nature of aviation, which creates some (though not limitless) potential for international relocation of flight paths to avoid region-specific taxes and regulations, international coordination is ideal. Government should therefore seek to achieve international agreement, with other governments and/or the airline industry for the imposition of either/both:

- **A carbon tax on aviation fuel** which grows steadily and in a predictable fashion to reach by 2050 the levels (e.g. US$200 per tonne) required to ensure an eventual complete shift to zero-carbon fuels;
- **A "green fuel" mandate** which specifies a gradually increasing percentage of aviation fuel which must be sourced from zero/low-carbon and clearly sustainable sources. These mandates should impose a growing share of zero-carbon fuels through time, aiming for 100% by 2050.

This effort could be led at a regional level first – on domestic and intra-regional flights, within regions with large volume of internal flights (such as China, India, the European Union and the US) – and then expand globally, potentially under the auspices of ICAO. Countries/regions should also assess how far national/regional carbon prices and green fuel mandates can be imposed on international flights without provoking significant changes to flight patterns.

**In addition, governments should:**

- Use public expenditure, guided by target driven R&D objectives, to support the R&D priorities described above;
- Define clear standards for "sustainable jet fuels" which ensure that it is produced from clearly sustainable sources, taking into account both the lifecycle carbon emissions of both biofuels and synfuels, and the broader environmental impact of biofuels given implications for land use;
- Prioritize biofuels use in aviation, as against other sectors of the economy, possibly through differentiated support schemes and/or taxations;
- Work with the airlines and airport operators to achieve maximum possible improvements in ATM efficiency.

## C.INDUSTRY COLLABORATION AND COMMITMENTS

Airlines have a huge private incentive to maximize energy efficiency, and purely private incentives are therefore likely to drive the airframe and engine suppliers to continue achieving major efficiency improvement. But shared industry commitments to an overall roadmap – such as set out by IATA in 2009 and reiterated subsequently – can play a crucial role in maintaining momentum for change.

**IATA should therefore continue to update its roadmap by:**

- Raising its targets to achieve not only a 50% reduction in carbon emissions by 2050, but a near-total decarbonization of the sector;
- Establishing a shared vision of how large the potential for airframe and engine efficiency improvement is and what investments are required to deliver these;
- Establishing a shared vision of how large the potential for operational efficiency improvement is and who has to do what (as between airlines, airport operators and ATM operators) to deliver those improvements;
- Committing to gradually increasing targets of Sustainable Aviation Fuels use, with a clear pathway to reach 100% by mid-century, which will provide a higher level of certainty on future volumes to alternative fuel producers and therefore facilitate the scale-up of the production of zero-carbon jet fuels;
- Committing to a phase-out of offsetting schemes over the next 20 years to be replaced by a decarbonization of the sector within itself through a shift to Sustainable Aviation Fuels.

In addition, coordination between airlines and major consumers of air travel (in particular through travel agents and major business flight consumers across multiple economic sectors) could lead to the **development of a "green flight" certified offer at a premium price**. Many companies already committed to climate-related commitments, for instance through initiatives like We Mean Business or Science-Based Targets, are taking commitments to offsets their emissions from air travel. The option to pay a premium for certified low-carbon air travel could be an alternative to these widespread offsetting commitments, which could drive initial growth in demand for sustainable fuels and trigger early economies of scale.

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