

# Powering the Skies: The Rise of Electric and Low-Carbon Aircraft



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**The aviation industry is in the early stages of the energy transition, with alternative technologies such as electric and hydrogen, as well as synthetic aviation fuels, under development. With rapid advancements in technology, the electric aircraft market is predicted to grow significantly over the next decade. Battery-powered aircraft are expected to take the largest share of the UK urban and domestic aviation markets by 2050, with synthetic aviation fuels and hydrogen emerging as the key technologies for medium and long-haul aviation. The UK has an opportunity to be at the cutting edge of these developments for all three of these technologies.**

## Introduction

Aviation is a large and diverse global industry, supporting 960,000 jobs and contributing 3.6% to UK GDP.<sup>1</sup> Aviation also contributes to 3% of global emissions and over 20% of the UK's transport emissions, making it a hard-to-abate sector due to high energy demand and performance requirements of alternative fuels. The UK Government has set an ambition for net zero UK aviation by 2050, with carbon emissions reducing from 38.2 MtCO<sub>2</sub>e in 2019 to 19.3 MtCO<sub>2</sub>e in 2050, with these remaining emissions being offset or eliminated.<sup>2</sup>

The direction of low carbon aviation is associated with a higher uncertainty than many other transport sectors. Kerosene is currently the primary aviation fuel in use, but technologies such as synthetic aviation fuels (SAF), pure hydrogen and batteries offer the potential to reduce emissions. Transitioning to new technologies at scale will require substantial research and international collaboration across the public and private sectors to enhance technological performance, ensure rigorous safety standards, establish effective regulatory frameworks and develop storage infrastructure.

This insight outlines the increasing size of the global electric market and explores the different low carbon technologies that could become available for aviation, particularly hydrogen,

batteries and SAF. The performance characteristics of battery technology for aviation and proposed actions to develop and support the UK aerospace industry in the transition are also highlighted.

**Battery-powered aircraft offer reduced noise, lower emissions and greater energy efficiency, as well as the capability to operate on shorter runways and at smaller airports. Widespread adoption will be dependent on improved energy density, meeting new safety standards and the development of recharging infrastructure.**

## Types of Electric and Low Carbon Aircraft

While the speed of the energy transition in aviation is uncertain, it is clear that different fuels (electric, hydrogen and SAF) and different types of electric aircraft, such as solely electric aircraft, hybrid electric aircraft, more electric aircraft and unmanned aerial vehicles, will each play a role.

Pure battery electric aircraft rely entirely on electric power for propulsion, typically using a battery or a combination of batteries. Batteries can also be used for other aircraft systems or in combination with other power sources.

\* Image: Vertical Aerospace: prototype VX4 aircraft.

<sup>1</sup> Oxford Economics (2011). *Economic Benefits from Air Transport in the UK*.

<sup>2</sup> Department for Transport (July 2022). *Jet Zero Strategy. Delivering Net Zero Aviation by 2050*, where MtCO<sub>2</sub>e is million tonnes of carbon dioxide equivalent.

Different types of pure electric-powered aircraft include short take-off and landing, conventional take-off and landing, vertical take-off and landing aircraft and rotorcraft.

**Electric-powered conventional take-off and landing (eCTOL)** aircraft are typically fixed-wing aircraft propelled by an electric motor and range from small, single-seat gliders to large commercial airliners. The energy source for the electric motor is typically a battery or a combination of batteries and fuel cells. The table below provides some estimates of the earliest and latest date when specific aircraft types and sizes are likely to be commercially available. For example, small electric aircraft equipped with two seats and typically used for training or leisure travel are already commercially available, while slightly larger aircraft accommodating up to 20 passengers, and typically used for business travel, could be commercially available from 2025 at the earliest and 2040 at the latest.

Current aircraft models such as the Boeing 737 and Airbus A320 have operational ranges of 2,000 to 4,000 nautical miles depending on the particular variant. However, many of their flights are significantly shorter than their maximum range capabilities. This difference between potential and actual flight distances supports the development of eCTOL aircraft, which are specifically tailored to efficiently cover the focus on more common shorter journeys.

**Electric vertical take-off and landing (eVTOL)** aircraft take off and land in a similar manner to a helicopter but are powered by electric motors. eVTOL technology enables aircraft to ascend, descend and hover directly to/from the ground and offers economic potential in the urban air mobility, logistics and defence sectors. eVTOL aircraft are typically smaller and more nimble than traditional helicopters and their electric motors make them quieter and more efficient. Designs include wingless multi-copters, vectored thrust winged aircraft, lift and cruise winged aircraft, hoverbikes and electric helicopters. Typical uses include personal transportation and air taxis for urban mobility, covering intra-city, inter-city and regional destinations.

Electric-powered rotorcraft are a subset of eVTOL, equipped with rotor blades driven by electric motors and include

helicopters, gyroplanes and multicopters. Both eVTOL and rotorcraft are more efficient and quieter than established vehicles, making them more suited to use within urban environments.

**Hybrid electric aircraft** combine an electric motor with a traditional internal combustion engine to provide propulsion. The electric motor is used for take-off and landing, while the combustion engine provides power during cruising. This hybrid power source can reduce fuel consumption and emissions compared to traditional aircraft. Commercial availability of hybrid electric aircraft is likely to be between 2025 and 2035 depending on size and use, which is between 5 and 15 years earlier than pure battery electric aircraft.<sup>3</sup>

Beyond electric propulsion, the scope for electrification extends to other onboard systems. Aircraft electrical systems comprise elements such as electrical generators, power electronics, energy storage units and actuators, connected through power distribution and control networks. These complex systems are vital for the functioning of key aircraft components including avionics, flight controls, environmental management systems, communications, lighting, auxiliary and other critical functionalities.<sup>4</sup> More electric aircraft (MEA), for example, is an aircraft design philosophy that aims to replace traditional hydraulic and pneumatic systems with electric systems.<sup>5</sup> The goal is to reduce weight, increase efficiency and improve reliability. MEA typically utilise electric motors to power aircraft systems such as fuel pumps, environmental control systems and landing gear. MEA can also use electric propulsion systems, making it a subset of electric aircraft.

In addition, the emerging market for commercial drones adds a new dimension to the electric aviation market. Unmanned aerial vehicles (UAVs) or drones are very small aircraft that are flown remotely without a human pilot.<sup>6</sup> Typical vehicles include high altitude long endurance (HALE) drones, medium altitude long endurance (MALE) drones, tactical drones and quad/octa-copter drones, which can be used for surveillance, mapping, delivery, search and rescue, agriculture and leisure. The world's first urban drone airport (Air-One) launched in Coventry in April 2022, providing a base for large cargo drones as well as air taxis and eVTOL aircraft.<sup>7</sup> There are also

**Table 1: Commercial availability of pure battery electric aircraft**

Type of battery electric aircraft	Earliest start date	Latest start date	Examples of aircraft
Leisure / training (1 to 6 seats)	Now	2030	Elektra One Solar, RX1E, Air Race E, ALPHA ELECTRO, TAURUS ELECTRO, eFlyer 4, eFlyer 2, Velis Electro
Business (5 to 20 seats)	2025	2040	E6 & E-10 SCYLAX, Energia E9-FE , eFlyer 800
Commuter / regional (9 to 100 seats)	2024	2045	ES-19, Alice
Short haul (100 to 150 seats)	2040	2050	No specific aircraft defined
Medium haul (100 to 250 seats)	2030	2050	Wright
Long haul (250+ seats)	Not realistic	Not realistic	N/A

**Source:** Catapult Connected Places & DfT (March 2022). The Roadmap to Zero Emission Flight Infrastructure.

<sup>3</sup> Catapult Connected Places & DfT (March 2022). The Roadmap to Zero Emission Flight Infrastructure.

<sup>4</sup> Aerospace Technology Institute (July 2018): Insight 07 Electrical Power Systems.

<sup>5</sup> IEEE (2022). The More-Electric Aircraft and Beyond.

<sup>6</sup> Unmanned underwater vehicles and unmanned surface vehicles are the marine equivalent of drones and are not included in this Insight focused on aviation.

<sup>7</sup> Urban-Air Port (April 2022) - World-first hub for flying taxis, Air-One, opens in Coventry, UK.

diverse uses for batteries in the space and defence sectors, powering various types of satellites as well as space and military applications.

New aircraft designs are also being developed for other technologies. Hydrogen-powered aircraft can take the form of hydrogen fuel-cell electric or hydrogen combustion.<sup>8</sup> A fuel cell converts stored energy into electricity through an electrochemical process, while in hydrogen combustion aircraft hydrogen liquid or gas is burned in a gas turbine engine in a process similar to conventional kerosene today.<sup>9</sup> Small hydrogen-powered aircraft could be operational between 2025-2030, with the possibility of regional hydrogen aircraft (40-100 seats) entering the market in the mid-2030s and the potential for mass adoption through the replacement of the UK regional fleet from 2040.<sup>10</sup>

Airbus has unveiled three concepts for what it terms the world's first zero-emission commercial aircraft, all of which rely on hydrogen as a primary power source. The three concepts include a turboprop design for short-haul trips, a blended-wing body design where the wings merge with the main aircraft body, and a turbofan design with a range of 2000+ miles for transcontinental flights.<sup>11</sup>

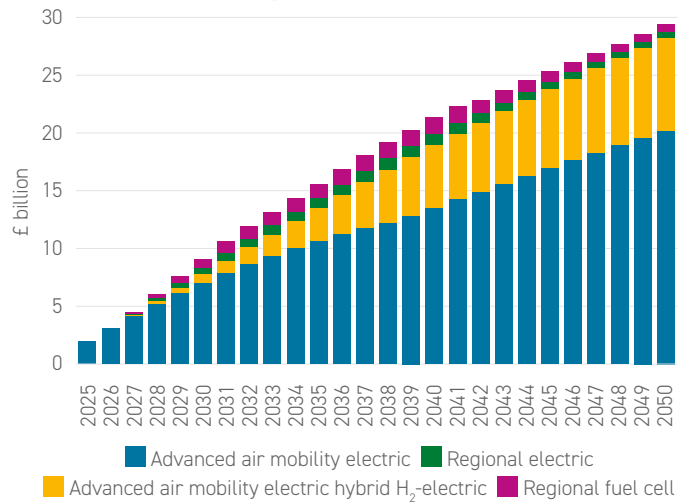
These different types of low carbon aircraft are used across the three main parts of the aviation industry: 'commercial aviation', which covers passenger and cargo transportation; 'general aviation', which covers personal use, business use and public services; and 'military aviation', which encompasses combat, cargo and reconnaissance operations.

### Market Size for Aircraft and Fuels

The market for electric aircraft is expected to grow significantly in the coming years, as companies and governments seek to reduce carbon emissions from aviation. Global revenues for electric and hybrid aircraft covering both advanced air mobility (i.e. urban and intra-city air transportation solutions) and regional markets are expected to reach nearly £30 billion per annum by 2050, amounting to a cumulative total of around £450 billion over the 2024 and 2050 period (Figure 1), with the UK expected to take around 15% of this market. In addition, the cumulative global revenue for aircraft batteries is estimated to be £37 billion over the same period, with the UK expected to secure 8% or £3 billion of this sector. The market for drones is also increasing in both civil and defence settings with 16% annual growth expected between 2022 and 2028.<sup>12</sup>

Despite a drop in global passenger traffic in 2020-22 due to the global pandemic, passenger numbers in Europe are expected to recover by 2025<sup>13</sup> and to continue to grow over the medium to longer-term. However, aviation energy demand is expected to remain largely similar over the 2025 to 2050 period due to

Figure 1: Global annual market revenues from the manufacture of electric planes



Source: [ATI Market Model](#)

improvements in aircraft design, electrification and increased load factors.<sup>14</sup> Aircraft fuel efficiency has improved by 80% compared to 50 years ago with improvements expected to continue.<sup>15</sup>

By 2050, the use of petroleum-based aviation fuel for UK domestic and international aviation is expected to decrease to half (51%) of energy demand, marking a significant shift from the reliance on oil-based aviation fuel, which has exclusively met all energy demands so far. Of the remaining total energy required, biofuels are expected to take the largest share (22%) followed by e-fuels (14%), hydrogen (7%) and electric (5%).<sup>16</sup>

Biofuel and e-fuels, which are forms of SAF, are produced through different methods. Biofuels are liquid fuels derived from various biomass sources such as vegetable oils, plant materials and animal waste, which are generally blended with traditional jet fuel to ensure high energy density.<sup>17</sup> E-fuels are typically produced through power-to-liquid (PtL) techniques and from renewable energy. They are synthesised by converting water and carbon dioxide into a fossil fuel substitute, predominantly employing the Fischer-Tropsch process.<sup>18</sup> The Altolto plant in Immingham UK, a joint venture between British Airways and Velocys, aims to convert

**Synthetic aviation fuels, encompassing biofuels and e-fuels, are anticipated to be the initial replacements for kerosene starting from the late 2020s. This will be followed by the mass adoption of battery-powered flights for short-haul and hydrogen-powered flights for longer distances from around 2040.**

<sup>8</sup> Airbus (2020). [Hydrogen fuel cells. Hydrogen combustion.](#)

<sup>9</sup> Cambridge University & World Economic Forum (July 2022). [Target True Zero Unlocking Sustainable Battery and Hydrogen-Powered Flight.](#)

<sup>10</sup> Heathrow Airport (2022). [Project Napkin - Making Zero-carbon Emission Flight a Reality in the UK.](#)

<sup>11</sup> Airbus (September 2022). [Airbus reveals new zero-emission concept aircraft.](#)

<sup>12</sup> Insight Partners (April 2023). [Drone Battery Market Size Report - Global Trends and Forecasts 2028.](#)

<sup>13</sup> ACI Europe (20 December 2022). [Passenger traffic full recovery pushed back to 2025.](#)

<sup>14</sup> ADNV (2022). [Energy Transition Outlook.](#)

<sup>15</sup> IATA (2022). [Net Zero 2050: New Aircraft Technology.](#)

<sup>16</sup> DNV (2023). [The Role of Hydrogen and Batteries in Delivering Net Zero in the UK by 2050.](#)

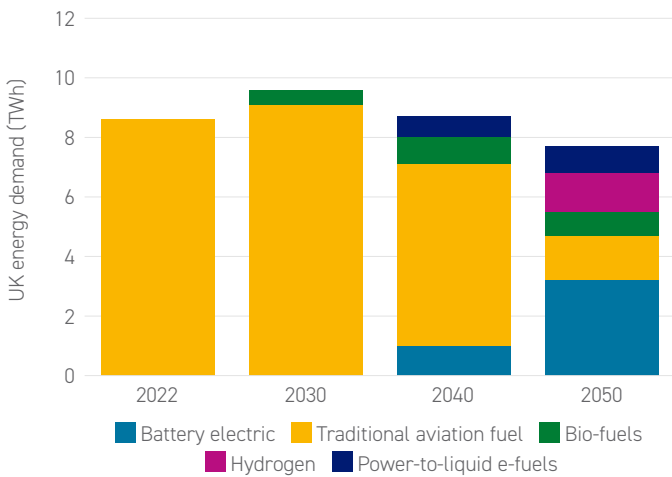
<sup>17</sup> Imperial College London, Grantham Institute Briefing Paper No 23 (November 27). [Aviation biofuels: strategically important, technically achievable, tough to deliver.](#)

<sup>18</sup> Airbus (2021). [Power-to-Liquids explained.](#)

500,000 tonnes of non-recyclable waste into 60 million litres of SAF.<sup>19</sup>

The adoption of battery technology is expected to be much greater in the UK domestic aviation market than in the international market. Because of the greater efficiency of battery-powered propulsion and the focus of battery technology on short-range flights, battery-electric aircraft could be the largest technology by 2050, accounting for 42% of energy demand in the UK domestic aviation market (Figure 2). Commuter and VTOL aircraft are expected to be the initial adopters of electric aviation because of their short flight durations and the development of new electric aircraft such as Heart Aerospace’s ES-19 and Wright Electric’s Spirit. The use of hydrogen for UK domestic aviation is also expected to be substantive, projected to reach a market share of 17%, while traditional aviation fuel is expected to constitute 20% of the market.

**Figure 2: UK domestic aviation energy demand by carrier (2022-2050)**



Source: DNV (2023). *The Role of Hydrogen and Batteries in Delivering Net Zero in the UK by 2050*. Numerical data for figures.

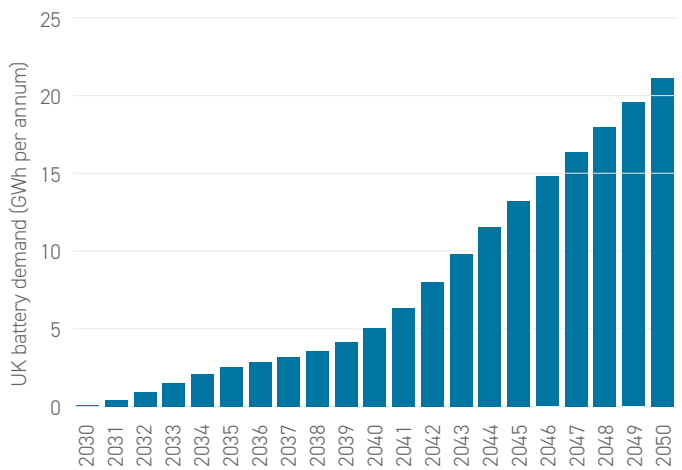
Hydrogen has the potential in the long-term to emerge as the primary technology for medium and long-haul aviation. However, commercial market adoption is anticipated to be gradual given the expected longer technological development time needed for ensuring the safe and efficient storage of hydrogen, improving fuel cell efficiency and enhancing airport infrastructure. It is unlikely that hydrogen will surpass other low carbon fuels, such as biofuels and e-fuels, until after 2050. Hydrogen fuel cell-powered aircraft use the same electric motor and propeller setup as a battery-powered aircraft. Hydrogen-powered aircraft offer the advantage of higher energy density by mass of hydrogen fuel, but the volumetric energy density of hydrogen is lower than traditional aviation fuel, which means that larger fuel tanks and changes to aircraft design are needed.

The shifting technological landscape extends beyond manned aircraft to drones and autonomous aircraft. The UK drone market is expected to depend almost entirely on battery technology, driven by an increasing range of applications in

the commercial and government sectors, such as utilities, logistics, agriculture and emergency services.

The total battery capacity required by battery electric aircraft in the UK is projected to reach just over 20 GWh by 2050 (Figure 3) with annual additional demand of 2 GWh per annum continuing beyond 2050. The battery demand captures the demand from both the UK international and domestic aviation market and assumes that each aircraft performs 700 flights per year, with battery capacity equal to twice the energy used on an average battery-electric flight.

**Figure 3: Potential aviation demand for UK-produced batteries**



Source: ADNV (2023). *The Role of Hydrogen and Batteries in Delivering Net Zero in the UK by 2050*. Numerical data for figures.

### Aircraft and Battery Performance

Aviation depends on high-speed and long-range aircraft with the ability to carry loads and fly at high altitudes, which all demand a significant amount of energy to operate. The choice of battery technology used in aviation in the future will rely heavily on the energy density of the system achieved, the power that can be delivered to the propulsion mechanism (e.g., at take-off) and the ability to meet high-safety standards. Energy density and performance metrics in this section are presented at the pack level unless otherwise stated.

### Safety

Aviation safety is a paramount concern in the UK where a highly regulated system for maintaining the continued airworthiness of air transport has been developed through agencies such as the Civil Aviation Authority (CAA). Aviation regulators require that any new technologies, such as lithium-ion batteries, introduced into the sector must undergo extensive and rigorous testing to ensure they meet or exceed the established safety benchmarks. Lithium-ion batteries are currently being used in first generation battery-electric aircraft designs because of their high energy density, but there are small risks of battery pack failure and the possibility of fire.<sup>20</sup> In addition, the cells currently used in aerospace were not originally designed for that particular application. New cell designs may need to be developed that

<sup>19</sup> [Altair website](#).

<sup>20</sup> MRS Bulletin (2021). *A Review of Safety Considerations for Batteries in Aircraft with Electric Propulsion*.

are suited to the performance requirements of aviation, while also providing a high level of safety.

As aviation requires high energy density technologies, new certification policies are needed to ensure the safe operation of battery-powered and hydrogen-fuel cell aircraft. New charging infrastructure may need to be developed as well. An example of this would be battery swapping, which could allow for faster turnaround times and reduced battery degradation but represents a significant engineering and safety challenge. Therefore, standards for aircraft safety and battery management need to be developed. The CAA may need to expand its responsibilities to cover certification for energy storage as part of approving the airworthiness of aircraft.<sup>21</sup> Achieving equivalent levels of safety with the introduction of these new technologies will require a coordinated effort from regulators, manufacturers and operators alike.

Research into improving the safety of lithium-ion batteries is a key topic in the electric vehicle (EV) industry, supporting growing demand and technological advancement, with spillover benefits for aerospace applications. The Faraday Institution launched the SafeBatt<sup>22</sup> project in 2021 to research lithium-ion battery safety, aiming to understand failure mechanisms and improve reliability and safety standards.<sup>23</sup>

### Battery energy density and power capacity

One of the principal limitations hindering the adoption of battery technology in aviation is their much lower energy density relative to conventional aviation fuels. Conventional aviation fuel has a gravimetric energy density nearly 50 times higher (12,000 Wh/kg) and volumetric energy density 14 times higher (9,690 Wh/L) than current lithium-ion batteries.<sup>24</sup> This disparity limits the applications of current generation batteries in aviation. Battery technology is suitable for eVTOL and short- and medium-haul flights, but their lower energy density compared to alternative fuels restricts the usefulness for long-haul journeys.

As the weight of the aircraft increases, greater levels of battery pack level gravimetric energy density are required ranging from 600 Wh/kg for small regional aircraft to 820 Wh/kg for narrow-bodied (single-aisle) aircraft and 1,280 Wh/kg for wide-bodied (twin-aisle) variants.<sup>25</sup> These estimates are based on assumed ranges of 350, 500 and 1,000 nautical miles and passengers of 30, 150 and 300 for regional, narrow-body and wide-body aircraft respectively.

Similarly, the achievement of 500 Wh/kg by 2050 has been identified by the ICCT as a key commercial requirement for regional electric aircraft, along with a volumetric energy density of 1,100 Wh/L. Regional aircraft typically cover short

distances of about 500 nautical miles and carry 30 to 75 passengers.

**Table 2: Pack-level battery gravimetric and volumetric energy densities for regional aircraft across different time frames**

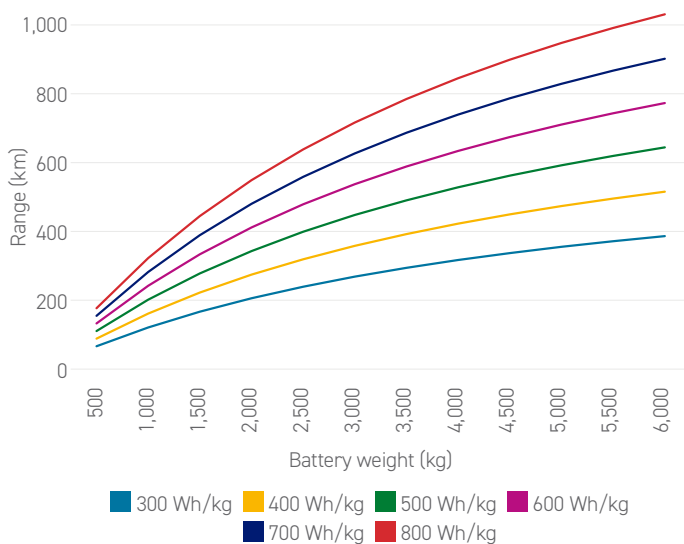
Year	Gravimetric energy density (Wh/kg)	Volumetric energy density (Wh/L)
Current	250	500
2030	300	630
2050	500	1,100

Source: ICCT (2022). Performance Analysis of Regional Electric Aircraft.

However, there is some debate amongst battery scientists about whether these densities will be sufficient. Other sources indicate a need for substantially higher energy densities, such as a study published in Nature which estimated requirements of 1,800 to 2,500 Wh/kg for aircraft designed to carry 150 and 180 passengers respectively.<sup>26</sup>

Figure 4 illustrates the important relationship between an aircraft's range, battery weight and energy density. For example, Eviation's 'Alice', a groundbreaking electric aircraft, aims to achieve a range of approximately 450 km once commercial operations commence in 2027. Constructed predominantly of lightweight carbon composites, the aircraft is lighter than conventional aircraft of the same size, enabling it to carry a battery weight of 5,000 kg. Future enhancements

**Figure 4: Electric aircraft cruise range by gravimetric energy density**



Source: BNEF (February 2022). Electric Aircraft Propulsion: Technology and Industry.

<sup>21</sup> ATI & WMG (May 2021). Aerospace Electrification. Accelerating the Opportunities in the UK.

<sup>22</sup> The Faraday Institution's SafeBatt project is a collaboration of seven universities led by Oxford University.

<sup>23</sup> Faraday Insight 17 (July 2023). Improving the Safety of Lithium-ion Battery Cells.

<sup>24</sup> ICCT (2022). Performance Analysis of Regional Electric Aircraft. Gravimetric energy density is the amount of energy stored in a material per unit mass, typically measured in watt-hours per kilogram (Wh/kg) whereas volumetric energy density is the amount of energy stored per unit volume of a material or system, typically expressed in watt-hours per litre (Wh/L).

<sup>25</sup> ACS (2020). Performance Metrics Required of Next-Generation Batteries to Electrify Commercial Aircraft.

<sup>26</sup> Nature (Jan 2022). The Challenges and Opportunities of Battery-Powered Flight.

in battery performance and the adoption of next-generation chemistries, along with weight reductions and aerodynamic efficiency improvements, could potentially increase this range. For example, an aircraft range could reach 600 km for a 5,000 kg battery with a gravimetric energy density of 500 Wh/kg.

In order to achieve these higher energy densities, next-generation technologies with new battery materials and chemistries are under development. These include lithium-metal and silicon anode materials for lithium-ion batteries, oxide and sulfide based solid-electrolytes for solid-state lithium-ion batteries, and lithium-sulfur based cells. Achieving these milestones and deploying next generation technologies comes with challenging aviation safety requirements. Substantial gains in cell performance can often be negated at the pack level when implementing safety measures and diagnostics to address issues such as thermal runaway events.

The energy density and performance metrics for various next-generation technologies are outlined in Table 3. Lithium metal and pure silicon anodes are expected to be deployed commercially by the end of the decade.<sup>27</sup> The development of solid-state batteries is currently driven by the EV market, with widespread deployment in high-performance EVs expected by the end of the decade. In contrast, lithium-sulfur batteries are still an early-stage technology and not expected to reach large scale deployment until the early 2030s. Lithium-air is another early-stage battery technology with potential applications in aerospace. Both lithium-sulfur and lithium-air technologies are considered potential candidates for aerospace due to their high gravimetric energy density

characteristics (Box 1). While alternative chemistries are being considered to improve energy density, they will also have to pass rigorous safety tests to be deemed viable for aviation use.

Power capacity is also a crucial factor for determining the maximum take-off loads that aircraft can achieve. Commuter and eVTOL aircraft require lower power capacity compared to short haul aircraft, so battery technology with performance improvements is expected to meet this market first. However, it should be noted that the duty cycle of a battery for eVTOL applications differs considerably from that of EVs, requiring sustained periods of high-power output for take-off and landing.<sup>28</sup> This requirement needs careful consideration during the development of cells for eVTOL and other flight applications.

### Efficiency

The efficiency of an aircraft depends largely on its size, design, propulsion system and energy source. Battery electric aircraft are highly efficient in converting stored energy into propulsion with an operating efficiency of 85%-90%.<sup>29</sup> Compared to e-kerosene, electric aircraft could be 4.5-6.9 times more energy efficient.<sup>30</sup> Hydrogen fuel cell powered aircraft have lower efficiency due to conversion losses, but it is advantageous to use fuel cell technology (compared to combusting liquid hydrogen) to reduce hydrogen fuel consumption. SAFs are more energy-dense than liquid hydrogen but require more energy for production and distribution, resulting in lower overall efficiency dependent on the methods used to create the fuel.<sup>31</sup> Battery-electric aircraft could enter the mass market in the late

**Table 3: Cell level energy density (ED) and performance metrics by battery technology**

Technology development	Current Li-ion (NMC vs graphite)	Lithium-metal anodes	Silicon anodes	Lithium sulfur	Solid state sulfidic	Solid state oxidic
Current gravimetric ED Wh/kg	~280	-	~350	-	-	-
Future gravimetric ED Wh/kg	~300*	~450*	~450*	~500*	~500*	~400*
Current volumetric ED Wh/L	~700	-	~850	-	-	-
Future volumetric ED Wh/L	~800*	~1,000*	~950*	~700*	~1,200*	~1,200*
Power capability	Average	Good	Good	Poor	Good	Good
High temperature operation	Poor	Poor	Poor	Good	Good	Good
Low temperature operation	Average	Average		Average	Poor	Poor

**Source:** Faraday Institution research. Energy density metrics are representative of each technology, exact figures will depend on cell format and design. Note: \* Denotes energy density values for future cells, i.e., energy density values that have not yet been obtained commercially.

<sup>27</sup> BNEF (June 2023). Long Term Electric Vehicle Outlook 2023.

<sup>28</sup> Alexander Bills et al., A battery dataset for electric vertical take-off and landing aircraft. Scientific data 10:344, 2023.

<sup>29</sup> NERL (October 2021). Electrification of Aircraft: Challenges, Barriers, and Potential Impacts.

<sup>30</sup> DNV (2023). The Role of Hydrogen and Batteries in Delivering Net Zero in the UK by 2050.

<sup>31</sup> See Figure 5-1 in the DNV 2023 study 'The Role of Hydrogen and Batteries in Delivering Net Zero in the UK by 2050'.

### Box 1: Lithium-sulfur and lithium-air battery chemistries for electric aircraft

Batteries utilised in aerospace applications have high gravimetric energy density requirements due to the critical constraint of weight. Currently, leisure drones typically use lithium-polymer and nickel-cadmium batteries. However, next-generation technologies such as lithium-sulfur or lithium-air batteries have the potential to substantially increase the available energy density.

Lithium-sulfur batteries offer high energy density, cost effectiveness and safety, as well as the opportunity to revolutionise the aviation and aerospace industries. Initially used in satellites, drones and military vehicles, lithium-sulfur batteries offer a broader potential for deployment in aviation, particularly in short-range electric aircraft and eVTOL vehicles.<sup>32</sup>

The advantage of lithium-sulfur batteries over current generation lithium-ion cells lies in their markedly superior gravimetric energy density currently reaching up to 500 Wh/kg and expected to increase up to 700 Wh/kg. This increase in energy density is partly due to the sulfur cathode, which has a theoretical energy density of 2,700 Wh/kg.

Lithium-sulfur batteries also have the potential to dramatically reduce battery costs and enhance the cell's environmental impact by minimising reliance on nickel and cobalt, which are extracted through intensive mining efforts. In contrast, sulfur is amongst the most abundant elements on earth, making it comparatively low cost. Lithium-sulfur batteries also have the potential to increase the safety of batteries compared to current lithium-ion technology.<sup>32</sup>

However, lithium-sulfur technology suffers from several drawbacks. The power density of lithium-sulfur batteries

is limited due to the low electronic conductivity of the sulfur cathode. Lithium-sulfur batteries also have much shorter cycle lives than conventional lithium-ion cells due to the polysulfide shuttling effect, which causes corrosion in the cell. In addition, the potential safety advantages of lithium-sulfur systems have not yet been demonstrated in a commercial system. These challenges are currently preventing lithium-sulfur technology from being utilised at scale.

The Faraday Institution's Lithium-Sulfur Technology Accelerator (LiSTAR) project is researching lithium-sulfur batteries, from materials discovery to system engineering. An example of the output of this research project is the use of pre-lithiated metallic 2D molybdenum disulfide as a sulfur host material in lithium-sulfur batteries, resulting in high gravimetric and volumetric energy densities of 441 Wh/kg and 735 Wh/L, with 85% capacity retention after 200 cycles.<sup>33</sup> The next steps for this material are to develop a scalable method for the manufacture of the  $\text{Li}_x\text{MoS}_2$  nanosheets. The cathode is just one component of a lithium-sulfur battery; research is also needed to optimise the anodes and electrolytes for these cells.

Another battery chemistry with potential applications in aerospace is lithium-air. Lithium-air cells have the potential to provide up to five times the energy density of current lithium-ion technology.<sup>34</sup> The range of a lithium-air battery, operating at just 10% of its maximum theoretical gravimetric energy density (1,000 Wh/kg), could reach 1,500 km.<sup>35</sup> However, the technology faces a number of challenges, including limited power density and poor energy efficiency during cycling. In addition, pure oxygen can be used to avoid having to deal with contaminants from air, however the roadmap for Li-air is to use air. These are not insurmountable issues but rather potentially addressable challenges that research should aim to resolve.

2030s, replacing more than 15% of the global jet aircraft fleet<sup>36</sup> and operating regional flights up to 1,000 km by 2050 (Figure 5).

#### Cost

There is considerable uncertainty about the costs associated with new technologies. Some analysts are very optimistic that "the cost advantages of electric propulsion systems are going to completely disrupt the current aviation market and allow more point-to-point journeys"<sup>37</sup> and estimate that the cost of electric aircraft to be 15% to 22% lower than conventional aircraft.<sup>38</sup> However, other studies do not see cost parity before the mid-2050s.<sup>39</sup> While the level of cost

savings is currently unclear, there is consensus on potential areas where cost savings are likely to arise, such as reduced energy cost, reduced maintenance and fewer parts and the potential for more efficient aircraft design.<sup>40</sup> The extent of any cost savings will not only depend on oil prices, with higher oil prices leading to a greater cost advantage for electric planes, but also on the cost and availability of renewable energy sources that are needed to produce alternative fuels, especially in the short to medium term where competition for these resources may be significant.

Battery usage in aircraft differs from passenger cars, with aircraft batteries expected to go through multiple cycles per day and have high discharge rates during take-off, which

<sup>32</sup> Faraday Insight 8 (July 2020). Lithium-sulfur batteries: lightweight technology for multiple sectors.

<sup>33</sup> Nature (2023). Lithiated metallic molybdenum disulfide nanosheets for high-performance lithium-sulfur batteries.

<sup>34</sup> Faraday Institution (January 2020). High-energy battery technologies report.

<sup>35</sup> Cambridge University & World Economic Forum (July 2022). Target True Zero Unlocking Sustainable Battery and Hydrogen-Powered Flight.

<sup>36</sup> Mission Possible Partnership (July 2022). Aviation Transition Strategy.

<sup>37</sup> Sustainable Aviation Symposium (October 2019). A Report on the Future of Electric Aviation.

<sup>38</sup> Linköping University (2017). Operating Cost Analysis of Electric Aircraft on Regional Routes.

<sup>39</sup> BNEF (October 2020). 2020 Aviation Fuel Outlook.

<sup>40</sup> Rolls-Royce (March 2020). Economic Feasibility Study for a 19 PAX Hybrid-Electric Commuter Aircraft.

Figure 5: Technology potential of low carbon fuels

	Battery-electric	Hydrogen	SAFs
Efficiency of fuel production and propulsion system	60%	25%	15%
Maximum range in 2050	Few 100s km up to 1,000 km	2,500 km up to no limitation	No limitation
Expected large-scale market entry	Around 2035–40		<2030
Share of cumulative GHG emissions reduction from renewable fuels (2022–50)	2%–3%	8%–22%	75%–91%
Share of final energy demand in 2050	~2%	13%–32%	65%–85%

Source: Aviation Transition Strategy (July 2022).

degrades the battery more rapidly. Battery technologies for aircraft are expected to have lifespans of an average of around 3,000 duty cycles.<sup>41</sup> This is equivalent to 8 flights a day for a year, or 4 flights a day for 2 years. However, other studies have cited battery duty cycle numbers between 500 and 10,000 cycles (depending on the aircraft), after which a replacement would be needed.<sup>42</sup> Given these wide and varying estimates, as well as differing views from experts on the pace of technological improvements, more data from real world tests of batteries in aviation applications is required to get a better understanding of battery life for the sector.

Battery-electric aviation would need airports to expand their electrical and energy storage infrastructure, requiring significant investment and coordination within the industry and grid operators. Currently, there are no economic charging solutions for medium and large range aircraft, so the development of rapid chargers will be particularly essential.

Aviation batteries need to be designed to withstand greater temperature extremes than ground-based EVs and to higher safety standards, both of which put pressure on cost-competitiveness with other technologies. Unlike aviation fuel, batteries have not been extensively deployed in wings, so larger aircraft have been required to accommodate batteries which has increased capital and operational costs. However, ongoing research is exploring such integration for fixed-wing planes and some eVTOL companies have started to test wing-based battery storage.

Hydrogen aircraft operations are forecast to be cost-competitive with fossil kerosene by the early 2030s, with liquid hydrogen costs expected to fall below that of fossil kerosene by 2050,<sup>43</sup> although the capital expenditure for hydrogen aircraft is expected to be higher due to the complex

fuel distribution system and the larger size required for hydrogen storage. A short-range hydrogen aircraft may have a cost increase of 25% compared to conventional kerosene, while sustainable aviation fuels are expected to be 32% higher by 2040.<sup>44</sup> Current airport operations will also need to be adapted to accommodate hydrogen handling and refuelling, with hydrogen supply requiring dedicated pipelines or on-site storage systems, with new refuelling procedures developed.

**Hydrogen fuel volumetric limitation**

Hydrogen-powered aircraft can also offer an increased energy density due to the low mass of hydrogen fuel. However, the volumetric energy density of hydrogen compared to conventional aviation fuels necessitates larger tanks to store the fuel making it challenging for current aircraft designs to adapt. Emerging aircraft designs, such as those featuring blended wing body configurations, could potentially facilitate the integration of hydrogen propulsion systems into commercial aviation while also providing aerodynamic advantages. However, they are likely to come only later in the 2040s, with hybrid hydrogen-electric aircraft more viable in the meantime. SAFs are more energy-dense than liquid hydrogen but demand higher input energy for production and distribution.

**Infrastructure**

Low-carbon aircraft will require the development of new airport infrastructure to accommodate the refuelling, re-charging and servicing of the aircraft.

For electric-powered aircraft, substantial capital investment in airport electrical infrastructure alongside the strengthening of connections to the electricity grid will be required to satisfy the demanding charging needs of aircraft.

<sup>41</sup> ICCT (2022). Performance Analysis of Regional Electric Aircraft.

<sup>42</sup> Cambridge University & World Economic Forum (July 2022). Target True Zero Unlocking Sustainable Battery and Hydrogen-Powered Flight.

<sup>43</sup> Aerospace Technology Institute (March 2022). Fly Zero – Key Findings.

<sup>44</sup> McKinsey (May 2020). Hydrogen-Powered Aviation.



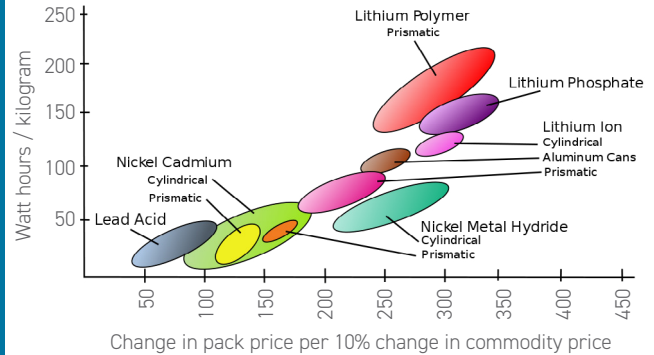
**Box 2: Battery chemistries for drones**

Lithium polymer (LiPo) batteries are currently the most popular choice for drones, with the main characteristic being the use of a solid polymer electrolyte component (a plastic or gel) compared to liquid electrolytes more commonly used in other lithium battery chemistries.

The performance of LiPo batteries is similar to lithium-ion batteries, but they have added advantages of higher density, higher power, lower weight and lower self discharge rate. This latter feature, which means that the battery can hold its charge for longer periods, makes them particularly attractive for drones, which may be used infrequently. LiPo batteries also have what is known as a flexible form factor, which means they can be made in a variety of shapes and sizes to fit different drone designs and configurations. LiPo batteries have an energy density range of 140 - 200+ Wh/kg and 250 - 350+ Wh/L (Figure 6).

Nickel-cadmium (NiCd) batteries, which uses nickel oxide hydroxide and metallic cadmium as electrodes, is currently another popular chemistry for UAVs. While less common than LiPo, advantages include a high discharge rate and the ability to deliver high power output. The batteries can also operate at more extreme temperatures than other chemistries. The main drawbacks are lower energy density, environmental concerns with the use of cadmium and a memory effect that causes batteries to gradually lose charge.<sup>45</sup>

**Figure 6: Relative energy densities by volume and weight of common battery types**



Source: A Guide to Lithium Polymer Batteries for Drones. (December 2021).

NiCd batteries are being replaced in the market today in favour of LiPo batteries, largely due to the higher energy density offered by LiPo batteries. In the future, drones could be powered with next generation battery chemistries such as lithium-sulfur or solid-state batteries. However, the current incumbent technology of choice for drones will remain LiPo batteries.

Much faster charging times will also be required as current recharging times are not suitable for the business models of many airlines, particularly low-cost airlines where fast turnaround times, as low as 25 minutes, are common.<sup>46</sup>

While conventional aircraft can be refuelled within 15-20 minutes,<sup>47</sup> the recharging of battery packs for aircraft can take from 30 minutes to several hours, depending on the battery type and charger capacity. Electrification of the aviation industry will therefore require the development of rapid chargers capable of safely and quickly charging high-capacity aircraft batteries. Smaller airports may find this particularly challenging because of the high initial investment costs and technical complexities of installing rapid-charging infrastructure. Battery swapping is an alternative option that could reduce turnaround times in commercial operations and help offset these costs. However, the high safety standards of the aviation industry and logistical challenges related to the size and weight of aircraft batteries, may mean the implementation of this approach is slower than in other transportation sectors.

Accommodation of hydrogen-powered aircraft would also require a comprehensive revamp of the existing airport

infrastructure. Initial implementation across limited routes and airports could be useful as a pilot exercise, but a more extensive programme of investment in airport infrastructure will be necessary for the next two decades to meet demand post-2040. Potential solutions for the supply of hydrogen to airports include onsite electrolyzers or dedicated pipelines leading to onsite storage systems. A new regulatory framework to ensure safe handling and refuelling will also be necessary.<sup>48</sup> If current practices, which allow aircraft refuelling to take place simultaneously with other servicing operations, prove incompatible with safe hydrogen refuelling, the logistics of airport operations would need a substantial overhaul.

The use of SAFs is likely to require less capital investment as blended versions can be integrated into existing aircraft, engines, infrastructure and refuelling systems.<sup>49</sup> Increased use of SAF is likely to reduce the higher costs involved in the use of SAF relative to conventional kerosene, achieved by relocating blending operations to airports to simplify the distribution network. The UK's Jet Zero Strategy has a target to construct five UK SAF plants and reach a 10% SAF mix in the UK aviation fuel blend by 2030.<sup>50</sup>

<sup>45</sup> Discovery of Tech, Types of Batteries used in Drones (March 2023).

<sup>46</sup> Simple Flying (October 2019). How Ryanair Manages Super Tight Turn Arounuds.

<sup>47</sup> Simple Flying (September 2022). How Is An Aircraft Refuelled?

<sup>48</sup> Blueprint for Zero Emission Flight Infrastructure, Catapult, 2022.

<sup>49</sup> Department for Transport (March 2023). Pathway to Net Zero Aviation: Developing the UK Sustainable Aviation Fuel Mandate.

<sup>50</sup> Department for Transport (July 2022). Jet Zero Strategy. Delivering Net Zero Aviation by 2050.

### Environmental issues

The extent of decarbonisation depends on the full life cycle of the fuel. For example, battery-electric aircraft have no carbon emission release from the aircraft itself, but there will be emissions developed through the battery and aircraft manufacturing process. It is estimated that electric aircraft can reduce carbon emissions by 49% to 88% compared to fossil fuels.<sup>51</sup> Electric aircraft manufacturers, such as Ampaire, project a 60% reduction in noise levels during take-off and landing for their 15-passenger aircraft, while others suggest a reduction of 85%. In addition, NOx emissions are between 50% and 70% lower for hydrogen than kerosene fuels, whether fossil or SAF.<sup>52</sup>

### Electrification in the UK aerospace industry

The aerospace industry, which encompasses the design, manufacture and maintenance of aircraft, spacecraft and related technologies for both civil and military applications is also in the early stages of the energy transition.<sup>53</sup> With an annual turnover of £35 billion, the UK aerospace industry plays a vital role in the UK economy, supporting over 120,000 highly skilled jobs, mostly located outside of London and the South East.<sup>54</sup>

Electrification in the UK aerospace industry falls into the following sectors:

- Electric aircraft design, manufacturing and maintenance, including propulsion systems, batteries and energy management systems (as discussed in previous sections);
- Satellites such as high-altitude pseudo satellites (HAPS), medium-earth orbit (MEO) satellites, low-earth orbit (LEO) satellites, GPS (global positioning system) satellites and miniature satellites (e.g., CubeSats), with batteries used for flight and take-off;
- Space applications, such as space transfer vehicles, planetary landers, launchers and rovers;
- Defence and military applications, covering both ground applications and dismounted soldier systems.

### Satellite and space applications

The UK's space sector is a vital part of the economy, supporting over 45,000 jobs and worth over £16.4 billion in 2019. The global space economy is expected to reach £490 billion by 2030, presenting significant opportunities for the UK sector to grow.<sup>55</sup>

Batteries for MEO, LEO and GPS satellites typically use nickel-cadmium as these batteries can be charged by

solar energy,<sup>56</sup> although nickel-hydrogen and lithium-ion batteries are also found in satellites. Selection of the specific battery chemistry required is dependent on the application with consideration of the power capacity, cycle life, weight, operating temperature range, resistance to shock and vibration, depth of discharge, ability to recharge, specific energy and cost critical to the use of satellites in space.<sup>57</sup> Key global battery suppliers in the industry include SAFT, ABSL, Redwire Space, Ibeos, EaglePicher and OCE Technology.

High-altitude pseudo satellites (HAPS) operate in the near-space or stratosphere, which is much closer to Earth than many satellites but higher than commercial planes and drones. HAPS are designed to operate at high altitudes for extended periods and serve as a cheaper and more flexible alternative to satellites. Popular chemistries used for HAPS are similar to UAVs, typically lithium-ion and LiPo and, to a lesser extent, nickel-cadmium chemistries. MEO and LEO satellites typically use lithium-ion batteries due to their high energy density, lighter weight and ability to operate in different temperature environments.

Next generation battery technology, such as 100% silicon anode lithium-ion cells, have also recently been used for satellites.<sup>58</sup> These batteries offer higher energy density and faster charging rates, which stem from using silicon-based material as the anode instead of the traditional graphite. The main drawback is the tendency of silicon anodes to degrade more quickly than graphite anodes because of volumetric changes during charging and discharging. Companies conducting research in this area include Nexeon and Talga Technologies<sup>59</sup> but the complexities associated with silicon usage remain significant and substantial research will be needed to develop commercially viable technology.

Battery technology is also increasingly being used for a range of space applications beyond satellites, such as planetary rovers, planetary landers and astronaut-operated tools. Such batteries must be designed to operate reliably in extreme conditions, including severe temperature fluctuations and high levels of radiation.

### Defence and military applications

UK government spending on defence and the military is currently about 2.3% of GDP,<sup>60</sup> with an aspiration to increase to 2.5% of GDP.<sup>61</sup> The Integrated Review 2023 of security, defence, development and foreign policy, identified an ability "to generate strategic advantage through science and technology" as an overarching objective.<sup>62</sup> Within the technology strategy is a recognition that the adoption of innovative technologies at pace is a route to achieve

<sup>51</sup> ICCT (2022). *Performance Analysis of Regional Electric Aircraft*.

<sup>52</sup> ATI (2022). *Sustainability report: The Lifecycle Impact of Hydrogen-Powered Aircraft*.

<sup>53</sup> Aerospace is an overlapping but distinct industry to aviation. Aviation refers to the operation and use of aircraft (commercial airlines, private planes, helicopters etc) within the Earth's atmosphere whereas aerospace encompasses the design, manufacture and maintenance of aircraft, spacecraft and related technologies that operate in the Earth's atmosphere or beyond.

<sup>54</sup> HM Government 2022. *Aerospace Sector Deal*.

<sup>55</sup> UK Government (February 2022). *National Space Strategy, Policy Paper*.

<sup>56</sup> NASA Space Technology 5.

<sup>57</sup> *Satellite Batteries* (February 2023). For CubeSats, nanosats and other form factors.

<sup>58</sup> Amprius announces commercial availability of silicon anode lithium-ion cells (February 2022).

<sup>59</sup> APC (October 2022). *2025 and Beyond: Promising Battery Cell Innovations for the UK Automotive Sector*.

<sup>60</sup> Statista (December 2022). *Defence expenditure as a share of GDP in the UK*.

<sup>61</sup> HM Treasury (March 2023). *Spring Budget 2023*.

<sup>62</sup> HM Government (March 2023). *Integrated Review Refresh 2023*.

competitive advantage.

The use of batteries in military and defence applications is particularly important as they provide a portable, reliable and efficient source of energy for various equipment and systems. Of particular relevance is the battlefield electrification research and experimentation area by the British Army.<sup>63</sup> The benefits of electrification and deployment of batteries include silent running, silent watch capability, quieter operations, less visible emissions, increased survivability, more efficient logistics and enhanced vehicle mobility. The UK has an opportunity to establish itself as a global supplier of electrical aircraft and electric aerospace motor design, particularly in the development of high-power electrical propulsion systems for both civil and military use, utilising experience and technologies from high-performance industries such as Formula E.<sup>64</sup>

Lithium-ion batteries are particularly useful for military and defence applications as they can power critical systems such as portable electronics, communication systems, navigation and weapons. These batteries are also well-suited for aircraft and unmanned ground vehicles (UGVs) because of their lightweight nature and high energy density. Other types of batteries such as nickel-metal hydride (NiMH) and lead-acid batteries are also used in military aerospace applications.

### Building on UK Strengths in Aviation and Aerospace

The UK is in a strong position to be at the forefront of technological developments in electric aircraft, hydrogen-powered aircraft and synthetic aviation fuels. The UK aviation industry is already one of the most important sectors in the UK, contributing around £22 billion each year to the UK economy, comprising £14 billion from air transport services and £8 billion from the aerospace sector.<sup>65</sup> The related defence and space sectors add a further £11 billion and £7 billion respectively.<sup>66</sup>

Before the global pandemic, UK air passengers travelling to and from UK airports reached over 297 million in 2019, with the market share of Heathrow and Gatwick dominating other UK airports. London's six airports represent one of the biggest regions in the world for passenger numbers, providing the critical mass necessary to experiment with and implement new low carbon flights and infrastructure at a commercially viable scale.

The UK aerospace industry, with a turnover of £35 billion, is the second largest in the world behind the US.<sup>67</sup> The UK is home to leading aerospace companies such as Rolls-Royce and BAE Systems, with a total of over 3,000 aerospace firms

and 98% of domestic production exported.<sup>68</sup> Technological expertise and a skilled workforce are focused on manufacturing complex aircraft engines, aircraft parts (e.g., wings), advanced systems (e.g., landing gear) and avionics (e.g., flight control, navigation and communication). The repair and maintenance sector is also a UK strength, providing comprehensive services for a wide range of aircraft.

The UK is a global leader in aerospace R&D, taking the lead in advancements in areas such as jet propulsion, avionics and material sciences. The UK government and industry have already provided matched contributions of nearly £3.9 billion towards aerospace R&D over the 2013 to 2026 period, focusing on the creation of more sustainable aircraft and innovative manufacturing techniques, research on electric aircraft and future designs for aircraft, wings and engines.<sup>69</sup>

In terms of electrification, the UK has strengths in the development of electric motor development, power electronics and advanced battery technology.<sup>70</sup> Significant UK efforts are also underway to develop electric aircraft and battery technology such as:

- Rolls-Royce's 'Accelerating the Electrification of Flight' programme is developing an all-electric aircraft the 'Spirit of Innovation' to break the air speed record by exceeding 300 mph.
- Electroflight develops modular battery systems and battery management systems, as well as undertaking battery maintenance, repair, repurposing and recycling to facilitate the commercial adoption of electric aircraft.<sup>71</sup>
- Wright Electric (easyJet's partner) in partnership with BAE Systems has commenced the engine development programme for its 186-seater electric aircraft, Wright 1. Plans included ground tests in 2021, flight tests in 2023, and a 2030 target for commercial service.<sup>72</sup>

The UK accounted for a 12% global share of eVTOL aircraft development between 2014 and 2020, ranking second in the world behind the US with a 41% market share.<sup>73</sup> The UK's strength is based on a robust industrial base, a vibrant startup ecosystem, supportive government policies and regulation. The UK Government has demonstrated support for urban air mobility projects, promoting trials and investments in eVTOL to reduce congestion and improve urban connectivity, such as the Vertical Aerospace £31 million project focused on developing a prototype propulsion battery system for eVTOL aircraft.<sup>74</sup> In addition, the Aerospace Technology Institute has provided £111 million of UK funding towards the development of electric aircraft<sup>75</sup> while the UKRI

<sup>63</sup> British Army Approach to Battlefield Electrification.

<sup>64</sup> Aerospace Technology Institute (March 2022). *Electrical Propulsion Systems: UK Capability and Overseas Landscape*.

<sup>65</sup> House of Commons (September 2021). *Aviation, Decarbonisation and Climate Change*.

<sup>66</sup> ADS Industry Facts & Figures 2023.

<sup>67</sup> Department for Business & Trade (2020). *Aerospace Sector Deal*.

<sup>68</sup> International Trade Administration (April 2023). *Aerospace & Defence Exporter Alert*.

<sup>69</sup> HM Government (July 2017). *Beyond the Horizon: The Future of UK Aviation*.

<sup>70</sup> Aerospace Technology Institute (January 2022). *FlyZero - UK Capability in Zero-Carbon Emission Aircraft Technologies*.

<sup>71</sup> Electro Flight: Providing Next-Generation Battery Systems for Aerospace.

<sup>72</sup> easyJet's (January 2020). *Wright Electric begins engine development program for 186 seat electric aircraft*.

<sup>73</sup> O. Uguwueze et al. (January 2023). *Trends in eVTOL Aircraft Development: The Concepts, Enablers and Challenges*.

<sup>74</sup> UK Government Press release (February 2023). *Over £110 million to unlock zero emission guilt-free flights*.

<sup>75</sup> Innovation News Network (February 2023). *UK Government announces £113m funding for emission-free electric aircraft*.

Future Flight Challenge has focused on the introduction of electric sub-regional aircraft, advanced air mobility ecosystem and drones.<sup>76</sup>

In addition, the UK-based company Velocys recently announced a second sustainable aviation fuel project (E-Alto), supported by a £2.5 million grant. This initiative aims to produce synthetic fuels from hydrogen, carbon dioxide and renewable electricity, aligning with the UK's Jet Zero strategy for net-zero aviation by 2050.<sup>77</sup> Johnson Matthey has also made a significant commitment to SAF, evidenced by their development of innovative technologies such as HyCOgen, FT CANS and BioForming S2A. Other companies involved in the manufacture and operation of eVTOL aircraft in the UK include Vertical Aerospace, Skyports, Joby Aviation and Urban Air Port.

While the mass-market automotive battery market is dominated by China, the UK should be able to take a leading role in the development of high-performance, lightweight and high-discharge-rate batteries for the aerospace industry, particularly given the success of WAE in supplying high performance batteries to Formula E.<sup>78</sup>

The UK also has strengths in developing international standards and best practice regulations, particularly in high-risk industries like aviation through the CAA and the International Civil Aviation Organisation. A coordinated approach to safety research, standards development and regulation for electric aviation battery safety is recommended.<sup>79</sup>

### Conclusions

Pressure to reduce carbon emissions from air travel is increasing. While battery technology has a lower energy density than fossil-based fuels, it has the potential to be widely used in short-haul and domestic aviation markets. Even this would fundamentally change aviation since around 15% of global revenue passenger-km and half of the global departures could be served by aircraft with a range of 600 miles.<sup>80</sup>

Battery-electric aircraft have shown to be highly efficient in converting stored energy into propulsion, mainly due to the high proportion of electrical energy used for propulsion. However, substantial research challenges still exist with academic and commercial research needed to overcome the current limitations of electrically propelled aircraft and make them commercially viable.

Enhancements in battery energy density, safety, fast-charging capabilities and thermal management systems are all crucial for the commercial viability of electric planes. Meeting the demands of commercial aviation will require transformative breakthroughs in energy density, materials science and system integration, not just incremental research

improvements. The following eight research areas have been identified by the Argonne National Laboratory to facilitate the development and commercialisation of electric aviation batteries:<sup>81</sup>

- Evaluate high-discharge operation of lithium-ion cells for eVTOL applications;
- Evaluate next-generation lithium-ion (silicon anode, advanced cathode, lithium metal) batteries under aviation conditions;
- Develop solid-state batteries to enable 50-passenger regional electric aircraft;
- Study 3 to 5 times higher energy density systems for large regional and 737-class planes;
- Identify opportunities for different aircraft classes as a function of battery energy density;
- Develop efficient battery pack designs for aircraft;
- Identify failure modes under different operating conditions;
- Connect aircraft propulsion models to battery performance to define battery targets under aviation conditions.

Hydrogen-powered aircraft have the potential to overcome the limitations of batteries for long-haul flights. While hydrogen fuel cell-powered aircraft have lower efficiency than battery-electric aircraft because of energy losses in converting hydrogen fuel to electricity, they offer greater energy density and the potential for longer flights. However, commercial adoption is expected to be slow and lagging the adoption of other SAFs until well after 2050 due to challenges in safe hydrogen storage, fuel cell efficiency and infrastructure development that need to be resolved.

The development of infrastructure and safety standards for SAF, battery and hydrogen-powered aviation will be critical for achieving widespread adoption of these technologies. Infrastructure facilities not only include the development of SAF, battery and hydrogen storage facilities but also the establishment of a comprehensive network of refuelling, recharging and servicing stations. Safe deployment of battery and hydrogen-powered aircraft for passenger travel will also require research and global collaboration to establish common safety standards.

Currently, UK-based aerospace companies face many of the same risks evident in the UK automotive industry. Retaining jobs in the UK will require keeping pace with technological advances to maintain UK competitiveness as the sector decarbonises. However, the UK's position as a leader in aerospace technology could be at risk without new discoveries from domestic research, which could lead to a decline in the industry's strength and increased offshoring of current areas of expertise.

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<sup>76</sup> UKRI Future Flight Challenge.

<sup>77</sup> Business Live (December 2022). [Second UK Sustainable Aviation Fuel Project Spearheaded by Velocys Unveiled.](#)

<sup>78</sup> Aerospace Technology Institute (January 2022). [FlyZero - UK Capability in Zero-Carbon Emission Aircraft Technologies.](#)

<sup>79</sup> Faraday Insight 17 (July 2023). [Improving the Safety of Lithium-ion Battery Cells.](#)

<sup>80</sup> Massachusetts Institute of Technology (December 2018). [Technological, Economic and Environmental Prospects of All-Electric Aircraft.](#)

<sup>81</sup> Argonne National Laboratory (September 2021). [Assessment of the R&D needs for Electric Aviation.](#)

At the opposite end of the spectrum of possibilities, the UK could combine its position as a global leader in the aerospace industry with world leading academic and commercial research to maximise the benefits for the UK economy. This opportunity is substantial with cumulative global revenues for aircraft batteries estimated to reach £37 billion over the 2024 and 2050 period.

### About the Faraday Institution and Faraday Insights

The Faraday Institution is the UK's independent institute for electrochemical energy storage research, skills development, market analysis, and early-stage commercialisation. We bring together academics and industry partners in a way that is fundamentally changing how basic research is carried out at scale to address industry-defined goals.

Our 'Faraday Insights' provide an evidence-based assessment of the market, economics, technology and capabilities for energy storage technologies and the transition to a fully electric UK. The insights are concise briefings that aim to help bridge knowledge gaps across industry, academia and government. If you would like to discuss any issues raised by this "Faraday Insight" or suggest a subject for a future Insight, please contact Stephen Gifford.

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