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Insights

Decarbonizing aerospace

A road map for the industry's lower-emissions future

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KEY MESSAGES

- The aerospace industry is expected to grow substantially but faces challenges in decarbonizing as the world moves to net-zero emissions. Without action, the industry would contribute to significantly higher global CO_2 emissions by 2050 and could face restrictions that could be detrimental to its revenues and jobs, such as the banning of flights less than 500 miles.

- Decarbonization is a key business priority, as is developing alternatives and implementing environmentally sustainable practices. However, the path to meeting 2050 emission reduction targets remains challenging as there is no silver bullet that will ensure the industry meets its goals.

- While all carbon emissions matter, Scope 3 emissions represent the largest proportion and are the most difficult to address, given the number of stakeholders involved.

- There are a range of solutions that have significant potential to drive meaningful Scope 3 emission reductions. Two of them include sustainable aviation fuels (SAFs) and electric propulsion. SAFs are likely to be the best possible solution for reducing emissions in medium-to-long-haul flights, while electric propulsion could be the most feasible zero-emission solution for smaller aircraft and short-haul flights.

- For long-haul aircraft, the focus should be on scaling the production capabilities of SAFs (both bio-SAFs and synthetic SAFs) to drive down the price and increase demand. However, while bio-SAFs could only be a net-zero solution over the fuels' life cycle, synthetic SAFs hold the potential to be a zero-emission solution. Yet, SAFs alone won't enable the industry to reach aggressive carbon reduction goals, and the overall solution must include true zero-emission propulsion systems such as electric aircraft.

- Electric propulsion could be a potential zero-emission propulsion solution for decarbonization in the long term, particularly for short-haul flights and urban air mobility. Because the challenge of scaling electric propulsion technology is so multifaceted, it requires seamless collaboration among all the key stakeholders across the entire aerospace value chain.

Aerospace: The final frontier of sustainability

AEROSPACE IS ONE of the most challenging industries to decarbonize. Very few other industries have as many challenges in reaching climate-neutral operations as aerospace, primarily because of the scale and the costs involved and the regulatory challenges of putting new technologies in the air. One of the most significant factors in addressing emissions is how an aircraft is powered through the air. Today, there's no other technology more efficient or economical than jet fuel.[1] But jet fuel emits carbon. A return flight from London to New York City generates over 1 ton of carbon dioxide (CO_2) per passenger. That's nearly the same as what the average citizen in a developing country produces in a year.[2]

Commercial aviation accounts for about 2%–3% of global CO_2 emissions (indirect emissions for the aerospace industry) and from 2013 to 2018, CO_2 emissions from commercial flights increased by 32%.[3] Business aviation has an even higher impact on the environment—in just one hour of flight, a typical business jet emits 2 tons of CO_2.[4] A typical business jet emits 860 kilograms of CO_2 per passenger compared to 108 kilograms of CO_2 per passenger for a commercial aircraft.[5] **By 2050, the commercial aviation industry could expect 10 billion passengers to fly 20 trillion kilometers, generating 2,350 million tons of CO_2 emissions, 2.6 times the emissions generated in 2019.**[6] That's a significant level of carbon emissions.

In 2009, the International Air Transport Association (IATA) put in place strategic targets for aviation, including carbon-neutral growth from 2020 and a reduction in net aviation CO_2 emissions of 50% by 2050, relative to 2005 levels.[7] However, **without decarbonization, aviation emissions could grow 3.6 times the emissions generated in 2005 and be responsible for 22% of the planet's total emissions by 2050**[8] (figure 1).

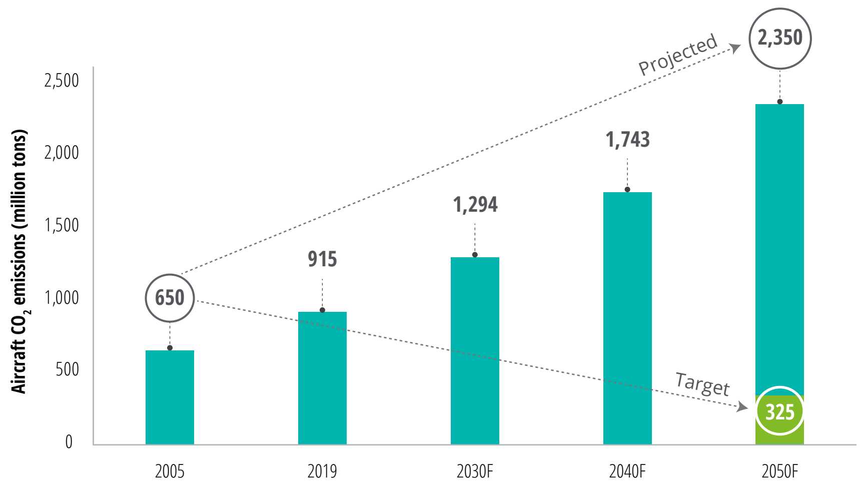
Aerospace and aviation industries defined

For the purpose of this study, we define the aerospace industry as a set of companies that design and manufacture aircraft; and the aviation industry as a set of companies that provide air transport services for passengers and freight.

FIGURE 1

Without significant intervention, aircraft CO_2 emissions will likely grow over 2.5 times from current levels through 2050

Aircraft CO_2 emissions (million tons): 2005–2050F



Note: *F indicates forecast.
Source: Deloitte estimates based on data from IATA and Boeing.

Despite the aerospace industry's 1.5% improvement in fuel efficiency (the distance an aircraft can travel on 1 gallon of fuel) annually over the past 10 years,[9] there is mounting pressure to do more, and it needs clear direction on the feasible pathways to address climate impact. Deloitte conducted executive interviews with 40 senior American and European aerospace and aviation industry leaders and extensive quantitative modeling to offer insights into decarbonization challenges and possible solutions to reducing CO_2 emissions. While this study provides an overview of considerations for decarbonizing the aerospace industry, the primary focus is on the potential for zero-emission electric aircraft to enable the industry to achieve emission reduction goals.

Specifically, the report addresses four important questions:

- What is the business imperative for reducing carbon emissions?
- How can the aerospace industry drive disruptive innovation to reduce carbon emissions?
- What is a potential road map for low-emission aerospace technologies?
- How can electric propulsion reduce the aerospace industry's Scope 3 emissions in the long term?

The aerospace industry's revenue models could be at risk if decarbonization is not adequately addressed

Globally, the aerospace industry continues to be a strong driver of mobility, economic growth, jobs, and trade. At the same time, the industry is one of many that has a heavy impact on global emissions as beyond CO_2, aircraft have an impact on global warming through the emissions of nitrogen oxides (NOx). Transitioning to a low-carbon future requires the industry to decarbonize urgently as its business models, revenues, and costs will otherwise be at risk, impacting not just aircraft manufacturers but also the entire supply chain. **Deloitte estimates that the commercial aerospace industry could experience a revenue decline of about US$40 billion and a workforce reduction of 110,000 jobs[10] if regulations pricing carbon emissions, reducing short flights, and promoting the use of more sustainable alternate modes of transportation, such as electric trains, come into force.**

The good news is that demonstrating sustainability initiatives can drive growth and contribute to long-term competitive advantage. Almost all the aerospace executives we interviewed indicated that sustainability efforts would likely positively impact revenue growth and overall company profitability, increase customer satisfaction, and enhance their ability to attract and retain talent.

While decarbonization is important, implementing economically feasible and scalable solutions can be an uphill task. Some of the more significant challenges for the aerospace industry to achieve 2050 emission reduction targets include technical feasibility and financial viability of new technologies and solutions, scalability of production and infrastructural challenges, measurement of the environmental and economic impact of sustainability initiatives, and regulatory support possibly in the form of incentives.

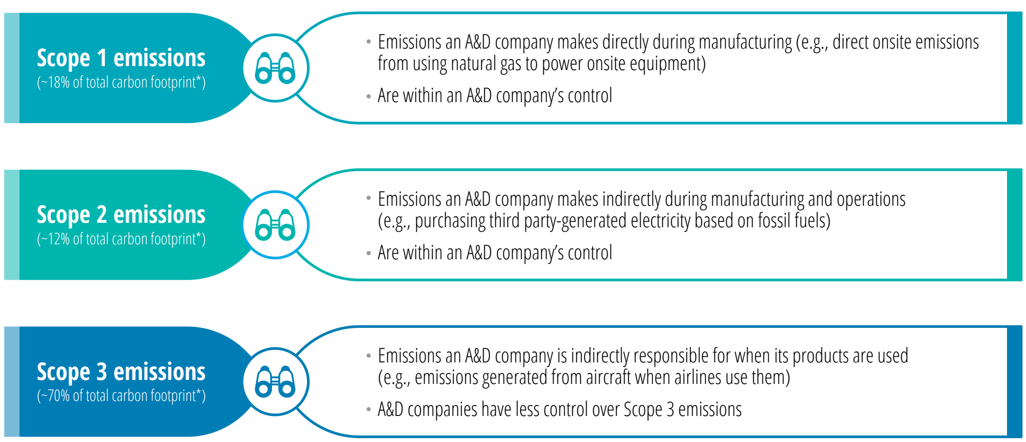
Addressing Scope 1 and Scope 2 emissions is foundational for sustainable aerospace manufacturing

WHILE SOME AEROSPACE companies are making good progress in understanding the emissions they directly generate, mapping their emissions footprint right across the value chain can be a far bigger challenge.

Scope 1, Scope 2, and Scope 3 are ways of categorizing the different kinds of carbon emissions an aerospace company creates in its own operations, and in its wider value chain (figure 2).

FIGURE 2

Aerospace companies have less control over Scope 3 emissions, which account for about 70% of their carbon footprint



Note: *Estimates as of December 31, 2020.
Source: Deloitte analysis based on executive interviews.

Sustainable aerospace manufacturing (reducing Scope 1 and Scope 2 emissions) involves designing and building commercial and military aircraft through economically sound processes that minimize negative environmental impacts while conserving energy and natural resources. The four main areas where sustainable practices can drive measurable improvements across the aerospace manufacturing value chain include improving product design and engineering using advanced technologies such as digital twin, rapid prototyping, and additive manufacturing; ethically selecting and sourcing sustainable alternative materials; forging the factory of the future by combining smart technologies and green energy; and streamlining shipping and distribution through supply chain reconfiguration and rationalization of trade routes. (Read *Sustainable manufacturing: From vision to action* for more details on major impact areas where sustainable practices can drive measurable improvements across the aerospace manufacturing value chain.)

IN DEFENSE, MILITARIES FOCUS ON MISSION, AND MANUFACTURERS FOCUS ON EFFICIENCY

While defense uses many of the same technologies as commercial aviation, the incentives and goals tend to be different. The burden of moving huge volumes of fuel has led most defense organizations to find innovative new ways to reduce their carbon footprint, ranging from personal solar generation to small-scale nuclear reactors. Yet, defense organizations still typically prioritize performance over all other considerations. So, while those defense organizations themselves may be reducing Scope 3 emissions, there is little demand for original equipment manufacturers (OEMs) to do so. Where there is a competitive advantage for OEMs is in improving the efficiency of their operations. As a result, most defense companies are trying to reduce their carbon footprint across facilities and assets by creating smart buildings, constructing and operating smart manufacturing facilities, and utilizing power efficiently. Defense aerospace OEMs are using advanced technologies such as digital twin to run thousands of digital/virtual simulations to optimize design and production, thereby reducing emissions that would have been otherwise generated.

The aerospace industry should focus on disruptive innovation along five key elements to reduce Scope 3 emissions

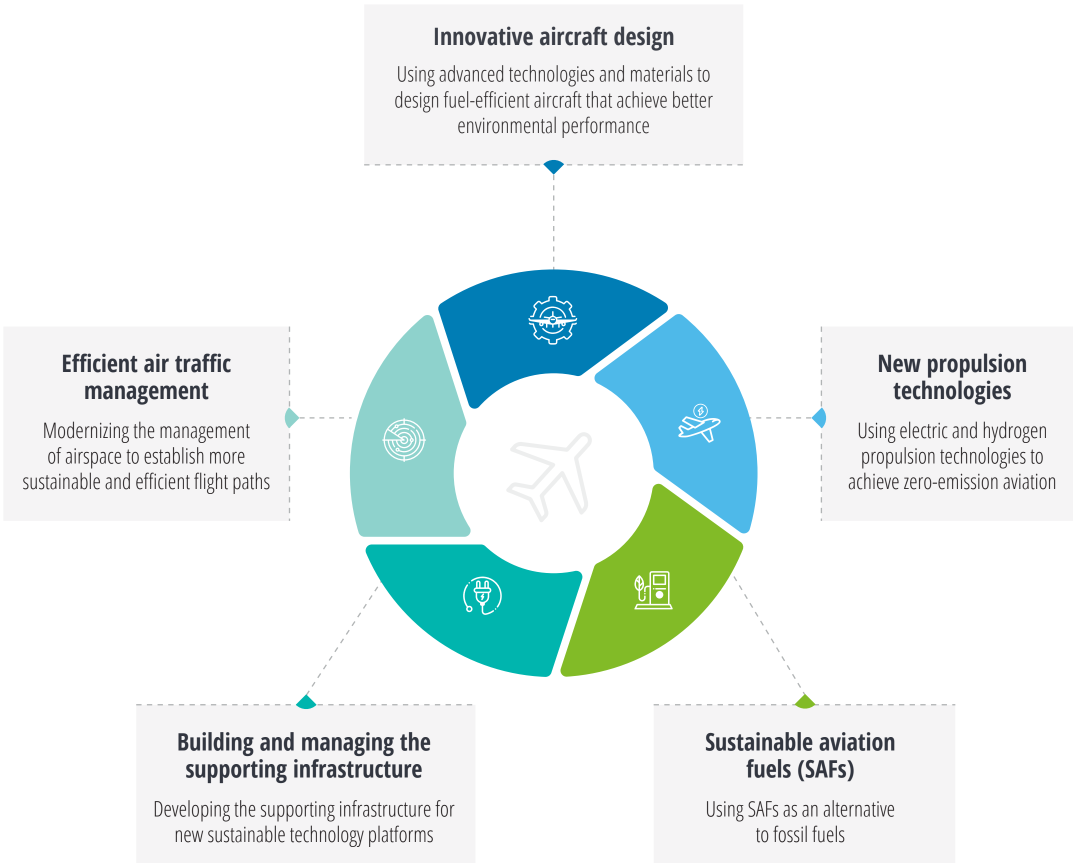
CALCULATING, THEN ELIMINATING, Scope 3 emissions can be an intimidating prospect. For most aerospace companies, they represent a much greater proportion (about 70%) of their carbon footprint than Scope 1 and Scope 2 emissions. While companies have less control over these emissions, addressing them can be critical for lowering aviation emissions.

Different promising technologies have emerged to reduce Scope 3 emissions in the long term.

While most aircraft emissions are related to the combustion of fuels and it's crucial to uncover sustainable ways to propel aircraft, the industry should focus on five key elements to help decarbonize (figure 3). Even as SAFs made from renewable feedstock represent an important solution, scalable innovations related to new propulsion technology, including electric propulsion, are important to reduce the industry's carbon footprint in the long term.

FIGURE 3

Five key elements to help reduce the aerospace industry's Scope 3 emissions



Source: Deloitte analysis based on executive interviews.

1. Innovative aircraft design

Fleet renewal with innovative aerodynamic designs, additive manufacturing of aircraft parts, and the use of advanced coatings is one area of focus that could boost fuel efficiency in aircraft, and in turn, would reduce emissions. While aircraft manufacturers can reduce Scope 1 and Scope 2 emissions using efficient processes during the product design stage, innovative aircraft design can also help in reducing Scope 3 emissions when aircraft are flying. Aircraft manufacturers have been focusing on weight reduction and aerodynamics to improve fuel efficiency for many decades.

They should continue to improve the efficiency of the current technology platforms and develop more fuel-efficient engines in new commercial jets that leverage light-weight carbon fiber. They need to explore new shapes that can further improve fuel efficiency by using thinner, lighter materials. Also, innovation at the design level, such as reducing the size of the vertical tail would decrease weight and drag, and in turn could help cut fuel consumption and emissions. Further, using additive manufacturing, aircraft manufacturers can reduce the weight of plane parts and cut fuel use.

INDUSTRY EXAMPLES: INNOVATIVE AIRCRAFT DESIGN

Boeing is leveraging additive manufacturing to build products with fewer raw materials, creating less waste, and thereby improving fuel efficiency. Each newly developed Boeing product is typically 15%–25% more efficient than the airplanes it replaces.[11] Spirit AeroSystems invests about US$10 million annually in energy efficiency investments and related performance improvement initiatives. This includes product innovation, such as increased use of composites, which reduces carbon emissions by about 20% over the life of an aircraft, compared to a metallic aircraft.[12] Airbus is investing in R&D to design fuel-efficient aircraft that achieve better environmental performance, including reduced NOx and CO_2 emissions. It is leveraging data from its end-of-life management processes and integrating the findings back into the design.[13]

2. New propulsion technologies

a) Electric/hybrid-electric propulsion: Electric propulsion technology is rapidly evolving, whether it's a hybrid aircraft (propelled by both fuel and an electric battery), or a fully electric aircraft. Electric/hybrid-electric propulsion is emerging as a promising technology in the long term as the aerospace industry can leverage recent advancements in the automotive industry to use batteries to power an electric motor and spin a propeller or ducted fan to generate thrust.

Though the operations using electric propulsion technology are in a nascent stage, they are likely to reduce emissions in the short-haul category on a per-seat-mile basis in the near term. The development of this technology could be important, as battery-powered aircraft would have no combustion emissions, therefore removing both CO_2- and non–CO_2-related global warming effects from aviation. However, one of the main challenges facing electric aircraft is the battery, as it remains relatively heavy for aviation. At the same weight, jet fuel typically provides about 14 times more usable energy than a brand-new lithium battery.[14] While today's battery energy densities can only power small aircraft for a short period of time, focusing on improving the energy density could make it possible for larger passenger aircraft to be powered by batteries over several hundreds and even thousands of kilometers. Zero-emission short-distance commercial aviation could be possible by using battery-electric airplanes beyond 2030.

b) Hydrogen propulsion: Hydrogen can be used in two main ways to power aircraft: either reacted in a fuel cell to provide electricity to an electric motor or combusted in modified jet engines to provide thrust. Hydrogen propulsion could significantly reduce climate impact by eliminating carbon emissions on medium- and potentially long-haul flights in the long run and could become the linchpin between renewable energy and energy-intensive industries such as aviation.

INDUSTRY EXAMPLES: ELECTRIC/HYBRID-ELECTRIC PROPULSION

Rolls-Royce is focusing on accelerating the development of disruptive new technologies and capabilities for future low-emission products, including the electrification of flight.[15] Eaton is leveraging its electrical expertise to help develop electrified aircraft that are safer, cleaner, and more cost-efficient. The company is working with OEMs worldwide to accelerate electrification and help build more efficient vehicles.[16] Textron Aviation has signed a purchase agreement with Surf Air Mobility Inc. to sell 150 Cessna Grand Caravan EX single-engine turboprop aircraft. The order is part of an exclusive relationship between the two companies supporting Surf Air Mobility's development of electrified Cessna Grand Caravan aircraft, powered by Surf Air Mobility's proprietary powertrain technology.[17] Joby Aviation plans to launch air taxi services by 2023 and become one of the first to commercialize electric vertical takeoff and landing (eVTOL) aircraft for passenger use in the United States.[18]

However, as hydrogen has an energy density per unit mass that is three times higher than traditional jet fuel,[19] significant challenges related to bringing the weight and cost down and storing it onboard the aircraft would have to be addressed. Powering long-haul flights using hydrogen propulsion would require extensive aircraft redesign, including changing the shape of the aircraft. Some of the biggest obstacles include significant investment in new aircraft, fuel storage systems, fuel distribution systems, and production itself.

3. Sustainable aviation fuels

Sustainable aviation fuels (SAFs) are produced from sustainable feedstocks and are very similar in their chemistry to traditional fossil jet fuel. Bigger aircraft and longer flights require more energy, and SAFs are emerging as a viable alternative to fossil fuels because they are among the most measurable solutions to address climate change and reduce carbon emissions.

There are two types of SAFs currently available; one option is bio-SAFs made from feedstocks ranging from plants to used cooking oil, municipal waste, and household waste. Typical feedstocks used are cooking oil and other nonpalm waste oils from animals or plants, as well as solid waste from homes and businesses, such as packaging, paper, textiles, and food scraps that would otherwise go to landfill or incineration. Other potential sources include forestry waste, such as waste wood, and energy crops, including fast-growing plants and algae. While bio-SAFs emit carbon when they're burned, they only release the carbon they've already taken out of the atmosphere and thus could at best be a net-zero solution over their life cycle. But bio-SAFs have a drawback—they are two to four times the cost of jet fuel. The second option is synthetic SAFs—synthetic kerosene made from hydrogen and CO_2—either from the air via direct air capture (DAC)

INDUSTRY EXAMPLES: HYDROGEN PROPULSION

Airbus is working to develop, build, and test hydrogen propulsion systems to help the aerospace industry reduce emissions.[20] Pratt & Whitney is investing in next-generation technologies such as hydrogen-powered propulsion to drive performance and efficiency across its engine portfolio.[21] Universal Hydrogen, an aerospace company specializing in carbon-free flight, announced deals with a US airline and two international carriers to supply green hydrogen fuel services to advance the decarbonization of flight operations.[22]

or carbon capture, but they are very expensive. Synthetic SAFs are six to 10 times more expensive than traditional jet fuel, primarily due to the small production runs.[23] Nevertheless, synthetic SAFs hold the potential to be a truly zero-emission solution.

SAFs can be dropped straight into the aircraft tanks, and don't necessitate significantly changing the aircraft, engines, or fuel supply system. But aircraft companies could still implement some changes to make different blends work in current engines. Further, SAFs are not entirely economically feasible today as the critical constraint is the economics of scaling. OEMs should consider partnering with engine companies to develop SAF solutions to achieve optimal fuel savings throughout their fleet's entire service life span. OEMs should also drive energy companies to invest in producing and supplying SAFs in sufficient quantities at feasible prices. Engine manufacturers should work with the energy industry to significantly ramp up the availability of SAFs and create more demand which, in turn, could lead to more production and lower costs. (Read *Decarbonizing aviation: Clear for take-off* for a detailed assessment of SAFs.)

INDUSTRY EXAMPLES: SUSTAINABLE AVIATION FUELS

Boeing has committed that its new commercial aircraft will be ready to fly on 100% SAFs by 2030.[24] Rolls-Royce conducted the first tests of 100% SAF in a business jet engine, as part of its ongoing ambition to play a leading role in enabling aerospace industry reach net-zero emissions by 2050.[25] Pratt & Whitney, through its participation in the American Society for Testing and Materials (ASTM) International committee, is helping in the evaluation and approval of SAFs.[26] Shell has invested in LanzaJet, a sustainable fuels producer, to scale up the production of SAFs.[27]

4. Efficient air traffic management (ATM)

Modernizing the management of airspace to establish more efficient flight paths (direct routes and less energy used) remains one of the key solutions to reduce energy use and emissions. Upgrading the regulatory framework to reduce fragmentation of the airspace can further help improve ATM performance in terms of not only safety and capacity but also cost efficiency and the environment. Policies such as avoiding congestion and suboptimal flight routes and promoting the market for data services needed for better ATM can help reduce aviation emissions. The industry should work with regulators such as the Federal Aviation Administration (FAA) to help develop ATM solutions to achieve optimal fuel savings (through reducing fuel burn). In this regard, implementation of NextGen Air Transportation System (FAA's ongoing navigation system upgrade that replaces

INDUSTRY EXAMPLES: EFFICIENT AIR TRAFFIC MANAGEMENT

Thales is working toward connecting flight management systems with ATM systems to achieve a 10% reduction in aircraft CO_2 emissions by 2023. Thales's new Air Traffic Flow Management (ATFM) system uses a predictive model of global air traffic to propose trajectories that are optimized in terms of environmental performance.[28] JetBlue has invested in NextGen Air Transportation System and is already reaping benefits such as lower fuel usage and carbon emissions. NextGen's custom guidance for each flight is helping JetBlue realize efficiencies, including reductions in predeparture taxi time, flight mileage at takeoff and during the flight due to modified routes based on real-time weather data, and taxi-in time because the pilot has gate/taxi information ahead of time.[29] EU nations agreed on a reform of the bloc's air traffic management aimed at cutting emissions, reducing costs for hard-hit airlines, and improving safety. The reform, known as Single European Sky, includes a variety of initiatives, such as beefing up the role of regulator EUROCONTROL in coordinating and optimizing air traffic flows.[30]

ground-based radar data with satellite-based data from the US Global Positioning Satellite System) and route optimization is expected to be a key contributor to emission reduction. The Civil Air Navigation Services Organization (CANSO) should work with more governments to free up airspace for more direct commercial routes when not required for military purposes.

5. Building and managing supporting infrastructure

Driving innovation across the new propulsion technologies, SAFs, and ATM requires developing and maintaining the best-in-class supporting infrastructure that helps achieve operational efficiencies. To drive an efficient transition to a greener future, developing a global network of infrastructure could be crucial to supply the electricity needed to recharge the electric aircraft, hydrogen needed to propel the aircraft, and SAFs as replacement fuels for conventional jet fuels in as many airports as possible. This includes developing infrastructure to supply alternative fuels at airports, thereby guaranteeing similar safety levels as conventional jet fuels. Airlines can work with airports to provide electricity to aircrafts at terminal gates using fixed electrical ground power rather than an aircraft's auxiliary power unit. The industry should also work with infrastructure companies to help airports pursue low-cost energy efficiency measures such as purchasing renewable energy, installing airport renewable energy systems, and buying low- or zero-emission vehicles and ground support equipment (GSE).

An efficient transition to a greener future will require a global network of infrastructure to supply the electricity needed to recharge the electric aircraft, hydrogen needed to propel the aircraft, and SAFs as replacement fuels for conventional jet fuels in as many airports as possible.

INDUSTRY EXAMPLES: SUPPORTING INFRASTRUCTURE

Since 2015, Oslo airport in Norway has been distributing SAFs to all airlines on a regular basis.[31] Vancouver International Airport is aiming to eliminate carbon emissions by 2030. The airport plans to electrify its entire light-duty vehicle fleet along with as much of its heavy fleet as possible. Further, it is using renewable natural gas to improve the energy efficiency of terminal lighting and HVAC systems.[32]

CARBON OFFSETS—A SHORT-TERM LEVER IN THE AEROSPACE INDUSTRY'S PUSH TO OFFSET EMISSIONS

Offsets, or carbon credits, are used by the industry to compensate for CO_2 emissions arising from airline operations, whether on domestic routes or on international routes, with the latter coming under the Carbon Reduction and Offsetting Scheme for International Aviation (CORSIA). Offsets allow industry players to "neutralize" their proportion of an aircraft's carbon emissions on a particular journey by investing in carbon reduction projects.

For example, Joby Aviation, JetBlue, and Signature announced a new pathway toward net-zero emissions by utilizing electric and hydrogen aviation credits.* The partners will define the framework for the creation, validation, and eventual use of these new credits on aviation carbon markets. In 2020, JetBlue became the first US airline to achieve carbon neutrality for all its domestic flights through the purchase of carbon offsets from solar, wind, and forestry projects across the globe.

Note: *For more details, see: Kelsey Reichmann, "New partnership between Joby, JetBlue and Signature aims to create credits for clean flight technology," Aviation Today, July 13, 2021.

Pathway to reducing Scope 3 emissions

CO_2 EMISSIONS FROM aviation (Scope 3 emissions) were 650 million tons in 2005, and the emissions target set by the aviation industry is 325 million tons by 2050 (or a 50% cut from 2005 levels).[33] Unless continued progress is made by the aerospace industry, CO_2 emissions from aviation could soar to 2,350 million tons by 2050.[34] This means the industry should reduce a potential 2,025 million tons of carbon emissions from 2021 through 2050 to meet the emission reduction target.[35]

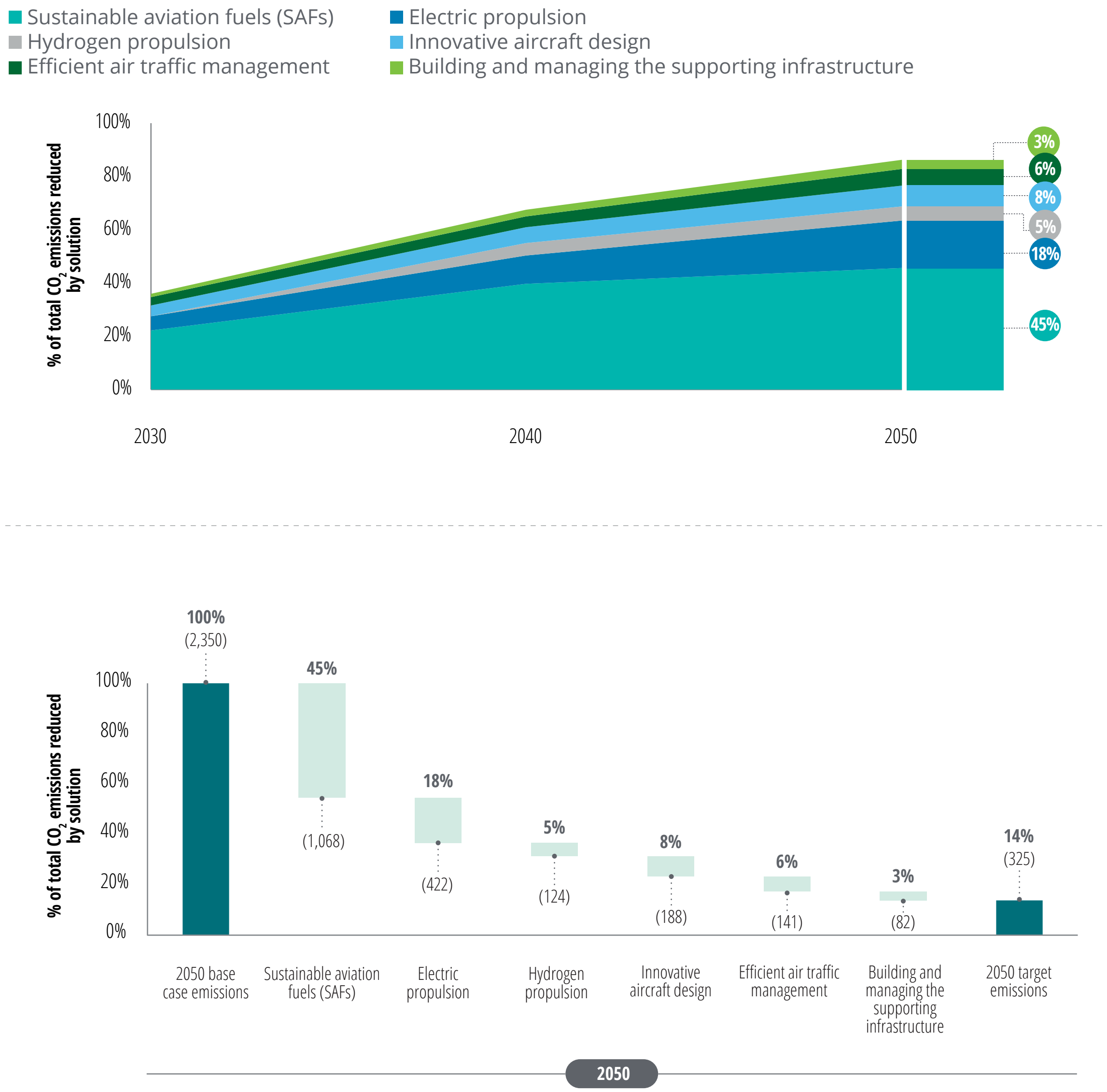
Deloitte's analysis indicates that SAFs and electric propulsion could be the primary levers for reducing Scope 3 emissions and meeting the 2050 emission reduction goals. **SAFs and electric propulsion together could reduce up to 63% or 1,490 million tons of CO_2 emissions through 2050** (figure 4).[36] (See the "Methodology" section for detailed information on the computations.)

Moreover, SAFs might be the best possible solution for reducing emissions in medium-to-long-haul flights, while electric propulsion is likely the most feasible zero-emission solution for smaller aircraft and short-haul flights. **Deloitte estimates that SAFs could help reduce 75% of the emissions generated by all long-haul flights (flight range beyond 1,000 miles) by 2050 and electric propulsion could reduce 60% of the emissions generated by all short-haul flights (flight range of up to 500 miles) by 2050** (figure 5). Further, SAFs and electric propulsion may help reduce 40% and 35% of the emissions generated by all the medium-haul flights (flight range of 500–1,000 miles) by 2050, respectively.

SAFs might be the best possible solution for reducing emissions in medium-to-long-haul flights, while electric propulsion is likely the most feasible zero-emission solution for smaller aircraft and short-haul flights.

FIGURE 4

Decarbonization potential pathway through 2050



Note: Percentages may not add to 100% due to rounding.
Source: Deloitte estimates based on data from IATA and Boeing.

FIGURE 5

Potential emission reduction opportunity by technology across aircraft type/flight range

Technology	2021–2030	2031–2040	2041–2050
Short-haul flight (flight range of up to 500 miles)			
SAFs	25%	40%	10%
Electric propulsion	25%	40%	60%
Hydrogen propulsion	0%	10%	20%
Medium-haul flight (flight range between 500 and 1,000 miles)			
SAFs	25%	50%	40%
Electric propulsion	10%	20%	35%
Hydrogen propulsion	0%	10%	10%
Long-haul flight (flight range beyond 1,000 miles)			
SAFs	30%	50%	75%
Electric propulsion	0%	0%	0%
Hydrogen propulsion	0%	0%	0%

Source: Deloitte estimates based on insights from executive interviews and data from IATA and Boeing.

Widespread use of SAFs is expected to be pivotal in reducing aviation emissions. However, there has to be an incentive structure in place for energy and aviation companies to scale SAFs' production and use. Moreover, for these fuels to be truly "sustainable," they must meet specific criteria such as life cycle carbon emission reduction, limited fresh-water requirements, no competition with needed food production (such as first-generation biofuels), and no deforestation.

Zero-emission short-distance commercial aviation could be possible by using electric propulsion through sustainable production of batteries beyond 2030 as battery costs are expected to decline significantly in the long term. However, electric propulsion requires design changes in propulsion systems and airframe design, as well as significant investments in battery charging and power infrastructure. Meanwhile, hydrogen fuel cell would be complex to commercialize (figure 6).

FIGURE 6

An assessment of select key levers of reducing Scope 3 emissions

Lever of decarbonization	Technology	Benefits	Challenges
Sustainable aviation fuels (SAFs)	• Produced from sustainable sources of energy such as waste cooking oil and agricultural residue, etc.	• Reduces life cycle carbon emissions from airline fuel by up to 80% • Can be just dropped into the aircraft tanks as aircraft companies don't have to modify the aircraft, engines, and fuel supply systems significantly	• Not yet available at the scale or price needed to be the primary source of fuel • Distribution, collection, and transportation of feedstock remains a challenge
Electric propulsion	• Fully electric aircraft that use propellers driven by battery-powered electric motors, or hybrid-electric aircraft propelled by both fuel and an electric battery	• Reduces emissions by 100% and lowers noise levels • Suitable for short-distance commercial aviation—all regional flights could transition to being 100% electric	• Requires design changes in propulsion systems and airframe • Requires developments in battery energy and power density, with range initially limited to short-haul flights • Aircraft speed compromised due to an increase in overall weight • Significant investments needed in battery charging, and power infrastructure (electric grid) needs to be in place
Hydrogen propulsion	• Uses chemical reaction in a fuel cell to provide electricity to an electric motor or by combusting it in modified jet engines to provide thrust	• Reduces emissions by 100% and lowers noise levels • Could be a more viable solution for medium-haul flights	• Powering long-haul flights means extensive aircraft redesign, including changing the shape of the aircraft and propulsion systems • Requires major infrastructure changes as storage and transportation will need entirely new infrastructure

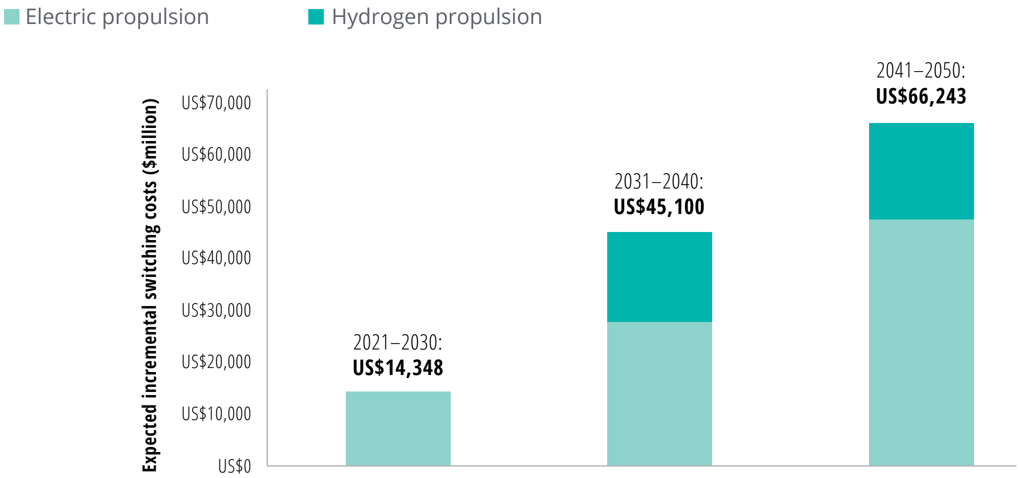
Source: Deloitte analysis based on executive interviews.

One of the biggest challenges of successfully scaling the new propulsion technologies is that the aerospace industry would have to make significant investments and work with the extended value chain to build infrastructure.

Deloitte estimated the incremental cost of switching to electric and hydrogen propulsion, mainly for short-to-medium-haul flights, could add up to US$125 billion by 2050 (figure 7).

FIGURE 7

Expected cost of switching to electric and hydrogen-powered aircraft through 2050



Sources: Deloitte analysis based on data from Airbus and Boeing annual reports; Bloomberg; MotorTrend; and InsideEVs.

Therefore, financing will likely play a big role in accelerating the transition toward zero-emission aircraft technology. Aerospace companies should align with the public sector to foster research and innovation activity and funding to achieve the technological breakthroughs. Also, having a clear road map and deliberate strategy can help the aerospace companies attract private equity funds relatively easily for their innovation and pioneering R&D activities. By working closely with governments and investors, existing industry players and startups can secure investments to drive technology readiness levels to reach market readiness levels.

Electric aircraft: A long-term potential solution to achieving zero-emission aviation, particularly for short-haul flights

WHILE BIO-SAFS ARE a net-zero solution over the fuels' life cycle, they are not a truly zero-emission solution. On the other hand, while synthetic SAFs hold the potential to be a zero-emission solution, they are very expensive compared to traditional jet fuel. Therefore, SAFs alone won't enable the industry to reach aggressive carbon reduction goals so the overall solution must include true zero-emission propulsion systems.

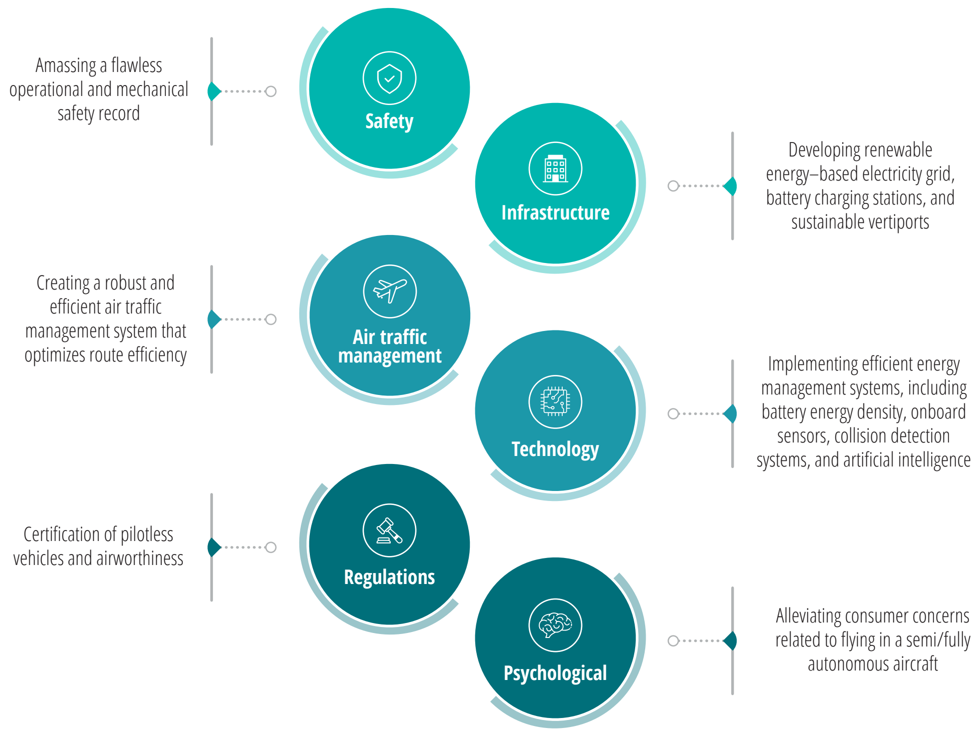
For short-haul flights and urban air mobility, a focus on electric propulsion can enable a more sustainable mode of transport for the aerospace industry. While not a short-term solution currently, electric propulsion promises to provide affordable and energy-efficient mobility across various commercial, civil, and defense uses. Using eVTOL aircraft that are usually short-range (currently up to 300 miles), runway independent, and highly automated, aerospace companies could incorporate nontraditional electric propulsion for piloted or automated operations for passenger travel or delivery of goods. **Six in 10 industry leaders believe that electric propulsion will be a more sustainable and environmentally friendly solution compared to the current modes of aerial mobility.**[37]

Electric motors and simplified electronic controls can improve on complex transmissions, flight-critical components, and mechanical reliability, while also substantially reducing the emissions generated during flight operations as well as manufacturing and sustainment costs. This aircraft design could also enable many new complex missions in urban, suburban, and defense environments, some of which are currently conducted by ground vehicles, traditional helicopters, and fixed-winged aircraft, thereby further cutting emissions.

Among the many new technology platforms the industry is working on, electric propulsion could be a first-mover in helping achieve zero-emission air travel. eVTOL aircraft's autonomous flight operations can trigger climate-friendly missions beyond passenger and cargo mobility, including public safety, humanitarian relief, infrastructure inspection, and remote sensing.

FIGURE 8

Challenges involved in embracing and scaling eVTOL aircraft



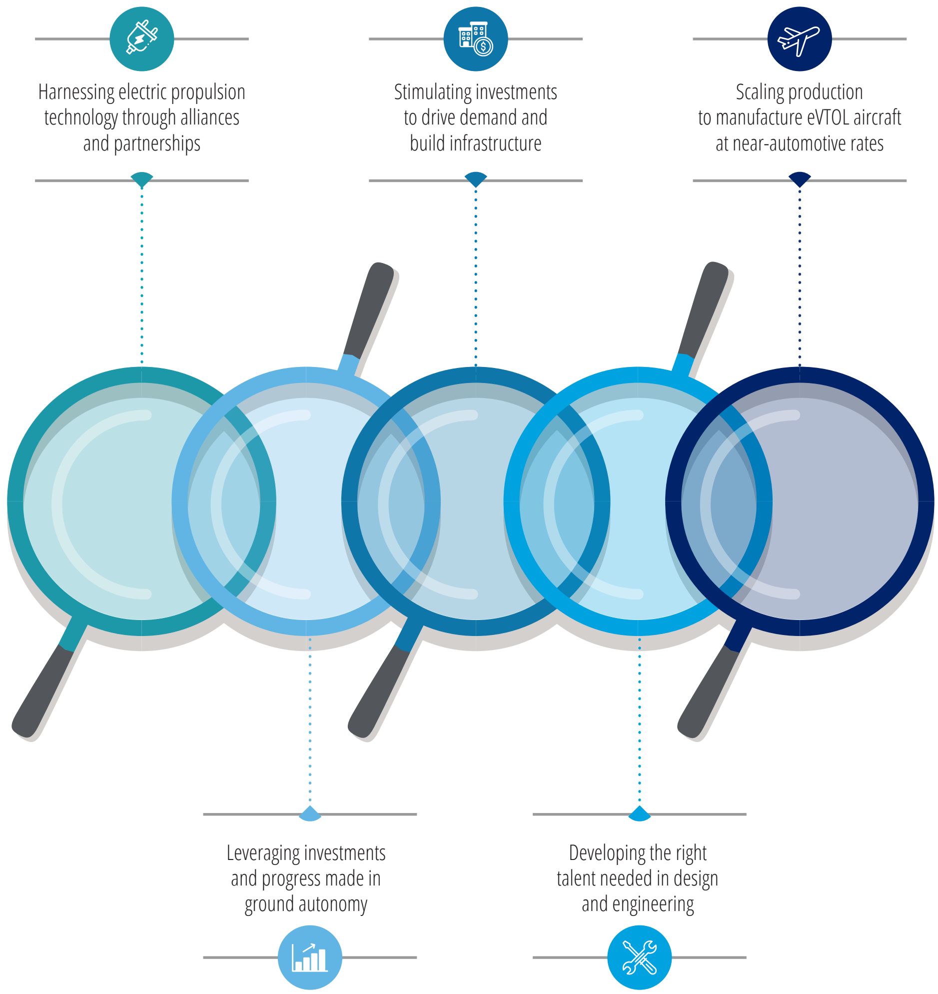
Source: Deloitte analysis.

However, several challenges must be overcome before the industry can see widescale adoption of eVTOL aircraft (figure 8). Regulations—especially regarding the allocation of airspace (lower altitudes to higher altitudes)—could challenge eVTOL aircraft's potential for exponential growth.[38]

Specifically, driving adoption and growth of eVTOL aircraft could be difficult without significant collaboration among all the ecosystem players. There are five focus areas the aerospace industry should consider to address the hurdles and scale electric propulsion to reduce emissions that can bring a paradigm shift in how it currently operates (figure 9).

FIGURE 9

Five focus areas for the aerospace industry to successfully scale eVTOL aircraft to reduce emissions



Source: Deloitte analysis.

1. Harnessing electric propulsion technology through alliances and partnerships: Since the future of eVTOL hinges on having a highly energy-efficient and high-performance propulsion system, the industry should focus on leveraging distributed electric propulsion (DEP) technology. eVTOLs need batteries that are light, powerful, long-lasting, cheap, and quick-charging. But achieving this would require the entire industry to work together since it involves developing advanced power sources, a combination of electrical power-producing devices such as electric generators and fuel cells, as well as energy storage devices such as batteries and capacitors. The industry should also invest in advanced technologies such as artificial intelligence, augmented reality/virtual reality (AR/VR), and high-performance computing.

2. Leveraging investments and progress made in ground autonomy: Industry players can benefit from strong tailwinds from the investments made in autonomous cars. On the computing side, semiconductor makers are fashioning powerful chips to allow manufacturers to perform advanced computations that weren't even fathomable a few years ago. For instance, embracing micro- and millimeter-wave technology in radar sensors is designed to advance collision detection and avoidance capabilities and presents an opportunity to establish safer navigation capabilities.

3. Stimulating investments to drive demand and build infrastructure: Aerospace companies should work with the entire aerospace ecosystem, including government agencies and regulators, to stimulate the market through fiscal arrangements, subsidies, and national procurement programs. By working closely with investors and governments, existing industry players and startups can secure investments to drive technology readiness levels to reach market readiness levels. Moreover, the industry should partner with governments by opening funding sources at the city, state, and national level to develop the physical infrastructure, including the electricity grid, electric recharging equipment, vertiports, aircraft hangars, and maintenance areas.

4. Developing the right talent needed in design and engineering: The shift from combustion to electric/hybrid-electric propulsion, piloted to autonomous, and centralized to distributed propulsion means the aerospace industry will likely need access to new skill sets. OEMs should partner with federal agencies, technical programs, and academia to attract, train, and hire skilled workers to meet current and future talent needs. They should also forge long-term partnerships with public and private educational institutions, industry associations, and agencies to develop programs that build a strong connection with companies, creating a skilled workforce for the future.

5. Scale production to manufacture eVTOL aircraft at near-automotive rates: To be commercially viable and economically feasible, the industry should scale its production capacities to levels not seen in the current aircraft manufacturing industry. As the materials used by the aircraft industry are generally more sustainable, advanced, and comparatively scarce, suppliers can demonstrate that the manufacturing processes developed for new materials can produce the needed quantities in a climate-friendly manner at aerospace grade. To truly eliminate emissions, the industry should enable a robust supply of materials with stable procurement costs and fabrication flexibilities, and scrap disposition and recycling capabilities.

METHODOLOGY

To estimate the potential CO_2 emissions from aviation by 2050, Deloitte created a base-case scenario, assuming there would be no measures taken to reduce carbon emissions. To calculate base-case emissions, we estimated revenue passenger kilometers (RPKs) and freight ton-kilometers (FTKs) for 2030, 2040, and 2050, using a 3% and 4% CAGR, respectively, with 2019 as the base year. Based on RPKs and FTKs, we estimated the number of flights using the 2017–2019 average of RPKs + FTKs per flight. Using the 2017–2019 average fuel consumption per flight, we estimated total fuel consumption. This led to the calculation of total CO_2 emissions, based on 2017–2019 average CO_2 emissions per gallon of fuel consumption.

To calculate the emission reduction by type of aircraft (regional jet, single-aisle, and widebody) as well as by each lever—sustainable aviation fuels (SAF), electric propulsion, and hydrogen propulsion—we split the RPKs + FTKs by type of aircraft in the ratio of available seat kilometers, i.e., 2019 aircraft fleet by type*average seats*average range. Based on our estimates of penetration of each lever of emission reduction, by aircraft type, for 2030, 2040, and 2050, we arrived at the emission reduction path for aviation. The contribution of emission reduction from other levers—aircraft design, operations/air traffic management, and ground infrastructure—is based on information from secondary sources.

To compute the incremental cost of switching to electric and hydrogen propulsion, we estimated the current cost of conventional aircraft propulsion systems based on the analysis of historical financial data of the two major aircraft OEMs. We extrapolated the cost differential of internal combustion engine automobiles and electric vehicles on the conventional aircraft propulsion systems to arrive at the incremental cost of manufacturing electric propulsion systems. For the hydrogen fuel cell propulsion system, we estimated a 10% incremental cost of manufacturing compared to electric propulsion. We estimated aircraft deliveries for 2020–2050 based on Boeing's 20-year aircraft delivery forecast. Equating the aircraft deliveries to arrive at cumulative deliveries for 10-year intervals, we calculated the incremental cost of electric propulsion and hydrogen fuel cell propulsion based on our estimates of penetration of these technologies in regional jets, single-aisle, and widebody aircraft in 2030, 2040, and 2050, respectively.

Please note that the underlying reason for the differences in the carbon emission reduction potential by major pathways such as SAFs and electric propulsion between this study and other Deloitte analyses is that this study includes all the potential solutions such as air traffic management and enabling ground infrastructure.

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About the authors

John Coykendall | jcoykendall@deloitte.com

John Coykendall is the US and Global Aerospace & Defense (A&D) leader and a principal in Deloitte Consulting LLP's Strategy practice. In his role as the US and Global A&D leader, he is responsible for Deloitte's services to companies that design, develop, and manufacture A&D products, including airplanes, ships, ground vehicles, satellites, launch vehicles, and other related products and services. He also steers the global network of Deloitte resources and capabilities which support Deloitte's global A&D clients.

Steve Shepley | sshepley@deloitte.com

Steve Shepley is a principal at Deloitte Consulting LLP's Aerospace & Defense (A&D) industry practice with more than 15 years of experience helping highly engineered product manufacturing companies drive performance improvements through the use of advanced techniques and technologies. Shepley specializes in the development of transformational solutions that enable clients to reduce operational costs, improve productivity, and drive growth. From an industry perspective, he primarily focuses on the aerospace & defense, automotive, and industrial products sectors.

Aijaz Hussain | aihussain@deloitte.com

Aijaz Hussain is a research and insights leader serving the manufacturing industry. He leads the aerospace & defense industry research for Deloitte. Hussain has led multiple major research campaigns, including leading global executive and consumer surveys with extensive exposure to C-suite and senior leadership engagement. He has authored numerous compelling, high-impact thought leadership studies on the future of mobility, Industry 4.0, digital transformation, innovation, the future of work, cybersecurity, and program management.

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Industry leadership

Paul Wellener
Vice chairman | Deloitte LLP | US Industrial Products & Construction sector leader
+1 216 830 6609 | pwellener@deloitte.com

Paul Wellener leads the US Industrial Products & Construction practice with Deloitte Consulting LLP.

John Coykendall
Principal | Deloitte Consulting LLP | Global and US Aerospace & Defense leader
+1 203 905 2612 | jcoykendall@deloitte.com

John Coykendall is a principal and leader of Deloitte US and Global Aerospace & Defense Industry practice.

Steve Shepley
Principal | Deloitte Consulting LLP
+1 213 688 4161 | sshepley@deloitte.com

Steve Shepley is a principal in Deloitte Consulting LLP's Aerospace & Defense (A&D) Industry practice.

Alan Faver
Partner | Deloitte & Touche LLP
+1 404 220 1701 | afaver@deloitte.com

Alan Faver is the Aerospace & Defense (A&D) leader of Deloitte's Risk & Financial Advisory practice.

Deloitte Research Center for Energy & Industrials

Kate Hardin
Executive director | Deloitte Research Center for Energy & Industrials
+1 617 437 3332 | khardin@deloitte.com

Kate Hardin is executive director of the Deloitte Research Center for Energy & Industrials.

Acknowledgments

The authors would like to thank **Paul Wellener**, **Chris Allen**, **Kate Hardin**, **Alan Faver**, **Daniel Haynes**, **Kerry Millar**, **Ann Scheuerman**, **Michael Condro**, **Louis Librandi**, **Rudy Sleiman**, **Scott Corwin**, **Bryan Terry**, **Willem Christiaan van Manen**, **Wendy Savage**, **Matt Metcalfe**, **Eric Fischer**, **Gerry Faustino**, **Tarek Helmi**, **Susan Cattozzo**, **Oscar Kraan**, **Blake Wellman**, **Rogier de Jong**, **Joe Mariani**, **Adam Routh**, **Katie Hennessy**, **Uri Fishelson**, **Jill Comer**, and **Ellen Carter** for their contributions to this study.

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