AIRLINES FOR
AUSTRALIA &
NEW ZEALAND

An Australian Roadmap for Sustainable Flying

REACHING NET ZERO BY 2050

AIR NEW ZEALAND A STAR ALLIANCE MEMBER
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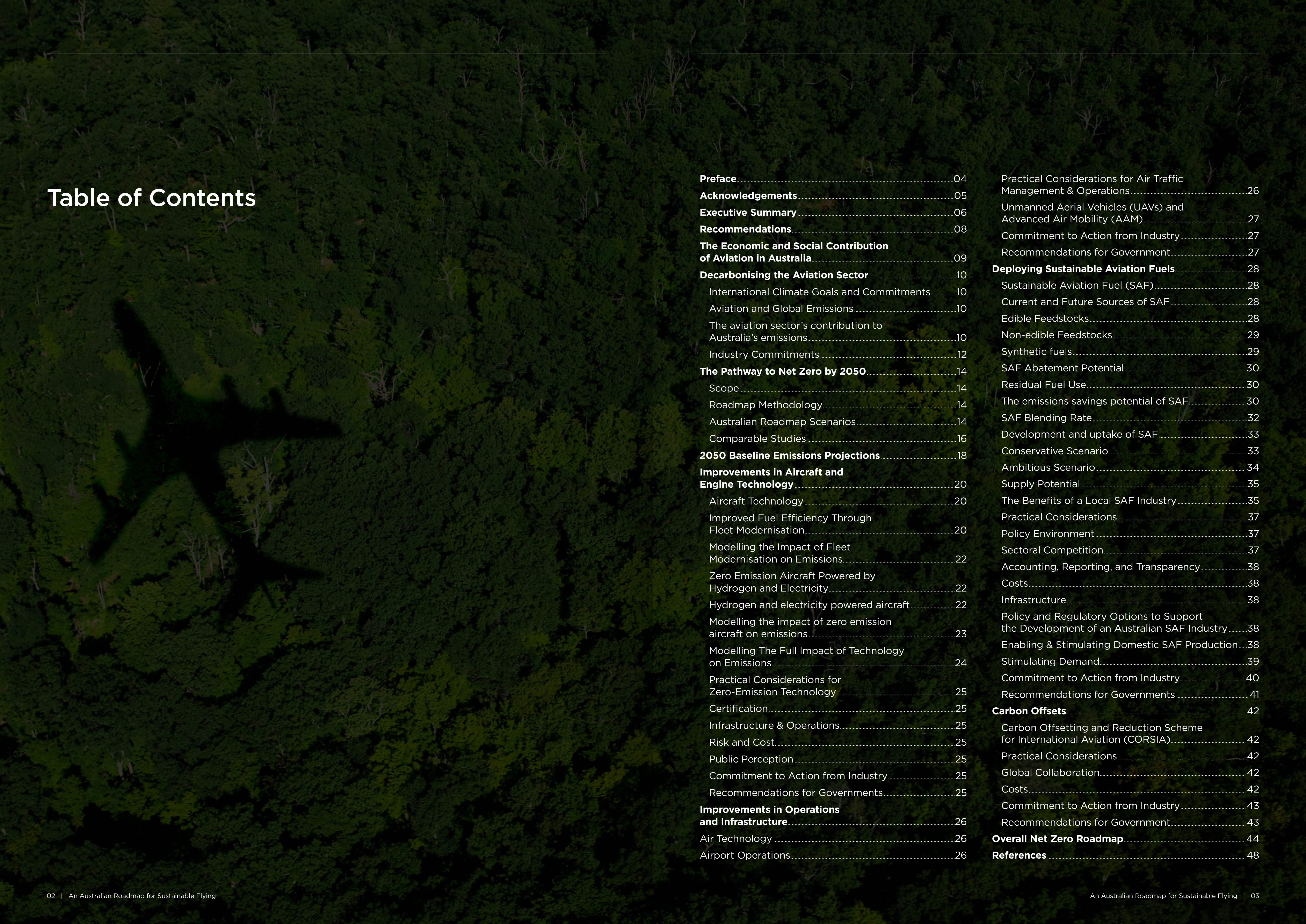

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Preface

It has long been said that Australians love to fly – but we also need to fly; our connectivity, our regions, and so much of our national economy depends on it. The COVID-19 pandemic has shown the importance of those connections more than ever, and a thriving aviation sector is a necessity for Australia.

However, as Australia's aviation sector has grown, so too have its emissions. As we face into a global climate crisis, the aviation sector is aware of its responsibilities to decrease emissions. More importantly, it is committed to meeting these responsibilities – even as air traffic increases and the sector recovers from the devasting impact of the pandemic.

This Roadmap aims to outline the path towards decarbonising flying in Australia, and to reach net zero emissions by 2050. While airlines are of course the major source of emissions within the aviation sector, reaching net zero by 2050 won't be possible without shared goals and collaborative efforts. It is from this perspective that the Roadmap has been drafted.

In keeping with other regional and country-specific roadmaps, the Australian Roadmap covers emissions from all domestic and departing commercial (RPT) international flights. Its scope does not include emissions from arriving international flights, general aviation, dedicated freight flights, or Australian Defence Force operations.

While commitment from stakeholders to the short- and medium-term targets will be necessary for the sector to reach its long-term target of net zero by 2050, this does not remove the need for our Roadmap to be adaptable to change. Compared to earlier international work, for example, this Roadmap – developed in 2022 – contains assumptions and projections which account for the impact of COVID-19 on aviation emissions.

In the short time since the Australian aviation sector committed to the goal of net zero by 2050, we have already seen changes – in governments, policy agendas, science and technology plans, corporate commitments, shareholder and societal expectations – all of which have shifted our thinking on both what is needed, and what is possible.

While there is still quite a bit of uncertainty, what is clear is that the Roadmap we design today will not be for a path set in stone, nor does this Roadmap describe the only pathway to reach net zero CO_2 emissions. Developments in technology, changes to policy, and investment decisions will help to shift and shape our pathway to net zero aviation by 2050.

Acknowledgements

The Australian Roadmap for Sustainable Flying: Reaching Net Zero by 2050 was initiated by Airlines for Australia and New Zealand (A4ANZ) on behalf of its members.

A4ANZ is an industry group representing airlines based in Australia and New Zealand, including international, domestic, regional, full service and low-cost carriers. Established in 2017, A4ANZ's members include Qantas, Virgin Australia, Regional Express (Rex), Jetstar, and Air New Zealand.

A4ANZ would like to acknowledge the early advice on scope and process from Airlines for Europe (A4E), and the superb work from Frontier Economics (Australia) who were engaged to undertake the modelling and analysis which underpins this Roadmap.

While A4ANZ has led the development of the Roadmap, our work has been supported and informed by stakeholders from across the aviation sector – with feedback and input provided by airlines, airports, aviation peak bodies, government agencies, and industry groups, and for this we are extremely grateful.

A4ANZ would especially like to acknowledge the valuable contributions made during the development and drafting of this Roadmap by representatives from Airservices Australia, Air New Zealand, the Australian Airports Association, Bioenergy Australia, Boeing, Low Carbon Solutions Australia, Qantas Group, the Regional Aviation Association of Australia, Regional Express, and Virgin Australia.

This Roadmap reflects the collective commitment to the challenging task of decarbonising aviation in Australia.

Disclaimer

The results and analyses contained in this report are based on technical, circumstantial, or otherwise specified assumptions and parameters, and are reflective of a single point in time. The results and analyses contained in this roadmap represent two potential pathways by which airlines in Australia might achieve net zero emissions by 2050 – this report does not purport to provide a formal or conclusive pathway towards net zero, nor is it exhaustive.

The reader must make their own assessment of the suitability for use of the information or material contained in or generated from the Roadmap. To the extent permitted by law, A4ANZ excludes all liability to any party for expenses, losses, damages and costs arising directly or indirectly from using this report.

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The views expressed in this report do not necessarily represent the views of any single or all participating organisations.

Executive Summary

Aviation plays a critical role in Australia's connectivity – linking our cities across vast distances and servicing the needs of regional communities, by providing access to transport and freight, medical and social services, and travel for business and tourism. It also facilitates connection to the world – enabling trade and tourism of significant value to Australia's GDP.

Emissions from domestic aviation account for just 1.5% of Australia's total emissions but total aviation emissions continue to grow, despite measures taken by the sector over the past decade to increase fuel efficiencies and decrease emissions intensity. Aviation emissions are projected to grow steadily over government projection horizons, as activity continues to grow generally in line with population. To reverse or even arrest this growth is no simple task. It is well recognised that aviation is one of the most challenging industries to decarbonise, and this is particularly so in a country like Australia which relies heavily on flying for its connectivity.

The aviation sector is committed to the firm target of achieving net zero emissions by 2050, backing in the global airline industry's 2021 net zero resolution[2], and supporting broader commitments by the Federal Government for Australia to reach net zero by 2050.[3]

As we note in this Roadmap, aviation in Australia has limited options for reducing its emissions to the extent required to reach this target. Frontier Economics was engaged to model the emissions reduction potential of various abatement options for meeting net zero by 2050.

This modelling produced two scenarios, based around the largest viable contributor to emissions reduction – the replacement of conventional jet fuel with Sustainable Aviation Fuels (SAF). The first was a conservative projection, using assumptions of SAF uptake by airlines based on previously-announced SAF purchasing commitments by Australian airlines and fuel blending targets consistent with those mandated in other jurisdictions. The second, a more ambitious projection, assumes an almost total replacement of conventional jet fuel with SAF by 2050, and relies on strong industry and government commitment, and a supportive policy environment. This second scenario envisages a greater contribution from measures that reduce gross emissions – the utilisation of SAF, as well as the implementation of new technology, and operational efficiencies – enabling a reduced reliance on carbon offsets.

Both scenarios – with the modelling and its associated inputs and assumptions – were benchmarked against existing international roadmaps. This again highlighted the significant limitation that Australia's unique geography and flight characteristics place on opportunities in the emerging technology area, e.g. hydrogen and electric planes are expected to be viable only for shorter flights and smaller planes well into the 2040s. Similarly, despite being an early-adopter of SAF, moves for Australia to have its own biofuels production capability are only just beginning, in comparison with some other jurisdictions such as the US and Europe, where this is an emerging and fast-growing industry. Notwithstanding these differences, the modelling demonstrated that the path outlined by these international roadmaps is also possible in Australia.

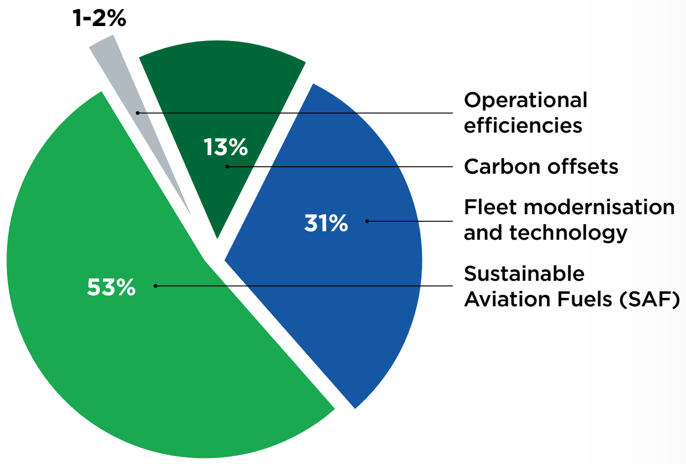


Figure 1 – Potential proportionate contributions of each measure in 2050.

If the available options are exploited to their full potential in Australia, it will enable the sector to reach its goal of net zero by 2050 through projected reductions in emissions they each contribute. See **Figure 1** (page 6) for the potential proportionate contribution of the key measures in 2050.

This Roadmap explores each of these emissions reduction measures, outlining the potential impact they will have on airline emissions in Australia. Importantly, the Roadmap sets out the commitments to action from industry, and the recommendations for governments to build policy and investment frameworks that will support and enable industry efforts. A good example of this need for collaborative effort is the fact that, while aircraft may eventually be certified for 100% SAF use, a persistent challenge for airlines will be its cost, with SAF currently 3-6 x conventional jet fuel prices. With fuel often being the largest cost for airlines – already operating at low margins and recovering from the effects of the pandemic – this is likely to defer the full uptake of SAF until it becomes commercially viable to do so. The Roadmap explores methods by which this cost gap might be bridged, drawing on international experience.

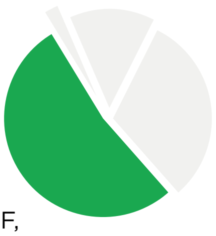
It is a reality of the challenge to decarbonise aviation that, in the short-to medium-term, well-designed, market-based measures and high-quality offsetting will remain the key to reducing emissions from domestic and international flying – especially in the Australian market, where SAF are not yet locally available. Then, in the longer-term, offsets will only be required to bridge the gap remaining after all the other measures to reduce emissions – have been implemented at scale. It is therefore critical that policy and investments in these other measures begin early, and we have set out a series of recommendations for Government accordingly.

Achieving the targets required to reach net zero emissions will not be easy and will take sustained and cooperative action by all stakeholders across the Australian and global aviation sectors – including airlines, airports, air traffic control, ground handling companies, fuel producers, investors, regulators, and governments. This Roadmap charts a realistic course and represents a clear commitment from the Australian aviation sector for achieving net zero emissions by 2050.

> ***"Aviation is an irreplaceable industry, especially for a country the size of Australia, and one that's located so far away from so much of the world. Future generations are relying on us to get this right so they too can benefit from air travel."*** [1]

Recommendations

These recommendations broadly outline what is required to facilitate the aviation sector to reach its full potential in achieving the ambitious pathway to net zero emissions by 2050. They are not intended to be an exhaustive list of actions that governments could take, and the industry will continue to contribute to more detailed policy development both through the Australian Jet Council and in other forums.



Sustainable Aviation Fuels

1. The collaborative forum announced by the Federal Government – akin to an Australian Jet Council – must be enabled to: provide leadership on SAF, establish a coordinated national strategy, and implement a supportive policy framework.
2. In consultation with the Australian Jet Council, the Federal Government should progress economic and regulatory policy measures to support the production and supply of SAF.
3. In consultation with an Australian Jet Council, the Federal Government should progress economic and regulatory policy measures to stimulate uptake and use of Australian-made SAF.

Fleet Modernisation and Technology

4. The Federal Government should work with industry to design and implement the necessary supporting policies, infrastructure, and investment required for new aviation technologies to be deployed in the Australian aviation sector.
5. The Federal Government should ensure that the regulator, the Civil Aviation Safety Authority, is adequately resourced and prepared to support the certification process of novel airframe configurations and propulsion systems.

Carbon offsets

6. The Federal Government should continue to support the CORSIA program and assist other nations in implementing CORSIA as required.

Operations

7. The Federal Government should ensure the optimisation air traffic management, through the implementation of OneSky and other Airservices Australia programs, is realised and evaluated for continual improvement.
8. The Federal Government should progress initiatives outlined in the NEAT Policy Statement and the National Strategic Airspace Issues Paper.

The Economic and Social Contribution of Aviation in Australia

Australia's unique geography means that there are remote communities that are only accessible by air or that are long distances from major population centres, making travel by road time consuming and expensive.[5] Aviation therefore plays an important role servicing the needs of these communities by providing access to key services, including transport and freight, medical services, social services and law enforcement, and travel for business and tourism.

Prior to the COVID-19 pandemic, the air transport sector contributed:

AUD$104B to the Australian economy,

and directly and indirectly supported **716,000 jobs.**[6]

The airline industry is a significant source of economic activity on its own; pre-pandemic, it contributed

$9.4 billion to the economy	and supported **50,000 jobs.**[7]

The effect of the COVID-19 pandemic, in bringing movements to, from and within Australia to a standstill, highlighted the critical and substantial importance of air transport to the Australian economy. Analysis published by the Business Council of Australia estimated that the economic fallout from the shutdown of domestic and international aviation in Australia for just the first six months of the pandemic alone (Mar-Oct 2020) was $17 billion and $61 billion respectively.[8]

Federal Government assistance enabled the aviation industry to play a significant role in maintaining economic and social links within Australia, throughout the pandemic. The various programs enabled critical aviation capacity to be preserved, supporting essential air connectivity to regional and remote communities and in maintaining freight links during the pandemic – the majority of which (approximately 80%) is carried in the cargo-hold of passenger aircraft.[9]

> ***"Aviation provides transport for both communities and businesses and plays a key role in connecting remote and rural areas. Regional regular public transport (RPT) air services... are central both to the community's lifestyle and wellbeing as well as regional development."*** [4]

Air freight is a significant contributor to the economy – generating $10 billion (0.5% of GDP) annually[10] – because it is predominantly used to transport high-value, time-critical goods, including pharmaceuticals, high-end manufacturing products, and highly-perishable goods such as seafood. In a typical year, 1 in every 5 dollars of Australia's goods trade travels via air freight, even though it is less than one percent of trade volume.[11]

Efficient air transport supply-chains lower the cost of goods and services, which in turn improves the international competitiveness of Australian businesses. This drives economic growth, tourism, investment, and trade. There is a strong relationship between improved air connectivity and business trade and investment, which together boost GDP and employment.

Ensuring that these economic and connectivity benefits can be maintained for Australia while simultaneously neutralising the aviation sector's impact on the climate is the priority for signatories to this Roadmap.

While the impact of the COVID-19 pandemic on the aviation industry has been devastating – and orders of magnitude greater than any other previous global event, including 9/11, SARS, and the global financial crisis[12, 13] – Australia's aviation sector remains steadfast in its commitment to achieving net zero emissions by 2050, and assisting Australia to meet its climate commitments and international obligations.

This Roadmap represents a major priority for the sector, to outline potential pathways for the Australian aviation sector to decarbonise and achieve net zero by 2050.

Decarbonising the Aviation Sector

International Climate Goals and Commitments

The 2015 Paris Agreement is a legally binding international treaty on climate change, which was entered into during the 21st Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC). The goal of the Paris Agreement is to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels.[15]

In 2018, a special report from the Intergovernmental Panel on Climate Change (IPCC) stated that the rise of global average temperatures – when compared to pre-industrial levels – should be limited to 1.5 degrees Celsius to prevent further and irreversible harm to the planet.[16]

The IPCC determined that in order to achieve this, net zero carbon emissions must be reached by 2050.[17]

In 2021, the then Australian Government affirmed its commitment to net zero emissions by 2050,[18] and in October 2021 released Australia's Long Term Emissions Reduction Plan.[19]

The newly-elected Labor Government has since legislated through the Australian Parliament a commitment to reduce Australia's emissions by 43% by 2030 – which will become Australia's target under the Paris Agreement – keeping Australia on track to reach net zero by 2050.[20]

Aviation and Global Emissions

In June 2020, the International Energy Agency (IEA) reported that CO_2 emissions from the aviation sector accounted for 2.8% of global CO_2 emissions from fossil fuel combustion in 2019.[21]

While there have been international (largely Scandinavian) calls for people to fly less as the key means of reducing aviation's contribution to global emissions,[22] such a proposal vastly oversimplifies what is a complex global challenge. More importantly, it ignores the positive, unique and vital role that the aviation industry plays in connecting the world, adding immense value to the global economy.

Prior to the COVID-19 pandemic, the global aviation industry

supported **87.7 million jobs** around the world

and contributed **$3.5 trillion** in worldwide economic activity – or 4.1% of global gross domestic product (GDP).[23]

Given this, flying less is not a viable alternative to progressing other, effective emissions reductions measures – particularly for countries such as Australia, a large island nation with challenging geography, which is reliant on aviation for so much of its connectivity.

Instead, the aviation industry – in partnership with governments – is actively exploring and implementing opportunities that exist for sustainable future growth in the sector, to reduce emissions and contribute to a cleaner environment, whilst enabling increased connectivity, jobs, and economic development.

The aviation sector's contribution to Australia's emissions

In 2019, emissions from domestic aviation were 8 Mt CO_2-e, or 8% of total transport emissions (see **Figure 2**).[24] While they account for a much smaller proportion of Australia's total emissions – just 1.5% – government projections show that in 2022, domestic aviation emissions are projected to reach a minimum of 4 Mt CO_2-e, and to return to and exceed pre-pandemic levels by 2024.[25] This growth in total aviation emissions continues, despite measures taken by the sector over the past decade to increase fuel efficiencies and decrease emissions intensity.[26]

From 2025 onwards, aviation emissions are projected to grow steadily over the remainder of the projection horizon, as activity continues to grow generally in line with population.[27]

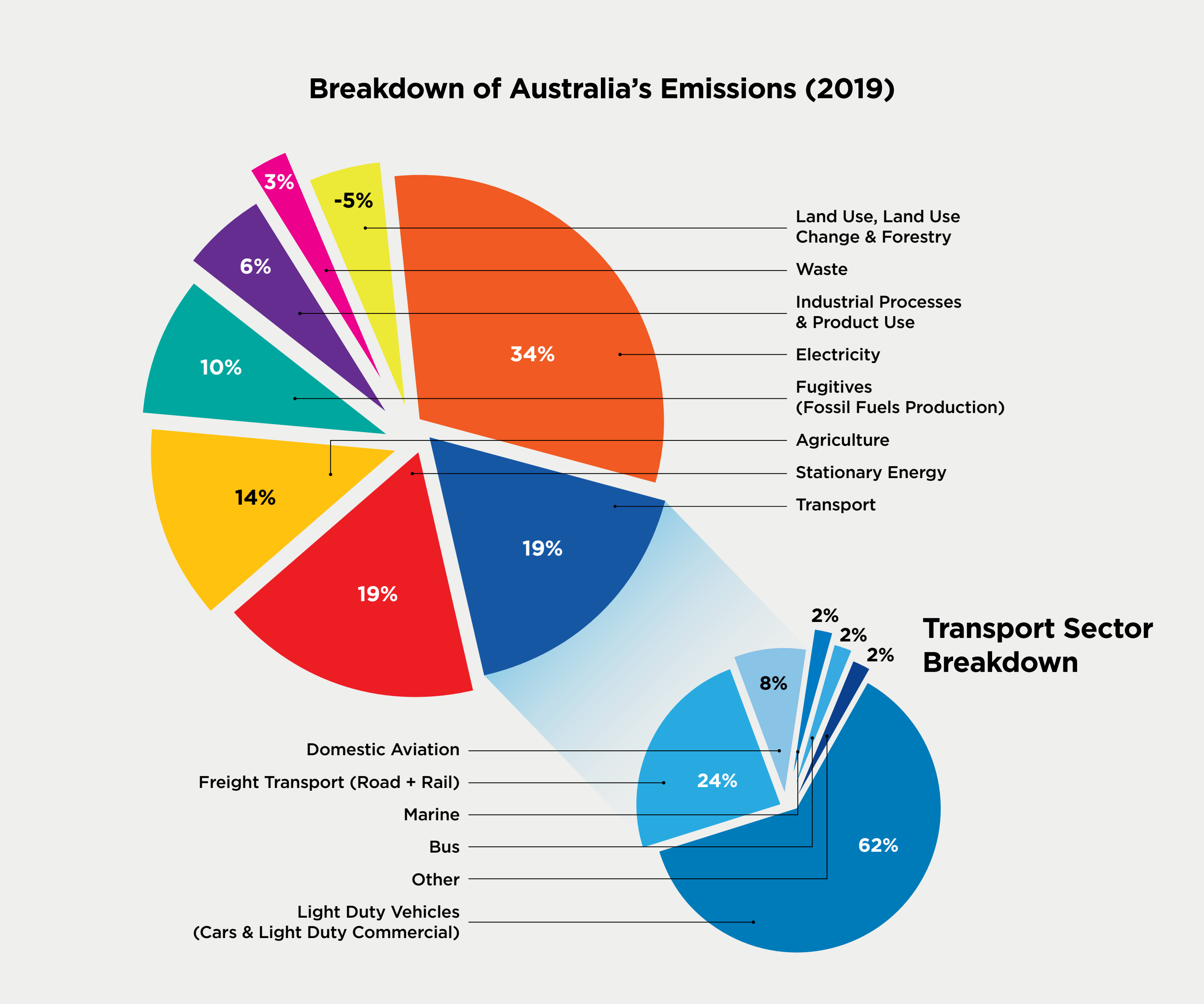


Figure 2 – Domestic aviation's contribution to Australia's emissions in a whole of economy context.

To arrest and reverse this projected growth is no simple task. It is well recognised that aviation is one of the most challenging industries to decarbonise,[28] and this is particularly so in a country like Australia which relies heavily on flying for its connectivity.[29]

As highlighted earlier, Australia's geography, and the resulting nature of longer-distance flying means that:

- modal substitution (e.g. train travel, driving) is not currently a realistic option given the distances and time involved;
- zero-emission aircraft will likely only have limited impact in the Australian market until 2045-2050, despite their promise earlier in other markets with shorter routes (e.g. EU, UK, NZ); and
- sustainable aviation fuel must be the mainstay of efforts to reach net zero, alongside other measures like electrification, operational efficiencies, and offsetting.

Achieving net zero emissions targets will not be easy and will take sustained and cooperative action by all stakeholders across the Australian and global aviation sectors – including airlines, airports, air traffic control, ground handling companies, fuel producers, investors, regulators, and governments.

This Roadmap reflects the collective commitment to the challenging task of decarbonising aviation in Australia.

Industry Commitments

Prior to the COVID-19 pandemic, many regions, countries, and individual airlines had pledged to reach net zero emissions by 2050.[31] A number of airlines based in Australia – and across the Tasman in New Zealand – have been leaders in not only making commitments to reaching net zero emissions by 2050[32,33] but by utilising Sustainable Aviation Fuels in early trial flights,[34] and recently, in pursuing other technologies such as zero-emissions aircraft.[35]

While efforts to reduce Australia's aviation emissions have been in place for more than a decade,[36] the aviation sector is now committed to the firm target of achieving net zero emissions by 2050, backing in the global airline industry's 2021 net zero resolution,[37] and supporting broader commitments by the Federal Government for Australia to reach net zero by 2050.[38]

Supportive government policy will be critical in enabling these commitments by industry to become the reality, and for the aviation industry to transition to low and zero-emissions technologies.

The Australian Government has recognised that this is a challenge that can only be overcome through collaboration and has made a welcome commitment to work across portfolios and with industry partners, to support the sector in achieving net zero.[39]

As noted earlier, aviation has limited options for reducing its emissions in order to reach its targets.

This roadmap explores the potential reductions in emissions that can be delivered by four key measures:

Efficiency gains from improvements in engine and aircraft technology, including through fleet modernisation, and the potential use of hydrogen and electric planes

Efficiencies through the optimisation of flight paths and air traffic management operations

Deployment of Sustainable Aviation Fuels (SAF)

Economic or market-based measures (i.e. carbon offsetting)

In the following sections, we explore each of these emissions reduction measures, outlining the potential impact these measures will have on airline emissions in Australia, the commitments to action from industry, and the recommendations for governments.

> ***"There is a great opportunity to develop a thriving sustainable fuels industry, which will help to reduce emissions and drive investment and jobs growth in Australia."***[30]

The Pathway to Net Zero by 2050

Scope

As noted in the Preface, this Net Zero Roadmap covers CO2 emissions from all domestic and departing commercial (RPT) international flights.

Many airlines – based in Australia and overseas – operate international flights to and from Australia. Emissions from arriving international flights are included in individual airline company emissions accounting, where relevant. These flights have therefore been purposefully excluded from the scope of this Roadmap, in order to avoid the double-counting of emissions and to respect international emissions accounting standards.

Consistent with other regional and country-specific roadmaps, this Roadmap does not include emissions from general aviation or dedicated freight flights. It is important to note that, in Australia, over 80% of all air freight – both domestic and international – is carried in the cargo hold of passenger flights, and as such, emissions from the carriage of the domestic portion of this freight are included in this Roadmap.[i]

There is also an expectation that dedicated freight aircraft will utilise the same measures as passenger aircraft – outlined in this Roadmap – to reach net zero emissions by 2050.

Emissions from airport operations, aircraft manufacturing, aircraft maintenance, and Australian Defence Force activities are not included in this Roadmap. Encouragingly, we understand each of these sub-sectors to be concurrently pursuing their own strategies to reach net zero by 2050.

Roadmap Methodology

Frontier Economics (Frontier) was engaged to develop baseline emissions forecasts, and to model the emissions reduction potential of abatement options for meeting net zero by 2050 for the aviation sector in Australia.

To develop the net zero roadmap, Frontier undertook the following steps:

1. Established baseline emissions growth in the absence of measures to reduce emissions.

   This required historical or reference year emissions, future growth (driven by population and travel per capita) and the emissions profile (domestic versus international and emissions by length of flight, as this affects potential abatement options).

   The baseline excludes any efficiency gains from fleet modernisation, as this is a source of abatement.

2. Estimating emissions reduction potential of each abatement measure. As noted above, the main measures for reducing aviation emissions include:

   - efficiency gains from improvements in engine and aircraft technology, including through fleet modernisation, and the potential use of hydrogen and electric planes;
   - efficiencies through the optimisation of flight paths, air traffic management operations;
   - deployment of Sustainable Aviation Fuels (SAF); and
   - economic or market-based measures (ie. carbon offsetting).

Australian Roadmap Scenarios

Frontier was asked to model two scenarios based on different levels of SAF uptake from 2025 to 2050, and the subsequent emissions reductions from this. The scenarios are presented on the following page.

The Conservative Scenario (see **Figure 3**) presents a projection of SAF uptake based on announced SAF purchasing commitments by Australian airlines. These blending targets are broadly in line with mandated blending targets in other jurisdictions.

A second Ambitious Scenario (see **Figure 4**) presents a more aggressive development path for SAF that may be realised with strong industry and government commitment, and a supportive policy environment.

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[i] Noting that more than 60% of airfreight in Australia is inbound – that is, being imported on flights that originate outside of Australia, and as such is outside the scope of this Roadmap. It is, however, captured as part of airline emissions' calculations at destinations or as part of their total international emissions accounting.

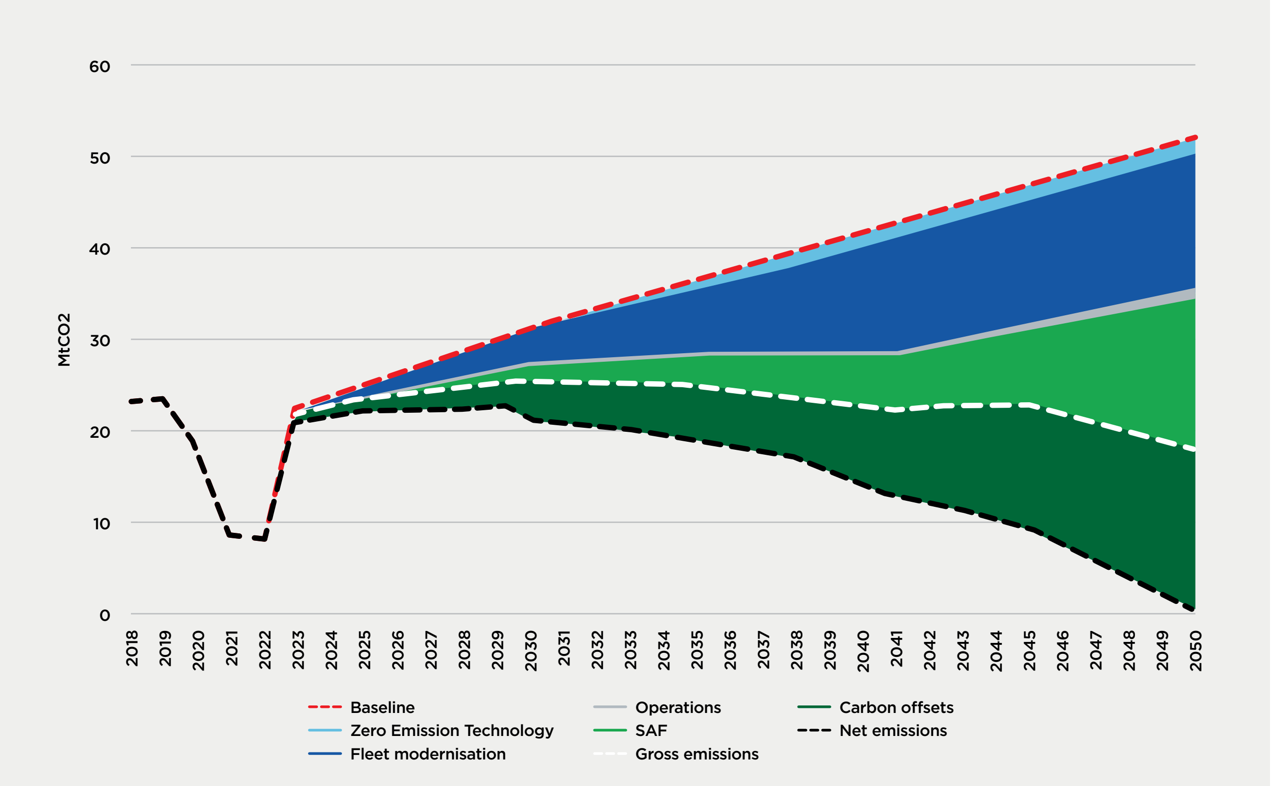

Figure 3 – Australian Roadmap for Sustainable Flying – Scenario of Conversative SAF Uptake

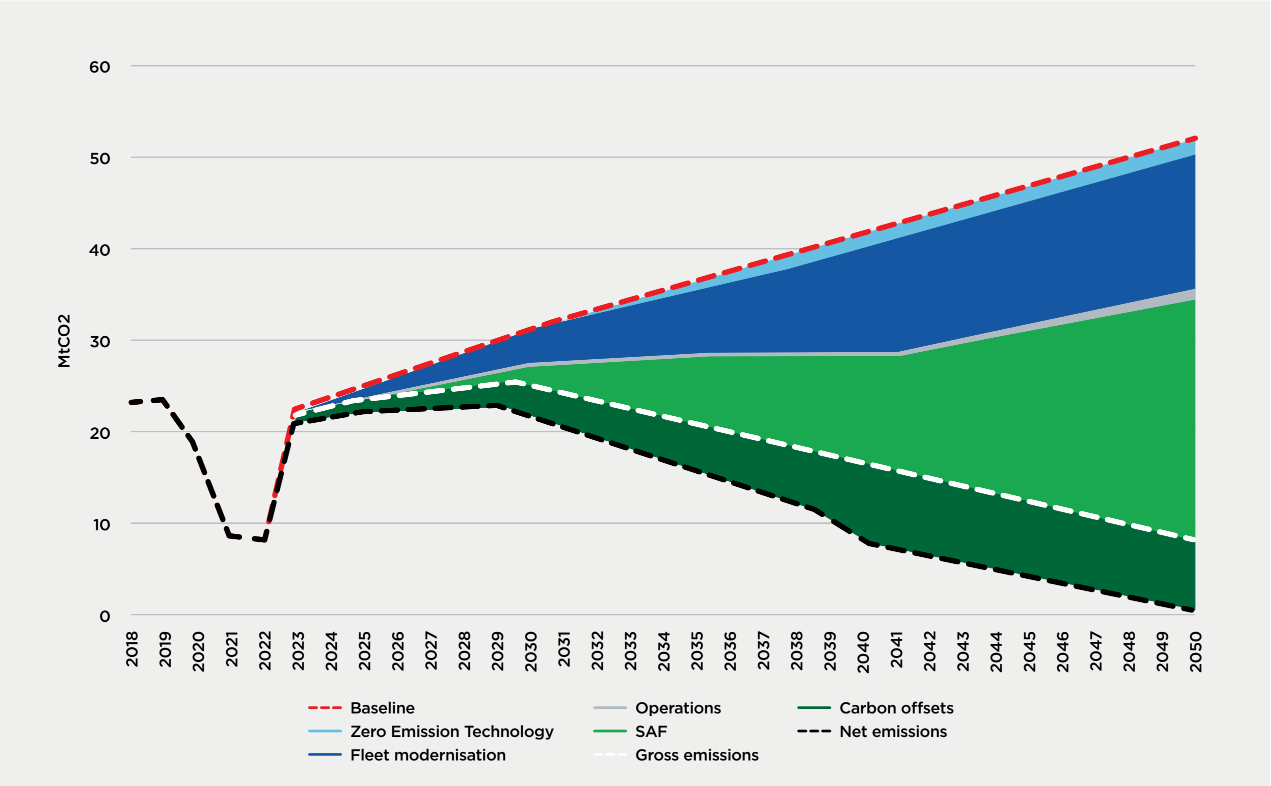

Figure 4 – Australian Roadmap for Sustainable Flying – Scenario of Ambitious SAF Uptake

Comparable Studies

To validate their modelling, and the accompanying assumptions and inputs, Frontier also benchmarked the two scenarios against existing international roadmaps (see **Figure 5**).

Differences in geography and flight characteristics explain differences in opportunities: for example, technology (hydrogen and electric planes) is limited to shorter flights. There are also differences in assumptions around potential future SAF blending rates given uncertainty around technical potential. Notwithstanding these differences, Figure 5 shows that there are many similarities between what is possible in Australia and what these international roadmaps have modelled.

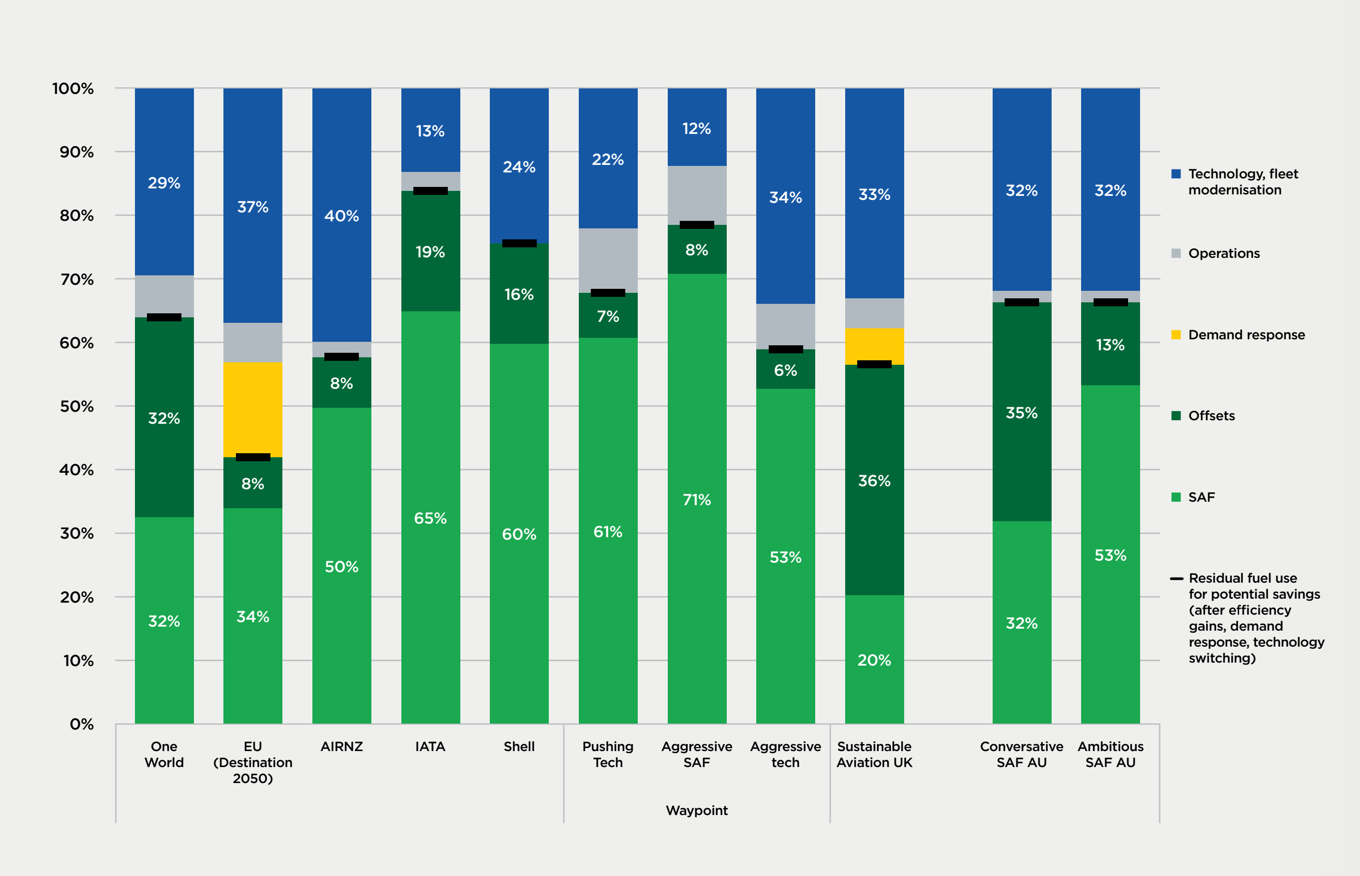

Figure 5: Benchmarking international aviation roadmaps against potential Australian scenarios

2050 Baseline Emissions Projections

The starting point for estimating the Baseline emissions projections is to establish historical emissions to 2019, being the last year unaffected by the significant distortions in air traffic as a result of Covid-19.

All estimates are based on domestic and international emissions for flights **departing** from an Australia airport.

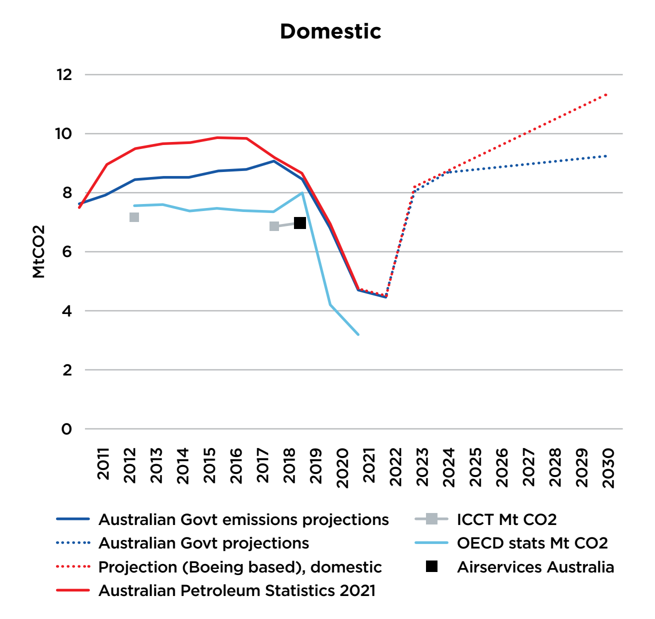

Figure 6: Historical and projected domestic aviation emissions

Estimates for historical emissions from a range of sources have been compared, including Australian Government emissions projections (2021)[40], estimates derived from Australia Petroleum Statistics (APS)[41] 2021 (from aviation fuel consumed), OECD, ICCT and Airservices Australia data (2019 only) (see **Figure 6** and **Figure 7**).

The estimates derived from the APS were used as the basis for the 2019 reference year because (a) these include data for both domestic and international emissions, which the government projections do not and (b) the domestic emissions derived from the APS were the closest to the official Australian Government emissions projections (particularly from 2018-21).

The APS also included data to 2021 which capture the temporary impact of Covid-19 on declining flight numbers. The growth applied to future emissions assumes recovery from Covid (return to trend) by 2023.

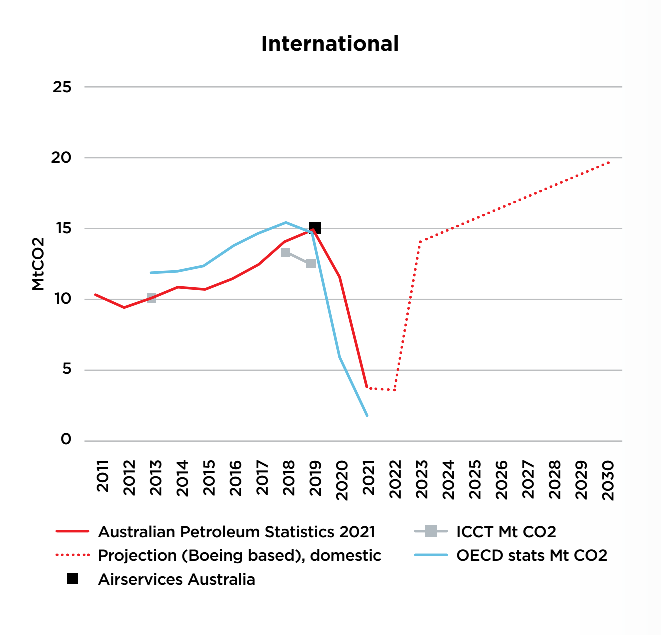

Figure 7: Historical and projected international aviation emissions

Beyond that, growth is assumed to be in line with the Boeing Commercial Outlook[42] from 2021-2040 for the Oceania region. This has Revenue Passenger Km (RPK) growth of 2.5% CAGR (compound annual growth rate) to 2030 and 2.9% from 2030-40.

This does imply higher domestic emissions by 2030 than the Australian Government projections for aviation, however, this is likely because the government projections include efficiency gains from fleet modernisation. Applying growth in line with RPK growth excludes any efficiency gains from the baseline projection, with efficiency gains from fleet modernisation reflected in the appropriate abatement proportion or 'wedge'.

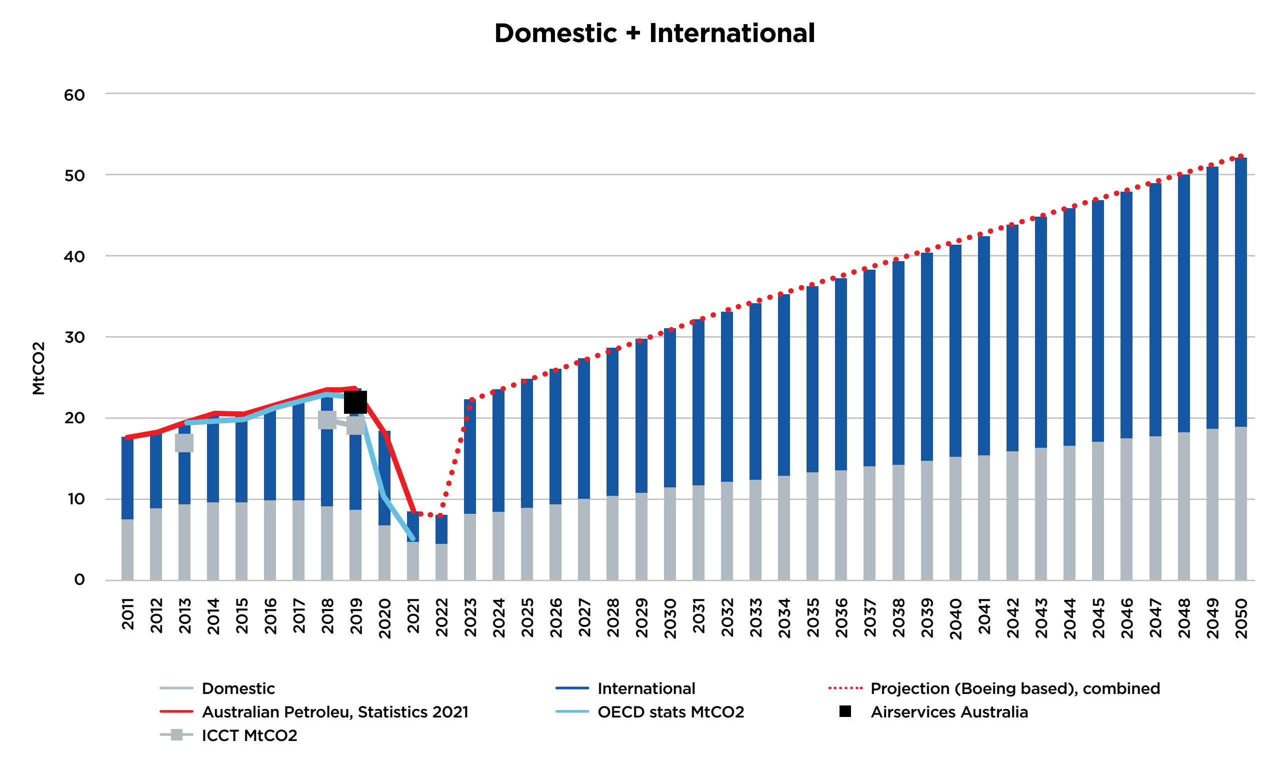

Figure 8 – Breakdown of domestic and international emissions (historic and projected baseline to 2050)

The overall baseline growth rate averages 2.6% p.a. This compares with a growth rate of 1.5% p.a. in the European net zero aviation roadmap.[43] However, most of the difference is explained by differences in population growth to 2050 (1.1% p.a. projected for Australia[44] vs 0% p.a. projected for the EU[45]); when adjusted on a per capita basis, these are both equivalent to 1.5% p.a. growth rate.

The profile of emissions is also important when accounting for abatement potential given step change technology options (hydrogen and electric aircraft) are generally limited to shorter domestic flights. Based on Airservices Australia data for 2019 flights, approximately 25% of total flights are international but they account for around 71% of emissions (see **Figure 9**). Conversely, short haul and regional flights that have more potential for technology change, account for nearly 60% of flights but only 12% of total emissions. This is reflected in the emissions mitigation estimates.

These baseline emissions projections are important because not only because they provide information about the trajectory the sector is on in terms of emissions, but they highlight the significant challenge ahead. The following sections address the critical measures that will arrest this growth, change the trajectory, and plot a roadmap to net zero by 2050.

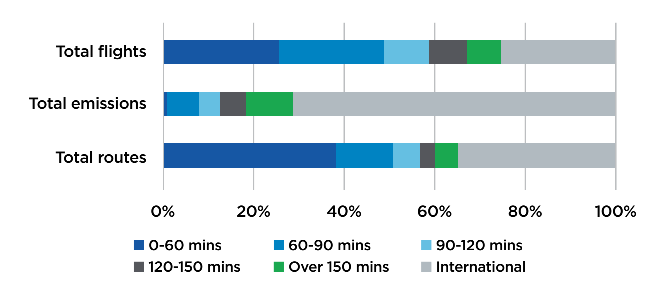

Figure 9: Breakdown of flights and associated emissions profile (2019)

Sources: Frontier Economics analysis of Airservices Australia data

Improvements in Aircraft and Engine Technology

Aircraft Technology

A broad scope of different technologies contribute to aircraft fuel efficiency improvement and emissions reduction, mainly relating to the:

- Airframe (aerodynamics, lightweight materials and structures, equipment and systems, new configurations, energy management and electrification), and
- Propulsion system (engine architecture, thermal and propulsive efficiency, combustor technologies, advanced materials and electrification).

Airlines can mitigate future emissions by implementing existing and upcoming aircraft technology. There are two broad ways in which technologies may impact emissions:

- The first involves replacing current aircraft powered by conventional jet fuel with more fuel-efficient aircraft, which can then be powered by conventional jet fuel, a blend of conventional jet fuel and SAF, or – in the future – 100% SAF. With improved fuel efficiency, aircraft produce fewer emissions on a per flight basis.
- The second involves replacing current or future aircraft with aircraft powered by alternative fuel sources such as hydrogen and electricity. These zero or low-emission propulsion technologies will likely produce fewer emissions than those using jet fuel on a per flight basis.

These two categories of technology, and their impacts on emissions, are described in more detail below.

In this Roadmap, the emissions reduction potential of the first technology pathway, fleet modernization, is considered separately to the contribution from the second technology pathway, zero emission aircraft.

Improved Fuel Efficiency Through Fleet Modernisation

Airlines implement new technologies through fleet modernisation. As aircrafts age and become less efficient to operate, airlines replace them with newer, more fuel-efficient aircraft. Similarly, airlines may retro-fit aircraft with improved technology. This section focuses on the impact of airlines continuously updating their fleets – replacing existing aircraft with relatively modern aircraft with improved fuel efficiency.

Fleet modernisation is a continuous process, with aircraft replacement typically occurring every 15 to 25 years. [ii]Even though fleet modernisation is an extremely expensive and time-consuming process, it is likely that by 2050 airline fleets are likely to have been replaced at least once. Generally, the timing of when replacement is first required depends on the age of the airlines current fleet – with this timing impacting the technology available to the airline, and therefore the fuel efficiency improvements that are achievable.

In the short-to-medium term, aircraft will either be able to be replaced with aircraft that are currently available, or aircraft which will be commercially available in the next few years. Indeed, Australian airlines' recent commitments for new fleets note the significant improvements in fuel efficiency from new aircraft from both Boeing and Airbus.[46, 47, 48] These aircraft may bring fuel efficiency improvements of 15% to more than 25%, compared to their predecessors.[49]

In the medium-term, other evolutionary aircraft technologies – those that can be fixed on a classical tube-and-wing aircraft configuration with jet fuel-powered turbofan engines (for example, riblet film or "sharkskin") – are expected to be adopted by commercial aircraft over the next 15 to 20 years. While this form of technological innovation is expected to reduce fuel burn,[50] achieving more than a 30 to 35% reduction in fuel burn with the current airframe-engine configuration is expected to be challenging.[51]

In the long-term, revolutionary, rather than simply evolutionary, changes to aircraft configurations and propulsion systems may become viable. Aircraft configurations may move away from the tube-and-wing configuration (a tubular fuselage with two predominantly flat wings on either side), which has been the standard from the beginning of commercial aviation.[52] Additionally, aircrafts may move away from using jet fuel-powered turbofan and turboprop engines, to alternative concepts using new energy sources.[53]

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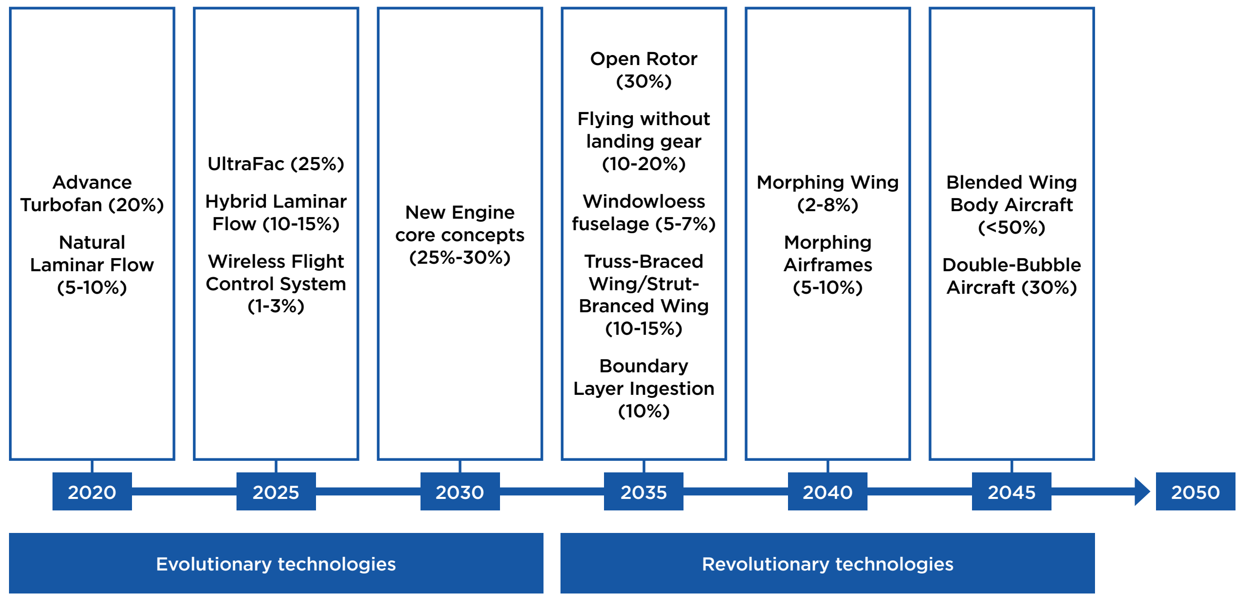
ii. As noted by IATA, aircraft assets are generally depreciated over 15 to 25 years with residual values of between 0 to 20 percent (see IATA's Airline Disclosure Guide – Aircraft acquisition cost and depreciation, 2016). This ignores how different components of an aircraft may age at relatively high rates, so that part replacement is required one or more times over the aircraft's useful life.

While it is likely that the technical development of these new aircraft concepts could be achieved in the next two to three decades, there are economic and commercial constraints that may delay or prevent their implementation, over such a long timeframe.[54]

Some examples of these new technologies – both evolutionary and revolutionary – that may be developed and implemented over the next three decades, and their impact on fuel efficiency compared to predecessor aircraft or engines, are displayed in **Figure 10**.[iii]



Source: Adapted from International Air Transport Association[55]

Figure 10: Timeline of expected future fuel efficiency improvements compared to predecessor aircraft or engine of the same category

Modelling the Impact of Fleet Modernisation on Emissions

The impact of fleet modernisation on fuel efficiency and emissions depends on the extent to which new technologies become available.

There is relatively high confidence in the short-term that emissions reductions will result from implementing existing or soon-to-be-available technologies (for example, airlines' existing fleet upgrade commitments).

There is moderate confidence in the impact that evolutionary technologies will have on emissions, as these are to be implemented in the medium-term. There is low confidence around the impact of revolutionary technologies on emissions in the long-term. These confidence levels have informed the assumptions underpinning the modelling undertaken by Frontier Economics for this Roadmap.

To model the impact of fleet modernisation on emissions, Frontier assumed two scenarios:

- Frozen fleet – airline fleets remain constant, therefore there is no change in fuel efficiency of fleets between 2023 and 2050. This is the assumption underlying the Baseline emissions projections.
- Fleet modernisation – airline fleets are upgraded with new technology over time, achieving 1.5% in fuel efficiency improvements per annum between 2023 and 2041.

This is consistent with historical improvements in fuel efficiency over time. The period between 1960 and 2008 saw a 1.5% average annual fuel efficiency improvement (although the change varies significantly over time),[56] while the period between 2010 and 2019 saw an annual increase of 2.1% per annum.[57, 58] It is, however, slightly below the aspirational goal set by the International Civil Aviation Organisation (ICAO) of a 2% fuel efficiency improvement per year through to 2050.[59]

We have assumed that, rather than continuing out to 2050, benefits from fleet modernisation conclude in 2041. This reflects that, in the short-term, there is more certainty around the benefits from introducing technology, whereas the likelihood of future technologies coming online is much more uncertain, as outlined above. Indeed, as noted by Deloitte in its aviation roadmap prepared for Shell,[60] industry regard the impact of efficiency gains due to design and operations improvements on emissions as important in the short-term, but with a diminishing impact over time.

This approach deviates from some roadmaps, which assume that growth continues at 1.5-2.0% per annum until 2050. For example, Jet Zero assumes an average annual improvement of 0.5% between 2017 and 2050 in their 'policy-off baseline' scenario,[61] 1.5% in their 'continuation of current trends' scenario and 2.0% in high ambition scenarios. Other international and regional roadmaps have built bottom-up reductions based on detailed fleet information and expected replacements.[62, 63]

Zero Emission Aircraft Powered by Hydrogen and Electricity

Hydrogen and Electricity Powered Aircraft

Airlines may eventually replace aircraft powered by jet fuel with those powered by alternative energy sources. These options include:

- Hybrid-electric aircraft, which utilise both combustion and electric propulsion systems;
- All-electric aircraft, which replace combustion engines with electric motors;
- Hydrogen-powered aircraft, which utilise hydrogen as a propulsion fuel for combustion in conventional engines rather than jet fuel, and in fuel cells for electrical power.[64]

Both all-electric and hydrogen-powered aircraft may have the potential to reduce tailpipe carbon emissions from flights by up to 100%, depending on the how the hydrogen and electricity used are produced.[65] These 'zero-emission aircraft' (ignoring emissions produced during aircraft production) are still in the early stages of development for use in commercial fleets, and there is significant uncertainty around the extent to which the technology can be developed and commercialised.

Some industry participants suggest that zero-emission aircraft could play a role within the next two decades, with 2035 often suggested as a plausible date for commercial use on short-haul flights.[66] Industry opinions differ on the extent to which technology can be rolled out, outlining the following:

- For electric aircraft, IATA notes that planes with up to 9 seats are already flying, while aircraft up to 19 seats are planned for the later 2020s.[67]
- For hydrogen-powered aircraft, expectations are that commercial activity will begin in 2035.[68] For example, Airbus has revealed three concepts for hydrogen-powered zero emission commercial aircraft which it aims to bring to market by 2035.[69]

However, as noted above, the timelines for zero-emission flights are highly uncertain, dependent on the continual progression of battery, fuel cell and liquid hydrogen propulsion technologies.[70] The cost of these technologies, their ability to be used over varying distances with varying seat utilisation, safety requirements and passenger demand, airport infrastructure, supply chains, and fuel costs, will all be important determinants of potential entry into the commercial aviation industry.[71]

Modelling the Impact of Zero Emission Aircraft on emissions

The rate at which zero emission aircraft are expected to be commercially viable depends – as has been outlined earlier – on flight characteristics, including the number of passengers and the distance to be flown.

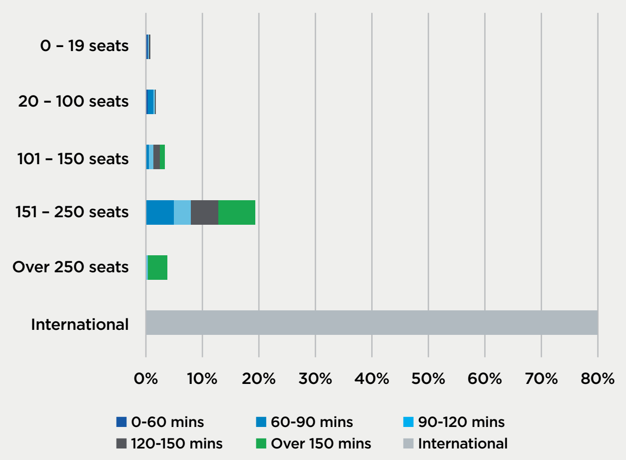
Table 1 illustrates the likely implementation timeframe for zero-emission aircraft in the global market, the potential flight range of these aircraft, and an indication of the percentage of total global aviation emissions attributable to different types of flying.

	2020	2025	2030	2035	2040	2045	2050	
Commuter 9-50 seats <60 minute flights <1% of industry CO2	**SAF**	**Electric** and/or **SAF**	**Electric** and/or **SAF**	**Electric** and/or **SAF**	**Electric** and/or **SAF**	**Electric** and/or **SAF**	**Electric** and/or **SAF**	**~27% of CO2 emissions**
Regional 50-100 seats 30-90 minute flights ~3% of industry CO2	**SAF**	**SAF**	**Electric** or **hydrogen fuel cell** and/or **SAF**	**Electric** or **hydrogen fuel cell** and/or **SAF**	**Electric** or **hydrogen fuel cell** and/or **SAF**	**Electric** or **hydrogen fuel cell** and/or **SAF**	**Electric** or **hydrogen fuel cell** and/or **SAF**	
Short-haul 100-150 seats 45-120 minute flights ~24% of industry CO2	**SAF**	**SAF**	**SAF**	**SAF**	**Electric**, **hydrogen combustion** and/or **SAF**	**Electric**, **hydrogen combustion** and/or **SAF**	**Electric**, **hydrogen combustion** and/or **SAF**	
Medium-haul 100-250 seats 60-150 minute flights ~43% of industry CO2	**SAF**	**SAF**	**SAF**	**SAF**	**SAF**	**SAF**	**SAF** potentially some **Hydrogen**	**~73% of CO2**
Long-haul 250+ seats 150 minute+ flights ~30% of industry CO2	**SAF**	**SAF**	**SAF**	**SAF**	**SAF**	**SAF**	**SAF**	

Table 1: Implementation of zero-emission aircraft into the global aviation market[72]

Source: Adapted from Air Transport Action Group

The potential emissions reduction from introducing these technologies in Australia is explored in further detail in **Figure 11**. Taken together with Table 1, these two images illustrate clearly the expectation that zero emission technologies are likely to only have a limited impact on emissions by 2050 in Australia.



Source: Frontier Economics analysis of Airservices Australia data on flights and emissions by aircraft and route within Australia. We merged this data with information on distances between Australian airports (which we converted to travel time) and seats per aircraft to generate the above figure.

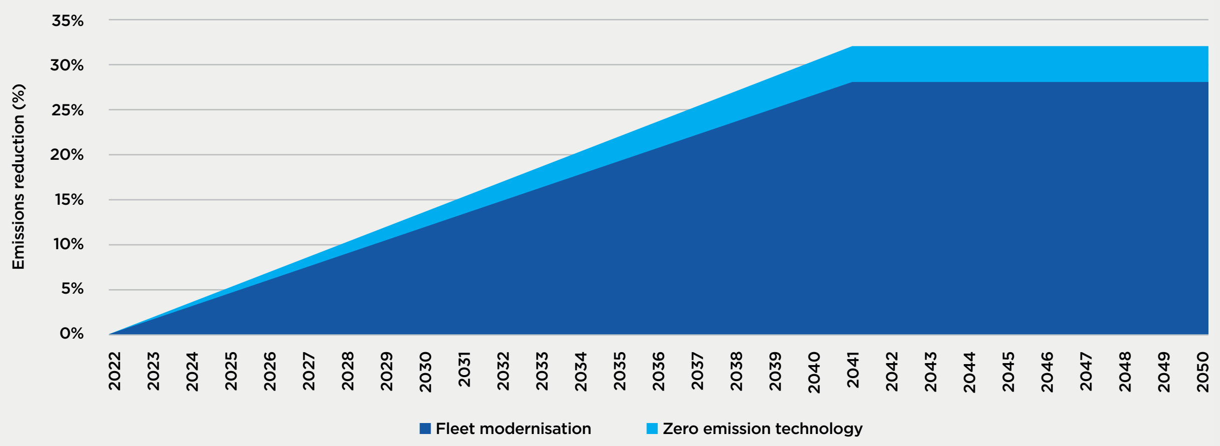
Figure 11: Emissions by flight characteristics in Australia, 2019

The significant majority of airline emissions – approximately 71% of total aviation emissions in Australia – come from international flights, as such Frontier have reasonably assumed will not be serviced by zero-emission aircraft. Similarly, 87% of domestic aviation emissions in Australia come from flights with seating for more than 150 people, with flight times exceeding 60 minutes; a combination of characteristics which place them out of scope for zero-emission aircraft in the foreseeable future.

Modelling The Full Impact of Technology on Emissions

To model the total joint impact of these technologies on emissions, Frontier deducted potential emissions savings following the introduction of zero-emission aircraft from baseline emission levels, then calculated efficiency improvements due to fleet modernization – continued efficiency improvements from fleet modernisation only relate to aircrafts using jet fuel, hence overall improvements only apply to the emissions remaining after accounting for zero-emission aircraft.

The result is the following emissions reduction pathway out to 2050 (see **Figure 12**). By 2050, zero-emission technology is estimated to reduce emissions by approximately 3.7%, while fleet modernisation is estimated to reduce emissions by approximately 28%.



Source: Frontier Economics, based on analysis of Airservices Australia data.

Figure 12: Reduction in emissions due to technology, 2022 to 2050

Practical Considerations for Zero-Emission Technology

With Australian airlines announcing future fleet renewal plans,[73, 74, 75] it is important to consider the practical considerations for and the implications of the introduction of zero-emission aircraft in the Australian market.

Certification

Safety is, and will always be, the number one priority for the aviation industry. Therefore, it is likely that certification and testing for novel airframe configurations or propulsion systems will be a rigorous and prolonged process.[76] Additionally, as these aircraft will be utilising novel technology, regulators will need to design and implement new certification procedures to ensure the safety level required for commercial aviation.[77]

Infrastructure & Operations

The introduction of zero-emission aircraft will also require a significant redesign of on-airport infrastructure, maintenance equipment, and workforce training. This is because the recharging and refueling of electric and hydrogen powered aircraft will require markedly different supply chains and infrastructure than the traditional refueling systems found at airports today. For example, liquid hydrogen needs to be stored in specialised tanks at very low temperatures (-253°C) and has a greater volume-to energy-ration than traditional jet fuel.[78]

It is also likely that recharging and refuelling times, at least initially, will be greater for electric and hydrogen powered aircraft.[79, 80] This presents a significant challenge for airlines, as increased turnaround times can result in loss of revenue if airline capacity is reduced.[81]

Given that recharging, refuelling and maintenance procedures for electric and hydrogen aircraft will be markedly different to conventional aircrafts that use traditional jet fuel or SAF, the entire support workforce – from flight crews, to ground handlers, maintenance and refuelling staff will require re-training and upskilling.[82]

Risk and Cost

International analysis suggests that global costs for the aviation industry to develop and implement new technology – including zero-emission aircraft – are likely to be considerable in the early years.[83] Significant cost, coupled with the novel nature of hydrogen and electric aircraft may result in airlines being wary of investing in zero-emission aircraft early.[84]

However, given the nature of flying in Australia – with the majority of routes being unsuitable for electric or hydrogen powered aircraft in the short to medium term[85] – it is likely that zero-emission aircraft technology will be at a more mature stage, with proven operational and commercial credentials, by the time it is able to be adopted at scale in the Australian market.

Public Perception

Zero-emission aircraft will also need to go through a process of introduction to the public to create trust and the acceptance of their safety credentials — particularly those that look very different to aircraft currently flying today.

Commitment to Action from Industry

While zero-emission aircraft are unlikely to have significant uptake in the Australian market before 2050, Australian airlines – and the industry more broadly – commits to working together to both introduce novel technologies, and ensure that the infrastructure required for these aircraft are fit-for-purpose.

Additionally, the industry commits to exploring partnerships to accelerate research and development of radical airframe designs, and electric and hydrogen propulsion.

Recommendations for Governments

Recommendation: The Federal Government should work with industry to design and implement the necessary supporting policies, infrastructure, and investment required for new aviation technologies to be deployed in the Australian aviation sector.

This could be done by convening a dedicated zero-emission aircraft subgroup of an Australian Jet Council. The concept of an Australian Jet Council is explored further on p.54.

Recommendation: The Federal Government must ensure that the regulator, the Civil Aviation Safety Authority, is adequately resourced and prepared to support the certification process of novel airframe configurations and propulsion systems.

Improvements in Operations and Infrastructure

Aircraft Technology

Most aviation roadmaps include some efficiency gains from optimised routes that reduce flying time or fuel burn – with estimates ranging from 0%[86] to 10% contribution to abatement by 2050.[87] The gains were estimated to be at less than 2% in New Zealand,[88] 6% in Europe,[89] with an average contribution of around 6%, from all the roadmaps reviewed.

Airservices Australia's analysis of this suggests potential gains for Australia are only around 1-2% because Australia has much more airspace than EU/US routes, which means that routes are already largely optimised, and any operational gains for Australia will be at the lower end of the estimated ranges. This is consistent with the estimate used for the Air New Zealand net zero roadmap.[90] On this basis, and following Airservices Australia advice, we adopt an assumed saving of 1.5% by 2050, in terms of this measure's contribution to the broader Roadmap.

While the nature and existing efficiency of Australian airspace means that emission savings resulting from improvements in from air traffic management are low – especially in comparison to regions with congested airspace – it is important for Government to continue investment in critical air traffic infrastructure, facilities, and services to preserve and further enhance the safety, efficiency, and capacity of the Australian air traffic network.

Airport Operations

While emissions from airport operations are outside the scope of this roadmap, Australian airports will play a critical role in Australia's aviation sector achieving net zero emissions by 2050.

Airports not only have a key role in supporting airlines to achieve net zero emissions – facilitating efficient ground handling operations and providing infrastructure to support the use of SAF and new technology – they have recognised that they also need to implement changes to reach net zero emissions from their own operations.

A number of Australian airports have already pledged to reach net zero emissions by 2050 under the Airports Council International Long Term Carbon Goal,[91] with some airports – including Sydney Airport, and airports operated by NT Airports – pledging to reach net zero carbon emissions by 2030.[92]

Additionally, Brisbane Airport has recently announced ambitious plans to achieve net zero emissions (for Scope 1 and Scope 2 emissions) by 2025.[93]

Air bp has also chosen Brisbane Airport as the first airport site in Australia to operate a next generation all-electric refueller ("refueller") for airline customers uplifting jet fuel.[94] This refueller uses Lithium-Ion batteries and digital charging mechanisms making it the first all-electric hazardous goods vehicle and refueller approved for use in Australia.[95]

The refueller can carry approximately 16,000 litres of fuel, has been designed to operate for a full day with overnight charging, and delivers jet fuel to aircraft with zero fuel consumed and zero tail pipe emissions.[96]

While emissions from both airport and ground operations are outside the scope of this roadmap, these announcements and actions from airports and other aviation sector partners, such as *Air bp*, demonstrate the strong commitment of the broader aviation sector to achieving net zero emissions by 2050.

Practical Considerations for Air Traffic Management & Operations

Often perceived as the "low-hanging fruit" in emissions reduction, improvements in operations – through greater efficiency – are changes that can be made by the sector without incurring significant costs. As noted above, however, Australian airspace is already efficient – with routes already largely optimised.

Despite this, it is widely accepted that there are a number of external factors which can introduce inefficiencies compared with ideal flight paths and conditions, for example:[97] safety considerations, capacity constraints, adverse weather conditions, and noise abatement procedures.[iv]

As such, it is critical that air navigation service providers, airports, and airlines work collaboratively to maintain Australia's efficient airspace, particularly as passenger numbers increase, new technologies emerge, and airspace becomes busier.

Unmanned Aerial Vehicles (UAVs) and Advanced Air Mobility (AAM)

Over the coming decades, both traditional and non-traditional aviation activities will increasingly need to operate within the same airspace, which is quickly evolving due to economic, social, and technological developments.[98]

Australian airspace operations will likely involve a mix of different aircraft types – including but not limited to: traditional jet aircraft passenger services (including ultra-long haul aircraft), helicopters, recreational aircraft, UAVs; and in the future, electric or hybrid AAM, using electric vertical take-off and landing (eVTOL) aircraft.[99]

The regulation and management of Australian airspace will therefore need to evolve to accommodate the changing airspace environment. The National Emerging Aviation Technologies (NEAT) Policy Statement,[100] and the recent consultation on the National Strategic Airspace Issues Paper[101] are positive steps to address this emerging issue.

As part of the NEAT policy statement, the former Federal Government committed to a range of whole-of-government initiatives that will create an efficient and adaptable operational ecosystem for emerging aviation technologies. These initiatives include development of Australia's Unmanned Aircraft System Traffic Management system, regulatory modernisation, and the provision of industry support.[102]

As technological advances are made, it is crucial that the Australian Government progress the initiatives and commitments in the NEAT Statement, and any recommendations that eventuate from the response to the National Strategic Airspace consultation, noted above.

Commitment to Action from Industry

The aviation industry commits to implementing the latest innovations and improvements in flight planning and air traffic management, and will continue to work collaboratively with relevant government agencies; the Civil Aviation Safety Authority (CASA), Airservices Australia, and Defence, to optimise the flow of air traffic and ensure that Australia's airspace remains safe, secure, and efficient.

Additionally, Australian airlines will continue to pursue continuous procedural improvements to reduce emissions by identifying opportunities for improvement, supporting staff through the implementation of improved operations, and measuring and maintaining subsequent improvements in fuel efficiency and emissions.

Recommendations for Government

Recommendation: The Federal Government should ensure the optimisation air traffic management, through the implementation of OneSky[103] and other Airservices Australia programs, is realised and evaluated for continual improvement.

The successful implementation of *OneSky* Australia and other programs to optimise air traffic flow and management will ensure that current airspace efficiency is maintained, and enable Australia to deliver more efficient air services, while supporting future air traffic growth and national security.[104]

Recommendation: The Federal Government should progress initiatives outlined in the NEAT Policy Statement and the National Strategic Airspace Issues Paper

In developing the Australian Future Airspace Framework – as flagged in both the NEAT Statement and the National Strategic Airspace Issues Paper – CASA must work closely with airlines, the broader aviation industry, government agencies, and other relevant stakeholders to ensure that the framework complements other relevant policies and regulations for emerging aviation technology whilst maintaining the highest levels of safety, security, and efficiency for Australia's airspace.[105]

[iv] To reduce noise impact on the ground, aircraft operations around airports are subject to noise abatement procedures and regulations (Air Navigation [Aircraft Noise] Regulations 2018) that may reduce noise for a certain suburb but may cause the aircraft to fly an approach or departure that is a less efficient route or accept suboptimal altitudes.

Deploying Sustainable Aviation Fuels

Sustainable Aviation Fuel (SAF)

Sustainable aviation fuels (SAF) are low-carbon fuels derived from a variety of biogenic and non-biogenic sources such as plant and animal wastes, used cooking oil, or chemical compounds – including carbon dioxide and green hydrogen.[106]

They offer an alternative to conventional jet fuel, which has traditionally been derived from crude oil – a non-renewable product of petroleum.[107] SAF are a credible solution to the decarbonisation challenge as they meet the same chemical and safety specifications as conventional jet fuels.

At present, ASTM[v] fuel standards permit blends of up to 50% SAF to be 'dropped in' to existing aircraft engines and refueling infrastructure without changes needed. Higher blending rates are expected to be approved by certification pathways, as engine and aircraft manufacturers work to better understand the potential implications of lower aromatic proportions in fuel, and augment engines (and associated engine components) to run safely and smoothly with higher SAF blends.

There is a wide range of feedstocks that can be processed and refined into a SAF via one of seven approved conversion technologies. The term 'SAF pathway' describes the specific feedstock-technology combination that produces an eligible fuel. For instance, the HEFA[vi] process refines vegetable oils, waste oils, or fats into SAF through a process that uses hydrogen (hydrogenation).

While a technology or pathway may be certified, that alone does not imply scale or commerciality of the technology[108] – certification denotes the approval of the pathway based on fuel output characteristics. Given the increasing demand for SAF and variety of potential feedstocks there is likely to be an increasing diversity of commercially viable production technologies to supplement HEFA production which to date has produced 95% of the worlds SAF.[109, 110]

Current and Future Sources of SAF

Feedstocks or sources for SAF can be categorised into three broad groups, according to the nature of the feedstock and its other uses.[vii] **Figure 13** provides an overview of these categories and processes.

Feedstocks	Processes
Edible, crop-based feedstocks	Fischer-Tropsch (FT), HEFA, Alcohol-to-jet (Atj) pathway
Non-edible crops and waste products	FT, HEFA, Atj, Synthesised iso-paraffins
Water, carbon dioxide, electricity	Power-to-Liquid (PtL)

Source: Frontier Economics; CORSIA, 2019. CORSIA Supporting Document: CORSIA Eligible Fuels – Life Cycle Assessment Methodology[111]

Edible Feedstocks

First generation biofuels use edible crops as feedstocks in the SAF production pathway. Typically, the starches, sugars and oils from the organic matter are extracted for the fuel conversion process.[112] These feedstocks can include the following sources:

- sugarcane and sugarbeet;
- corn, palm, rapeseed, soy, wheat; and
- mustard and canola.

The use of these inputs for SAF production raises the potential issue of competition with crop production for food and feed for livestock. Using these feedstocks to meet the expected increase in demand for SAF may also place greater pressure on natural resources such as water and land – impacting sustainability and creating a potential constraint on the supply of edible crop-based feedstocks that may, in turn, limit domestic SAF production at scale.

There are also trade-offs associated with the environmental impacts of these crop-based fuels. Key indicators often include the fossil energy input of a feedstock, its emissions intensity and eutrophication potential, and land and water use requirements. For example, the use of sugarcane molasses as a feedstock has demonstrated greater emissions abatement potential compared to microalgae or oil made from the seeds of Indian Beech trees but has greater water requirements and eutrophication potential.[113]

Managing these trade-offs will be critical to the sustainability of the industry. The EU Renewable Energy Directive limits the use of edible crop-based biofuels for these reasons, preferring to support production of other feedstocks that are more sustainable.[114]

Non-edible Feedstocks

SAF derived from non-edible feedstocks, are also known as 'advanced biofuels'. The production of these fuels often require advanced chemical processes to convert what are, in some cases, waste products from unrelated commercial activities into renewable fuels. Feedstocks for these processes typically include:

- biological wastes from agriculture, forestry and human sewage;
- animal waste fats such as tallow;
- municipal solid waste, i.e. general rubbish such as food scraps, garden waste, office and computer waste, plastic, aluminium, and steel;
- used cooking oil; and
- energy and woody crops.

The redirection of waste products to biofuels presents a valuable opportunity for "circular economy benefits", which refers to the value created in the recovery and transformation of worthless waste from landfill disposal sites into a valuable input for fuel production. This is particularly true for producers of commercial and industrial waste, who must otherwise incur a significant cost for its disposal. Whilst this transformation sometimes requires investment in aggregation and processing facilities, this strategy can offer organisations of all kinds an additional source of income that reduces their environmental impact and increases their sustainability credentials. One such example is Southern Oil, which found substantial supply potential for forestry, agricultural and landfill wastes when coordinating feedstocks for its Renewable Fuels Pilot Plant in Gladstone between 2016 and 2018.[115] They concluded that waste produced in Australia far exceeds the input needs of a renewable fuel refinery.

Synthetic Fuels

Synthetic SAF are liquid hydrocarbons that are produced using water, carbon dioxide and electricity.[116] Commonly referred to as 'power-to-liquid' (PtL) technologies, they promise greater resource efficiency than other SAF and emissions savings potential of between 85% and 100%, depending on the fuel source powering the electricity.[117] The conversion process involves the electrolysis of water (H_2O) to produce oxygen (O_2) and hydrogen (H_2). The hydrogen is then combined with carbon feedstocks captured from industrial sources or the atmosphere, through Direct Air Capture technology, to produce a synthetic equivalent of kerosene.[118]

Despite their potential, PtL technologies are currently limited by relatively high costs – costing between 3 and 6 times more than fossil fuel-based jet fuel – and low scale.[119] Dedicated policy support, low-cost renewable energy, and demand guarantees from industry are therefore crucial to the commercialisation of synthetic SAF. This is evident in the EU, where sub-mandates will take effect from 2030 to stimulate the progressive uptake of synthetic SAF that will drive emissions reductions out to 2050.[120]

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[v] ASTM International is a globally recognized leader in the development and delivery of voluntary consensus standards. ASTM and UK Defence Standard (Def-Stan) specifications dominate the majority of jet fuel sold across the world.

[vi] Hydrotreated Esters and Fatty Acids (HEFA)

[vii] In contrast, CORSIA classifies feedstocks according to their position in the manufacturing process, i.e. as either 1) primary products; 2) co-products, or 3) wastes and residues.

SAF Abatement Potential

The contribution of SAF to the aviation industry's emissions reduction targets depend on three key components. These are summarised in **Figure 14**, and expanded upon further below.

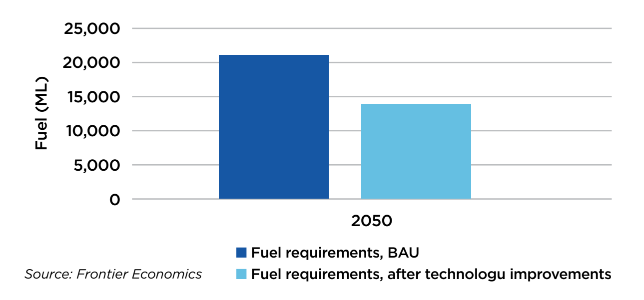
Figure 14: The three key components that determine the emissions abatement potential of SAF.

Source: Frontier Economics

Residual Fuel Use

As noted earlier, over the next 30 years, aircraft engines and operations are expected to become more fuel efficient and zero-emission aircraft will not require jet fuel at all. The contribution of SAF to emissions abatement is therefore limited by the industry's residual fuel needs after these developments have taken place.

For instance, by 2050, we expect fuel demand to be approximately 30% lower than what it would be under business-as-usual (BAU) projections. The blending of SAF with conventional jet fuels will then lead to emissions savings *relative to this residual fuel demand,* rather than to BAU levels. The greater the fuel efficiency savings that are already in place, the lower the emissions abatement contribution that is required to be made by SAF.



Source: Frontier Economics

Figure 15: Residual fuel needs compared to fuel needs under BAU baseline projections.

The Emissions Savings Potential of SAF

The emissions savings potential of SAF is typically expressed as a percentage reduction of emissions relative to conventional jet fuel, as measured on a life cycle basis.[ix] This can vary depending on the feedstock, the technological process used to produce the SAF, the location of the refinery and its distance from the airport where it will be deployed.

For example, when rapeseed oil is used as a feedstock in the HEFA conversion process, this results in an emissions reduction of approximately 47% relative to conventional jet fuel.[121] In comparison, when used cooking oil is employed in the same process, the emissions savings is 84%.[122]

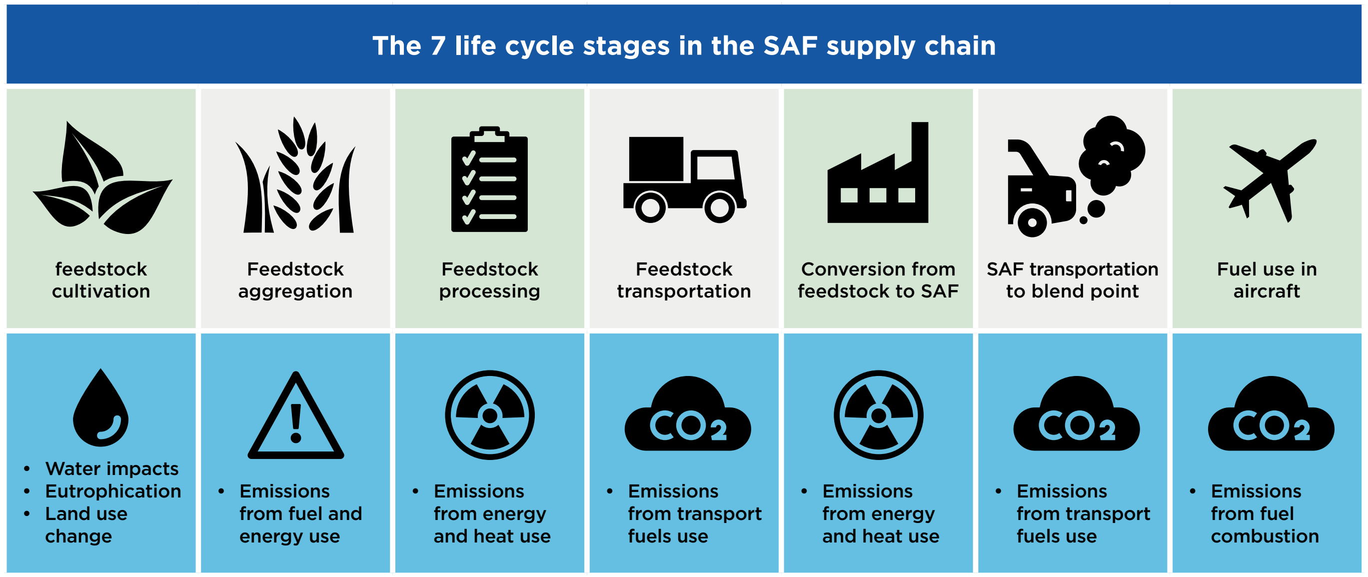
Calculation of the emissions intensity of a fuel is made using a life cycle assessment (LCA) approach, which includes the emissions associated with the production and transport of feedstocks, the manufacturing process and physical delivery into the aircraft in addition to emissions released upon combustion.[123]

Hence there is a wide range of emissions values that a particular SAF pathway (i.e. feedstock-technology combination) could generate, depending on the energy and fuel types used across the supply chain.

Figure 16 (opposite) illustrates how each stage in the supply chain influences the LCA emissions profile of a SAF.

This multi-layered approach to emissions accounting adds complexity to determining the viability of each SAF production pathway. It also reinforces the need for a strong sustainability certification system. Given the global nature of travel, fuel purchasers around the world need assurance of genuine emissions savings resulting from SAF use, irrespective of where it was produced.

[ix] Conventional jet fuel is assumed to have a baseline life cycle emissions value of 89 gCO2e/MJ.



The 7 life cycle stages in the SAF supply chain

feedstock cultivation	Feedstock aggregation	Feedstock processing	Feedstock transportation	Conversion from feedstock to SAF	SAF transportation to blend point	Fuel use in aircraft
• Water impacts • Eutrophication • Land use change	• Emissions from fuel and energy use	• Emissions from energy and heat use	• Emissions from transport fuels use	• Emissions from energy and heat use	• Emissions from transport fuels use	• Emissions from fuel combustion

Figure 16: The seven life cycle stages in the SAF supply chain and associated environmental concerns.

Source: CORSIA, 2019. CORSIA Supporting Document: CORSIA Eligible Fuels – Life Cycle Assessment Methodology, p.11.

Sustainability criteria for SAF in other jurisdictions

The EU Renewable Energy Directive II blending mandate requires a minimum emissions reduction threshold of 65% for 1st and 2nd generation SAF. Additional sub-mandates apply to the use of synthetic SAF, which must result in a lifecycle emissions reduction of 70% to satisfy sustainability criteria.[124]

In comparison, the recently passed U.S. Sustainable Aviation Fuel Credit provides for a $1.25 baseline credit for each gallon of SAF used in aviation. To qualify as a SAF, the production process must result in a lifecycle emissions reduction of at least 50 percent compared with conventional fuels. An additional tax credit of 1 cent applies to every percentage point of emissions savings above 50%, with an upper tax credit limit of $1.75 per gallon. This effectively rewards producers of fuels with greater emissions savings, while providing regulatory flexibility as production capacity develops.[125]

SAF Blending Rate

Current ASTM International Standards limit most SAF blends to 50% by volume with conventional jet fuels.[126] This places a cap on the potential emissions reductions from SAF at 50%, assuming 100% emissions savings potential. ASTM standards ensure SAF satisfy the same fuel specifications and safety requirements as conventional fuel and are compatible with existing aircraft engines and refuelling infrastructure. Future blending scenarios require further testing and evaluation of sustainable fuels to enable blending limits to increase to 100%, which significantly increases the emissions abatement potential of SAF.

There are currently seven SAF technology pathways approved for use as 'drop in' fuels under ASTM Standard D7566. These approved SAF technology pathways are displayed in **Table 2**.

More pathways are in various stages of development and testing, and international efforts are seeking to expedite the qualification process for more SAF pathways.

This is critical to the timely commercialisation and scaling required to satisfy the growing demand for SAF that in turn affects its cost competitiveness with conventional jet fuels.

SAF Technologies	Feedstocks	Maximum Blend
• Fischer Tropsch Synthetic Paraffinic Kerosene (FT-SPK) • Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics (FT-SPK/A)	Synthetic gas from biomass or municipal solid waste, forest waste, wood and energy crops	50%
• Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK) • Catalytic Hydrothermolysis Sythesized Kerosene (CH-SK)	Fatty acids and fatty acid esters Lipids from plant and animal fats oils and greases	50%
• Hydroprocessed Fermented Sugars to Synthetic Isoparaffins (HFS-SIP)	Sugars	10%
• Alcohol to Jet Synthetic Paraffin Kerosene (ATJ-SPK)	Ethanol and isobutanol Eventually will cover any 2 or 5 carbon alcohols	50%
• Hydroprocessed Hydrocarbons, Esters and Fatty Acids Synthetic Paraffinic Kerosene (HHC-SPK)	Bio-derived hydrocarbons, fatty acid esters, free fatty acids Tri-terpenes produced by Botryococcus braunii species of algae	10%

Table 2: Currently approved technology pathways for drop-in SAF

Source: Adapted from Commercial Aviation Alternative Fuels Initiative[127]

Development and uptake of SAF

We model the uptake of SAF and subsequent emissions reductions under two scenarios from 2025 to 2050:

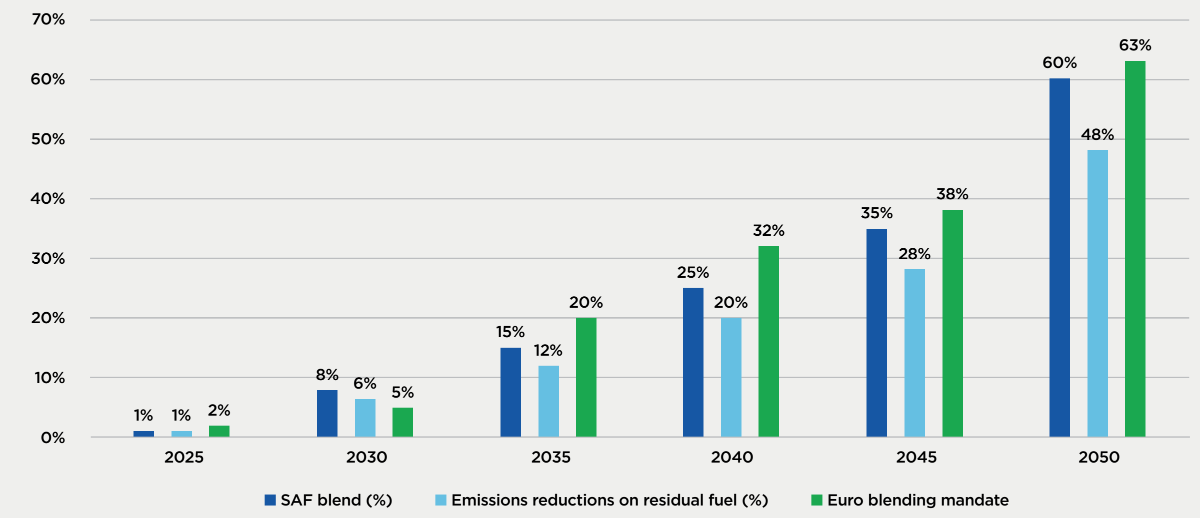
1. The **Conservative Scenario**, which presents a projection of SAF uptake based on announced SAF purchasing commitments by Australian airlines. These blending inputs have also been informed by mandated blending targets in other jurisdictions.
2. The **Ambitious Scenario**, which presents a more aggressive development path for SAF that may be realised through a strong commitment by industry, and supportive policies and investment from Government.

Conservative Scenario

The blending rates that Frontier modelled under this scenario closely follow the EU RED II mandated blending levels for each five-year milestone out to 2050.[128] **Figure 17** illustrates how these Australian targets compare, using an assumption of an average emissions reductions level of 80% for the SAF used.

The starting blend level of 1% in 2025 is based on a conservative estimate of SAF procurement levels by Australian airlines for domestic travel and international flights departing Australia. The biofuels refinery proposed by Oceania Biofuels in Gladstone is expected to produce over 350 ML of sustainable fuels for both aviation and road transport from 2025.[129] This figure represents 3.5% of Australia's projected aviation fuel requirements that year,[130] assuming that: fuel requirements return to their pre-COVID-19 levels by 2025, airlines enter purchasing agreements with local biofuel producers, and all of the SAF produced is utilised in Australia and is not sold to international markets.

A key assumption in this blending trajectory is a SAF blending limit of 60% or higher by 2050. This is entirely plausible, given the current international coordination efforts focused on the development and testing of alternative aviation fuels at higher blend levels.[131, 132] The European use of blending sub-mandates for synthetic SAF also explains the substantial increase in the EU targets between 2045 and 2050[133] – with targets rapidly increasing from 11% in 2045 to 28% in 2050, by which time PtL technologies are expected to achieve cost competitiveness with other biofuels.



Source: Frontier Economics analysis; European Commission, 2021[134]

Figure 17: Blending path for SAF in the Conservative Scenario based on 80% average emissions savings

Ambitious Scenario

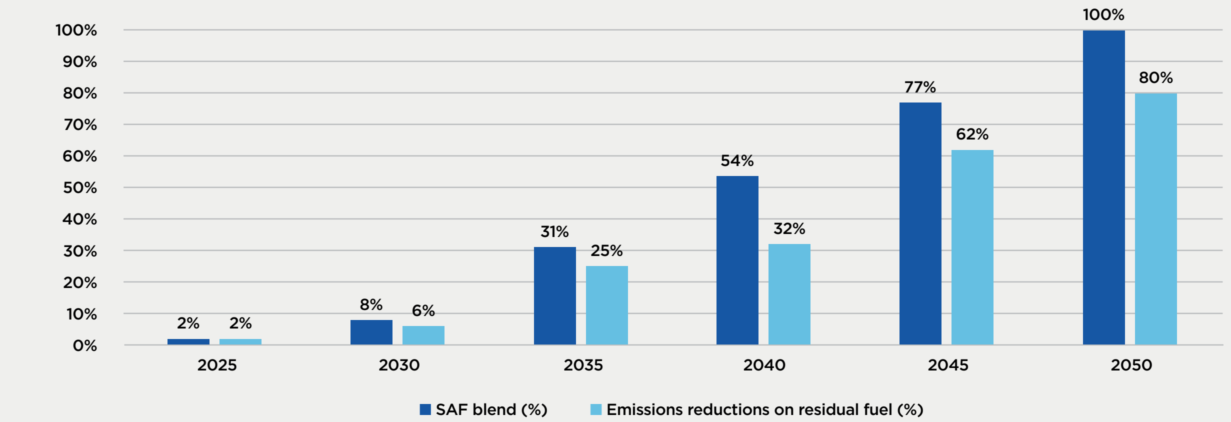
This scenario presents a more aggressive SAF blending trajectory in Australia between now and 2050. The key feature of this scenario is the blending target of 100% by 2050, which can be achieved with consistent increases in SAF use at every five-year milestone. This would result in a total emissions savings of 80% on residual fuel use, based on an average life cycle emissions savings of 80%. While many biofuels abate fewer emissions than this amount, the potential of PtL technologies to achieve carbon neutrality (i.e. 100% emissions abatement potential) will likely balance this out. **Figure 18** depicts the aspirational blending path for SAF under this scenario.

This scenario also assumes technology will evolve to enable up to 100% SAF blending by 2050, which is likely given recent trials and commitments from aircraft manufacturers. Boeing has announced that by 2030, all its commercial aircraft will be certified and compatible to fly with 100 per cent sustainable aviation fuels by 2030.[135] Similarly, Airbus has stated that their goal is to achieve certification of 100% SAF by 2030 for both commercial aircraft and helicopters.[136]

It is of note however, that while aircraft may be certified for 100% SAF use, one of the key challenges for airlines will be the cost associated with SAF, and therefore 100% SAF use will likely remain rare until the price of SAF becomes commercial – this is explored later on, under *Practical Considerations.*

While this trajectory has been termed "ambitious" for the purposes of this roadmap, it proposes an aspirational – but achievable – action path that could be realised with concerted commitment from Australian airlines and strong, targeted policy support from governments. Its plausibility is underpinned by a series of ground-breaking pilot projects in recent years that demonstrate the potential to significantly upscale SAF use, including:

- United Airlines using 100% SAF in one of its two engines on a passenger flight in 2021. This amounted to 500 gallons (~1900 L) of SAF.[137]
- Regional aircraft manufacturer ATR Aircraft completing a series of test flights in February 2022, using 100% SAF made from renewable wastes and residues in one engine. This was conducted as part of collaboration with Braathens Regional Airlines and fuel producer Neste to achieve certification for 100% SAF use on ATR aircraft by 2025.[138]
- Similarly, in March 2022, Airbus conducted a third 100% SAF test flight, this time with an A380 out of Toulouse, France – Airbus has previously conducted 100% SAF test flights with an A350 and A319neo.[139]
- The success of the Northern Oil Advanced Biofuels Laboratory project that was completed in 2019.[140] It also demonstrates the benefits of strong state and Federal Government support, where the latter contributed $3.18 million through ARENA's *Emerging Renewables Program.*[141]



Source: Frontier Economics' analysis.

Figure 17: Blending path for SAF in the Ambitious Scenario based on 80% average emissions savings

Supply Potential

The supply chain for SAF in Australia is underdeveloped, as are the regulatory frameworks that certify producers' adherence to sustainability standards. Currently, Australian airlines seeking to purchase SAF must source SAF offshore from international producers.

The volume of SAF required to satisfy demand under both the conservative and ambitious scenarios is substantial. Australian aviation fuel use was approximately 9,400 ML in 2019.[142] While it has dropped to around 3,200 ML in 2022 due to the COVID-19 pandemic, it is expected to return to 2019 levels by 2024 and to increase to up to 14,000 ML by 2050 under the ambitious scenario (with up to 100% blend). [x]This fuel volume – equivalent to ~500 PJ – constitutes nearly double the expected demand for bioenergy in the Australian aviation sector (255 PJ) which was predicted in ARENA's BioEnergy Roadmap under the targeted deployment scenario, modelled in 2021.[143] In order to meet this revised demand, supply from synthetic fuels (for example, PtL) will be required.

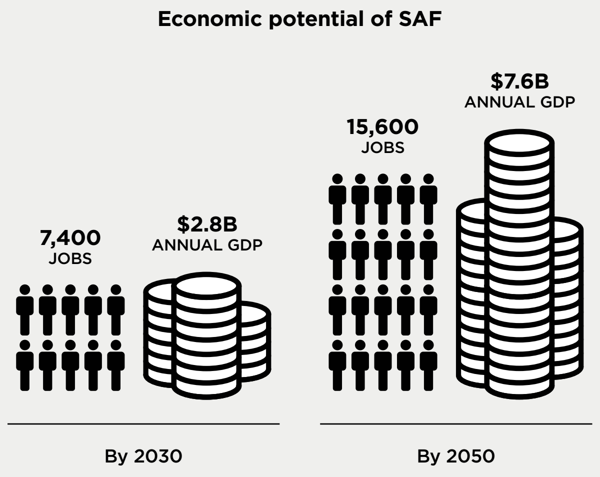
The significant and rapid upscaling of SAF production both in Australia and globally is therefore critical to the realisation of these decarbonisation targets. Recent developments in this space indicate significant potential for a domestic SAF industry, particularly if it aligns with sectors that supply 2nd generation feedstocks at scale. These developments include:

- The planned construction of a $500 million refinery in Gladstone, Queensland, starting in 2023. Oceania Biofuels intends to produce over 350 ML of sustainable fuels for both aviation and road transport from 2025 onwards using waste and sustainable feedstocks sourced locally.[144] Australia would need 40 production facilities of an equivalent size in order to satisfy the expected growth in demand for SAF under the Ambitious Scenario after fuel efficiencies are taken into account.
- QANTAS, ANZ and Japanese oil company INPEX entering into a Memorandum of Understanding (MoU) to progress a potential carbon farming project in Western Australia, starting in 2023. This collaboration may involve the harvesting and processing of biomass crops and agricultural waste residues to produce renewable biofuels. The expected volume of production from this project is not yet known.[145]
- More recently, BP have announced plans for the production of SAF at their Kwinana refinery by 2025.[146]

The Benefits of a Local SAF Industry

It is important to note that while SAF is the single biggest facilitator of the Australian aviation sector reaching net zero by 2050, a local SAF industry also has the potential to provide major benefits to the Australian economy and community more broadly.

The economic potential of SAF is significant to both GDP and jobs growth. Preliminary analysis and benchmarking from Frontier Economics estimates that an Australian SAF industry could – across the total supply chain – create more than 7,400 jobs and contribute an additional $2.8B annually in GDP by 2030.[147] By 2050, Frontier estimate that a local SAF industry could contribute more than 15,600 local jobs and an additional $7.6B annually in GDP.[148]



Importantly, a supply of local SAF will also significantly improve Australia's domestic fuel security.

Australia is heavily reliant on commercial stocks of crude oil and refined products to maintain fuel supplies – with this increasing dependency most pronounced for aviation fuel. Since 2010, aviation fuel imports have increased from 30% to 80%.[149]

In 2020-21, more than 80% of Australia's aviation fuel was imported – as a result of this, the sector is exposed to a variety of risks, including from geopolitical events, natural disasters, and supply chain disruptions.[150]

x. Based on Frontier Economics' analysis of fuel projects and the assumption of a robust post-COVID-19 recovery.

Avoiding the disruption associated with moderate or severe fuel disruption is of benefit to the entire economy and country – the recent AdBlue shortage demonstrates this point, elaborated below.

More broadly, this illustrates the legitimate role for government intervention to protect fuel security, a highly relevant consideration in the development of a robust domestic biofuels industry, with significant – and sufficient – production capabilities.

Domestic fuel security risk: the global AdBlue shortage

Australia's reliance on fuel imports and vulnerability to global market disruptions can be observed through the impact the global shortage of AdBlue had on Australia's supply chain in late 2021 and early 2022.

A shortage of chemical urea in China, and subsequent Chinese export ban of urea, resulted in a shortage of AdBlue in Australia and concerns that trucks could be taken off the road, sparking supply chain shortages across the country.

AdBlue is a liquid used to reduce the nitrous oxide emissions of diesel engines and is made up of a mixture of urea and deionized water that is sprayed into the exhaust system. Without AdBlue, it would be more difficult to lower the emissions of diesel vehicles and ensure compliance with the latest standards – additionally, some newer vehicles require AdBlue to run properly.

Potential crisis was averted when the former Federal Government intervened and made a deal with local fertiliser manufacturer Incitec Pivot to expand AdBlue production at its Gibson Island plant in Brisbane. In early 2022, Incitec Pivot produced more than three million litres of AdBlue, which is about 75 per cent of normal national demand.

To avoid such a situation in the future, the Federal Government has committed to creating a national stockpile of diesel exhaust fluid (Adblue). The Government is investing $49.5 million to establish an emergency stockpile of urea and support Australia's sovereign manufacturing capacity.

Practical Considerations

It is broadly agreed that there are three primary challenges to establishing a SAF industry in Australia:[153]

1. Securing sufficient quantities of appropriate feedstocks that can be integrated from a supply chain perspective with a biorefinery;
2. Challenging economics, particularly for an emerging industry whereby SAF will continue to be multiple times the cost of conventional jet fuel in the absence of measures to bridge the cost gap; and
3. The lack of a supportive policy framework to encourages cross-sector development and investment, and stimulate demand.

Despite recent announcements regarding the development of SAF production facilities[154, 155] there is currently no commercial production of SAF in Australia.

There has also been a dearth of funding opportunities for industry to access to develop in this space, notwithstanding the 2021 allocation by the former Federal Government of $33.5 million in additional funding to the Australian Renewable Energy Agency (ARENA), to *"further support and advance Australia's bioenergy sector through co-funding additional research, development and deployment of advanced sustainable aviation and marine biofuels."*[156]

However, the announcement by the current Federal Government of their intention to establish an Australian body analogous to the UK Jet Zero Council or the Council for Sustainable Aviation Fuels in Canada[157] should enable the creation of the appropriate framework for collaboration and a supportive policy environment, to support the domestic production and deployment of SAF.

Policy Environment

Most countries, including Australia, have adopted some form of renewable energy policy at a national level. It is well-recognised that supportive public policies play a pivotal role in the development and scaling of the current renewable energy markets, e.g. wind, solar, and biofuels for road transport[158] – the same supportive framework is now needed for an Australian SAF industry.

To accelerate the decarbonisation of Australia's aviation sector, a nationally consistent suite of policy interventions – that unlock industry investment, bridge the price differential, and stimulate SAF demand – is needed. Failure to implement this will result in slower emissions reductions and potentially slow Australia's progress to net zero by 2050, necessitating a faster and higher cost of transition in the future.

As noted above, the Federal Government's announcement of an Australian Jet Council is an important first step to developing these policies.

Sectoral Competition

The transport sector is Australia's third largest source of emissions – with the majority of these emissions attributable to road transport.[159] It is therefore unsurprising that, currently, road transport uses the majority of available renewable fuels, as part of its efforts to reduce emissions.

While demand for biofuels from both the road transport and aviation sectors should stimulate the development of a domestic biofuels industry, there is the potential that as the industry moves to scale, demand from competing sectors and markets may constrain the availability of feedstocks for SAF production.

This, coupled with the higher production costs associated with SAF output and limited demand thus far (due to the lack of a supportive policy framework) has acted as a disincentive for producers to direct feedstocks to SAF production.[160]

It is therefore critical that incentives and policy settings for the production of biofuels recognise and make allowance for the fact that aviation is one of the most difficult sectors to abate.

Given the nature of most commercial flying in Australia, and the limited application of other solutions (ie. zero-emission aircraft) on emissions, SAF is the key to decarbonising the aviation sector, both now and into the future.

Furthermore, it is likely that international long-haul flying will remain dependent on liquid fuels well after 2050[161] while other sectors, such as road transport, have alternative decarbonisation options through renewable electrification.

Ensuring domestic production capability and access to feedstocks for sustainable aviation fuels must therefore be prioritised by governments and industry stakeholders alike.

Accounting, Reporting, and Transparency

The lack of transparent frameworks – at both a domestic and global level – to provide certainty and credibility regarding lifecycle emissions reductions, and feedstock integrity has a direct impact on SAF demand.[162]

To address this in Australia, the Government could consider implementing a Guarantee of Origin (GUO) scheme – modelled on the hydrogen GUO scheme currently being trialled by the Clean Energy Regulator[163] – which would allow SAF purchasers to be appropriately credited with the resulting emissions reduction.[164]

Furthermore, it is important that any Australian standards are aligned with international standards to both prevent market distortion and facilitate international trade.

Costs

The current price of SAF can be three to six times more expensive than conventional jet fuel.[165]

This difference in price presents a significant challenge for airlines, as fuel is often the largest operating cost for an airline. In a post-COVID environment, and in the absence of supportive policies to bridge the price gap, airlines are ill-equipped to absorb this increased cost.

It is clear that Government investment, incentives, and supportive policies will be critical in establishing a sustainable, commercial, and viable domestic SAF industry in Australia – setting up the basis for the long-term energy transition for air transport.

Infrastructure

Local analysis notes that one of the primary non-economic barriers to SAF uptake in Australia is the interaction between SAF supply chains and existing fuel infrastructure and supply chains.[166] A number of stakeholders have advised that the distribution of SAF within an airport is a particularly significant barrier to overcome.[167]

Given that SAF requires blending with conventional jet fuel – in the short- and medium-term at least – it will be critically important to explore how existing refineries and fuel producers can work with industry to enable access to airport distribution facilities and provide into-wing solutions for airlines to facilitate the utilisation of SAF.

The need for a national long-term policy framework to support the production and uptake of SAF is clear. A number of international policy mechanisms have been successful in stimulating production, demand, and uptake of SAF, and while there is no one-size-fits-all solution, the following section highlights potential policy mechanisms that could be used to support SAF production and use in Australia.

Policy and Regulatory Options to Support the Development of an Australian SAF Industry

No individual policy will drive SAF growth on its own. As such, a range of policies to stimulate supply and demand, and measures to enable adequate and sustainable feedstock for the sector will be required to develop and sustain a strong and viable SAF industry in Australia.

Separate to the specific policies (below) to support SAF production and supply, and stimulate demand, the Government will also need to collaborate with industry to develop and implement the necessary ancillary policies to support a local SAF industry. Potential initiatives could include setting a domestic SAF production target, facilitating an Australian SAF certificate standard, and leveraging the existing Safeguard Mechanism to drive SAF production and uptake.

It is important to note that the policy and regulatory options outlined below are not exhaustive, and it will be important for Government to collaborate with industry – including through the recently announced Jet-Zero Council-like body – on the best and most appropriate way forward for the Australian market.

Enabling and Stimulating Domestic SAF Production

Incentivising and Prioritising Feedstock for SAF

As noted above, sectoral and international competition for feedstock is a key barrier to a robust and sustainable domestic SAF industry. As such, appropriate action must be taken by Government to prioritise and incentivise the use of current and future feedstocks for the production of Australian-made SAF.

For example, Government may support the development of non-biofuel decarbonisation options in other sectors, i.e. electrification in road transport, and gradually phase out existing subsidies for non-aviation renewable fuels to prioritise and facilitate the redirection of these feedstocks for SAF production.[168]

In Europe, the EU's Fit for 55 legislative package proposes a ban on new fossil fuel-powered vehicles after 2035, and potential support for lower-income families to convert to electric cars.[169]

Supporting and De-risking Refineries[xi]

While Australia may have two SAF refineries operational by 2025,[170] it is still important that government supports early SAF deployment through de-risking the first wave of Australian SAF refineries. Even with a favourable policy environment, significant risks remain that may lead to high-financing costs and long lead times for production. These conditions will likely persist throughout the first decade of SAF production and deployment in Australia.

Previous local analysis noted that to minimise the price gap between SAF and conventional aviation fuel, Governments should consider specific funding or co-financing mechanisms to encourage the construction of commercial refineries in Australia, as well as appropriately incentivising airlines to transition to SAF.[171] The analysis identified two potential options for supporting and de-risking SAF refineries:

Capital Funding

Government investment could be provided in the form of grants or low-interest loans to strengthen the commercial attractiveness of developing and operating a SAF refinery and capture competitive advantages for Australia.

Subsidies to De-risk Production

To de-risk SAF refineries, the Government could utilise a "reverse auction" or "contract for demand". These programs aim to bring long-term certainty to investors and producers, and have already been used successfully in other renewable energy schemes.[172] By guaranteeing purchase, these mechanisms minimise investment risk by locking in demand to return capital investments.[173] Often, a competitive reverse auction determines a "strike price" – in the event that the market price the producer receives is lower than this strike price, government funds meet the difference.[174]

These mechanisms are used to partially, or entirely, bridge the price gap with conventional fuels by providing guarantees to fuel producers that governments (and ultimately customers) will pay the difference between the market price of fossil fuels and the price needed to produce cleaner alternatives.[175]

Stimulating Demand

Direct Subsidies for SAF

A supportive policy framework to facilitate closing the cost gap between Australian-made SAF and conventional jet fuel will be key to stimulating demand and uptake – and could take the form of the provision of tax credits or exemptions and subsidies; all of which have been used in other jurisdictions, to good effect.[176]

The Biden Government in the United States, as part of the Inflation Reduction Act, has passed legislation for the Sustainable Aviation Fuel Credit – a $1.25 baseline credit for each gallon of SAF used in aviation, with additional tax credit of 1 cent for every percentage point of emissions savings above 50%, with an upper tax credit limit of $1.75 per gallon.[177] This tax credit was part of a suite of policy measures proposed in the Sustainable Aviation Fuel Act,[178] designed to support the production and uptake of SAF.

In Australia, there is precedent for local refineries to receive direct subsidies from Government – although not product specific – the Fuel Security Services Payment is available to Australia's existing fossil fuel refineries as part of the previous Government's Fuel Security Package 2020-21.[179]

[xi] This section has been informed by the analysis undertaken by EnergyLink Services on behalf of Bioenergy Australia. The full analysis and report, "Bridging the Price Gap for Sustainable Aviation Fuel" are available here: https://cdn.revolutionise.com.au/cups/bioenergy/files/ephcnscv89wbfzjz.pdf

Including SAF in Public Procurement

To stimulate local SAF demand, the Government could also participate in voluntary corporate SAF purchasing programs, and introduce a SAF target for the Department of Defence.[180, 181]

An active example of Government participating in airlines' SAF purchasing programs is in the Netherlands, where the Federal Government participates in KLM's Corporate SAF Program. Public servants flying on KLM pay the premium difference between conventional jet fuel and the SAF equivalent for their flight.[182]

Similarly, the Government and industry could work together to develop a national framework for a voluntary consumer purchasing program for SAF, to enable customers to opt-in to procure a portion of SAF for their flight.

Emissions Intensity Scheme or SAF Mandate

Additionally, in consultation with the Jet Council and broader industry, the Government could introduce a progressive SAF blending mandate or emissions intensity scheme (preferred industry option).[183]

Currently, the largest, most active international program driving the uptake of SAF (and other types of biofuels) is the Low Carbon Fuel Standard (LCFS) in California.[184] The LCFS is based on reducing the emissions intensity of fuels relative to a benchmark over time.[185] An emissions intensity mandate is generally accepted by industry as one of the most effective mechanism for driving domestic SAF uptake[186] – however, it is of note that this policy option is one of the more complex to design and implement. For this policy option to be most effective, Australia would require a domestic SAF industry, with appropriate supportive policies.

SAF blending mandates have been introduced in multiple European countries, with Norway first introducing a SAF blending mandate of 0.5% for 2020 back in 2008.[187] Similarly, the EU Fit for 55 package proposes an obligation for aviation fuel suppliers to ensure that all fuel made available to aircraft operators at EU airports contains a minimum proportion of SAF from 2025 and, from 2030, a minimum proportion of synthetic fuels, with both proportions increasing progressively until 2050.[188] It is of note that the European market has access to locally produced SAF – something which is currently missing from the Australian aviation market

Critically, SAF mandates must be accompanied by appropriate supporting policies, so as not to distort the market, and financially disadvantage airlines or the broader travelling public.[189] The introduction of a SAF mandate without appropriate policies to support production, supply and demand could adversely impact the industry – especially as the sector seeks to recover from the devasting impact of the COVID-19 pandemic.

Commitment to Action from Industry

The industry commits to working at pace with governments and other stakeholders to create a robust, sustainable, and viable Australian SAF industry.

Airlines are in the process of developing voluntary passenger and corporate buying programs to facilitate the purchasing of sustainable aviation fuel.

Furthermore, airlines are committed to investing in the development and offtake of SAF.

Despite recent announcements, airlines in Australia are currently having to explore and execute offtake agreements offshore, given that there is no domestic SAF industry, and a lack of a supportive policy environment.

The Australian airline industry would prefer to purchase SAF in Australia, and looks forward to favorable policy decisions to facilitate this.

Recommendations for Governments

Recommendation: The collaborative forum announced by the Federal Government – akin to an Australian Jet Council – must be enabled to: provide leadership on SAF, establish a coordinated national strategy, and implement a supportive policy framework.

Realising the full potential of Australian production and deployment of SAF requires Government and industry working together to develop a coordinated national vision and strategy.

The Australian aviation industry is united in the desire to support the Federal Government in its efforts to convene a body such as an Australian Jet Council[190] – analogous to the model established in the UK,[191] and currently being progressed in New Zealand.[192]

Industry's view of a Jet Council's purpose is to bring together key industry stakeholders and governments (both State and Federal) to accelerate the commercial production and use of Australian-made SAF in Australia.

Recommendation: In consultation with the Australian Jet Council, the Federal Government should progress economic and regulatory policy measures to support the production and supply of SAF.

Recommendation: In consultation with an Australian Jet Council, the Federal Government should progress economic and regulatory policy measures to stimulate uptake and use of Australian-made SAF.

> ***"No individual policy will drive SAF growth on its own. A range of policies to stimulate supply and demand, and measures to enable adequate and sustainable feedstock for the sector will be required to develop and sustain a strong and viable SAF industry in Australia."***

Carbon Offsets

The technical limits to emissions abatement from technology (efficiency, electric, and hydrogen) and SAF requires high-quality carbon offsets to bridge the remaining gap, in order to meet a net zero 2050 target. This is effectively a balancing item for any remaining emissions that cannot be abated within the sector. This would require purchase of carbon credits issued for abatement from other sectors, which may include either international credits or Australian credits.

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

In 2016, the International Civil Aviation Organization (ICAO) adopted a global market-based mechanism, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), to address CO_2 emissions from international aviation.[193] As of 2023, 109 countries (including Australia and New Zealand) will be participating in CORSIA program.[194]

CORSIA only applies to international flights and requires airlines to offset any emissions above a 2019 threshold by purchasing carbon offsets from projects that reduce emissions in other sectors. It comprises three phases of implementation: the pilot phase (2021-2023), a first phase (2024-2026) and a second phase (2027-2035). During the pilot phase and first phase, offsetting requirements will only be applicable to flights between countries that have volunteered to participate.

Strictly speaking, this reflects a minimum obligation to purchase offsets against growth in international emissions, relative to 2019. At this stage it does not require purchase of offsets to meet net zero obligations (since this would reduce net emissions well below the 2019 baseline). However, as airlines look towards 2050, it is likely that more offsets will be voluntarily purchased to ensure that net emissions fall to zero.

This obligation would be reduced by other measures which limit increases in emissions international aviation; for example, fleet modernisation and SAF, thereby reducing the obligation to purchase significant offsets.

Practical Considerations

As noted earlier, aviation is one of the most difficult sectors to decarbonise. Therefore, in the short-to medium-term, well-designed, market-based measures and high-quality offsetting will remain the key to reducing emissions from domestic and international flying[195] – especially in the Australian market, where SAF are not yet locally available.[xii] Then, in the longer-term, offsets will only be required to bridge the gap remaining after all the other measures to reduce emissions – outlined earlier – have been implemented at scale.

Global Collaboration

At present, CORSIA is expected to last until around 2035, with periodic reviews of its performance. As the international aviation sector continues to pursue emissions reduction opportunities, these efforts may be complemented by an appropriate global market-based measure from 2035 onwards.[196] Such global measures are preferable to piecemeal and inconsistent regional or national measures, which may impact airlines' costs in different ways, and can cause market distortion.[197]

As such, a well-designed market-based measure to replace CORSIA (or indeed a re-designed, more ambitious CORSIA) after 2035 will require genuine collaboration and cooperation within the international community.[198]

Costs

Market-based measures and offsetting assign a price to emissions, thereby increasing airline costs – and it is widely accepted that these costs may increase over time as the market reacts to the scarcity of carbon credits.[199] As airlines operate in a competitive market, these costs may be passed on to the end user, potentially making travel more expensive.

Countries must also work together to ensure that the cost of compliance with market-based measures do not reduce airlines' ability to invest in new aircraft technologies, fleet renewal, and sustainable aviation fuels – measures that have the potential to more substantially drive down emissions.

Commitment to Action from Industry

While airlines are aiming to reduce gross emissions by implementing new technology, operational efficiencies, and the utilisation of SAF, high-quality carbon offsetting will remain a key lever in achieving the industry's commitment to net zero emissions by 2050.[200] As such, the industry commits to continuing to invest in robust, high-quality, and high-integrity offsetting projects – both domestically, and internationally – with tangible community and biodiversity benefits.[201, 202]

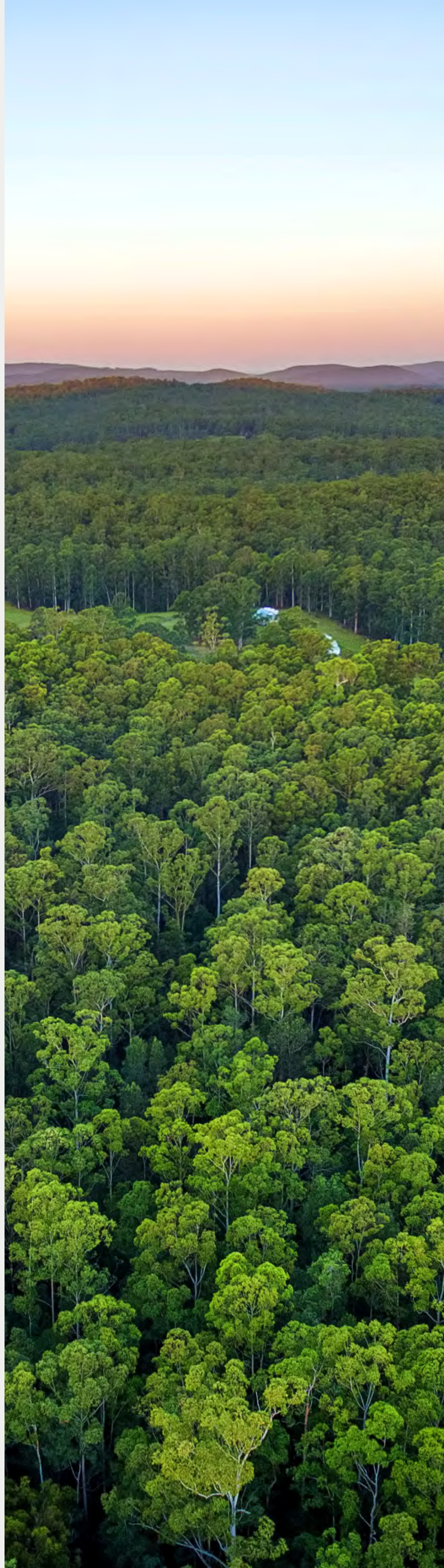
Recommendations for Governments

Recommendation: The Federal Government should continue to support the CORSIA program and assist other nations in implementing CORSIA as required.

Australia has been an active participant in CORSIA since the commencement of the program – volunteering for the early phases – and has assisted six other countries to implement the scheme through ACT-CORSIA[xiii] buddy partnerships.[203]

Through ICAO, the Federal Government should work with other countries to ensure CORSIA meets the intended long-term industry environmental goal and remains fit-for-purpose.

Governments should continue to recognise CORSIA as the single market-based measure for international flying – and not deploy any additional market mechanisms for international aviation emissions – avoiding duplication and market distortion.



[xii] While there is currently no Australian SAF industry, the airline industry – and indeed the aviation industry more broadly – is committed to working with the Federal Government to ensure that a scalable, sustainable, and commercial domestic SAF industry is established.

[xiii] Under the ACT-CORSIA Buddy Partnership, Australia has aided Brunei, Indonesia, Nauru, Papua New Guinea, Sri Lanka, and Thailand, through capacity building and the provision of technical expertise. See more: https://bit.ly/3M6C493

Overall Net Zero Roadmap

The combination of baseline assumptions and estimated abatement by source, results in the following roadmap for the Conservative SAF scenario (**Figure 19**). Under these assumptions, zero-emission aircraft and fleet modernisation reduce emissions by 4% and 28% respectively by 2050. In this scenario, SAF reduces emissions by 32% with offsets required for the remaining 35% of emissions that can't be abated by other means.

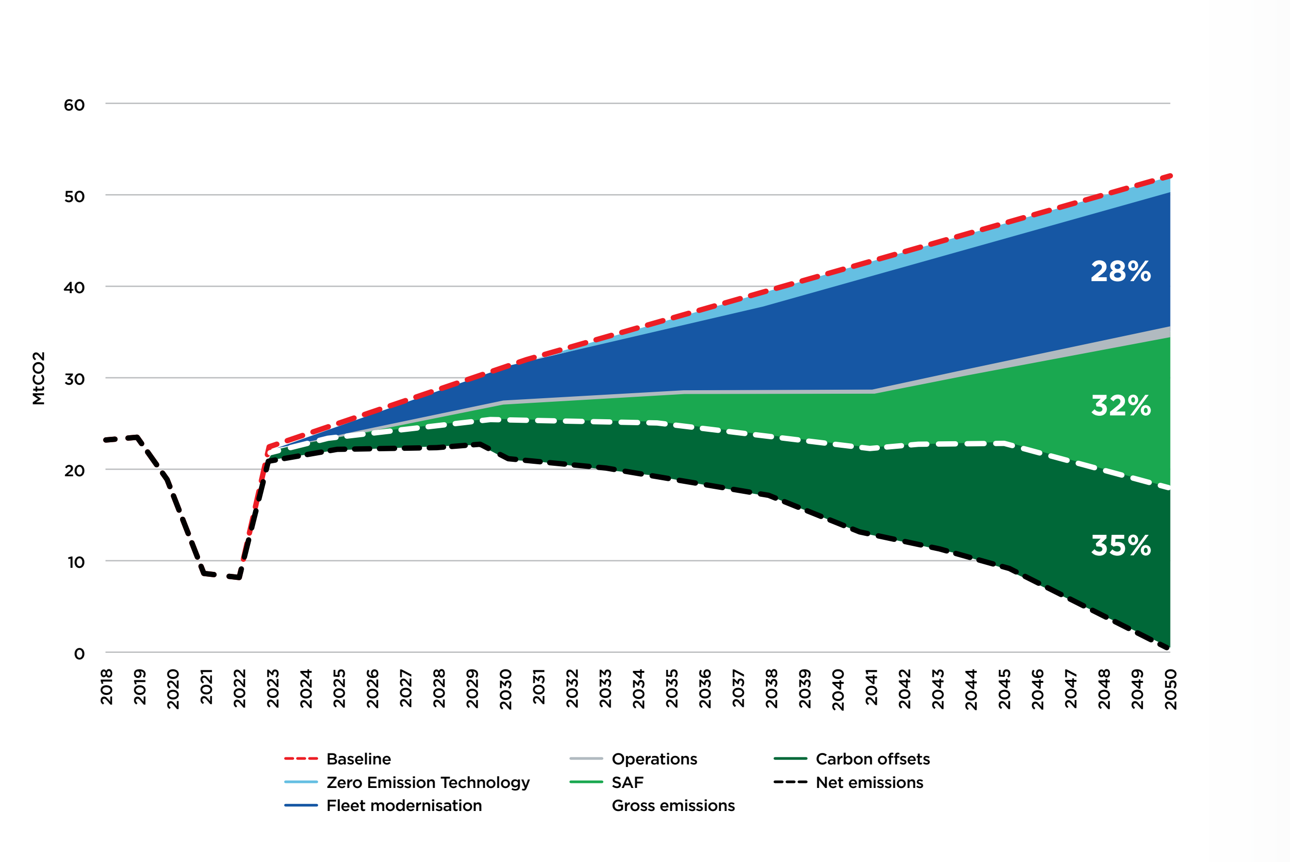


Figure 19: Australian Roadmap for Sustainable Flying: Conservative SAF Scenario

Under the Ambitious SAF scenario (**Figure 20**), the contribution of SAF rises to 53% of abatement, with offset reliance falling to 13% (other contributions from technology and fleet modernisation remain unchanged).

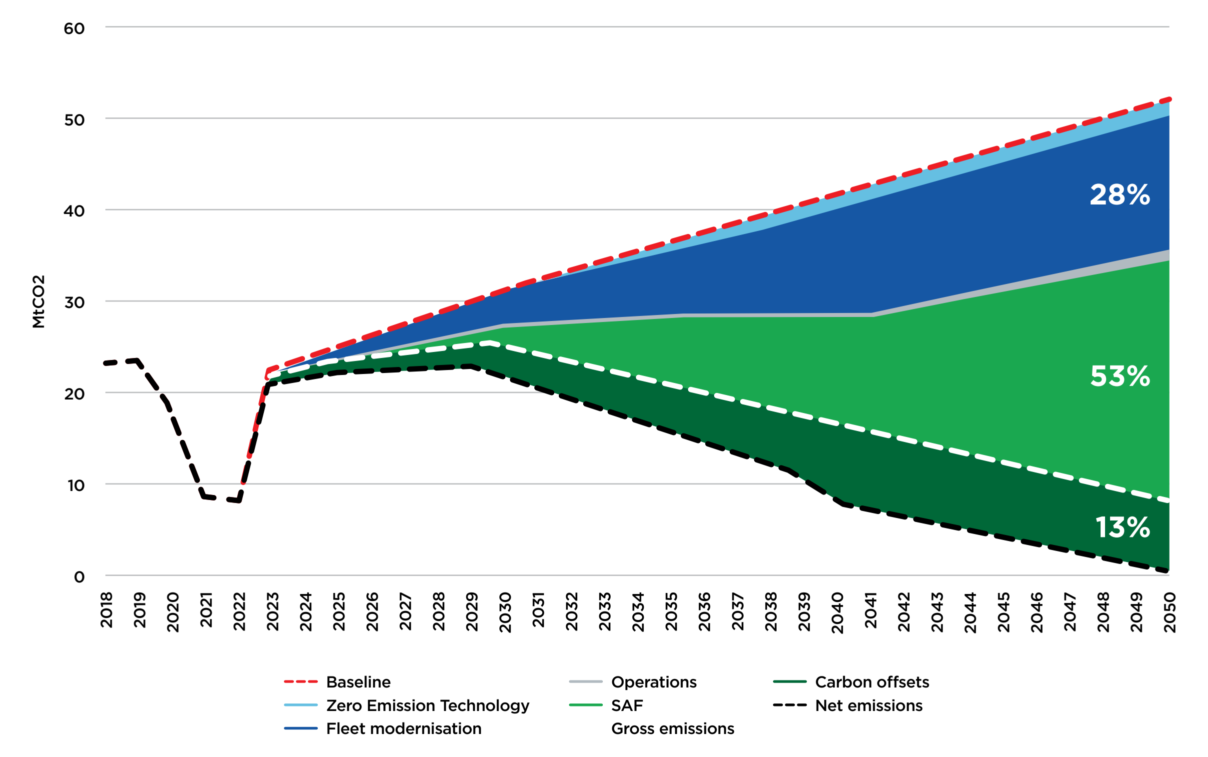


Figure 20: Australian Roadmap for Sustainable Flying: Ambitious SAF Scenario

Figure 21 compares these roadmap pathways to the other aviation roadmaps considered for this study. A simple average of the other international studies[xiv] has:

- **Technology and fleet modernisation** contributing 26% by 2050, compared with 32% in this study
- **Offsets** contributing 22% by 2050, which is within the range of our scenarios (13-35%)
- **SAF** contributing 44% by 2050, which is within the range of 32-53% in our scenarios, including 34% for EU Destination 2050 and 32% for Oneworld.

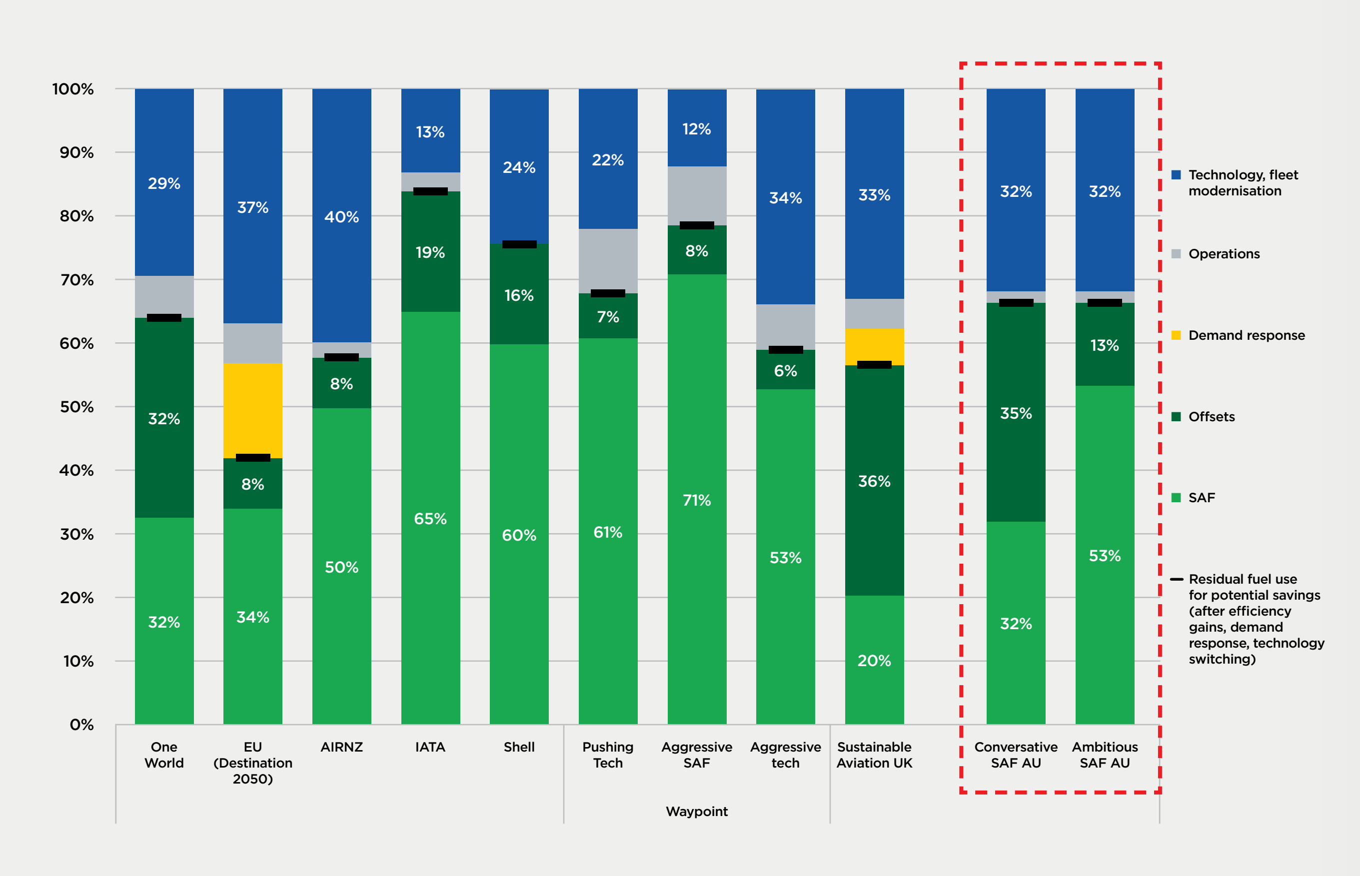


Figure 21: Australian net zero roadmap: 2050 abatement wedges versus international roadmaps

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xiv. Including only the Pushing Tech Waypoint scenario to avoid overweighting the study.

All studies highlight the significance of SAF in decarbonising the aviation industry. **Figure 22** shows the comparable assumptions for SAF contribution to residual fuel use after adjusting for assumed efficiency/technology saving. This also highlights that increased SAF abatement will directly reduce reliance on offsets.

Much of the difference between roadmaps relates to different assumptions about potential blending rates or emissions avoided from SAF; many of the studies assume 80-90% potential SAF contribution, which requires blending rates of at least 80-90%. Outcomes are not the same as projections though, so if technology allows higher SAF blending rates, then SAF will contribute more abatement under all jurisdictions.

For example, the OneWorld and SAUK studies adopt more conservative assumptions about SAF potential, though if 80-90% blending is technically proven then the actual SAF contributions for those groups/jurisdictions will exceed the roadmap assumptions.

Figure 22: International comparisons of SAF contribution to residual fuel use

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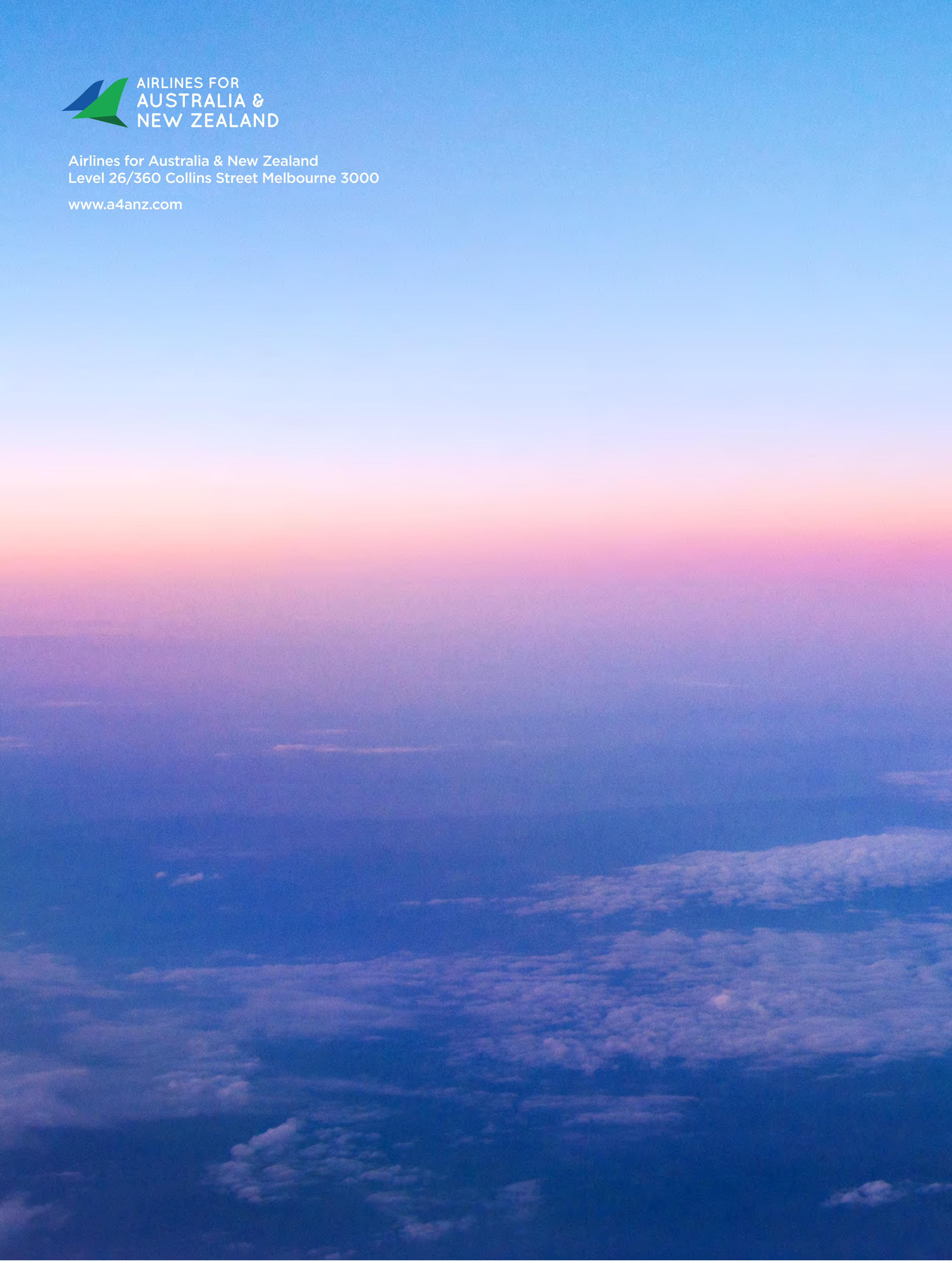

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