Baselining the Skills Required for the Transition to Zero Emission Aviation and Aerospace

Final Report

Transport Scotland /
Skills Development Scotland

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J3379

Executive Summary

Transport is currently Scotland's largest sectoral emitter, responsible for 36% of Scotland's greenhouse gas emissions in 2018. Aviation accounts for 15% of total Scottish transport emissions with domestic aviation accounting for 0.67 $MtCO_2e$ and international aviation accounting for 1.6 $MtCO_2e$. Since 1990, domestic aviation emissions have decreased by 22.1% and international aviation emissions have risen by 186.2%. The Scottish Government's National Transport Strategy 2 identifies taking climate action as one of four key priorities, with the associated outcomes including helping deliver the net-zero target, adapting to the effects of climate change and promoting greener, cleaner choices.

The Scottish Government has also set a target to fully decarbonise scheduled flights within Scotland by 2040 and is in the process of developing an aviation strategy, which is expected to be published early in 2023.

The range of aircraft operating in, out and around Scotland is diverse and includes commercial drones, sub-regional (<20 passengers), regional (20-100 passengers) and short-medium haul international (100-250 passengers) aircraft, and helicopters. Furthermore, there is a number of low carbon and zero emission technologies either being deployed or under development that could support decarbonisation of the Scottish aviation sector. These include, for example, the replacement of conventional aviation fuels with sustainable / synthetic aviation fuels (anticipated as being the major contributor to decarbonisation in the long term, up to 2050), innovative aircraft design (such as lightweight materials and novel component designs), new propulsion technologies (battery and/or fuel cell electrification and hydrogen combustion) and data driven, advanced air traffic management. The use of carbon markets, removals and off-setting will also make a significant contribution to decarbonisation in the short to medium term (up to 2035 and beyond). Scottish airports are also implementing a number of measures to reduce the carbon emissions associated with their operations including, for example, vehicle electrification (hybrid, battery and, to a lesser extent, hydrogen fuel cell) together with the associated charging / refuelling infrastructure.

The Scottish Aircraft Fleet and Low Carbon Technology Options

Given that aviation is a global industry, quantification of the aircraft fleet within Scotland is complex. Aircraft are generally registered in the jurisdiction in which the carrier is based and flights are not always consistent, changing with season, customer demand, weather conditions and other operational demands. Numbers of aircraft are, therefore, continually changing. Over the period April – September 2022, there were approximately 550 flights per day, on average, across airports required to report to the Civil Aviation Authority (CAA).

The current adoption of low carbon technologies in the existing fleet is still quite low with much of the emphasis, currently, being on lightweighting and enhanced aircraft design to improve fuel efficiency. The use of carbon markets, removals and offsets, however, accounts for the majority of abatement measures currently. The rates of technology adoption will have to increase significantly to contribute to achievement of the net zero target.

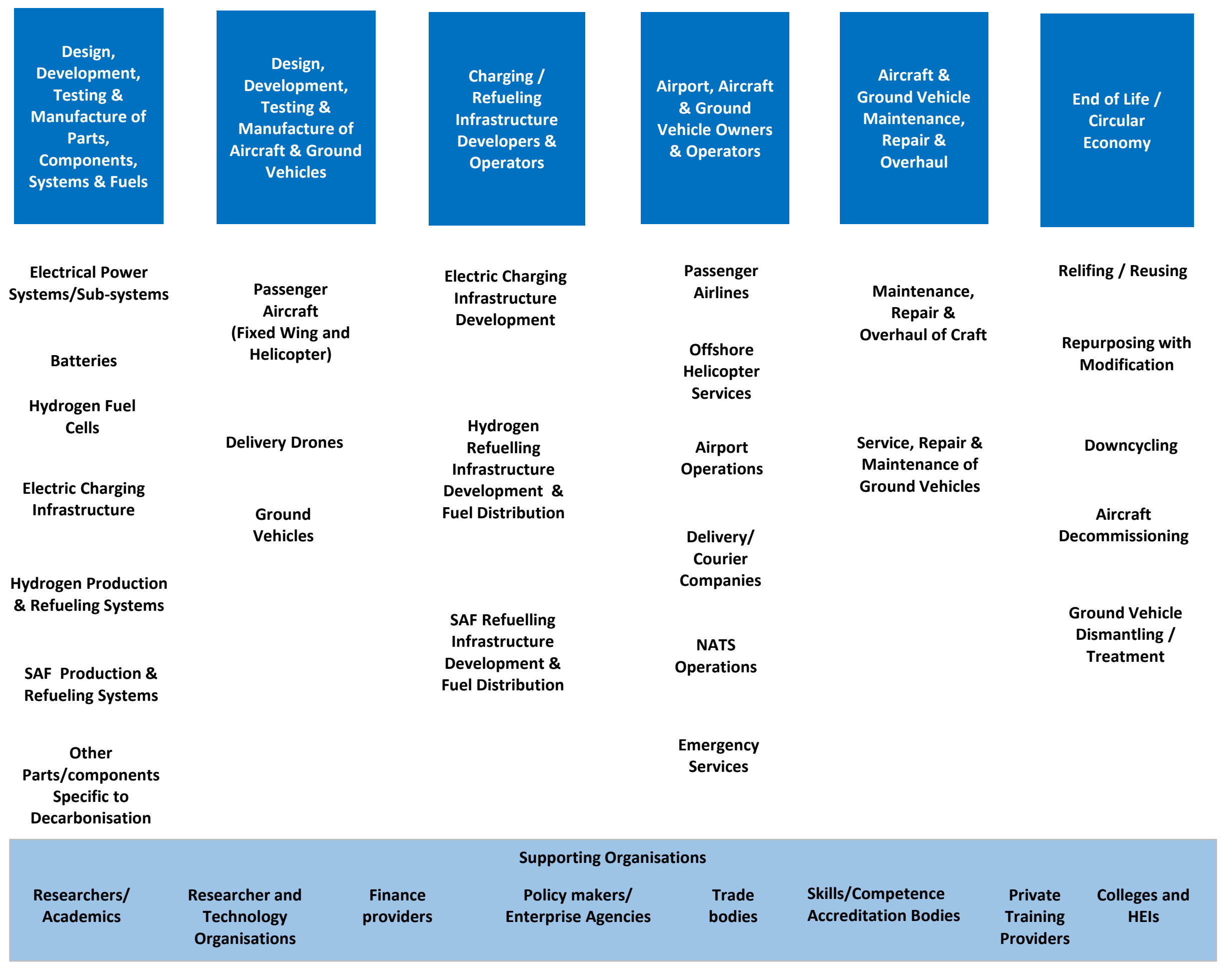
The main drivers for the adoption of low carbon and zero emission technology options are environmental, political and societal pressures. Short and medium-term objectives for greenhouse gas emissions from international aviation (to 2035) are being co-ordinated by the International Civil

Aviation Organisation (ICAO), a specialised agency of the United Nations. The main focus of action on emissions up to 2035 is the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) which seeks to reduce emissions from international flights via a global, sector-specific, market based mechanism. Looking forward from 2035, the International Air Transport Association (the trade association for the world's airlines, representing some 300 airlines or 83% of total air traffic) has pledged to achieve net zero by 2050, through its Fly Net Zero commitment.

There are, however, significant barriers to the move towards decarbonised and zero emission aviation. There is a lack of clarity on the future evolution of the sector in Scotland. Whilst many of the major aviation OEMs are investing significantly in R&D to develop and demonstrate the next generation of decarbonised and zero emission aircraft, it is not clear what technologies will emerge first, when these aircraft will come to market or what the implications of this will be for the sector in Scotland in terms of, for example, supply chain opportunities, aircraft flying in and out of Scotland, infrastructure, power generation, MRO, etc. In addition, there is lack of clarity as to whether government support (at a UK level and, to a lesser extent, at a Scottish level) will focus on one technology over another (e.g. SAF over hydrogen combustion). It is also highlighted that the aviation industry is highly regulated and, as a result, new technologies, such as those that will support decarbonised / zero emission aviation, cannot be deployed until they are fully certified to relevant standards and regulations. Many of the necessary standards and regulations either do not exist or are still under development, meaning skills needs cannot yet be defined at a detailed level. As a result, many companies, and especially aircraft owner/operators, are reluctant to invest in these new technologies until there is more clarity and certainty.

All of these factors create uncertainty about how the level of adoption of low carbon and zero emission aviation will change in the short to medium term (2027) and the medium to longer term (by 2032). In turn, this impacts on when, and at what scale, skills will be required to support the uptake of many low carbon and zero emission technologies on aircraft and in airports. The relationship between skills availability and levels of technology adoption is interdependent as a lack of skills in some areas can also act as a barrier to adoption. It is expected that the fleet, in 2050, will still include a significant percentage of traditionally powered aircraft or aircraft powered by SAF. As SAF, when blended in the correct proportions with conventional aviation fuel, is a drop in technology then there is unlikely to be any significant requirement for new skills.

The figure below summarises the different segments in aviation, and the supply chain relating to decarbonisation in Scotland, together with the key stakeholder groups within each. In total, 25 stakeholders were interviewed during the research for this study. This has provided a representative sample of opinions across the aviation landscape.



It has been estimated that there are approximately 12,450 people employed across this aviation landscape. The scale of demand for new or enhanced skills to support decarbonisation of the sector is, however much more challenging to calculate due mainly due to the lack of employment data for two of the categories shown above. It has not been possible, therefore, to provide quantitative estimates of the number of people requiring skills training in each aviation sub-segment.

Companies in the aviation landscape will likely develop skills aligned with the technology options as they develop. In the short to medium term this will include, for example, skills in computational modelling, design, materials engineering and manufacturing to facilitate the development and implementation of innovative design concepts as a means of improving fuel efficiency and reducing CO_2 emissions, an activity that is already underway. Similarly, skills to provide air traffic control services will be necessary and as new tools to facilitate more effective and efficiency flight path management are developed and implemented, data science, data management, software and other digital skills will be necessary.

Over the period from 2030 and beyond, there will likely be a growing need for skills relating to hydrogen service, ranging from enhanced engineering skills to manufacture parts and components to the relevant standards and quality to skills in working with high pressure gas systems, particularly hydrogen (either in combination with fuel cell technology or direct combustion). There will also be some level of skills development covering both high voltage systems and high-pressure flammable gas systems to enable safe working on electrified aircraft and aircraft burning new, zero emission fuels.

Skills Shortages and Gaps in the Decarbonised and Zero Emission Aviation Landscape

A number of skills shortages and gaps have been identified across different segments of the aviation landscape including:

- Fundamental, industry wide STEM skills shortages, especially in several of the key disciplines, such as mechanical engineering, electrical and electronic engineering, chemical engineering, software, and data and digital technologies, that will have a significant impact on decarbonisation of the sector
- A shortage of experienced technicians, fitters and welders, with the latter being highlighted as a particular issue
- Shortages around digital/data skills to support flight path management, automation, and local air traffic management (urban air mobility)
- Engineering and manufacturing skills related to hydrogen service exist in Scottish supply chains but are concentrated in other sectors (e.g. oil and gas) and will be insufficient to meet potential demand
- A gap in skills to communicate with the public about actual vs perceived risk related to hydrogen infrastructure
- Lack of an apprenticeship framework focused on hydrogen refuelling infrastructure installation and maintenance
- Skills gaps around detailed safety case development relating to hydrogen and urban air mobility
- Skills gaps relating to the design and development of liquid hydrogen systems. This technology is still at a very low technology readiness level (TRL) for aviation and there are questions as to whether it will ever be viable for commercial aviation due to safety issues, costs and energy requirements to liquify hydrogen
- Skills to repair and maintain electric and hydrogen fuelled ground vehicles
- Upskilling of emergency responders to deal safely with incidents involving high voltage and hydrogen powered craft

It is considered that some of these shortages and gaps can be addressed by reskilling and upskilling of existing staff. This could be achieved through short courses and “on the job” learning to understand different requirements and techniques and by adapting further and higher education courses to include relevant new content for new entrants to the sector. There will also be further action required to address these skills shortages and gaps to support the uptake of low carbon and zero emission technologies in the aviation sector in Scotland. It is recognised, however, that this is most likely to be in the longer term (2035 and beyond) due to the long timescales over which these technologies are likely to be introduced into commercial aviation and, subsequently, begin to operate in, out and around Scotland.

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Prepared By: Deborah Creamer, John Taylor and Kayleigh Nelson	**Date:** 13 March 2023
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1 Introduction

This report has been prepared by Optimat Ltd for Transport Scotland to present the results of a study into the skills required to support the decarbonisation of aviation and aerospace sector and to maximise the associated economic opportunities for Scotland. It is based on research carried out over the period November 2022 to February 2023 including 25 stakeholder interviews.

1.1 Background

The Climate Change Act, passed by the Scottish Parliament, commits to reduce greenhouse gas emissions to 75% of 1990 levels by 2030, 90% by 2040 and net-zero emissions by 2045. Scotland's total greenhouse gas emissions in 2018, including international aviation and shipping, were 41.6 $MtCO_2e$.

Transport is currently Scotland's largest sectoral emitter, responsible for 36% of Scotland's greenhouse gas emissions in 2018. Aviation accounts for 15% of total Scottish transport emissions with domestic aviation accounting for 0.67 $MtCO_2e$ and international aviation accounting for 1.6 $MtCO_2e$. Since 1990, domestic aviation emissions have decreased by 22.1% and international aviation emissions have risen by 186.2%. The National Transport Strategy 2 identifies taking climate action as one of four key priorities, with the associated outcomes including helping deliver the net-zero target, adapting to the effects of climate change and promoting greener, cleaner choices.

The Scottish Government has set a target to fully decarbonise scheduled flights within Scotland by 2040 and is in the process of developing an aviation strategy, which is expected to be published early in 2023. The main findings of the consultations, carried out as part of this new aviation strategy development process, included wide support for electric and hydrogen flight options and calls to support the development of infrastructure to support this. Analysis of the consultations also identified encouragement for investment in sustainable aviation fuel, with an appetite for domestic production in Scotland. Investment in training, to ensure the availability of a skilled Scottish workforce to support these new developments, was also highlighted. In addition to reducing the environmental impact of air travel, there is also a focus on supporting and facilitating greater use of rail where this is a viable alternative.

The Scottish Government recognises that the decarbonisation of aviation and aerospace operations also has the potential to benefit the Scottish economy, through opportunities in the supply chains of hydrogen and electric aircraft, sustainable aviation fuel production, etc. To facilitate decarbonisation and secure economic benefits from this, requires a range of skills. There is, therefore, a need for an evidence based to be established about what these skills are and where current and future skills gaps and/or shortages may act as a barrier to decarbonising aviation and aerospace.

1.2 Study Scope and Objectives

The scope of the research study includes:

- Operation of aircraft within Scotland, including passenger aircraft and delivery drones and operation of associated ground vehicles

- Activities in the supply chains for the development, manufacture, maintenance and decommissioning of aircraft and ground vehicles to address Scottish and international opportunities

The aviation and aerospace landscape consists of a number of segments, including:

- Design, development, testing and manufacture of parts, components, systems and fuels
- Design, development, testing and manufacture of craft and ground vehicles
- Charging / refuelling infrastructure developers and operators
- Craft and ground vehicle owners and operators
- Craft and ground vehicle maintenance, repair and overhaul
- End of life/ circular economy (relifing, repurposing, decommissioning, etc.)
- Supporting organisations including researchers/academics, research and technology organisations, finance providers, policy makers/enterprise agencies, trade bodies, skills/competence accreditation bodies, private training providers and colleges/higher education institutes

Skills to support the decarbonisation of aviation and aerospace have been considered in the short to medium term (2027) and the medium to long term (2032).

The key research objectives of this study were to:

- Understand the scale and nature of the aviation and aerospace craft and ground vehicles currently operating in Scotland
- Understand the potential technologies and practices likely to be utilised to support decarbonisation, up to 2032
- Estimate the potential levels of adoption of decarbonisation technologies and practices in the craft and ground vehicles operating in Scotland
- Identify the current scale of Scottish employment in different segments of the overall aviation and aerospace landscape
- Identify the scale and nature of key skills required to support decarbonisation, up to 2032
- Define the current skills provision landscape servicing the Scottish aviation and aerospace landscape
- Identify key skills gaps and shortages with potential to act as a barrier to the decarbonisation of aviation and aerospace in Scotland and the potential wider economic opportunities
- Identify the barriers to skills development
- Identify any transferrable skills and talent from other sectors

2 Research Method

The research was carried out using a combination of secondary and primary activities. A review of relevant policies, strategies, articles and other data sources was conducted. This provided an understanding of the scale of Scottish based activity across the various segments of the aviation and aerospace landscape. Key policies, strategies and initiatives, driving the decarbonisation of the sector were also identified. The measures being developed to achieve decarbonisation targets were defined (technical and non-technical) and investigated, along with potential barriers to implementing the measures. This secondary research provided a baseline of information to test, and build upon, during the primary research. A target database of over 60 stakeholders was developed, with representation sought over the different segments of the aviation and aerospace landscape, where relevant organisations were present in Scotland. Some organisations based outside Scotland were also approached for consultation where they had a UK wide remit (e.g. trade associations and companies headquartered outside Scotland but with Scottish-based operations). Potential stakeholders were approached with an email containing briefing information about the study and intended discussion topics, which aligned with the research objectives described in Section 1.2. Where stakeholders expressed an interest in participating, an online meeting was arranged. In total, 25 stakeholders contributed to the study. A list of contributing organisations is included in Appendix A.

Information gathered during the secondary and primary research was then analysed to address each research objective and discussed in detail in this report. A summary presentation and infographic have also been produced.

3 Segmenting and Quantifying Aviation and Aerospace Craft

3.1 The Scottish Aviation Context

Scotland has 4 main *commercial* airports; Aberdeen International Airport, Edinburgh Airport, Glasgow Airport and Glasgow Prestwick Airport (known henceforth as Prestwick Airport for clarity). HIAL, Highlands and Islands Airports Limited, operates a number of small airports in the Highlands region, including Barra, Benbecula, Campbeltown, Dundee, Inverness, Islay, Kirkwall, Stornoway, Sumburgh, Tiree and Wick. Argyll & Bute Council also own and operate Oban & the Isles Airport. Perth Airport is operated by ACS Aviation Ltd for private aircraft, business aircraft as well as commercial pilot training. There is also a seaplane operator, Loch Lomond Seaplanes, which operates a single Cessna T206H.

Regional airlines operate regional aircraft to provide passenger air service to communities without sufficient demand to attract mainline service. Loganair, domiciled in Scotland, is the UK's largest regional airline and aims to become carbon neutral by 2040. Its fleet consists of regional and subregional aircraft (Saab 340s, Twin Otters, Britten Norman Islanders, ATR 42-500s, ATR 72-600s, Embraer 135s and 145s). It should be noted, however, that this is not a true representation of the wider fleet operating in Scotland's airspace. As part of a fleet renewal, the Saabs are being retired in favour of turboprop ATRs (stated to enable a 27% reduction in carbon emissions per seat versus the current Saab 340s).

Scotland also has two NHS funded helicopters (Airbus H145 helicopters, based in Glasgow and Inverness) and The Scottish Ambulance Service operates two fixed wing aircraft (Beechcraft B200C King Air, based at Aberdeen Airport and Glasgow Airport). Supplementing these rescue efforts are two helicopters (Eurocopter EC135s) provided by Scotland's Charity Air Ambulance (based at Perth and Aberdeen Airports) and these respond to trauma incidents and medical emergencies. There is a consultation on their re-procurement underway with current contracts live until 31st March 2024.

Scotland is home to four of the ten UK Coastguard helicopter bases; Inverness (2 x Leonardo AW189), Prestwick (2 x Leonardo AW189), Stornoway (2 X Sikorsky S92) and Sumburgh (2 X Sikorsky S92) - data sourced from a direct DfT request. Bristow Search and Rescue also operates a dual fleet of search and rescue-configured Sikorsky S-92A and Leonardo AW189 aircrafts.

Police Scotland operate two helicopters (Airbus H135-T3s), one typically used as a backup or operated simultaneously in the event of major incidents. The organisation has three operational remotely piloted aircraft systems, with one based at each of Aberdeen, Inverness and Glasgow.

The Royal Air Force in Scotland primarily operates from RAF Lossiemouth (Moray), where there are four Typhoons and nine submarine-hunting Poseidon P-8A maritime patrol aircraft. Lossiemouth is one of two QRA (Quick Reaction Alert) stations in the UK and the only one in Scotland. Surveillance aircraft (E-7 Wedgetails) are set to be housed at RAF Lossiemouth from 2023. The RAF provides in-house training and skills provision for the aircraft in its service, therefore, has limited impact on the wider industry and associated skills requirements.

Scotland's location means that air services are essential for good international connectivity. Air services also play an important role in domestic connectivity, including to the remote island communities. This highlights that although there can be considered to be a core fleet of aircraft, which operate within Scotland, there remains a need to consider all aircraft that may fly in and out the region, even if only occasionally. Prestwick Airport, for example, is uniquely placed to receive unusual aircraft including the world's largest aircraft (Antonov 225 Mriya), which was refuelled there in 2020.

The aviation industry was heavily impacted by the COVID-19 pandemic and, as a result, data on airport operations and airline capabilities has been skewed by the considerable restrictions imposed on travel during this time. In order to establish the fleet and anticipated demand (and associated skills) for Scottish aviation, it was deemed prudent to assess data following the end of travel restrictions in Scotland (from March 2022). Figure 1 shows the main Scottish airports, where the 'bubble' is scaled, according to the average number of 'aircraft movements' from April 2022 to September 2022.

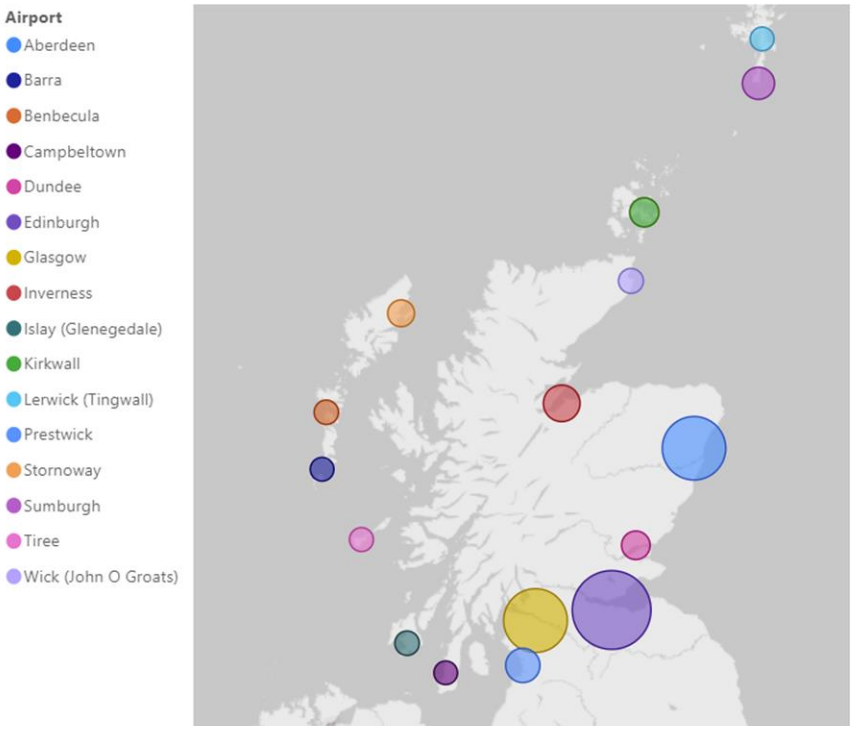

Figure 1: Average Number of Aircraft Movements from April 2022 to September 2022 by Airport

The total aircraft movements across Scottish airports are outlined in Figure 2, which shows a steady increase, whilst remaining around 75% of that in 2019. This is consistent with general observations in the UK where flight numbers remain below pre-pandemic figures.

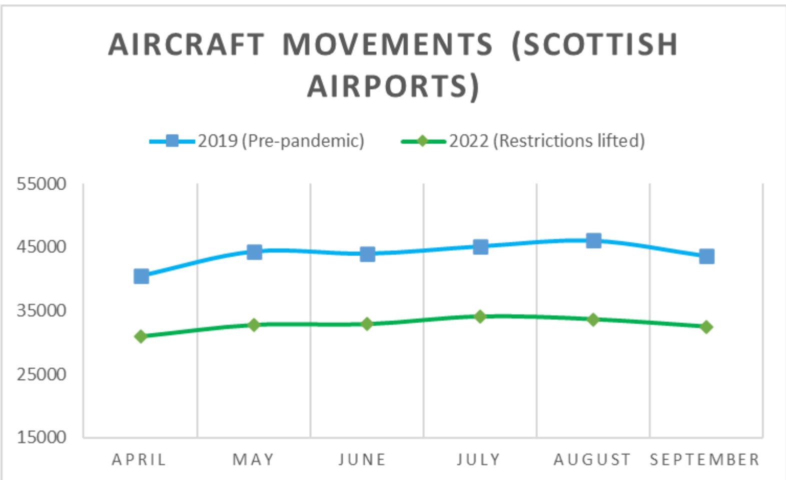

Figure 2: Total Number of Aircraft Movements Across all Airports from April to September 2019 and 2022

3.2 Defining the Scottish Fleet

Given that aviation is a global industry, quantification of the subregional fleet within Scotland is complex. Aircraft are generally registered in the jurisdiction in which the carrier is based and flights are not always consistent, changing with season, customer demand, weather conditions and other operational demands. Also, any available data only covers scheduled flights and chartered flight information is only available retrospectively.

Aviation includes a wide variety of different types of aircraft ranging from light aircraft to freight carriers. Due to the wide variation in types and their operation, different low carbon technologies will be more or less appropriate. It is, therefore, prudent to segment the aircraft fleet into groups with common characteristics. To this end, in accordance with the purpose of this research, aircraft have been categorised as shown in Figure 3.

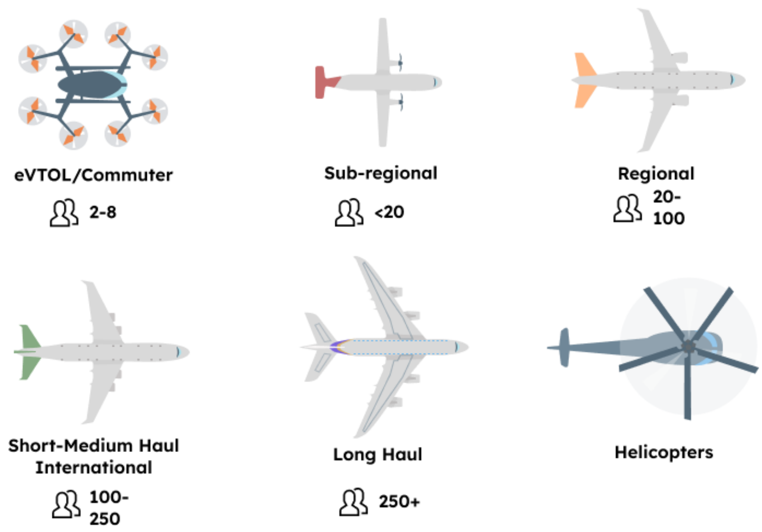

Figure 3: Categorisation of Aircraft Used in this Study

Table 1, provides some examples of the makes and models of aircraft in each category..

Category	No. of Passengers	Example Aircraft (Make and Model)
eVTOL/commuter	2-8	n/a

Category	No. of Passengers	Example Aircraft (Make and Model)
Sub-regional	<20	Jetstream 32, King Air 100
Regional	20-100	ATR 42, Embraer 135/145
Short-Med Haul	100-250	Boeing 737, 787 and Airbus A320 variants
Long Haul	250+	Boeing 777,787, Airbus A330, A340 A350 and A380 variants
Helicopters	All	Leonardo AW189, Airbus H145, Wildcat AH Mk1

Table 1: Examples of Different Makes and Model of Aircraft in Each Category

Aircraft must be registered by the Civil Aviation Authority (CAA), however, there is no breakdown between the individual nations and Scottish aircraft are, therefore, registered under UK aircraft. The total number of valid registered UK aircraft is 6,529 landplanes and 851 helicopters, as of January 2022. Note, airships, balloons, and hang gliders, etc., are excluded from the present study.

Aircraft are generally registered in the jurisdiction in which the carrier is resident or based and does not necessarily represent the number of aircraft operating within a country. The number of aircraft by each carrier is provided here, this is considerably lower than the number of registered UK aircraft mentioned previously.

eVOTLs (electric Vertical Take-off and Landing) vehicles are an emerging aircraft type, and remain nascent within Scotland currently. They are limited to small scale pilot projects, such as those pioneered by Skyports and Argyll and Bute Health and Social Care Partnership. Joby Aviation, a California based company, is looking to be the first eVTOL company to apply for foreign validation of its FAA (U.S. Federal Aviation Administration) type certificate. Certification is expected to take a number of years before these are in common use. Vertical Aerospace has demonstrated an electric prototype able to carry four passengers, and aims to achieve certification of this aircraft by 2025. The underlying ecosystem for eVTOLs is not yet established although work is underway by various bodies including UK Urban Air Mobility Consortium. In Coventry, Air One, demonstrated one of the first fully operational Urban-Airport for drones and eVTOL aircraft, in May 2022.

Gliders are unpowered and are, therefore, excluded from the current study.

The majority of UK airlines operate fleets with regional, short-medium haul and long haul craft. Accounting for all UK airlines, regional craft represents 11%, short-medium haul craft are the most common at 70%, with the remaining 19% being long haul craft. This has been calculated via a review of airlines within the UK and their fleets.

On average, a plane’s lifecycle is deemed to be approximately 30 years. This is an established estimation which has held true for a number of years. Analysing the airlines within the UK highlights that the average fleet age is currently 15.4 years, with average fleet ages for airlines ranging from three to just over thirty years.

The calculation of the fleet age is approximate, as it is only based on supported aircraft. The data is further limited as it only contains a number of airlines deemed to be flying within the UK. Freighter craft have been classified herein based on size and range in accordance with the above categories where required. The Scottish fleet has been estimated from the wider UK fleet in accordance with the proportion of flights (Figure 4).

This ‘30-year-lifespan’ assumption has however been challenged by a number of stakeholders contacted during this study, and there is some evidence to suggest that plane lifecycles are reducing, for example, the emergence of new, fuel efficient aircraft may drive early retirement of those that are less efficient . Lifespan is also typically measured in pressurisation cycles as opposed to flight time, as a result of the stress imposed on the wings and fuselage. Therefore, aircraft used for longer haul flights typically have longer overall lifecycles.

According to the CAA, which collates data on flights across the UK, there are 16 Scottish airports which actively contribute to CAA data (known as ‘reporting airports’). Air movements that include Scottish airports make up 16% of the total UK Air Movements. The Scottish data on air transport movements has been compared to equivalent UK data. Figure 4 highlights the difference in destination of air transport movements occurring at all UK airports and Scottish airports and this may be used as a proxy for aircraft type as different craft are used for different flight paths.

The charts contained in Figure 4 have been generated via data provided by CAA for September 2022.

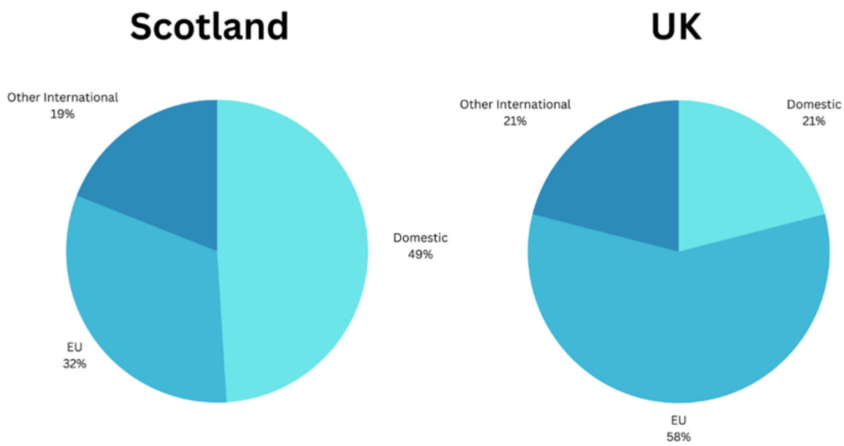

Figure 4: Percentage of Flights to EU, International or Domestic Destinations, Comparing Scotland and the Wider UK.

The larger proportion of domestic flights observed at Scottish airports compared to all UK airports (49% versus 21% for the UK as a whole) suggests a higher proportion of smaller planes operating to and from Scottish airports, whilst a similar percentage of ‘Other International’ flights suggests equivalent proportions larger craft, suitable for long haul flights. It should be noted, however, that ‘Other international’ data includes flights to and from offshore platforms. On average (between September 2022 and November 2022), 12% of flights in Scotland involve rotary wing craft (mainly from Aberdeen and Sumburgh airports). It is reasonable to assume these are helicopters mainly servicing offshore oil and gas facilities. By comparison, only 3% of total UK flights involve rotary wing aircraft. Therefore, a lower proportion of the Scottish ‘Other international’ flights involve fixed wing craft, typically of larger size than required for domestic and EU routes.

3.3 Data Limitations

It is important to note that the data collected does not consistently calculate all flights and, in some instances, excludes small airlines' public transport operations, such as those used between remote Scottish islands.

Only reporting airports are included in UK CAA data sampled, although this covers a range of Scottish airports.

It is also worth noting that, whilst Ryanair operates a fleet of 514 aircraft, the data from the UK CAA indicates operation of only 8 Boeings. This is likely due to the holding company being based in Ireland and, therefore, only the UK entity/subsidiary is involved in this calculation, despite having numerous planes operating within the UK. This is not, however, a fair reflection of the number of aircraft operating in and around the UK owned by Ryanair and its related companies as Ryanair houses 10 aircraft at Edinburgh Airport alone. In addition, aircraft movements cover both take off and landing, which needs to be considered from an airport operational and an air traffic control perspective.

Trunk routes are flights from the principal London airports to/from Manchester, Edinburgh, Glasgow, Aberdeen, and Belfast. They are typically served multiple times a day by both narrow and wide-body aircraft. There is difficulty in classifying flights along such routes as the information provided by the CAA is categorised as 'domestic' meaning within the UK, as opposed to within Scotland, but flights in and out of Scotland are likely to account for a considerable proportion of these aircraft movements.

Finally, a positioning flight is a flight without revenue passengers that is used to position the aircraft. These flights are required and although airport operational efficiencies are expected to increase, meaning that the impact of these flights will decrease or, at least remain the same, it is expected that these will continue to be included in our analysis as it is pertinent to the operational demand of the airports and airlines and nontrivial to remove.

4 Low Carbon and Zero Emission Technology Options

4.1 Drivers and Barriers

The main drivers for the adoption of low carbon and zero emission technology options are environmental, political and societal pressures.

The fundamental need to address current and projected climate change risks is driving efforts to reduce the rate of increase of greenhouse gases accumulating in the atmosphere. According to the International Civil Aviation Organisation, aviation (domestic and international) is estimated to account for approximately 2% of global CO_2 emissions produced by human activity, with approximately two-thirds from international aviation and one-third from domestic aviation. Other research, funded by the National Environment Research Council (amongst others), states that, *"taking into account non-CO_2 emission effects* [such as contrail formations]*, aviation contributed approximately 4% to observed human-induced global warming to date, despite being responsible for only 2.4% of global annual emissions of CO_2"*. The non-CO_2 climate impacts of aviation are recognised in the UK Government's Jet Zero strategy, which highlights that roughly two thirds of aviation's historical climate impacts are due to non-CO_2 but there is high uncertainty about this figure in current research. Impacts caused by factors such as contrail formations are not typically in scope of quantitative emission reduction measures, which focus on the basket of greenhouse gases used by the United Nations Framework Convention on Climate Change. Therefore, the drivers to reduce climate impacts of aviation caused by these non-CO_2 impacts are relatively weak in comparison to the drivers for the reduction of greenhouse gas emissions.

This environmental driver is the rationale behind political efforts to measure, monitor and reduce greenhouse gas emissions. One of the most significant political mechanisms driving action is the Paris Agreement. This legally binding, international, treaty has a goal of limiting global warming to well below 2, preferably to 1.5 degrees Celsius compared to pre-industrial levels. Each country signatory is required, on a five-year cycle, to submit plans for climate action, referred to as Nationally Determined Contributions (NDCs). These NDCs identify the actions the countries plan to take to reduce greenhouse gas emissions aligned to meeting the overall goal of the Paris Agreement. Greenhouse gas emissions from domestic aviation are included in these NDCs but emissions from international aviation are not.

Short and medium-term objectives for greenhouse gas emissions from international aviation (to 2035) are being co-ordinated by the International Civil Aviation Organisation (ICAO), a specialised agency of the United Nations. The main focus of action on emissions up to 2035 is the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) which seeks to reduce emissions from international flights via a global, sector-specific, market based mechanism. This approach is summarised in Figure 5, below.

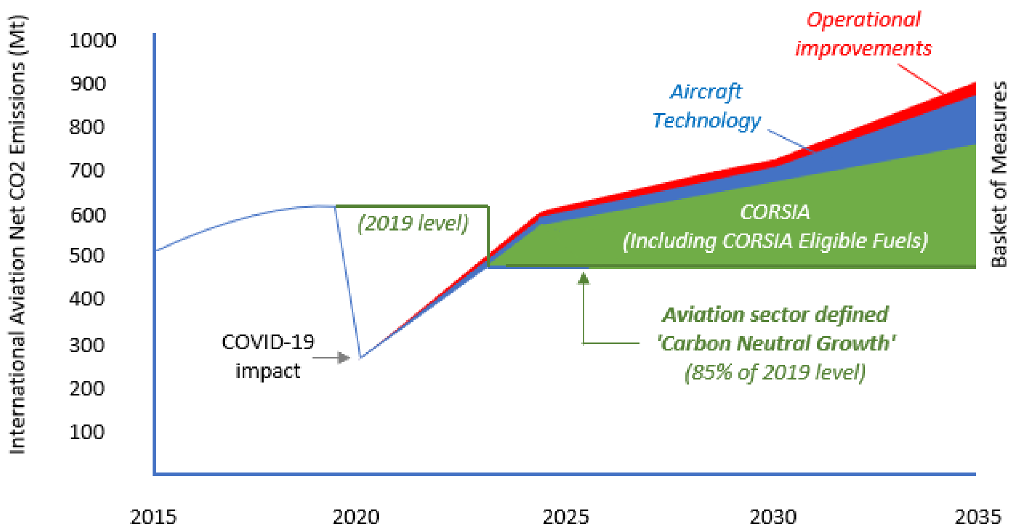

Figure 5: Contribution of CORSIA to the Aviation sector's Objective of Not Exceeding 85% of 2019 CO_2 Emissions From International Aviation Through to 2035 (Source: based on published information from The International Civil Aviation Organisation)

By inspection of Figure 5, it is clear that the CORSIA market-based mechanism is intended to be the main contributor to the aviation sector's plans for limiting CO_2 emissions from international aviation to 85% of 2019 levels to 2035.

Looking forward from 2035, the International Air Transport Association has pledged to achieve net zero by 2050, through its Fly Net Zero commitment. This relates to carbon emissions from both international and domestic flights. Figure 6, below, shows the proportionate contribution of different mitigation measures projected to achieve net zero by 2050.

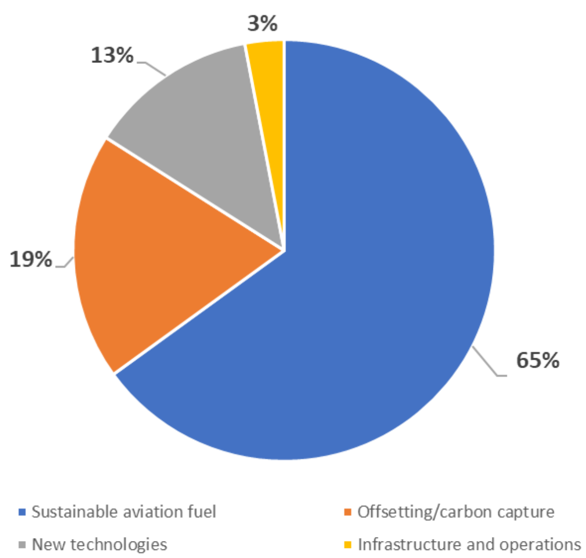

Figure 6: Contribution to Achieving Net Zero Carbon from Domestic and International Aviation in 2050 (source: IATA Net Zero Resolution)

Sustainable aviation fuel and offsetting/carbon capture are the two largest contributors to achieving net zero aviation by 2050.

The UK Government Department of Transport published the Jet Zero Strategy in 2022, which it describes as a 'framework and plan for advancing net zero aviation by 2050'. This strategy contains a target for all domestic flights to achieve net zero by 2040 and for all airport operations in England to be zero emission by the same year.

Figure 7, below, shows the contribution of different measures to achieving net zero by 2050 in the UK.

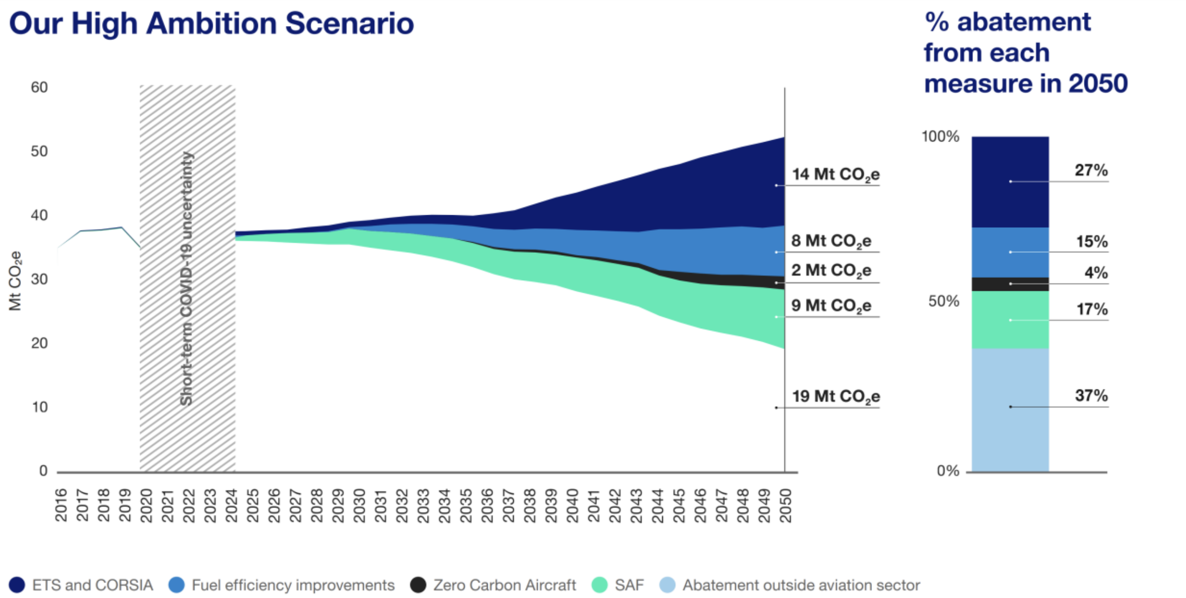

Figure 7: UK Jet Zero Strategy – High Ambition Scenario for Carbon Emissions Reduction from Aviation by 2050

It is not clear why the 2050 contribution of SAF in the UK (17%) is significantly less than the SAF contribution to addressing global carbon emissions, shown in earlier Figure 6 (65%). Some of the difference may be from the inclusion SAF use in the CORSIA measure in Figure 6, which is identified as a separate measure in above Figure 7.

It is also noticeable that market-based measures, such as the ETS, CORSIA and offsetting from outside the aviation sector account for almost two-thirds of abatement measures (64%). It may be difficult to account for the location of the skills required to deliver these measures. For example, offsetting via voluntary carbon credits involves a global supply chain, much of which will not be located in Scotland.

The above scenario for carbon emissions reduction in the UK shows a relatively low contribution to the decarbonisation of aviation by battery and hydrogen powered aircraft by 2032 (the scope of this study). Even by 2050, the role of zero carbon aircraft is limited to 4% contribution to carbon emission abatement measures. This could be interpreted as limited need for operational skills related to zero carbon aircraft by 2032.

In addition to the top-down, policies and legislation driving carbon emissions abatement measures, there is also consumer and wider societal pressure to take action on climate change. These drive change to maintain the aviation sector's social licence to operate.

4.2 Key Technology Developments

The majority of the world's major aircraft (aeroplanes and helicopter) original equipment manufacturers (OEMs) have set out sustainability and innovation strategies, either dedicated to or encompassing decarbonisation. This includes companies such as Boeing, Airbus, Embraer, Bombardier, Leonardo and Bell Flight. Of the leading OEMs, only Sikorsky, a helicopter manufacturer, gives no indication of any activities relating to decarbonisation (based on a review of the company's website carried out on 24th October 2022).

In the course of this study, we have identified four main technology themes relating to decarbonised and zero emission aviation, which will be underpinned by the development of the supporting infrastructure for new sustainable technology platforms. These are summarised in the following figure and described in more detail in the subsequent sections of this report.

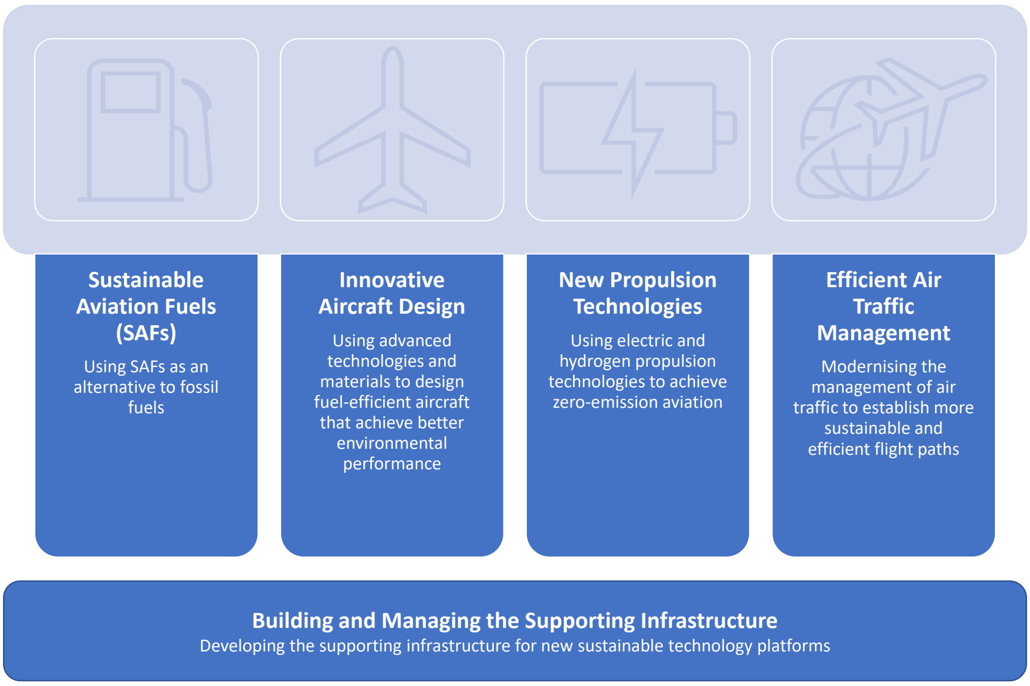

Figure 8: Key Technology Options for Decarbonised and Zero Emission Aviation

4.2.1 Sustainable and Synthetic Aviation Fuels

The replacement of conventional aviation fuel (CAF) with more sustainable alternatives will be key, to achieving low carbon and zero emissions aviation, based on the data provided in Figure 6 and Figure 7. Sustainable / synthetic aviation fuels (SAF) offer up to 80% reduction in carbon emissions over the lifecycle of the fuel and are, therefore, key short-to-medium term solutions to meeting net zero targets and objectives.

According to the international ASTM technical standards, aviation fuel is characterised using a range of physical and chemical properties, including volatility, fluidity, combustion specific energy, content of aromatic molecules and contaminants. In addition to meeting these specifications, SAF production methods are subject to additional regulation. At present, a total of nine fuel conversion processes are certified by ASTM D7566 for aviation use in current infrastructure (so-called drop-in fuels). In order to qualify as sustainable, SAF must also comply with ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) that includes a greenhouse gas lifecycle assessment of the feedstock.

The table below summarises the seven certified fuel conversion processes plus two co-processing methods, the sustainable feedstocks used in their manufacture and the certified blending ratio.

Conversion Process	Abbreviation	Feedstocks	Certified Blending Ratio
Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT-SPK	Waste biomass	50%
Synthesized paraffinic kerosene produced from hydroprocessed esters and fatty acids	HEFA-SPK	Bio-oils, animal fat, recycled oils	50%
Synthesized iso-paraffins produced from hydroprocessed fermented sugars	SIP-HFS	Biomass used for sugar production	10%
Synthesized kerosene with aromatics derived by alkylation of light aromatics from nonpetroleum sources	SPK/A	Waste biomass	50%
Alcohol-to-jet synthetic paraffinic kerosene	ATJ-SPK	Alcohols synthesised from biomass (such as starch)	30%
Catalytic hydrothermolysis jet fuel	CHJ	Triglycerides such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil	50%
Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10%
Co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery	Co-processed HEFA	Fats, oils, and greases (FOG) co-processed with petroleum	5%
Co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery	Co-processed FT	Fischer-Tropsch hydrocarbons co-processed with petroleum	5%

Table 2: Certified SAF Conversion Processes and Feedstocks Used

Furthermore, the current regulations only permit the blending of SAF into CAF at a ratio of up to 50%. This limitation is due to the fact that pure SAF does not necessarily meet the ASTM technical specifications, especially in the content of aromatic compounds. Aromatic compounds in aviation fuel are a double-edged sword: they are needed to ensure the swell of aircraft fuel system sealings; however, aromatics burn more slowly than other fuel components, thus contributing significantly to soot particulate emissions. ASTM specifications dictate the aromatics content in jet fuel to be between 8% and 25%, however the minimal concentration of aromatics needed for optimal seal swelling is unknown. This issue is being further addressed by engine manufacturers. At the correct mixing ratios, however, a blend of different types of SAF can meet the ASTM physical and chemical requirements for drop-in fuel.

The majority of current aeroplanes produced by the main OEMs, such as Airbus, Boeing, Embraer and Bombardier, and other aeroplanes using Rolls Royce engines, are compatible with up to 50% SAF blends. Further to this, all leading manufacturers have pledged to make 100% SAF-compatible aeroplanes by 2030. From a practical point of view, this would involve the use of novel materials for engine seals that do not require aromatic compounds to facilitate swelling.

Several ground and flight tests have been conducted using 100% SAF and it is now agreed that, whilst fuel leaks due to insufficient seal swell is a problem with older generation sealing materials (especially in the first 15-20 minutes of engine operation), SAF has no negative effects on overall engine health.

There are similar trends being seen in the helicopters sector with major OEMs, such as Airbus, Leonardo and Bell, having craft in service or under development that are capable of running on SAF fuel blends. More recently, an Airbus H225 helicopter, fitted with two Safran Makila 2 engines, performed the first ever flight powered by 100% SAF. Test are expected to continue, with a view to certifying the use of 100% SAF by 2030.

SAF technologies are rapidly developing and there are also several emerging conversion technologies at lower technological readiness levels (5-7) being actively developed by researchers and SAF producers. These are summarised in the following table.

Technology	TRL	Feedstock	Description
Power-to-liquid (electrofuels)	6	CO_2, green hydrogen and renewable electricity	Green hydrogen is generated using renewable electricity-powered electrolysis. Climate-neutral CO2 (e.g., direct capture) is converted into feedstock (syngas or carbon monoxide); liquid fuel is then produced via FT reaction.
Carbohydrates-to-jet	7	Various types of carbohydrates such as sugar, lignin, cellulose	Similar to the certified SIP-HFS technology; improved strategies for carbohydrate polymer breakdown
Pyrolysis-to-jet	6	Any carbon-based materials: biomass, waste, plastic	Material is heated to extremely high temperature in absence of oxygen resulting in molecules dissociating into a crude oil-like product that can be recovered and re-synthesised into kerosene. As a by-product, hydrogen-enriched gas is produced that is useful for further synthesis.
Hydrothermal liquefaction	5	Any carbon-based materials: biomass, waste, plastic	Like pyrolysis-to-jet, but with more moderate temperature and higher pressure
Aqueous phase reforming	6	Any carbon-based materials: biomass, waste, plastic; methanol	Biomolecules react with water under high pressure. Releases a large amount of hydrogen gas with methane, CO_2 and water as by-products that are captured and directed to SAF synthesis
Anaerobic fermentation	5 for aviation	Food waste, agricultural and forestry waste (depending on the microorganisms used in the production)	Fermentation exploits methanol, alcohol or syngas synthesis pathways present in many microorganisms. The biological product can be recovered and converted into fuel. Other biochemical pathways can be engineered into GMOs

Table 3: SAF Conversion Processes Under Development

4.2.2 Innovative Aircraft Design

There is already a huge amount of activity going on in the area of innovative aircraft design as a means of decarbonising aviation. In Scotland, Spirit Aerosystems, a key supplier of components to Airbus, has invested in innovation for a number of years in areas including composite materials and manufacture, component design and automation as a means of meeting customer requirements to reduce weight, improve efficiency and reduce costs.

The developments, in terms of innovative aircraft design can be categorised according to two main thematic areas, as follows:

4.2.2.1 New and Improved Materials

Composite materials are now commonplace in the construction of aircraft but work continues to replace more traditional metallic components with components manufactured from these materials as a way of reducing weight and, therefore, fuel consumption and CO_2 emissions. Boeing has taken this approach in its 787 aircraft, for example, by incorporating simplified carbon fibre composite structures, whilst Bombardier won an award for its innovative resin-infused advanced composite aircraft wing that not only reduced waste during the manufacturing process but also improved aerodynamics and reduced weight.

In addition to traditional composites materials that, typically, involve glass or carbon fibre embedded in a polymeric or epoxy resin matrix, there is increasing interest in biocomposites where both the fibres and the matrices (resins) are derived from biological sources, mainly plant oils, natural fibres (e.g. bamboo) and biomass / biowaste (e.g. water algae, sugar cane waste and cellulose). These materials are being investigated by Airbus.

There is also significant interest in the application of composites in helicopters as a means of reducing weight. Airbus, Leonardo and Sikorsky, for example, are running programmes in this area with Airbus launching its first all composite, civil helicopter in 2015 and Sikorsky planning a significant composite upgrade to its CH-53K helicopter, which is already equipped with a large number of composite components. Leonardo expects to obtain European certification of its first all composite helicopter airframe by the end of 2022.

Whilst composites and metallic materials (e.g. aluminium and aluminium alloys) dominate in the aviation industry, there are also other examples of new, lightweight materials being developed, specifically, for this application. These include, for example:

- RAU-FLIGHT – a range of innovative polyamide materials developed by REHAU Ltd. that deliver a weight reduction of up to 10% in aircraft construction components whilst delivering required mechanical properties
- Hollow profile hybrid – an innovative plastic metal hybrid concept, developed by Lanxess, that offers weight saving potential of up to 35% whilst also increasing torsional stiffness and strength
- Silicon carbide fibre reinforced silicon carbide ceramic matrix composites – this is a novel lightweight, reusable and non-metallic materials that has been developed by NASA for high performance machinery, such as aircraft engines

- TitanWeave – an innovative technology, developed by QinetiQ, that introduces titanium based, shape memory alloy wired into a fibre reinforced polymer to provide cost effective, lightweight and penetration resistant composites

4.2.2.2 New Design Approaches and Concepts

New design approaches and concepts covers a broad spectrum of activities, ranging from the redesign of existing components to reduce weight or improve aerodynamics, through to the emergence of novel aircraft design concepts for aircraft of all sizes.

The design of existing aircraft components is a well established approach to improving fuel efficiency with all major OEMs and the their Tier 1 and Tier 2 suppliers active in this area. There are a plethora of design approaches that can, currently, be taken including, for example, reducing thickness, integration of components to reduce the number of parts, proprietary design concepts, such as Airbus's 'Sharklet' wing tips and Boeing's 'Advanced Technology' winglets.

To support these design activities, companies, such as Siemens, are introducing new modelling and design software and other digital technologies that enable more agile product development and design processes.

A number of aircraft OEMs are also working on more radical aircraft design concepts, especially as a way to support more widespread uptake of hybrid-electric or fully electric propulsion technologies. Current aircraft designs have evolved to exploit the characteristics of fossil aviation fuels and, therefore, are often not suitable or appropriate for these emerging technologies. Airbus has an R&D programme focused on biomimicry, defined as "biologically inspired engineering", to make aircraft lighter or more fuel efficient. This involves the study of, for example, the anatomy of bird and their flight mechanics and applying these to the design of new aircraft components or aircraft themselves.

One of the most radical design innovations to have emerged in recent years is the electric vertical take-off and landing (eVTOL) aircraft, that is being developed for urban air mobility (i.e. very short, commuter flights). eVTOLs build on the vertical take-off and landing principles that underpin helicopter flight but are being designed and developed especially to exploit electrical propulsion technologies, e.g. batteries and/or fuel cells that are discussed in the next section of this report. To that end, these aircraft designs incorporate ultra-light weight materials, cutting edge aerodynamic designs, and propeller based propulsion systems. Most of the major aircraft OEMs that are investing in eVTOL technology development are doing this either through in-house projects or in partnership with other companies. This includes, for example:

- Airbus's urban air mobility programme
- Embraer's newly created urban air mobility business, known as Eve, in partnership with Zanite acquisition group
- Boeing's $450 million investment in Wisk Aero to develop a certified autonomous, all electric, passenger carrying aircraft
- Leonardo's collaboration with Vertical Aerospace to develop a 4 person, air mobility aircraft

As well as these OEMs, there is an increasing number of smaller companies and start-ups entering this market. These include Lilium GmbH, Joby Aviation, Volocopter GmbH, Aurora Flight Sciences, Urban Aeronautics Ltd., and Beta Technologies. Furthermore, there are two start-up companies in Scotland active in this area, namely Mako Aerospace (developing electric aircraft technology at its base in

Dunfermline) and Flowcopter (developing an industrial, heavy lifting drone powered by fossil fuels from premises in Loanhead).

The European Union Aviation Safety Agency (EASA) has stated that urban air mobility is expected to become a reality in Europe within 3-5 years and there is already a number of pilot projects underway. The first commercial operations are expected to be the delivery of goods by drones and pilot operated passenger transport services. In the longer term, remote piloting or autonomous services could follow. Software will play a central role in the growth of urban air mobility and some of the market leaders are building this into their business models. The design, build, operation, maintenance and support of these new aircraft assets will be highly complex and data driven, requiring software to aggregate, analyse and action the plethora of data that will be generated.

4.2.3 New Propulsion Technologies

There are a number of new propulsion technologies under development, particularly targeted at achieving zero emission aviation. These include, for example, hybrid-electric, fully electric and hydrogen powered aircraft. Each of these is discussed in more detail below.

4.2.3.1 Hybrid-Electric Aircraft

Similar to hybrid-electric cars, hybrid-electric aircraft technology combines two power sources, typically, aviation fuel and an electric battery or fuel cell. This technology is considered to be a key step towards zero-emission, fully electric aircraft as it addresses one of the key issues with battery technologies, in particular, where the energy density of currently available lithium ion batteries is insufficient to power electric aircraft. The weight of batteries is also a limiting factor.

Aircraft OEMs, such as Airbus and Boeing, are collaborating with major engine manufacturers, such as Rolls-Royce, GE and Safran to develop and test hybrid-electric propulsion systems. At this stage these are, typically, smaller aircraft of the type that would be suitable for short range, regional, commercial travel.

In addition, Safran Helicopter Engines is working on three complementary areas to reduce its CO_2 emissions, one of which is hybridisation where electrical energy can be used transiently, for different phases of helicopter flight and to meet different needs depending on the aircraft model, range and mission. The company's goal is to reduce helicopter fuel consumption by 20% by the end of the 2030s. Leonardo Helicopters has also confirmed plans to develop a hybrid-electric powered, light helicopter that could be commercially available in the second half of the 2020s.

4.2.3.2 Fully Electric Aircraft

Full electrification of aircraft can be achieved either through the use of batteries or fuel cells that provide electricity to an electric motor. In both cases, this technology is still at a relatively early stage of development. Nonetheless, the world's leading aircraft OEMs are investing significantly in the development of all electric aircraft with both Airbus and Boeing running a number of innovation projects focused on the development of electric aircraft. Smaller aircraft OEMs as well as helicopter OEMs are also undertaking development in this area.

Considering, in the first instance, battery powered aircraft: one of the main challenges is the weight of the batteries required for this application. Jet fuel has an energy density that is six to eight times that of the most advanced lithium ion batteries currently available so to achieve equivalent flight distances in a like for like aircraft the number and, therefore, weight of batteries required would be impractical. Nonetheless, there is significant investment in innovation in this area and, again, all of the major aviation OEMs have at least some involvement in this area. Research and development to improve the energy density of lithium ion batteries whilst reducing their weight and improving safety is a major focus for battery manufacturers across the world and an area of strategic importance for the European Commission, for example. In addition, there are next generation lithium ion battery technologies, such as solid state, as well as post lithium battery technologies, such as lithium sulphur also being investigated. This latter battery chemistry is considered to be particularly suitable for aviation applications due to it light weight and high theoretical energy density, although there are still a number of performance issues to be resolved before it can be fully commercialised.

The design of aircraft to facilitate electrification is also an area of considerable activity and this has already been discussed in more detail in section 4.2.2 above. As a result of these developments, there has now been a number of early flight trials and demonstration of fully electric aircraft.

Pipistrel Aircraft is the market leader in electric aircraft and has already commercialised an EASA Type-Certified 2 seater electric aircraft as well as unmanned aerial vehicles and eVTOL aircraft (discussed in more detail in section 4.2.2 above). The company has also developed a liquid cooled battery pack constructed of cylindrical lithium ion (Li-ion) cells based on nickel-manganese-cobalt (NMC) chemistry. Eviation also conducted engine testing of its all-electric passenger aircraft in early 2022, with flight trials underway. This company hopes that fully electric planes that can carry between 20-40 passengers will be commercialised within the next seven to ten years. It is likely, certainly in the short to medium term, that battery powered, fully electric aircraft will be targeted at the sub-regional, helicopter and, possibly, regional aircraft sectors of the aviation industry. There would need to significant technology advances in terms of battery chemistry, engine design and aircraft design to achieve battery powered, regional or short-haul international flights.

The other main technology being developed, with respect to fully electric aircraft, is fuel cells and the industry view is that these could be utilised to power larger, regional aircraft. As with battery powered aircraft, leading aircraft OEMs, both aeroplane and helicopter, are investigating the potential of all electric aircraft powered by fuel cells. For example, in May 2022, Airbus opened its Zero Emission Development Centre (ZEDC) for hydrogen technologies (fuel cells and hydrogen combustion) at Filton near Bristol. One of its early priorities will be the development of a low cost cryogenic tank that the company believes will be necessary if zero emission aircraft are to enter service by its target date of 2035.

There are also a several start-up companies active in this sector of the market including, for example ZeroAvia, which is working to build a new, fuel cell based, aircraft powertrain that uses green hydrogen. The technology will be scalable and able to power 20 seat regional aircraft, with this powertrain expected to be available in 2024, to over 100 seat long-distance flights.

An interesting point to note, particularly with respect to hydrogen fuel cells, is the ability of this technology to be retrofitted into existing aircraft. This is the aim of a recently launched public private partnership in the Netherlands known as the Hydrogen Aircraft Powertrain and Storage System (HAPSS). The partners involved in HAPSS have scheduled the first commercial flight of a fuel cell powered 40-80 seat capacity plane for 2028.

4.2.3.3 Hydrogen Combustion

The International Air Transport Association (IATA) suggests that hydrogen combustion would be suitable for larger, long range aircraft and aircraft carrying higher payloads. This view is reflected by industry and hydrogen combustion engines have been highlighted as being the only viable option, currently, for intercontinental flights. In addition to the development of hydrogen fuel cell powered aircraft, major OEMs are also developing and testing hydrogen combustion technology. This includes, for example, Airbus's ZEROe demonstrator, that aims to test this technology on an A380 aircraft platform with the view to achieving a mature technology readiness level (TRL) system by 2025, although it is unlikely to be certified for commercial operation for a number of years thereafter.

Aircraft engine manufacturers are also working to develop engine technologies for hydrogen powered aircraft. Rolls Royce, for example, has work underway to adapt its gas turbines to burn hydrogen and is also working with EasyJet to develop hydrogen combustion engines capable of powering a range of aircraft. A ground test was conducted on an early demonstrator engine using green hydrogen with a second set of tests being planned and a longer term ambition to undertake flight tests.

Three Rolls Royce led projects have been awarded funding totalling £82.8m through the Aerospace Technology Institute programme. This includes a project to develop technologies and sub-system architecture for the combustor element of a liquid hydrogen gas turbine, a project to develop key technologies and integrated powerplant architecture for a liquid hydrogen gas turbine and a project to develop technologies for the delivery of a liquid hydrogen fuel system for a hydrogen gas turbine.

4.2.4 Efficient Air Traffic Management

There are significant developments already underway to modernise the management of air traffic and airspace to establish more efficient flight paths. This, in turn, reduces the amount of fuel used for each flight and, therefore, reduces the associated emissions.

In Scotland and the UK, NATS is the leading provider of air traffic control services and has a strong track record in R&D covering areas such as the development of new technology platforms as part of its core systems, to providing next generation air traffic management solutions to customers. It is undertaking or is involved in a number of projects and initiatives covering a wide range of technologies including, for example, automation decision making tools; data transmission, management and mining; artificial intelligence and machine learning; and advanced human-machine interface development.

NATS is also a key participant in the Single European Sky (SES) initiative, which was "*launched in 1999 to improve the performance of air traffic management and air navigation services through better integration of European Airspace*". The SESAR (Single European Sky ATM Research) joint undertaking manages the development and deployment of the technologies required for the new European air traffic management system that is required to fulfil the objectives of SES.

4.2.5 Supporting Infrastructure

Underpinning all of the above innovations and technology developments will be the requirement to develop the supporting infrastructure in Scotland, as well as around the rest of the world.

With respect to the delivery of SAF, as this will be a direct drop-in replacement for conventional aviation fuels (either as a blend or as 100% SAF) there will be little or no technical development required for the refuelling infrastructure.

As new aircraft powered by alternative fuels, such as hydrogen, or incorporating alternative propulsion systems such as batteries and fuel cells, are commercialised and start to operate in and out of Scottish airports, the infrastructure to charge electric and hybrid electric aircraft and to supply hydrogen will need to be developed and deployed.

Importantly, the safety issues associated with the storage and handling of alternative fuels, such as hydrogen, must also be considered as safety requirements and standards will be quite different from those currently in place. Stakeholders consulted during this study indicated that, currently, the industry focus is on the production, storage and transportation of high pressure gaseous hydrogen. There is, however, some debate around liquid hydrogen, particularly whether this is a realistic option for commercial aviation and aerospace applications. Hydrogen is liquefied by cooling it to below -253°C, after which it can be stored in large insulated tanks. Liquid hydrogen is, typically, used as a primary rocket fuel in the space sector and, due to the extreme temperatures and pressures, storage and transportation requires specialised vessels and pipework able to withstand these. The codes, standards and regulations with which they would need to comply, together with the highly hazardous nature of liquid hydrogen, could limit or, indeed, negate its commercial application.

There is also an increasing shift towards the use of low carbon and zero emissions airport ground vehicles, to support decarbonisation of the industry. Currently, this includes hybrid and fully electric vehicles across the range of categories utilised, which includes cars, small vans, buses, and small heavy goods vehicles (HGVs). These hybrid and fully electric vehicles, together with the required infrastructure, are now mainstream options for airports with many already having deployed them to support their operations. This includes, for example, Heathrow Airport that also provides advice and guidance to other airport operators through its Clean Vehicles Partnership.

The use of hydrogen powered airport ground vehicles is less well developed and has not progressed much beyond pilot projects. This is similar to the more general status of hydrogen powered vehicles which are being trialled and demonstrated but have not entered into commercial production or deployment. Teesside Airport, for example, is set to pilot the UK's first hydrogen transport trial and will deploy 100% hydrogen powered engines in its commercial and support vehicles. There have also been a number of other airports around the world that have invested in a small number of hydrogen powered demonstration vehicles including, for example, Memphis International Airport and Oslo Airport.

Whilst these low carbon and zero emission airport ground vehicles will make a contribution to the overall decarbonisation of the aviation and aerospace industry, this contribution will be very small compared to the significant impact that will be made by reducing the carbon emissions of the aircraft themselves.

Another aspect of the supporting infrastructure, that is of particular importance to Scotland's aviation and aerospace industry sector is the provision of maintenance, repair and overhaul (MRO) services. Many of Scotland's companies in this sector deliver MRO components and services, currently targeted at conventional aircraft. As aircraft innovations, such as new materials, alternative fuels and alternative propulsion systems, enter into commercial operations, MRO components and service providers will have to evolve and adapt to meet changing requirements.

The above represents only a cross section of the recent activity in the development and deployment of technologies to support decarbonised and zero emission aviation and this is a very active area given the pressures from policy developments and stakeholder demands for action on carbon emission reduction.

4.3 Potential Adoption Levels of Low Carbon and Zero Emission Technologies

Having identified the nature and scale of the current fleet in Scotland in Section 3 and the drivers and barriers of the potential low carbon technologies in Section 4, it is necessary to estimate the levels of decarbonisation and zero emission technology adoption that the different aviation segments are likely to achieve over the short and medium term. As defined earlier, and with respect to this study, short term is defined as 2027 and medium term as 2032.

This step is required as it will have a direct influence on the scale and nature of future skills requirements to support the transition to zero emission aviation.

Based on a combination of literature review, consultation with industry and stakeholders (including input from the study Steering Group involving representatives from the public sector, academia and industry) and interpretation of the analysis in the preceding sections, the following indicative range of scenarios on adoption rates was developed. It should be noted that, although the timeframe for this study was up to 2032, the scenarios below are extended out to 2040+. There are two key reasons for this. Firstly, whilst it is generally accepted that new technologies will be adopted by the aviation industry, and a number of these are under development and being demonstrated, there is still some uncertainty around when they will actually begin to be used in commercial aircraft operations, especially the zero emission technologies that are at a lower technology readiness level (TRL) currently. Estimates vary between 2025 and 2035 for commercial, hydrogen powered flight, for example. Secondly, even when low carbon and zero emission aircraft enter into commercial operation, stakeholders consulted during this study were uncertain, at this stage, when they will be operating in and out of Scotland.

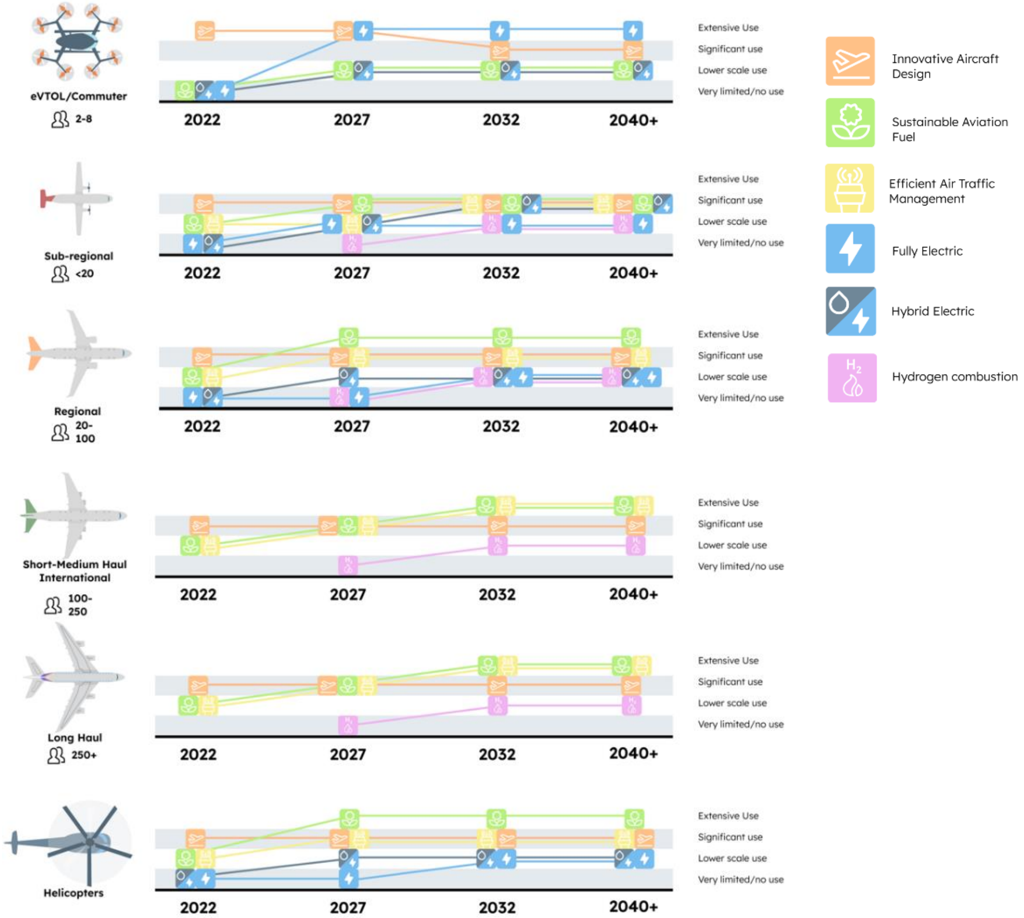

Figure 9: Possible Relative Use of Technologies by Different Aviation and Aerospace Segments Now to 2040+

This analysis shows that over the timeframe, the development and application of innovative design concepts, including the use of new and improved lightweight materials, and the use of SAF over conventional aviation fuel are likely to be used most extensively as a way of reducing the carbon emissions of the aviation industry. This is across all aircraft types.

The implementation of more effective and efficient air traffic management will also continue to gather pace across the timeframe although it is recognised (and demonstrated in Figure 6) that this will only make a small contribution to decarbonisation of the industry. Future developments may, therefore, be more focused on new and improved systems to support the emerging urban air mobility sector, for example, rather than for regional or international air traffic where the returns will be diminishing.

As noted previously, there is some uncertainty over when the newer, zero emission technologies, such as batteries, fuel cells and hydrogen combustion, are likely to be used in commercial operations. Stakeholders consulted during this study agreed that due to the limitations of current Li-ion battery chemistries, e.g. relatively low energy density, weight and restricted operating temperatures, they are unlikely to be used in anything but aircraft undertaking very short regional flights. This may change in the future as new and improved battery chemistries, such as lithium sulphur, are developed and commercialised. The same applies to electrification of aircraft utilising fuel cells with stakeholders indicating that performance needs to be improved and costs reduced before this technology becomes more mainstream.

It is also noted that the emerging urban air mobility sector is much more likely to exploit battery technologies, with electrification being considered from the outset.

Of the zero emission technologies under development, hydrogen combustion is considered by a number of stakeholders to be most likely to be utilised commercially by the aviation and aerospace industry in the longer term, particularly for short haul and long haul flights. As already discussed, the timelines for this are still uncertain and there are also questions over whether the focus will be on the use of gaseous hydrogen or liquid hydrogen. It is likely that, over the timeframe of this study, any commercial operations utilising hydrogen combustion are likely to be based at major airport hubs, such as Heathrow in the UK.

As well as new aircraft, new technologies will be developed that can be retrofitted into existing aircraft, for example the hydrogen fuel cell technology being developed by ZeroAvia and described earlier in this report. Whilst it is likely, initially, that the retrofitting of these technologies will be done by the developer or by their specialist subcontractors, in the longer term, these activities could be undertaken by more general maintenance, repair and overhaul (MRO) companies. Once again, however, there remains some uncertainty around the timescales over which this is likely to happen.

Aside from the deployment of low carbon and zero emission technologies in the aircraft themselves, there is also a drive to reduce the carbon impacts of airport operations with a number of airports across the UK starting to deploy electric vehicles (mainly battery electric but some are also considering hydrogen fuel cell). As highlighted in Figure 6, however, this will make a very small contribution to decarbonisation of the sector, compared to reducing the CO_2 emissions of aircraft.

5 Skills Needs and Gaps in Decarbonising Aviation and Aerospace

5.1 The Scale of Aviation and Aerospace in Scotland

Figure 10 below provides an overview of the scope of aviation and aerospace operations and the supply chain relating to decarbonisation.

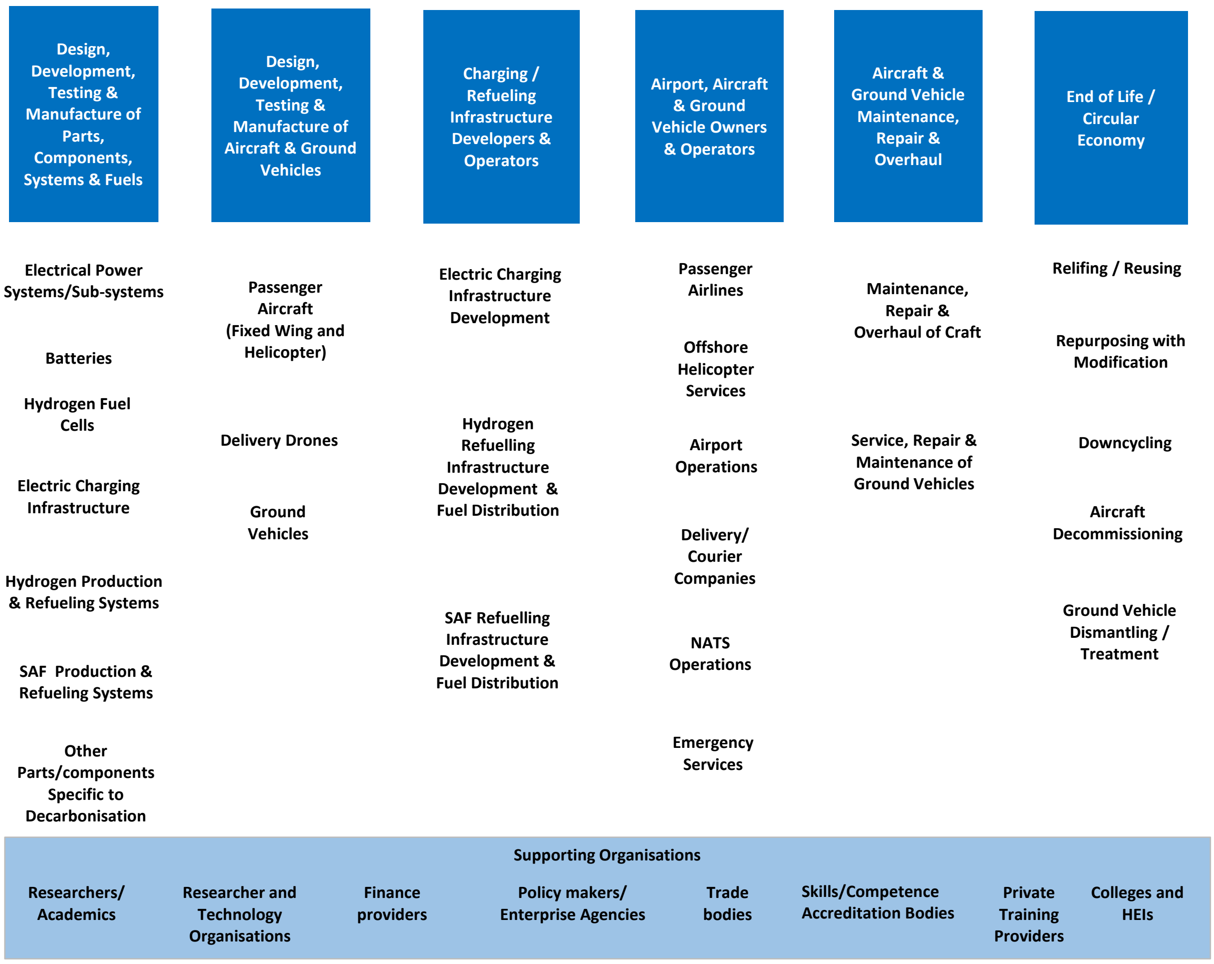

Figure 10: Scope of the Aviation and Aerospace Decarbonisation Supply Chain and Operational Landscape

The top line represents the sub-sectors where skills would be required and includes:

- Design, development, testing and manufacture of parts, components, systems and fuels
- Design, development, testing and manufacture of aircraft and ground vehicles
- Charging / refuelling infrastructure developers and operators
- Aircraft and ground vehicle owners and operators
- Aircraft and ground vehicle maintenance, repair and overhaul
- End of life and circular economy

The middle part of the diagram shows the range of different applications within these sub-sectors. In addition, there are various supporting organisations including researchers/academics, research and technology organisations, finance providers, policy makers/enterprise agencies, trade bodies, skills/competence accreditation bodies, private training providers and colleges/higher education institutes.

It is necessary to understand the scale of Scottish based activity within each segment to assess the approximate number of employees potentially requiring skills development to support the decarbonisation of maritime operations and maximise associated economic opportunities.

Appendix B contains a detailed description of the data sources used and how estimates were made for employment in the different segments of the aviation and aerospace landscape.

Table 4 below, provides indicative estimates of the scale of employment within different segments of the aviation and aerospace landscape being investigated.

Aviation and Aerospace Segment	Indicative total employment by segment
Design, development, testing of parts, components, systems and fuels	2,250
Design, development, testing and manufacture of aircraft and ground vehicles	<100
Charging / refuelling infrastructure developers / operators	Limited data
Aircraft / ground vehicle owners / operators	8,100
Aircraft / ground vehicle maintenance, repair and overhaul	2,000
End of life /Circular economy	Limited data

Table 4: Indicative Number of Employees in Different Segments of the Aviation and Aerospace Landscape in Scotland

It should be noted that, for two of the segments, 'Limited data' has been entered. This is due to the lack of alignment of the segment activities with Standard Industry Classification, Standard Occupational Classification or other data. For the remaining segments an estimate of employment is provided.

The International Civil Aviation Organisation has modelled a 4.7% Compound Annual Growth Rate in Revenue Passenger Kilometre demand over the next 10 years. If Scottish aviation activity follows a similar growth trend, then it is reasonable to assume that the identified number of employees in the aviation and aerospace sector will increase in response to this demand. However, it is also reasonable to assume that not all of the employees identified in Table 4 will require additional skills development by 2032 to support the decarbonisation of aviation. Some employees will have no, or very limited, need to upskill as a result of decarbonisation (for example, baggage handlers) whilst the limited demand for new skills in the next ten year period, particularly at the operational stages, is likely to mean only a proportion of employees will need new skills. The scale and nature of this demand for skills related to decarbonisation are discussed in the following section.

5.2 Scale and Nature of Key Skills Required

5.2.1 Scale of Employees Likely to Require New/Enhanced Skills to Support Decarbonisation

Typically, the indicative scale of the number of employees likely to require new skills would be derived by combining the previously identified data on employee numbers within each aviation sub-segment, from Table 4, with the potential decarbonisation options described earlier in

Figure 9. For the aviation and aerospace sector, however, this is a very challenging analysis to carry out. For two of the categories defined in Table 4 it has not been possible to define the indicative total employment by segment as discussed. It should be further noted that many of the employees included in the 12,450 total for the other categories will not require skills development in response to the move to decarbonisation of aviation and aerospace but, at this stage, stakeholders consulted during this study were unable to give an indications of numbers requiring skills development. It was only possible for them to provide more qualitative information on the types of skills that might be required.

The situation is further complicated by the lack of clarity on when some of the low carbon and zero emission technologies under development will be introduced into commercial aircraft and, subsequently, when these aircraft will begin operating in and out of Scotland.

As a result, it has not been possible to provide quantitative estimates of the number of people requiring skills training in each aviation sub-segment. It is clear, however, that companies in the aviation landscape will likely develop skills aligned with the technology options as they develop. In the short to medium term this will include, for example, skills in computational modelling, design, materials engineering and manufacturing to facilitate the development and implementation of innovative design concepts as a means of improving fuel efficiency and reducing CO_2 emissions, an activity that is already underway.

Similarly, skills to provide air traffic control services will be necessary and as new tools to facilitate more effective and efficiency flight path management are developed and implemented, data science, data management, software and other digital skills will be necessary.

Over the period from 2030 and beyond, there will likely be a growing need for skills relating to hydrogen service, ranging from enhanced engineering skills to manufacture parts and components to the relevant standards and quality to skills in working with high pressure gas systems, particularly hydrogen (either in combination with fuel cell technology or direct combustion). There will also be some level of skills development covering both high voltage systems and high-pressure flammable gas systems to enable safe working on electrified aircraft and aircraft burning new, zero emission fuels.

These skills are discussed in more detail in the following section.

5.2.2 Nature of New/Enhanced Decarbonisation and Zero Emission Skills Required

The nature of the skills required to support decarbonised / zero emission aviation varies across the different segments. These requirements are described below for each segment of the aviation landscape.

5.2.2.1 Design, Development, Testing and Manufacture of Parts, Components, Systems and Fuels

The skills required to support the design, development and manufacture of parts, components and systems are wide ranging and will include, for example, mathematical and computational modelling, product design engineering, mechanical engineering, aeronautical engineering, materials engineering (especially relating to lightweight metals, composites and other lightweight materials), mechatronics, electrical and electronics engineering, CNC machining and welding. Depending on the degree to which the supply chain has design autonomy, there may also be a need to improve skills in navigating the regulatory and standards requirements for new aviation parts and components.

Stakeholder feedback is that many of the component parts required for low carbon / zero emission aircraft will be produced by suppliers outside of Scotland. Supply chains will develop around the major aerospace OEMs designing and building innovative aircraft as well as the major tier 1 suppliers developing, for example, new engine technologies, the majority of which are located outside of the UK. There is a question, therefore, as to the level of demand for new skills relating to the design, development and manufacture of parts, components and systems. A key exception, in Scotland, is Spirit AeroSystems, a major Tier 1 supplier to Airbus. To support the company's Wing of Tomorrow initiative, suppliers like Spirit AeroSystems, must be able to deliver high performing wing technologies, such as advanced and innovative designs, new manufacturing techniques and extensive use of composites and new and improved joining technologies. This will require the wide range of skills, highlighted above, to deliver.

There are a number of smaller Scottish companies manufacturing and supplying parts and components into the aviation and aerospace sector (e.g. precision engineering companies supplying larger MROs) but, typically, these parts will have no, or very limited, influence on aircraft emissions. There may be a skills development need for some sub-contract precision engineering suppliers where there is a requirement to work with novel light weight alloys and composites.

In the short to medium term, the use of SAFs is likely to make the biggest contribution to decarbonisation of the aviation sector in Scotland. As this fuel will be a direct drop-in replacement for conventional aviation fuels, stakeholder feedback indicated that this will have negligible impact on operations and, therefore, no reskilling or upskilling will be required.

There is, perhaps, more scope in future for skills to support the development of new fuels and propulsion systems such hybrid electric, fully electric (battery and fuel cell) and hydrogen combustion. Considering, in the first instance, battery hybrid and fully electric aircraft. Whilst such aircraft are at the demonstration stage, it is unlikely that they will reach full commercial maturity before 2030 and, even then, will likely only be relevant for some specific applications, such as very short regional flights (which could be relevant for Scottish air services to remote and island communities), eVTOLs and some helicopter applications. Stakeholders highlighted the potential need for battery scientists and engineers to support the development of new and improved battery chemistries for aviation applications, potentially building on the skills that already exist in AMTE Power and those that will be required to staff the recently announced megafactory that will be built in Dundee.

Similarly, there may be scope in the future for skills to support the development of hydrogen production systems, the fuel itself and fuel cell technologies but current demand is limited and there are only a small number of regionally based hydrogen production facilities (e.g., at EMEC in Orkney). Some stakeholders indicated that, for the aviation industry, the focus will be on hydrogen combustion rather than electrification via the use of fuel cells. In either case, there will be a requirements for mid- to large- sized electrolysers to produce hydrogen for large, commercial applications. In developing and deploying these systems, the skills required will centre on the safe handling of hazardous, flammable gases, high pressure gas systems as well as specialised engineering and welding skills relevant to hydrogen service. One stakeholder, involved in projects that included the development and operation of small scale hydrogen production facilities, that was consulted during this study, highlighted the difficulties in finding the general engineering skills required to manufacture parts that meet hydrogen service specifications and standards.

"The parts would be fine for less demanding applications but just weren't good enough for hydrogen service"

Stakeholders provided differing opinions in the likelihood of use of cryogenically cooled liquid hydrogen in aviation. Some viewed this as being required to increase energy density of hydrogen to increase the feasibility of hydrogen combustion and hydrogen fuel cell technology options. Others viewed the use of cryogenic cooling for hydrogen as being inherently unsafe for aviation and unlikely to meet regulatory safety requirements. It is likely that this will mean that any skills requirement by 2032 will be limited to pilot system design, testing and navigating the regulatory process. It is unlikely operational skills related to storage and handling of cryogenics will be required in the next ten years.

At this stage of the supply chain, innovators, whether they are SMEs or large companies, may be seeking to secure funding to support their research, development and innovation (RD&I) activities. This can include both public sector (e.g. Innovate UK grants) and private sector (e.g. venture capital and/or private equity) and there is potentially a requirement for upskilling of the technical community, which could also include researchers considering spinning out a company, to further understand the investment / funding community and to prepare successful grant applications or investment ready business plans. There are, however, many companies to which these activities can be outsourced as well as organisations that provide training, mentoring and support to those that want to develop these skills themselves.

5.2.2.2 Design, Development, Testing and Manufacture of Aircraft and Ground Vehicles

As noted previously, there are two start-up companies in Scotland involved in design, development, testing and manufacture of aircraft in Scotland. Early-stage company, Mako Aerospace is developing electric aircraft technology at its base in Dunfermline. Flowcopter is developing an industrial heavy lifting drone from premises in Loanhead, South of Edinburgh, initially using fossil fuels but with the potential to use SAF. These companies are both at pre-commercial stage and the skills needed are likely to relate to design and engineering, testing and understanding of safety certifications and regulations. The EMEC SATE 2 project, based in Orkney, aims to support demonstrations of hydrogen-electric regional aircraft and a drone flight from Scotland to Norway. This requires skills in safety case development, safety certification and other regulatory compliance, in addition to supply of electric charging and hydrogen refuelling infrastructure.

In terms of ground vehicles, these will range from small passenger automotive vehicles that are used by staff to move around the airport to medium and heavy duty vehicles used to transport luggage and freight and to provide emergency services, e.g., fire service. The production of low carbon airport ground vehicles will require very similar skills to traditional fossil fuel, internal combustion engine vehicle production. With the exception of a few specialist drivetrain areas, the skills for vehicle manufacture and systems integration would change very little. The main difference will be additional safety skills required when working with high voltage (battery electric vehicles) and high-pressure gas (fuel cell electric vehicles) components.

Relevant ground vehicle production activities in Scotland are restricted to those carried out by Emergency One, that manufactures electric fire and rescue service vehicles. The activities can best be described as systems integration of off-the-shelf components and the skills required include design engineering (designing a vehicle superstructure that integrates all of these components to produce a vehicle that meets specific use needs) and production line technical skills, again with a focus on working safely with high voltage and high pressure gas components. Systems integration skills were noted as a strong requirement for manufacturers as there is a need to integrate a variety of mechanical, electronic and software systems into a working vehicle. However, this was not unique to low carbon and zero emission ground vehicles with a number of stakeholders noting a current high demand for electrical skills at a craft level, as well as electrical and electronic engineering at a graduate level and that this demand was likely to grow as the number of low carbon and zero emission vehicles increase.

As before, there may also be a requirement, at this stage, for upskilling of the technical community to help them secure funding to support their research, development and innovation (RD&I) activities from either the public or private sector.

5.2.2.3 Charging / Refuelling Infrastructure Developers and Operators

The skills required to develop and operate charging / refuelling include traditional civil engineering and construction skills, which are well developed. Research highlighted the project management skills shortages to develop new electric charging and hydrogen refuelling infrastructure.

For SAF refuelling there are unlikely to be any changes required to current infrastructure or refuelling operations. As has already been noted, SAF will be a direct drop-in replacement for conventional aviation fuels and, therefore, this will not require any upskilling or reskilling.

There will be a requirement for skills to specify electrical power infrastructure and work with Distribution Network Operators (DNOs). This was highlighted in the zero emissions heavy duty vehicles study carried out by Optimat on behalf of Transport Scotland (TS) / Skills Development Scotland (SDS) where stakeholders report skills issues on both the DNO side and the potential operator side. In the latter case, skills issues are more likely to occur relating to airport infrastructure rather than larger scale public charging infrastructure. There was also a potential need for skills in analysing electrical demand and designing options to manage peak load at the design and build stage of electrical recharging infrastructure. In terms of the practical deployment of electrical recharging infrastructure, the need for electrical engineering skills was highlighted although stakeholders suggested that there was a shortage of suitably skilled people rather than a lack of appropriate skills. Some providers of electrical engineering skills may need opportunities to expand into electric vehicle (aircraft and ground vehicles) charging work from other industrial high-voltage electrical work.

For hydrogen refuelling operations there is a need for skills in working with high pressure gases and stakeholders report a lack of training options for this in Scotland. For hydrogen refuelling, deployment of the infrastructure would likely need the same specific skills as deployment of electrolysers discussed previously (specialist welding and specialist pipework). In the previous Zero Emission Heavy Duty Vehicles study carried out by Optimat on behalf of TS / SDS, stakeholder feedback highlighted that current Modern Apprenticeship Frameworks do not adequately cover all the skills necessary to install and maintain hydrogen refuelling infrastructure. Based on the feedback obtained from stakeholders during this aviation study, this situation does not appear to have changed. Companies involved in this activity which take on Apprentices need to select from existing frameworks including: domestic plumbing and heating; heating, ventilation and refrigeration; electrical installation or; upstream oil and gas production. Whilst elements of the training provided via these frameworks are relevant, other elements are not focused on the skills needed for hydrogen refuelling infrastructure (e.g., plumbing focuses on skills around copper pipework and methane gas whereas hydrogen infrastructure development companies need people with skills in steel pipework and hydrogen gas). There will also be a need to expand these frameworks to include hydrogen storage, which will require very specific skills relating to, for example, storage vessel manufacture, testing, maintenance and safety. It would, therefore, be beneficial to give young people a clear and focused pathway into a career in hydrogen, although, this would involve changes to National Occupational Standards. It is noted, however, that the timeframe for the rolling out of hydrogen refuelling infrastructure, especially for aircraft, is still uncertain. It is more likely that this will be required, at a smaller scale, for the refuelling of hydrogen powered airport vehicles.

The uncertainty around the use of liquid hydrogen in commercial aviation has already been highlighted and in terms of the development and operation of refuelling infrastructure, the same uncertainty is relevant. However the future of hydrogen as a fuel develops, it is unlikely that the skills required to support liquid hydrogen will be required within the next 10-15 years.

There is also a need for skills relating to hydrogen safety, regulations, planning, etc and especially the skills required to navigate the many regulatory and certification requirements and to facilitate the development of the complex safety cases that will be associated with the design and installation of hydrogen storage and refuelling infrastructure at airports and ongoing service and calibration certification. Non-technical skills, such as communication, have also been highlighted to address safety concerns and the perceived danger associated with hydrogen.

5.2.2.4 Airport, Aircraft and Ground Vehicle Owners and Operators

It has been highlighted a number times already in this report that, in the short to medium term, the use of SAF as a replacement for conventional aviation fuels will be one of the major ways in which the aviation and aerospace industry will decarbonise over the period specified in this study. As a result, there will be no additional skills required to facilitate this, either in terms of airport or aircraft operations.

Stakeholders consulted during this study suggested that, in terms of zero emission aviation, which will require the development, demonstration and commercialisation of the new fuels and propulsion systems discussed earlier in this report, it is still too early for aircraft owner operators to define the skills gaps as it is still unclear which technologies will emerge first and for which applications (e.g. fuel cells versus hydrogen combustion). It was also highlighted that there may be a requirement for some pilots to reskill but as the aircraft incorporating these new technologies are not yet available then it is unknown what additional, specific skills will be required.

It was highlighted, however, that in certain aviation sub-sectors, such as commercial helicopter operations, companies are already seeing an increasing interest in sustainability amongst their clients. Stakeholders suggested that sustainability will become a “soft” skill, initially in forward-thinking companies but, over time, will become more mainstream. This will require colleges and universities to include sustainability in, for example, HNC, HND and under-graduate technical courses as well as Modern Apprenticeship programmes. It will also require training providers to develop specific courses to help the existing workforce to upskill.

There is a similar situation with respect to airport operations and, at this stage, stakeholders were only able to suggest, at a relatively high level, the skills that would be required to facilitate low carbon and zero emission aviation through the deployment of new fuels and propulsion technologies. These include, for example, health and safety (particularly for hydrogen), skills for the maintenance and management of more complex electrical infrastructure, battery handling (e.g. swapping out batteries in small aircraft), etc. As before, however, until there is clarity on which technologies will achieve commercial operation first and, subsequently, when these new aircraft begin to fly in and out of Scottish Airports, it is difficult to be more specific on what skills will be required and when.

Airport emergency services and first response personnel will also have a skills requirement to enable them to work safely in situations where they need to deal with incidents involving low carbon and zero emission aircraft, specifically what they can and cannot do. The situation will, potentially, be more complex than for an incident involving aircraft running on conventional aviation fuels and SAF due to the potential for high voltages and/or high pressure flammable gases. Having the skills to identify risks and, for example, safely isolate electric batteries are skills needs that that will have to be developed. Importantly, these skills will not just be required at airports into and out of which low carbon and zero emission aircraft operate. When aircraft are flying, there always has to be two airports within reach (depending on route, levels of fuel on board, etc) at which an aircraft can make an emergency landing if necessary. It will, therefore, be necessary to consider the skills that may be required at other airports and airfields and how this is dealt with. In addition to the need to deal safely with hydrogen powered aircraft, airport emergency services will also have to be prepared to deal with incidents involving battery and hydrogen powered ground vehicles (and associated recharging/refuelling infrastructure). For example, hydrogen powered ground support tugs for towing aircraft are being trialled at Teesside International Airport. The need for skills to deal with incidents involving battery/hydrogen powered ground vehicles is likely to arise sooner than equivalently powered aircraft.

The skills required by those responsible for the operation of low carbon and zero emission airport ground vehicles will include the ability to identify and assess the new vehicles most appropriate for the particular application. Peer learning appears to be one of the main ways in which skills are developed with, for example, Heathrow Airport's Clean Vehicles Partnership providing wide ranging information and advice on the vehicles available on the market and how to build a business case.

With respect to air traffic control, companies highlighted that, due to an ageing workforce, there is likely to be a general shortage of air traffic controllers in the industry so there is a need, therefore, to attract new people. Typically, the skills required to become an air traffic controller are delivered by air traffic control companies themselves although, it was highlighted that these are, typically, delivered in person, over a number of weeks at company headquarters, and can be quite costly which can makes it an unattractive option. There is, therefore, an argument for the provision of more online and/or decentralised skills provision.

To support the already significant activity in proactive flight management to optimise flight paths, reduce fuel consumption and reduce the production of contrails, for example, there will be a need for skills across a range of digital and data technologies including, for example, mathematical modelling, data science, coding and programming, machine learning, artificial intelligence and cyber security. These skills are already well-established in Scottish supply chains and could be readily applied to meet the needs of the aviation industry. The main issue, however, is more related to skills shortages and the ability of companies to attract and retain staff. Increasingly, skills in areas such as environmental science and meteorology will also be required.

For operators seeking to exploit drone technologies to offer new services, such as delivery of medicines, for example, there is likely to be new skills required to develop safety cases and navigate regulatory requirements associated with commercial use of airspace. These skills may also be required by local authorities which could be involved in assessing applications for permission to operate unmanned delivery operations and in the longer term urban vertiports for advanced air mobility. This need to increase skills relating to safety certification, regulation and air traffic management were highlighted as the top three skills gap in future flight by a Knowledge Transfer Network (KTN) survey of its Future Flight community.

The Civil Aviation Authority offers a range of training in these areas, including a one day course: 'Introduction to Unmanned Aircraft Systems Regulation' to an Aviation Safety Management, Risk and Regulation MSc offered in partnership with Cranfield University.

5.2.2.5 Aircraft and Ground Vehicle Maintenance, Repair and Overhaul (MRO)

Due to the highly regulated nature of the aviation industry, aircraft maintenance engineers must obtain an approved European Aviation Safety Agency (EASA) and / or a UK Civil Aviation Authority (UKCAA) Part 66 Certificate of Recognition which is a licence to operate in the industry. This specifies the skills required by aircraft maintenance technicians and engineers. As a result, any future skills required by people working in the MRO industry will be defined by the EASA and or the UKCAA and will, to an extent, be driven by industry demand.

As aircraft incorporating the range of technologies described in section 4.2, begin to require MRO services, technicians will require the skills to work with different types of materials (e.g. composites, advanced polymers, and advanced lightweight metallic materials) as well as the skills to work safely on aircraft that run on alternative fuels and propulsion systems, such as high-pressure, ultra-low temperature gases such as hydrogen (in the context of both fuels cells and hydrogen combustion), high voltage battery systems and associated electrical systems. Compared to current aircraft, there is potential for new low carbon and zero emission aircraft to exhibit greater levels of non-standardisation in the technical functioning of the aircraft and the location of parts and components between different vehicle manufacturers. Developing skills to work on low carbon and zero emission aircraft is, therefore, likely to involve training on specific manufacturers' aircraft as well as more generic qualifications / awards.

As new low carbon and zero emission fuel and propulsion technologies become available, these will not just be in new aircraft but will also be developed such that they can be retrofitted into existing aircraft. This is a service that will, to a large extent, be delivered by MROs although, in the first instance, it is likely to be delivered by specialist companies in the sector as it will require skills, knowledge and expertise in the specific propulsion technology (e.g. batteries and fuel cells) as well as electrical and engineering skills relating to high voltage, high power systems, the development of advanced electric motors, etc.

Service, repair and maintenance of decarbonised ground vehicles is likely to be carried out by employees of the specialist companies which provide ground handling services. It is likely that this will involve battery electric vehicles and there may be a requirement for Level 2 and Level 3 IMI qualification in how to safely work with and repair hybrid and electric vehicles. Where large ground vehicles are concerned, the IMI provides a Level 3 award in heavy electric/hybrid vehicle system repair and replacement. In addition, there may be skills training offered by OEMs providing the ground vehicles.

5.2.2.6 End of Life and Circular Economy

The nature of skills required for end of life treatment of low carbon and zero emission aircraft will focus on safe working with high voltage systems and high pressure gas systems. Otherwise, skills will be focused on decommissioning, i.e. understanding how to depollute aircraft, recover parts and components with an aftermarket value and recover any valuable metals. It is likely that the non-standard design of low carbon and zero emission aircraft could make ongoing skills development difficult as new models are placed on the market. No specific training has been identified for the safety risks associated with end of life treatment of low carbon and zero emission aircraft. Since it is likely to be a number of years before these aircraft become commercially available at scale (in terms of numbers) and that they, typically, have a design life running into 10s of years then it could be somewhere in the region of 30 years before these new aircraft reach end of life.

No significant activity in remanufacturing / refurbishing end of life aircraft or their parts / components has been identified in Scotland. In common with battery electric vehicles (BEV) there could be future interest in utilising end of life batteries in stationary storage solutions and this would require diagnostic skills to assess the battery's state of health then technical skills to combine batteries into a storage system (requiring design engineering and electrical engineering and technician skills). There is no evidence of any activity planned in this area.

5.3 Key Skills Gaps

Analysis of the research for this study highlights a number of skills gaps and skills shortages which may impact on the shift to decarbonisation of aviation operations in Scotland and the exploitation of wider economic opportunities. The main focus of this study is on the skills required to support decarbonisation up to 2032. The early decarbonisation activity will involve the use of SAF, changes to air traffic management practices for more efficient flight patterns and changes to aircraft design and construction, mainly around the area of lightweighting.

SAF is a drop-in solution that can be used by existing aircraft and there are no additional skills required in using SAF. There is no current SAF production in Scotland and, whilst it remains a possibility that this might develop, any skills required will reside in the chemical sciences and industrial biotechnology industry sectors and will not, therefore, impact on the aviation and aerospace sector.

Changes to aircraft component design and construction, to reduce weight and improve aerodynamics, is an ongoing activity and parts of the Scottish aviation supply chain are already pursuing this to improve the competitiveness of their products and secure opportunities arising from decarbonisation. There are general skills shortages for design engineers and materials engineers, for example. However, these are not skills gaps, as skills development offerings already exist at higher education and CPD level, such as at the Lightweight Manufacturing Centre.

Skills to support decarbonisation via new propulsion technologies are likely to only be relevant at the design and demonstration stage up to 2032. This is due to the long lead times necessary for new aviation craft to go through safety certification processes. This means that the demand for skills to support the operation of craft with decarbonised propulsion is unlikely to be significant in Scotland within the period up to 2032. This will obviously change as decarbonised craft come into service and fly in and out of Scottish airports.

The Single European Sky initiative is already underway and the skills required for NATS to implement this in Scotland are mainly in place. Much of the skills requirement for this activity relate to data and digital skills. There is a general shortage of such skills across many economic sectors, but NATS can draw upon internal expertise from its IT team based in England.

The study findings related to decarbonisation skills shortages and skills gaps, within each segment of the aviation and aerospace landscape, are described below.

Design, development, testing and manufacture of parts, components, systems and fuels – Our research estimates that this segment contains approximately 2,250 employees in Scotland. A significant number of these will be involved in developing and producing lightweight components for aircraft. General shortages of employees with engineering skills were highlighted with electrical engineers and power electronics being key areas. Future economic opportunities, related to aviation decarbonisation, include supply of components for hydrogen systems. Initially, this will involve hydrogen gas and a shortage of skills in high integrity welding and inspection were identified. In the longer term, skills gaps were identified for the design and development of liquid hydrogen systems including the design and development of power electronics capable of functioning at the ultra low temperatures required.

Design, development, testing and manufacture of aircraft and ground craft – Our research estimates that this segment contains fewer than 100 employees in Scotland. This includes a very small number of start-ups developing prototype aviation craft and testing facilities in Orkney for electric and hydrogen craft. This segment is also likely to be impacted by the general shortage of skilled engineers and wider STEM skills. No skills gaps have been identified for this segment and the activity in Scotland is currently very limited.

Charging / refuelling infrastructure developers and operators – Poor alignment between SIC Code data and activities defined for this segment led to no estimate of the scale being possible to calculate. It is not yet clear whether existing airport fuel system operators, such as Air BP and Menzies Aviation, will be restricted to operating new airport electric charging infrastructure and hydrogen refuelling infrastructure or whether they will diversify into installing such infrastructure as well. Skill shortages in this segment include project managers for installation, electrical engineers, high integrity welders/inspectors. Skills gaps include a lack of an apprenticeship framework focused on hydrogen infrastructure installation and maintenance. In the short to medium term this would be for hydrogen gas. Beyond 2032, this could also include the need for skills in installation and maintenance of liquid hydrogen systems. A further skills gap was identified relating to the development of detailed safety cases for new electric charging and hydrogen refuelling infrastructure and associated planning requirements.

Airport, aircraft and ground vehicle owners / operators – Our research estimates that this segment contains approximately 8,100 employees in Scotland. This includes employees involved in scheduled and non-scheduled passenger air transport, freight air transport, service activities incidental to air transport and cargo handling for air transport. Service activities includes firefighting in airports and air traffic control. Shortages of data/digital skills to support efficient flightpath management and automation of conflict detection in urban air mobility applications was identified. Skills gaps include the development of detailed safety cases and understanding of the regulatory environment around urban air mobility and drone applications. There is also a skills gap related to the ability of airport emergency responders (and wider public emergency services) to deal safely with incidents involving high voltage and hydrogen powered craft. There is also a skills gap in hydrogen refuelling and electric recharging for airside operators. Finally, a skills gap was identified for the service, repair and calibration certification of electric recharging and hydrogen refuelling systems.

Aircraft and ground vehicle maintenance, repair and overhaul – Our research estimates that this segment contains approximately 2,000 employees in Scotland. The skills and competences required by these employees is highly regulated and specified in response to what is required for safe operation of the aircraft fleet in operation. Due to the uncertainty about the timing and type of new propulsion technology introduction into the aircraft fleet no clear feedback was obtained on the skills gaps or shortages likely to be faced in this segment. However, it is reasonable to assume that additional skills in dealing safely with high voltage systems and high pressure gas systems will be a requirement. In the longer term, there could also be skills gaps relating to the overhaul, repair and maintenance of liquid hydrogen systems and hydrogen combustion engines.

End of life/circular economy – Poor alignment between SIC Code data and activities defined for this segment led to no estimate of scale of this segment being possible. There is currently limited decommissioning of end of life aircraft carried out in Scotland so no detail on skills shortages or gaps was identified. It is possible that some second life battery storage system activity could develop, but this would be well beyond 2032 given the long lifetime of aircraft service.

5.4 Skills Provision to Support Decarbonised and Zero Emission Aviation

5.4.1 Further and Higher Education

In terms of the specific skills and training provision in the current aviation and aerospace market, targeted at low carbon and zero emission aviation, much of this is delivered by further education colleges and universities to develop general skills required by the sector and, increasingly, the new skills that will be required in the future in areas including aircraft design, lightweight materials, fuel cells and electric systems for example. This is summarised in the table below.

Organisation	Course / Programme Name	Relevant Decarbonisation Skills Provision	Qualification
Ayrshire College	Performing Engineering Operations - Aeronautical	None identified	SVQ (SCQF Level 5)
Ayrshire College	Aircraft Engineering	How design improves aerodynamic efficiency; high speed aerodynamics; composite materials and lightweighting	NC, HNC, HND, (SCQF Levels 5-7)
NMIS Manufacturing Skills Academy	Doctorate Centre in Advanced Manufacturing – various research doctorates available	Lightweight materials and processes; fuel cell development; manufacturing improvements	EngD / PhD
University of Glasgow	Aerospace Engineering and Management	None identified	MSc (taught)
University of Glasgow	Aerospace Engineering	None identified	MSc (taught)
University of Glasgow	Aeronautical Engineering	None identified	BEng / MEng
University of Glasgow	Aerospace Systems	None identified	BEng / MEng
University of Glasgow	Mechanical Engineering with Aeronautics	None identified	BEng / MEng
University of Glasgow	Autonomous Systems and Connectivity – various research doctorates available	Aircraft design; bio-inspired engineering; renewable energy; helicopter flight dynamics; eVTOL propellor optimisation; greener aviation with advanced propulsion systems;	EngD / PhD

Organisation	Course / Programme Name	Relevant Decarbonisation Skills Provision	Qualification
UHI North Highland	Energy Engineering	Renewable energy technologies	BEng
UHI North Highland College	Engineering – wide range of practical, vocational and undergraduate courses	None identified	NC, HNC, HND (Levels 5-7) and BEng
UHI Perth	Engineering and Aviation – designed to produce graduate calibre aircraft maintenance engineers	None identified	HNC, HND, BSc, BEng, MBA (Aviation)
UHI Perth	Green Skills Academy with Fabrication and Welding	Hydrogen awareness; safety and risk assessment	NC, HNC, HND (Levels 5-7)
University of Strathclyde	Integrated Systems for Decarbonising Aviation	Lightweighting; electrical systems	BEng / MEng
University of Strathclyde	Renewable Energy and Decarbonisation Technologies	General energy transition; modules on propulsion and product design	MSc (taught)
University of Strathclyde	Sustainable Engineering: Renewable Energy Systems and the Environment	Sustainable energy systems	MSc (taught)
University of Strathclyde	Machine Learning for Reliable Automated Inspection of Aerospace Composites	Lightweight materials; electrical systems; data science	EngD
University of Strathclyde	Advanced Mechanical Engineering (with Aerospace)	None identified	MSc (taught)
University of Strathclyde	Aerospace Centre of Excellence – Future Air-Space Transportation Technologies Laboratory	None identified	PhDs offered with various supervisors
University of Strathclyde	Aero-Mechanical Engineering	None identified	BEng / MEng
University of the West of Scotland	Aircraft Engineering	None identified	BEng / MEng

Table 5: University and College Based Provision of Training to Support Low Carbon and Zero Emission Aviation

It is also noted that the Energy Skills Partnership, together with a number of other stakeholders, including SGN, Orkney College UHI, Dundee and Angus College, Aberdeen City Council, H2 Aberdeen, H2 Accelerator, HyTrEc2 and SMART-HY-AWARE, have developed hydrogen resources for use in schools and colleges. These are the Hydrogen Awareness Course and the Hydrogen for Transport Course.

Stakeholders consulted during this study indicated that more of the training required by companies across the aviation supply chain to support decarbonisation activities will be delivered by the further education sector through existing courses, if they can be satisfied that there is sufficient demand to justify investment. Stakeholders in the sector indicated that this demand is not there, currently. Qualifications will likely be updated as different low-carbon and zero emission technologies become more prevalent.

University graduates will be important for leading teams in companies across the aviation supply chain and to provide specific expertise. Specific graduate level skill demands cited by stakeholders were in electronics and electrical engineering, battery chemistry, hydrogen fuel cell fundamentals and, more general engineering (e.g. mechanical, design) to address the engineering skills shortage in the UK.

Stakeholders suggested that the development of further, focused capabilities (e.g. in hydrogen service) could be developed through 'on the job' training.

The figure below provides an indication of the numbers qualifying each year for further education courses that could have a relevance to low carbon and zero emission aviation across manufacturing, operations, servicing and maintenance, and end of life.

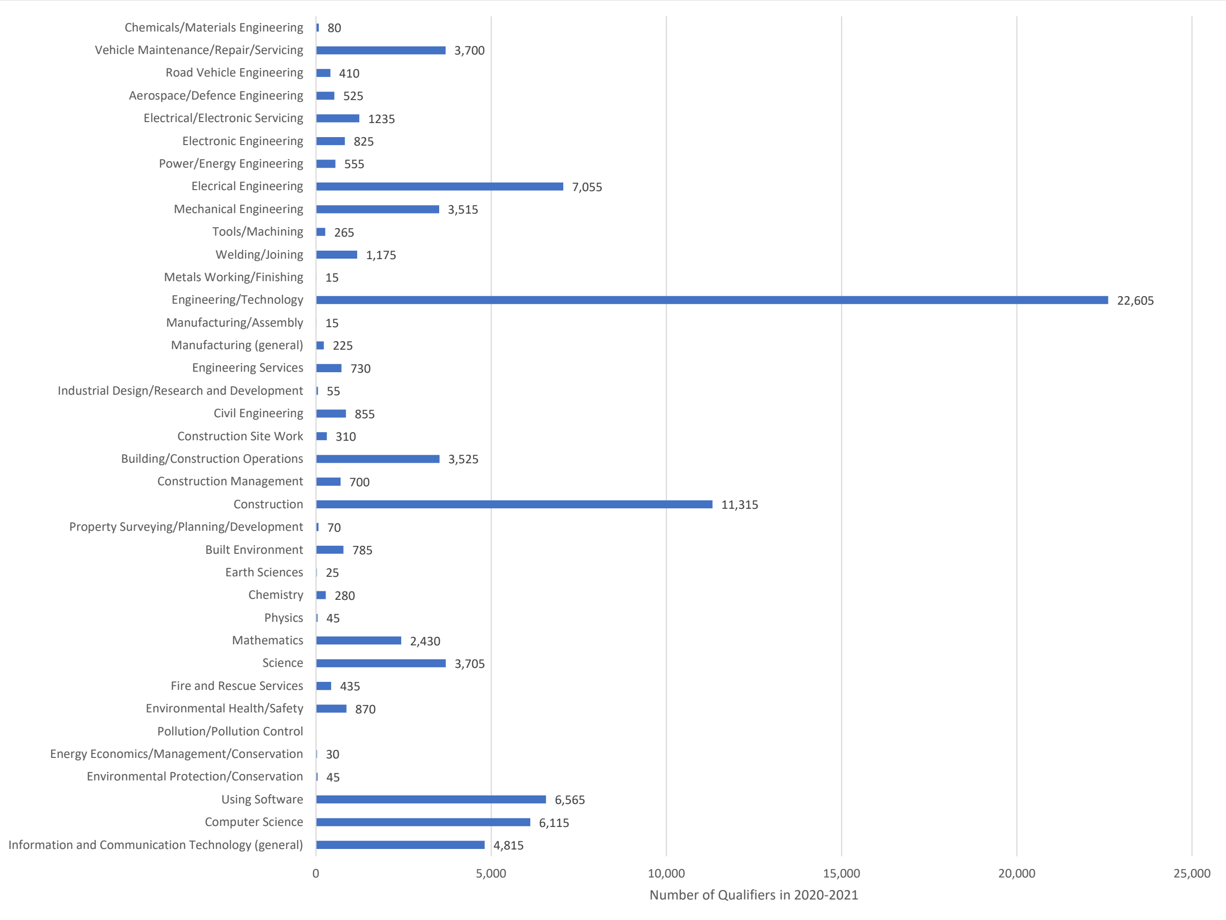

Figure 11: Qualifiers From Courses that have Relevance to Aviation Manufacturing, Operations, Servicing and Maintenance, and End-of-Life (InFact Data 2020-2021)

5.4.2 Modern and Graduate Apprenticeships

5.4.2.1 Modern Apprenticeships

There were approximately 5,150 individuals enrolled in modern apprenticeships in 2022 that have some relevance to the manufacture, operation, servicing, maintenance and end-of-life of aircraft and airport infrastructure. This can be broken down as follows:

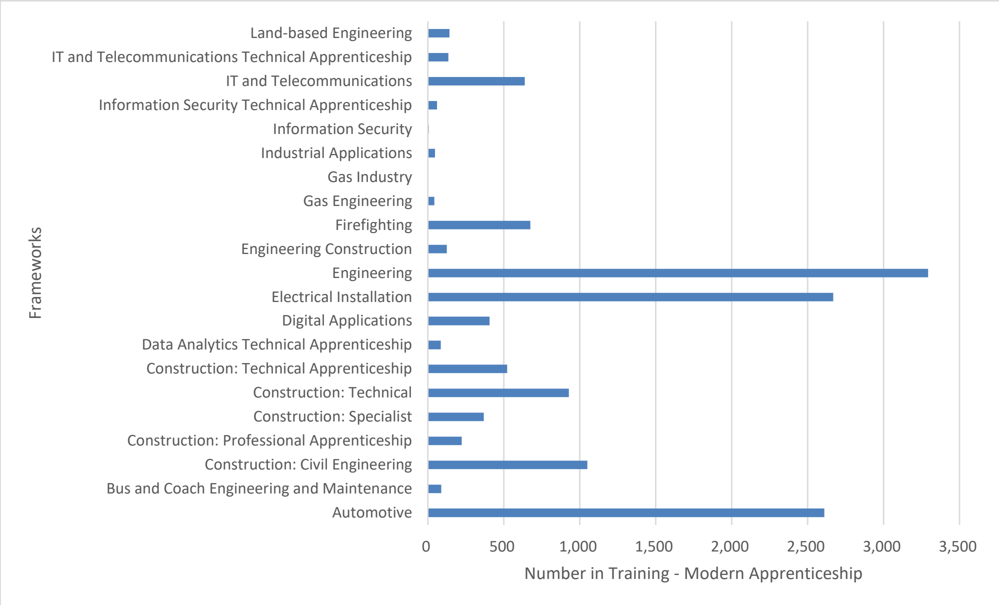

Figure 12: Modern Apprentices in Training in Frameworks that have Relevance to Aviation Manufacturing, Operations, Servicing and Maintenance, and End-of-Life (SDS Data 2021-2022)

5.4.2.2 Graduate Apprenticeships

There were approximately 650 individuals enrolled in graduate apprenticeships in 2022 that have some relevance to the manufacture, operation, servicing, maintenance and end-of-life of aircraft and airport infrastructure. This can be broken down as follows:

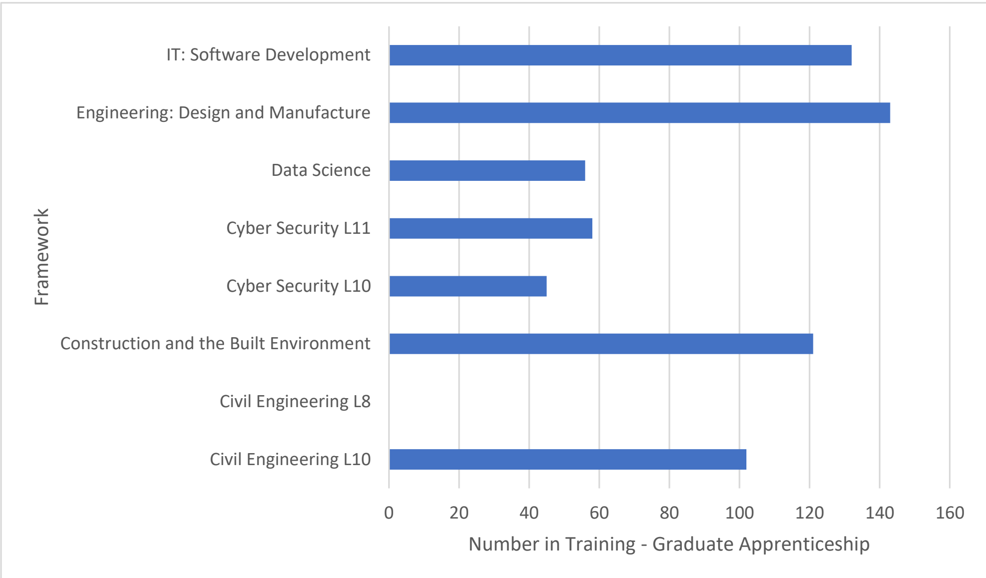

Figure 13: Graduate Apprentices in Training in Frameworks that have Relevance to Aviation Manufacturing, Operations, Servicing and Maintenance, and End-of-Life (SDS Data 2021-2022)

5.4.2.3 Foundation Apprenticeships

There were over 770 individuals enrolled in foundation apprenticeships in 2020 (latest available data) with some relevance to the manufacture, operation, servicing, maintenance and end-of-life of aircraft and airport infrastructure (civil engineering, engineering, IT: software development and scientific technologies – 1 year and 2 year delivery models).

5.4.3 Private Sector

There are also a number of private sector companies in Scotland and the UK offering training across the aviation supply chain, including a number that have developed courses and modules directly relevant to low carbon and zero emission activities. These are summarised in the following table.

Organisation	Location	Type of Training	Examples
IATA	Online, International	Delivers a wide range of training targeted at the air transport industry including a range of aviation environment and fuel courses	Fuel Efficiency and Conservation Managing Green Airports Sustainable Aviation Fuels
UK Civil Aviation Authority	Online, Crawley	Provides a wider range of training courses for aviation professionals including those focused on environmental aspects	Aviation and the Environment
NATS	Online, Hampshire	Delivers a wide range of training courses relating to air traffic control and operation and management of infrastructure.	N/A
Air Service Training	Crieff	Delivery of a range of training modules towards achievement of aircraft maintenance licence. Also works in partnership with UHI Perth to deliver BSc in Aircraft Maintenance Engineering	Classroom based and practical EASA Part 66 approved modules
Renewable Energy Institute	Online, Edinburgh	Delivers a range of renewable energy courses directly or via partner educational institutes, including hydrogen technologies and electric vehicles	Hydrogen energy course Electric vehicles course
MIRA Technology Institute	Online, Nuneaton	Provides a range of courses on hydrogen fuel cells and their applications from short/CPD through to degree level	Hydrogen Fuel Cells & their Applications
Pure Energy Centre	Unst (Shetland)	Training courses on fuel cell technologies and introduction to hydrogen technologies	N/A
EINTAC	Various	IMI and C&G accredited courses for hybrid/electric vehicles, relevant to decarbonised ground vehicles	Tailored courses for businesses working with high voltage battery systems

Table 6: Private Sector Provision of Training to Support Low Carbon and Zero Emission Aviation

Industry skills needs drive the development of the training provision examples highlighted above. A key source of information about an industry's need for skills, knowledge and understanding is National Occupational Standards. There are approximately 23,000 NOS over 900 suites and these are developed by organisations with close connections with organisations operating with each industry, i.e. the source of demand for workforce skills. NOS are a key input into skills development. The key organisations leading development of NOS relevant to aviation and aerospace include:

- People 1st International - developed a range of National Occupational Standards within the Aviation Operations on the Ground suite. This includes, for example, a standard for monitoring aircraft fuelling system serviceability and maintenance operations.

- Sector Skills Council, Enginuity - developed a number of National Occupational Standards within Aeronautical Engineering Suite 2 and Aeronautical Engineering Suite 3. This includes, for example, a standard for carrying out maintenance on aircraft electrical/electronic systems by component replacement.

5.4.4 Other Initiatives

The University of Warwick WMG , The Faraday Institution (consulted during this study) and the High Value Manufacturing Catapult, have, in partnership with the Automotive Council, UK Government and industry, undertaken a large piece of work to develop a National Electrification Skills Framework and Forum. Whilst this is initially focused on the up-skilling, re-skilling and new-skilling of workers in the automotive industry in response to the growth in the number of electric vehicles predicted in the coming years, many aspects of this framework will also be relevant to other parallel sectors, including aviation. The framework approach is summarised opposite.

One of the overarching themes of this work was the need for collaboration between employers, training providers, accrediting organisations and learners themselves to ensure that "*businesses of all sizes are able to access a skilled workforce able to meet their business needs and to compete in growing markets*." And to "*provide individuals with initial and lifelong learning opportunities to secure their future work opportunities in expanding green industries*".

This framework advocates a mix of long courses and short modular courses, designed to enable credit accumulation towards qualification and awards, where appropriate. One of the main benefits of this is that it will provide both companies and learners with the flexibility to develop bespoke training to meet their specific needs. Furthermore, as new needs are identified, new courses can be developed to meet these needs. The framework also recommends that all courses, whether long or short, will be designed with accreditation from professional bodies in mind.

Framework Approach

- Levels 2 - 8 (or equivalent)
- Informed by industry partners from a wide range of sectors
- **Sector agnostic** – electrification is considered as a whole rather than as separate industry sectors
- **Common and less common curriculum** – makes use of cross cutting electrification themes that are the same regardless of sector, level or role to ensure consistency and efficiency. Sector specific elements are then attached
- **Modular** – Long course programmes, such as apprenticeships, are deconstructed into short course offerings in order to allow employers to select aspects that are required to allow for up-skilling and re-skilling of workers where a full development programme is not required
- **Current** – Incremental changes to short course portfolios wll be readiy reflected into long course programmes
- **Consistency** – Regardless of the mode of delivery the content, competencies and assessments are the same which gives parity
- **Credit accumulation** - Individuals will be able to accumulate credit from the courses that they attend and use it against larger qualifications
- **No dead ends** - Individuals will always have opportunity to further their careers through training and education with progression routes clearly articulated and made available
- **Widening participation** - multiple entry points and opportunities for experience based achievements will help to engage learners more widely through an inclusive and accessible approach to accessing education and careers in electrification

5.5 Skills Requirements, Gaps and Shortages

Table 7 overleaf summarises the specific skills requirements, gaps and shortages related to the decarbonisation of aviation.

In addition, a number of stakeholders consulted during this study highlighted a requirement for employees, across the supply chain and across departments within companies, to have better knowledge and understanding of sustainability and 'green' issues. This was viewed to be a cross-cutting requirement with options for development including, for example, building this into university and college courses as well as to provide options for relevant members of the workforce to enhance their knowledge through short modular or CPD type courses.

Aviation and Aerospace Landscape Segment	Skills Required	Training Provision	Skills Gaps	Skills Shortages
Design, development, testing and manufacture of parts, components, systems & fuels	Not necessarily specific to low-carbon drivetrains, but include: • Computational modelling • Design engineering • Engineers and technicians for high voltage, electrical, electronic, power (including low temperature power electronics), high-pressure gas, cryogenics and digital/software • Materials engineering, scientists and chemists • Precision engineering of lightweight alloys and coatings • Quality inspection and control of component parts	In-house, further and higher education, private training providers	Design and development of liquid hydrogen systems, including low temperature power electronics. This technology is at a low TRL for aviation and opportunities for the supply chain will be limited to involvement in pilots and demonstration in the short and medium term. Commercial flights of liquid hydrogen powered aircraft are likely to be introduced well beyond 2035.	General shortages noted for employees with STEM skills, with electrical engineering and power electronics being a key area of shortage for electrification of aviation. High integrity welding/inspection for hydrogen systems
Design, development, testing and manufacture of aircraft and ground vehicles	• Design engineering • Aeronautical engineering • High-voltage electrical systems • High-pressure gas systems • Liquid hydrogen systems • Systems integration • Regulatory, standards and safety certification requirements • Detailed safety case development	In-house, further and higher education, private training providers, Civil Aviation Authority	None identified at present. Limited activity in Scotland in this segment	General shortage of engineers and other STEM skills but limited activity in Scotland in this segment
Charging/ refuelling infrastructure developers/ operators	• System design and engagement with Distribution Network Operators • Planning and associated safety case development • High-voltage electrical system installation • High-pressure gas system installation • Civil engineering and construction	In-house, further and higher education, and private training providers, system manufacturers	Lack of an apprenticeship framework focused on hydrogen refuelling infrastructure installation and maintenance (medium term for hydrogen gas, longer term gap for liquid hydrogen and associated cryogenic systems). Possible earlier need for	Specific shortages identified for electrical engineers, high integrity welding/inspection and, more generally, STEM skills

Aviation and Aerospace Landscape Segment	Skills Required	Training Provision	Skills Gaps	Skills Shortages
	• Project management • High integrity welding and inspection • Public communication		infrastructure to fuel hydrogen powered ground vehicles at airports. Detailed safety case development for new infrastructure and related planning needs (required by both engineering consultants developing applications and local authority and other stakeholders evaluating applications) Skills in communicating with the public about actual vs perceived risk related to hydrogen infrastructure	
Airport, aircraft and ground vehicle owners/operators	• Development of detailed safety cases for urban air mobility and drone applications • Navigating safety and regulatory requirements for urban air mobility • Public communication • Emergency response to incidents involving electric/hydrogen powered craft • Electrical charging and hydrogen refuelling operations • Digital and data skills to support efficient flight initiatives • Pilot training for new craft	OEMs, system/component suppliers, in-house, further education, private providers	Detailed safety case development and understanding of regulatory requirements for urban air mobility and drone applications (required by both companies developing new drone application and local authority and other stakeholders evaluating applications) Upskilling of emergency responders to deal safely with incidents involving high voltage and hydrogen powered craft Hydrogen refuelling and electric recharging skills for airside operators Service and calibration certification for hydrogen refuelling systems	Shortages around data/digital skills to support efficient flightpath management initiatives and develop automation of some elements of crash detection and local air traffic management related to potential new drone applications and urban air mobility
Aircraft and ground vehicle maintenance, repair and overhaul	• High voltage system overhaul, repair and maintenance – battery and fuel cell • Hydrogen system (fuel cell and combustion) overhaul, repair and maintenance • Overhaul, repair and maintenance of batteries and battery management systems	OEMs system/component manufacturers, further & higher education, and private training providers	Specific skills gaps will only become apparent when new decarbonised craft come into service. Could include skills for safe working on high voltage systems, battery systems, high pressure gas systems and, in the longer term, liquid hydrogen systems. Skills to repair	The skills required for MRO will be defined in response to what new propulsion technologies are introduced onto the market. It is likely that this will be a combination of electrification and hydrogen

Aviation and Aerospace Landscape Segment	Skills Required	Training Provision	Skills Gaps	Skills Shortages
	• Overhaul, repair and maintenance of parts/components manufactured using new alloys/composites, etc. • Service, repair and maintenance of electrically powered ground vehicles		and maintain electric and hydrogen fuelled ground vehicles are likely to be needed sooner than for aircraft. There could also be skills gaps related to precision engineering capabilities to work with new lightweight alloys and composites	combustion but it is likely that there will be only limited demand by 2032.
End or life/ circular economy	• Safe isolation and removal of high-voltage electrical and high-pressure gas systems • Valuable material identification and recovery • Second life use of batteries	Further education, and private training providers	No skills gaps yet identified	Limited aircraft decommissioning activity currently in Scotland

Table 7: Summary of Skills Requirements, Provision, Gaps and Shortages by Aviation and Aerospace Segment

5.6 Barriers to Skills Development

The main current barriers to skills development include:

1. There is a lack of clarity on the future evolution of the aviation sector in Scotland. Whilst many of the major aviation OEMs are investing significantly in R&D to develop and demonstrate the next generation of decarbonised and zero emission aircraft, it is not clear what technologies will emerge first, when these aircraft will come to market or what the implications of this will be for the sector in Scotland in terms of, for example, supply chain opportunities, aircraft flying in and out of Scotland, infrastructure, power generation, MRO, etc
2. Even when decarbonised craft become commercially available, there may be a further delay in some of these craft flying in and out of Scotland (especially hydrogen powered craft, where significant investment in refuelling infrastructure will be required). Therefore, the need for additional related skills may experience a lag after their initial commercial introduction
3. The low carbon / zero emission aviation market is currently very small and, therefore, companies are unwilling to invest in training as there is limited need. This means that there is little or no demand for new skills development, particularly in operational segments
4. Based on currently available information and feedback from stakeholders, SAFs are likely to make the biggest contribution to decarbonisation of aviation in the short to medium term. As this is a drop in replacement fuel, no specific skills needs have been identified in the operational segments
5. The policy environment and lack of clarity as to whether government support will focus on one technology over another (e.g. SAF over hydrogen combustion)
6. The aviation and aerospace industry is highly regulated and, as a result, new technologies, such as those that will support decarbonised / zero emission aviation, cannot be deployed until they are fully certified to relevant standards and regulations. Many of the necessary standards and regulations either do not exist or are still under development, meaning skills needs cannot yet be defined at a detailed level
7. Aircraft maintenance engineers and technicians must obtain an approved European Aviation Safety Agency (EASA) and / or a UK Civil Aviation Authority (UKCAA) Part 66 Certificate of Recognition. The training syllabus is defined by these regulatory bodies and, therefore, training providers will not invest in the development and delivery of new training modules and programmes relevant to decarbonised and zero emission aviation until an updated syllabus is produced
8. The need for new skills, in the parts and components manufacturing segment of the Scottish landscape, is a function of the commercial opportunities the current and future companies in this supply chain are likely to target. A significant proportion of the 2,250 employees currently active in this segment are involved in lightweighting parts and structures of craft for OEMs and Tier 1 suppliers based outside Scotland. The supply chain opportunities relating to new propulsion technologies do require new skills but if no, or a small number of, Scottish suppliers pursue these opportunities then there will be limited demand to develop skills in this area
9. There is a perception that aviation and aerospace is an environmentally damaging industry resulting in companies finding it difficult to attract people into the industry, particularly young talent. Furthermore, the recent COVID 19 pandemic has resulted in some viewing it as a volatile sector in terms of job security, making it a less attractive option

10. Focus on immediate business operations leads to lack of prioritisation of decarbonisation skills development when the market is currently very early stage

5.7 Transferable Skills and Talent

Although it is challenging to define many of the skills required to support decarbonisation of aviation and aerospace with detail, due to the early stage of technology development of potential solutions, some high level skills can be identified which already exist in other sectors. Attracting talent from these adjacent sectors is one way of addressing future skills needs, in addition to upskilling the existing workforce and training new entrants. The priority transferable skills and talent include:

- Designing, developing and operating on high voltage systems. Skills currently present in electric vehicle design and manufacture are relevant to battery and fuel cell electric aviation. There is very limited automotive manufacture in Scotland, with only a few systems integrators involved in electrification of buses (ADL), trains (Ballard Motive Solutions) and fire appliances (Emergency One). However, skills from automotive manufacturing based outside of Scotland could be attracted to support opportunities in electrification of aviation. Further skills, in working with high voltage systems, are present in electricity transmission and distribution (e.g. SP Energy Networks) and within the rail sector (e.g. Network Rail). It may be that more immediate opportunities relate to electrification of airside ground vehicles require charging point installation. It is likely that the skills already present in current installers of heavy vehicle electrical charging points will be sufficient to address this opportunity.
- Designing, developing and operating high pressure gas systems for hydrogen combustion and hydrogen fuel cells. Whilst it is not clear that there will be significant amounts of supply chain activity in designing and developing parts and components for hydrogen combustion and hydrogen fuel cell craft, there will likely be some need to instal, service, repair and maintain hydrogen refuelling infrastructure. Skills currently present in gas network engineering (e.g. SGN) and the oil and gas supply chain are likely to be relevant for hydrogen storage and distribution systems. Skills in the chemical sector, where gases are used as inputs to production operations are also likely to be relevant. This includes technical skills, such as high integrity welding and more general skills relating to operating on safety critical systems.
- Designing and developing digital solutions will require skills that are in short supply across many sectors. Skills in data analytics, artificial intelligence and software development for digital twins, etc. will be required to support efforts to increase flight management efficiency in air traffic control and automate anti-collision systems for urban air mobility. These skills are present in many other sectors

6 Conclusions and Recommendations

6.1 Conclusions

6.1.1 Overall Conclusions

By 2032, the main practices adopted to decarbonise aviation in Scotland will be the use of SAF, increased presence of lighter weight and more fuel efficient craft in the overall fleet, more efficient air traffic control management and the use of carbon markets. The use of SAF and lighter weight and more fuel efficient craft do not require any change in operational skills. Achieving more efficient air traffic control management will require additional skills that are already being developed within NATS, including skills in data analytics and design of digital solutions. The use of carbon markets is typically a head office function so only operators in Scotland will require skills in carbon measurement, monitoring and reporting and contracting with credible carbon market suppliers.

By 2032, the role of alternative propulsion technologies will have a very limited impact on operational practices. There may be a small number of battery electric and hybrid craft in operation, but more significant adoption of this technology will most likely occur after 2032. It is unclear as to how hydrogen propulsion will develop by 2032, with alternatives such as hydrogen combustion (hybrid/100%) and hydrogen fuel cells being investigated. Within hydrogen combustion there are alternative development paths being pursued for hydrogen gas and liquid hydrogen, the latter with associated cryogenic systems. Much of the activity related to hydrogen propulsion, up to 2032, will consist of design, prototype development and testing of systems and aircraft but with very little commercial operation of these aircraft. Hydrogen gas combustion and hydrogen gas powered fuel cell activity is likely to develop faster than liquid hydrogen propulsion systems. The timescale for commercial operational introduction of all types of hydrogen powered craft is likely to be beyond 2032.

Analysis of Scottish activity across the segments of the aviation and aerospace landscape indicates that there is very limited design, development, testing and manufacture of aircraft or ground vehicles, with employment estimated at fewer than 100. This relates to a small number of start-up businesses developing electrically powered small aircraft and heavy lifting drones. There is also a testing facility in Orkney focused on hydrogen and electrically powered craft. There is more estimated activity (~2,250 employees) involved in design, development, testing of parts, components, systems and fuels. Some of these employees are already developing additional skills in areas such as lightweighting. The extent of additional skills requirements is a function of the opportunities open to them from aircraft OEMs and Tier 1 suppliers based outside of Scotland. Due to the uncertainty relating to the timescale and technical pathway of different alternative propulsion technologies and the commercial opportunities the Scottish supply chain will be able to access, there is a lack of clarity about the additional skills required in the supply chain. The main activities carried out in Scotland include just over 10,000 employees in aircraft operations, including operation of scheduled and non-scheduled passenger transport, freight transport, air traffic control, airport firefighters, baggage handlers and maintenance, repair and overhaul. Only a small proportion of these employees are likely to require additional skills by 2032 as a result of changes in practice arising from decarbonisation.

6.1.2 Areas Where Skills Gaps Exist

Skills gaps have been identified across several of the segments in the aviation and aerospace landscape. These are described below along with an indication of the timing of the potential demand for related skills development.

Within the design, development, testing of parts, components, systems and fuels segment, there is a future skills gap in the design and development of gaseous and liquid hydrogen systems. For the latter, this will also involve skills related to the development, manufacture and installation of ultra low temperature power electronics. It is likely that any skills need in this area, prior to 2032, will be related to early TRL research and prototype/demonstration activity. The level of demand for this skill is, however, uncertain as it is unclear what the activity in the Scottish supply chain will be in pursuing and winning work in this area. Any commercial scale production of related liquid hydrogen parts, components and systems (and therefore demand for related skills) is likely to occur after 2032 with the caveat that it is still unclear as to whether liquid hydrogen systems will be developed and deployed in commercial aircraft, due to the high levels of risk associated with them.

No skills gaps were identified for the design, development, testing and manufacture of aircraft and ground vehicles. This is a reflection of the very limited presence of Scottish companies currently active in this segment. This may change if more companies become active in this area in Scotland.

Within the charging/refuelling infrastructure developers/operators segment, there is a future skills gap in hydrogen refuelling infrastructure installation and maintenance. Although the expected commercial adoption of hydrogen fuelled aircraft is likely to be beyond 2032, the demand for hydrogen refuelling at airports could arise sooner than this, driven by the potential introduction of hydrogen powered ground vehicles, such as aircraft tugs. There is a related skills gap in the development of detailed safety cases for new hydrogen refuelling infrastructure that would accompany a planning application. These skills will be required at a detailed level for consulting engineers engaged to support the planning process. Skills will also be required, at a less detailed level, to enable local authority planners, and associated stakeholders, to interpret these detailed safety cases. Skills in communicating actual risk levels and dealing with perceived risk levels by the public were also highlighted as a gap. As with the skills related to the installation and maintenance of hydrogen infrastructure, the demand for skills relating to detailed safety cases and communication are likely to arise after 2032 relating to the introduction of hydrogen aircraft, but potentially much sooner if hydrogen powered ground vehicles are adopted.

Within the airport, aircraft and ground vehicle operators segment, there is a future skills gap in developing detailed safety cases and understanding wider regulatory requirements associated with urban air mobility and drone applications. These skills will be required by companies proposing urban air mobility business cases and drone applications, their professional advisors and the local authority and other stakeholders evaluating these proposals. Skills requirements for drone applications are likely to start being required in the short to medium term, before 2027. Skill requirements relating to urban air mobility applications are likely to take longer for significant demand to emerge. Skills for emergency responders to deal with incidents involving electric and hydrogen fuelled craft has also been identified as a gap. The demand for skills development in this area is likely to occur initially for safely dealing with high voltage, battery or fuel cell powered planes, potentially before 2032. The demand for skills to safely deal with incidents involving hydrogen combustion powered craft is likely to arise after 2032. The exception to this is for emergency personnel servicing airports where test and demonstration flights of electric / hydrogen craft may occur, such as Kirkwall airport which hosts the Sustainable Aviation Test Environment project. A future skills gap also exists for airside operators in the operation of hydrogen refuelling and electrical charging infrastructure. The requirement for skills to operate electrical charging infrastructure is likely to precede that for hydrogen refuelling with the former starting to experience demand between 2027 and 2032 and the latter experiencing demand after 2032. A future skills gap has also been identified relating to the service and calibration certification of hydrogen refuelling systems. It is likely that demand for this skill will arise after 2032, for aviation.

Within the aircraft / ground vehicle maintenance, repair and overall segment, the specific skills required will only become apparent when hydrogen combustion and electric craft are operating commercially. At a high level, this will include safe working on high voltage systems and high pressure gas systems. It is expected that the skills required to work on electrically powered aircraft will start to arise between 2027 and 2032, with the demand for skills to work on hydrogen powered craft being after 2032. The demand for skills to work on liquid hydrogen craft is likely to arise after the requirement for skills to work on hydrogen gas powered craft. As the move to the use of lightweight parts and components continues to grow there may also be a skills gap relating to precision engineering of new alloys and composite materials. The demand for these skills are likely to occur between 2027 and 2032 as more craft using novel lightweight materials are adopted commercially and require maintenance, repair and overhaul.

No skills gaps were identified for the end of life / circular economy segment. This is partly a function of the limited current activity in this area in Scotland.

6.1.3 Transferable Skills and Talent

Transferrable skills and talent exist in the Scottish economy which could support the decarbonisation of aviation and aerospace.

Skills to support the design, development and operation of high voltage systems can be found in vehicle manufacture across bus, trains and emergency services vehicles, albeit in limited numbers due to the small number of companies active in this area in Scotland. Relevant high voltage skills relating to recharging infrastructure can be found in electricity distribution network operators, the rail network and existing vehicle charging installer, particularly those with experience of installing recharging infrastructure for heavy duty vehicles.

Skills to design, develop and operate high pressure gas systems can be found in the oil and gas sector, chemical processing sectors and within gas distribution network operators.

Skills to design and develop digital solutions to support urban air mobility, drone applications and efficient flight management exist across a variety of sectors. However, it should be noted that digital skills are in high demand across sectors.

6.1.4 Extent of Skills Supply Activity

A broad range of suppliers are active in the development of skills for new entrants, upskilling of the existing workforce and reskilling of the workforce operating in adjacent sectors.

Much of the skills development provision for new entrants is delivered by further and higher education institutions. This includes both general degrees, such as electrical and electronic engineering to specialist degrees, such as aerospace systems. A variety of relevant NC, HNC and HND courses are also offered, such as Aircraft Engineering. The University of Strathclyde, University of Glasgow, Ayrshire College and UHI Perth are all key providers of skills in this area.

Several Modern and Graduate Apprenticeship frameworks also offer relevant skills development for new entrants. This includes MA frameworks such as Engineering and Digital Manufacturing, Electrical Installation and Scientific Technical and Formulation Processing. Relevant GA frameworks include Engineering, Design and Manufacture.

Shorter upskilling and reskilling courses are offered by both the public and private sector. This includes provision such a six week course including hydrogen awareness, welding and fabrication offered at UHI Perth and a range of private provision relating to awareness of new propulsion technologies and specific training to develop and certify aircraft maintenance skills and competence. Skills related to air traffic control and efficient flight management are delivered internally by NATS.

Other relevant skills development bodies include People 1st International (which develops National Occupational Standards for Aviation Operations on the Ground) and Enginuity (which develops National Occupational Standards for Aeronautical Engineering).

6.1.5 Key Barriers to Skills Development

Uncertainty about the nature and timing of skills required for decarbonising aviation and aerospace is the underlying factor behind a number of barriers to skills development in this area. This applies to both operational skills needed to safely work with aircraft based on new propulsion technologies and the skills potentially required within the supply chain to address any economic opportunities which may arise.

The early stage of technical development of aircraft based on new propulsion technologies mean that regulatory and standards processes will have to be satisfied prior to specific skills requirements being defined. This is particularly the case in areas such as maintenance, repair and overhaul. This lack of detail and certainty on the actual skills required acts as a barrier to updating National Occupational Standards, upon which new skills development accreditations are based.

Even after commercial adoption of hydrogen aircraft by the market, it is possible that the use of such craft in Scotland could lag this due to the significant airport infrastructure costs required for hydrogen refuelling. This could further delay the need for associated skills development.

The Scottish aviation supply chain is developing skills to support decarbonisation measures such as lightweighting of parts and components. However, the lack of aviation OEMs and the very small number of Tier 1 suppliers based in Scotland means that the supply chain influence in other measures, such as new propulsion technologies, can be limited. This acts as a barrier to investment in skills if it is uncertain whether these new skills will align with the future direction of OEM and Tier 1 customers.

More broadly, stakeholder feedback suggested that a further barrier to skills development was attracting new entrants into the industry, due to negative perceptions about the environmental sustainability of the sector.

6.2 Recommendations

A number of recommendations are made relating to skills to support the decarbonisation of the aviation and aerospace sector:

- The decarbonised and zero emission aviation and aerospace sector is still relatively immature with the emphasis, to 2032, being on the replacement of conventional aviation fuel with SAF. There is still some uncertainty around what new zero emission technologies will emerge and when, although it is generally accepted that they will enter into commercial operation. It is recommended, therefore, that, at this stage, a more strategic approach should be taken to the development of a skills framework (using that developed by the Faraday Institution and discussed earlier in this report as an example) involving industry, skills providers and accreditation bodies. This will allow the appropriate plans to be put in place to ensure that the workforce across the aviation and aerospace supply chain are able to begin developing the skills that will be required when the time is right.

- As identified in the previous report on skills to support low carbon heavy duty vehicles, it is recommended that there is provision of skills for hydrogen refuelling infrastructure development, installation and maintenance. In the first instance, this would likely focus on refuelling infrastructure for airport fleet vehicles (buses, tugs and other medium and heavy duty vehicles) as these are likely to reach commercial operation before hydrogen powered aircraft. The skills will, however, be transferrable and should include skills development for new entrants, including via options in appropriate apprenticeship frameworks, and for upskilling the existing workforce.
- The previous report on skills to support low carbon heavy duty vehicles highlighted a recommendation to investigate how the skills of consulting engineers could be developed to meet the needs of planning and consenting processes for hydrogen refuelling infrastructure. This is also relevant to this aviation study.
- High level awareness raising and skills provision should be developed for local authority representatives (e.g. planning), with respect to relevant regulations, standards and public communication for urban air mobility and different drone applications. This could incorporate learnings from the Coventry vertiport and involve NATS.
- Operational skills amongst airport emergency service crews, and the wider public emergency services need to develop skills to enable them to work safely with incidents involving electrically powered flights, in the first instance, and then hydrogen powered flights. The latter is expected to only be commercially available after 2032, although there may be demonstration flights (such as at the SATE test facility at Kirkwall airport). This recommendation could be taken forward via the emergency services group engaged during and after the low carbon HDV skills study

Appendix A – Contributors to the Study

Stakeholders from the following organisations kindly provided input to the study. This list includes only those who consented to their organisations being named. Opinions provided reflect individual's views and are not necessarily the views of their organisations.

Companies	Skills Providers / Academia / Research Orgs	Other Stakeholders
Altrad Babcock	EMEC	ADS Scotland
Belcan	University of St Andrews – Hydrogen Accelerator	Aerospace Technology Institute
CHC Heliport Terminal	University of Strathclyde – DER (joint aviation / maritime)	Michelin Scotland Innovation Park
Glasgow Airport Limited	South Ayrshire College	Royal Air Force
HIAL	University of Glasgow – Aerospace Sciences	Scottish Hydrogen and Fuel Cell Association
LoganAir		Faraday Institution
MB Aerospace		PA Consulting
NATS (HQ)		
Wood Group		
NATS Prestwick Control Centre		
British Aerospace		
ULEMCo		

Appendix B – Characterising the Aviation and Aerospace Landscape in Scotland

To set the context for research and analysis into the skills required for aviation decarbonisation, the scope of the different parts of the relevant supply chain and operations need to be defined. Figure 14, below, summarises the overall scope of this study.

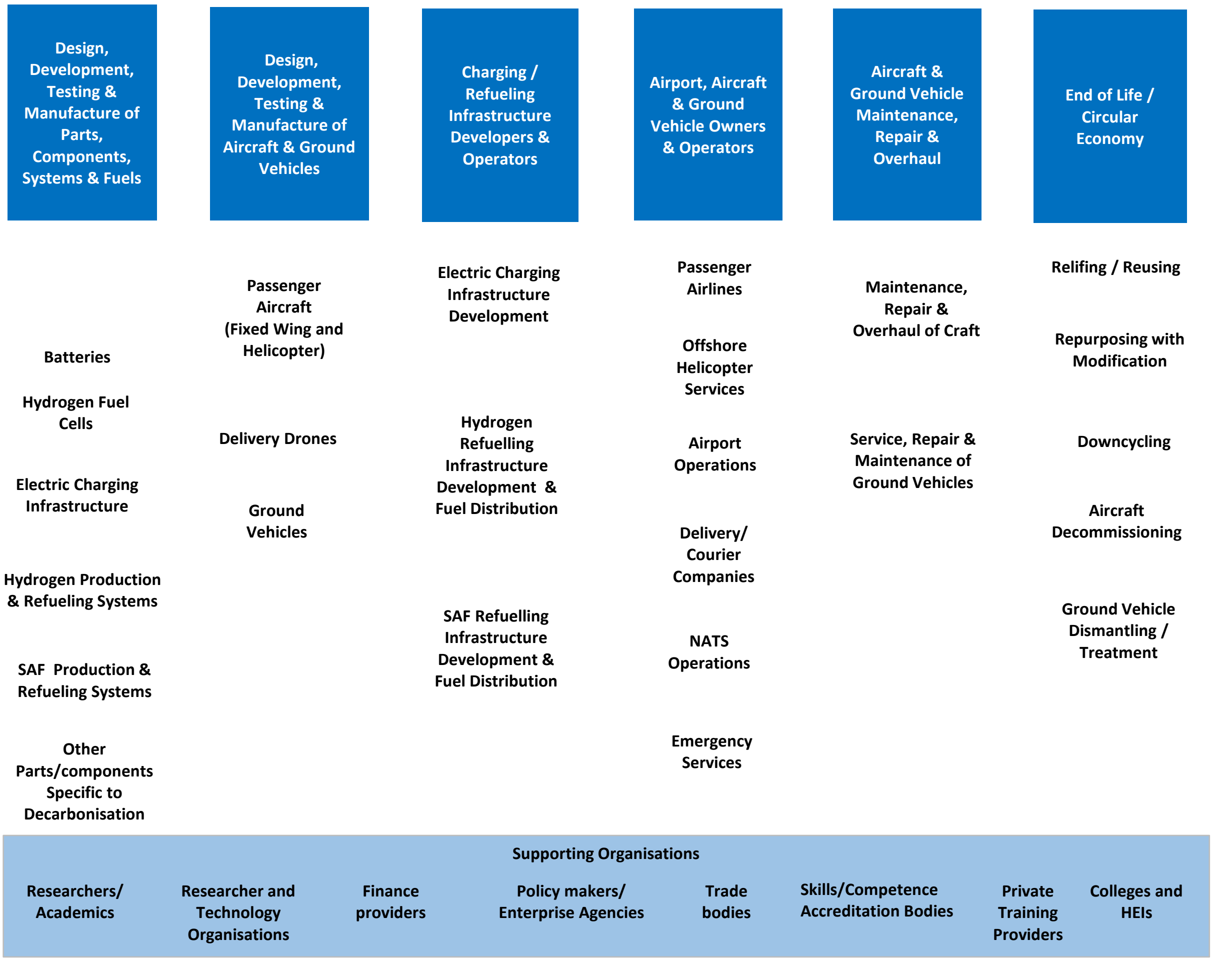

Figure 14: Scope of the Aviation and Aerospace Decarbonisation Supply Chain and Operational Landscape

Figure 14 illustrates the different decarbonisation options arising from the supply chain and the key elements of operation, use and end of life. It includes:

- Design, development, testing and manufacture of parts, components, systems and fuels
- Design, development, testing and manufacture of aircraft and ground vehicles
- Charging / refuelling infrastructure developers and operators
- Aircraft and ground vehicle owners / operators
- Aircraft and ground vehicle maintenance, repair and overhaul
- End of life / circular economy

In addition, there are various supporting organisations including researchers/academics, research and technology organisations, finance providers, policy makers/enterprise agencies, trade bodies, skills/competence accreditation bodies, private training providers and colleges/higher education institutes.

It is necessary to understand the scale of Scottish based activity within each segment to assess the approximate number of employees potentially requiring skills development to support the decarbonisation of aviation and aerospace operations and maximise associated economic opportunities.

The analysis below uses data sourced from the Office for National Statistics service, nomis. Specifically, the databases used were:

- UK Business Counts – enterprises by industry and employment size band (accessed 3/11/22, latest data 2022)
- Business Register and Employment Survey – data based on 'Employment' numbers (accessed 3/11/22, latest data 2021)

Where possible, the scale of each of the segments is quantified in terms of number of enterprises operating in Scotland and employment within these segments. The quantification is based on the following methods:

- Search of several databases accessible via the Office for National Statistics, Nomis website for official labour market statistics (as defined above). Both sources enable searching for Scottish level data within industries defined at the 5-digit Standard Industrial Classification (SIC) Code level. Whilst this is the most disaggregated level of SIC Code data available, there are still limitations with using this approach due to potential lack of alignment between the supply chain/market segments defined in Figure 14 and the activities included in the most relevant 5-digit SIC Codes. Notwithstanding these limitations, this approach can provide a reasonable indication of scale of activity present in Scotland. It should be noted that when data from nomis is presented in figures later in this section, all figures are rounded to avoid disclosure. In some cases the values may be rounded down to zero. However, all zeros are not necessarily true zeros.
- Due to the potential limitations with the SIC Code approach, described above, it is also useful to use other sources of data such as company databases (e.g. FAME), trade body directories, general internet searching, etc.
- Where SIC Code data does not have a good fit with the types of organisations, defined for aviation operations and the supply chain, it can be useful to identify whether Standard Occupational Classification (SOC) data for Scotland has an occupation category(s) that fits with the segment definition. The database used, in this instance, is the Annual Population Survey – regional employment by occupation (available via the Nomis website) (accessed 26/1/23, latest data 2021)
- Where none of the above sources can provide a robust point value for number of organisations or employees present in Scotland then a range estimate may made which will, necessarily, include an element of subjectivity. If no range estimate is possible then 'no data' is displayed

Each of the main segments is described and quantified below.

Design, Development, Testing and Manufacture of Parts, Components, Systems and Fuels

Activities included in the scope of this segment are:

- Electrical power systems/sub-systems
- Batteries

- Hydrogen Fuel Cells
- Electric Charging Infrastructure
- Hydrogen Production & Refuelling Systems
- SAF Production & Refuelling Systems
- Other parts/components specific to decarbonisation

The SIC Codes that have some alignment with these activities are:

- 20110 - Manufacture of industrial gases (which includes manufacture of liquefied or compressed inorganic industrial or medical gases, including elemental gases such as hydrogen). However, this SIC Code also includes non-relevant activities such as manufacture of other industrial gases such as liquid/compressed air, refrigerant gases etc.
- 20130 - Manufacture of other inorganic basic chemicals (which includes the manufacture of chemicals using basic processes. The output of these processes are usually separate chemical elements or separate chemically-defined compounds). However, this SIC Code also includes non-relevant activities such as the manufacture of chemical elements (except industrial gases and basic metals), manufacture of inorganic acids except nitric acid, manufacture of alkalis, lyes and other inorganic bases except ammonia, manufacture of other inorganic compounds, roasting of iron pyrites, manufacture of distilled water and enrichment of uranium and thorium ores
- 27110 - Manufacture of electric motors, generators and transformers (which includes the manufacture of electric motors (except internal combustion engine starting motors) and manufacture of substation transformers for electric power distribution). However, this SIC Code also includes non-relevant activities such as manufacture of distribution transformers, manufacture of arc-welding transformers, manufacture of fluorescent ballasts (i.e. transformers), manufacture of transmission and distribution voltage regulators, manufacture of power generators (except battery charging alternators for internal combustion engines), manufacture of motor generator sets (except turbine generator set units) and rewinding of armatures on a factory basis
- 27120 - Manufacture of electricity distribution and control apparatus (which includes manufacture of power circuit breakers, control panels for electric power distribution, surge suppressors (for distribution level voltage), electrical relays, duct for electrical switchboard apparatus, electric fuses, power switching equipment and electric power switches (except pushbutton, snap, solenoid, tumbler). However, this SIC Code also includes non-relevant activities such as prime mover generator sets.
- 27200 - Manufacture of batteries and accumulators (which includes manufacture of primary cells and batteries containing lithium). However, this SIC Code also includes non-relevant activities such as the manufacture of non-rechargeable batteries and lead acid batteries.
- 27900 - Manufacture of other electrical equipment which includes manufacture of battery chargers and manufacture of fuel cells). However, this SIC Code also includes a significant number of non-relevant activities such as electrical signs, electrical welding/soldering equipment, etc.
- 30300 - Manufacture of air and spacecraft and related machinery (which includes manufacture of aeroplanes for the transport of goods or passengers, for use by the defence forces, for sport or other purposes, manufacture of helicopters, manufacture of parts and accessories of the aircraft of this class, such as major assemblies such as fuselages, wings, doors, control surfaces,

landing gear, fuel tanks, nacelles etc., airscrews, helicopter rotors and propelled rotor blades, motors and engines of a kind typically found on aircraft, parts of turbojets and turboprops for aircraft). However, this SIC Code also includes several non-relevant activities including: manufacture of ground flying trainers, manufacture of gliders, hang-gliders, manufacture of dirigibles and hot air balloons, manufacture of spacecraft and launch vehicles, satellites, planetary probes, orbital stations, shuttles, manufacture of intercontinental ballistic missiles (ICBM). This class also includes overhaul and conversion of aircraft or aircraft engines (which is a better fit for the later MRO segment) and manufacture of aircraft seats

The number of enterprises and level of employment in each of the above SIC Codes, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Aviation activities in segment
20110	Manufacture of industrial gases	5	125	Med
20130	Manufacture of other inorganic basic chemicals	5	50	Med
27110	Manufacture of electric motors, generators and transformers	20	700	Low
27120	Manufacture of electricity distribution and control apparatus	30	500	Low
27200	Manufacture of batteries and accumulators	5	100	Med
27900	Manufacture of other electrical equipment	30	300	Low
30300	Manufacture of air and spacecraft and related machinery	30	2,250	High

Table 8: Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and aviation and aerospace activities covering design, development and testing of parts, components systems and fuels (Scottish data)

Based on SIC data, there are 125 enterprises employing 4,025 people in the defined categories. However, the alignment of most of these SIC Codes with the types of companies involved in the segment is assessed as medium or low. Whilst the SIC codes are likely to be used by companies designing, developing, testing & manufacturing parts, components, systems & fuels, the extent to which companies having these SIC codes service the aviation and aerospace market is unclear. The selected SIC Codes also contain a significant proportion of non-relevant activities. Therefore, the overall number of both enterprises and employment is almost certainly overstated.

The only SIC Code with a high alignment with sector activities is IC 30300, 'Manufacture of air and spacecraft and related machinery'. This SIC code includes manufacture of parts, components and systems for aircraft. Stakeholder feedback indicates that there is no craft manufacture in Scotland so, it can reasonably be assumed that these 2,250 employees work in the supply chain for aircraft and related machinery.

It is assessed, therefore, that there are 2,250 employees in this segment.

Design, Development, Testing and Manufacture of Aircraft and Ground Vehicles

Activities included in the scope of this segment are:

- Passenger Aircraft (Fixed wing and helicopter)
- Delivery Drones
- Ground Vehicles

The SIC Codes that have some alignment with these activities are:

- 29100 - Manufacture of motor vehicles (which would include the manufacture of airport ground vehicles but also includes a significant range of non-relevant activities, including manufacture of passenger cars, manufacture of commercial vehicles such as vans, lorries, on-road tractor units for semi-trailers etc., manufacture of buses, trolley-buses and coaches, manufacture of motor vehicle engines, manufacture of chassis for motor vehicles, manufacture of other motor vehicles: (incl. snowmobiles, golf carts, amphibious vehicles, fire engines, street sweepers, travelling libraries, armoured cars etc., concrete-mixer lorries), ATVs, go-carts and similar including race cars and factory rebuilding of motor vehicle engines)
- 29201 - Manufacture of bodies (coachwork) for motor vehicles (except caravans) (which includes manufacture of bodies, including cabs for motor vehicles and outfitting of all types of motor vehicles (except caravans))
- 29202 - Manufacture of trailers and semi-trailers (which includes manufacture of trailers and semi-trailers such as tankers, removal trailers etc., manufacture of containers for carriage by one or more modes of transport)
- 30300 - Manufacture of air and spacecraft and related machinery (which includes manufacture of aeroplanes for the transport of goods or passengers, for use by the defence forces, for sport or other purposes, manufacture of helicopters, manufacture of parts and accessories of the aircraft of this class, such as major assemblies such as fuselages, wings, doors, control surfaces, landing gear, fuel tanks, nacelles etc., airscrews, helicopter rotors and propelled rotor blades, motors and engines of a kind typically found on aircraft, parts of turbojets and turboprops for aircraft). However, this SIC Code also includes several non-relevant activities including: manufacture of ground flying trainers, manufacture of gliders, hang-gliders, manufacture of dirigibles and hot air balloons, manufacture of spacecraft and launch vehicles, satellites, planetary probes, orbital stations, shuttles, manufacture of intercontinental ballistic missiles (ICBM). This class also includes overhaul and conversion of aircraft or aircraft engines (which is a better fit for the later MRO segment) and manufacture of aircraft seats

The number of enterprises and level of employment in each of the above SIC Codes, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Aviation activities in segment
29100	Manufacture of motor vehicles	40	2,000	Low
29201	Manufacture of bodies (coachwork) for motor vehicles (except caravans)	35	400	Low
29202	Manufacture of trailers and semi-trailers	10	700	Low
30300	Manufacture of air and spacecraft and related machinery	30	2,250	Med

Table 9: Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and aviation and aerospace activities covering design, development, testing and manufacture of craft and ground vehicles (Scottish data)

Based on SIC data, there are 115 enterprises employing 5,350 people in the defined categories. However, the alignment of these SIC categories with the types of companies involved in the segment is assessed as medium or low. Whilst the SIC codes are likely to be used by companies designing, developing, testing & manufacturing craft and ground vehicles, the extent to which companies having these SIC codes service the aviation and aerospace market is unclear. The selected SIC Codes also contain a significant proportion of non-relevant activities. Therefore, the overall number of both enterprises and employment is almost certainly overstated.

Stakeholder feedback suggests that there is very limited, if any, manufacture of finished aircraft in Scotland. The enterprises and employment numbers identified under SIC Code 30300, 'manufacture of air and spacecraft and related machinery' are more likely to be engaged in manufacture of parts and accessories of aircraft (e.g. Spirit Aerosystems). This 'parts and accessories manufacture' is part of the previous segment described in earlier Table 9, and the employment data related to SIC 30300 has been included in that segment.

Whilst it is assumed that most of the employee numbers in this SIC Code are related to parts and component manufacture, two small early-stage companies, Mako Aerospace (developing electric aircraft technology at its base in Dunfermline) and Flowcopter (developing an industrial heavy lifting drone from premises in Loanhead, South of Edinburgh) were identified. There is also some activity in the testing of low carbon craft at the Sustainable Aviation Test Environment at Kirkwall Airport in the Orkney Islands.

Based on this low level of current activity, it is assessed that employment in this segment is less than 100 and mainly related to testing.

Charging / Refuelling Infrastructure Developers and Operators

Activities included in the scope of this segment are:

- Electric Charging Infrastructure Development
- Hydrogen Refuelling Infrastructure Development & Fuel Distribution
- SAF Refuelling Infrastructure Development & Fuel Distribution

The SIC Codes that has some alignment with these activities are:

- 33200 - Installation of industrial machinery and equipment (which includes installation of industrial machinery in industrial plant) However, this SIC Code also includes non-relevant activities such as assembling of industrial process control equipment, installation of other industrial equipment, e.g.: communications equipment, mainframe and similar computers, irradiation and electromedical equipment etc., dismantling large-scale machinery and equipment, activities of millwrights, machine rigging, installation of bowling alley equipment
42210 - Construction of utility projects for fluids (which includes the construction of distribution lines for transportation of fluids and related buildings and structures that are an integral part of these systems). However, this SIC Code also includes non-relevant activities such as construction of civil engineering constructions for long-distance and urban pipelines, water main and line construction, irrigation systems (canals), reservoirs construction of, sewer systems, including repair sewage disposal plants, pumping stations and water well drilling
- 43210 - Electrical installation (which includes the installation of electrical systems in all kinds of buildings and civil engineering structures of electrical systems. This class includes installation of, electrical wiring and fittings). However, this SIC Code includes non-relevant activities such as telecommunications wiring, computer network and cable television wiring, including fibre optic, satellite dishes, lighting systems, fire alarms, burglar alarm systems, street lighting and electrical signals, airport runway lighting, electric solar energy collectors and connecting of electric appliances and household equipment, including baseboard heating)

- 46719 - Wholesale of fuels and related products (other than petroleum and petroleum products) (note that SIC 46711, 'wholesale of petroleum and petroleum products', only includes wholesale of automotive fuels. Companies supplying jet fuel, including SAF, typically register with the primary SIC Code 46719). However, this SIC Code also includes non-relevant activities such as wholesale of greases, lubricants, oils, etc.

The number of enterprises and level of employment in each of the above SIC Codes, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Aviation activities in segment
33200	Installation of industrial machinery and equipment	155	1,250	Low
42210	Construction of utility projects for fluids	40	500	Low
43210	Electrical installation	2,785	26,000	Low
46719	Wholesale of fuels and related products (other than petroleum and petroleum products)	95	800	Med

Table 10: Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and aviation and aerospace activities covering charging/ refueling infrastructure developers/ operators (Scottish data)

SIC Code data for this segment totals 3,075 enterprises and 28,550 employees. However, the degree of alignment between most SIC Codes and segment activities is assessed as low due to the significant level of non-relevant activities included in each of the SIC Codes marked as 'Low'. Alignment with SIC Code 46719 is assessed as medium but the actual number of enterprises active in the production of jet fuel is very low (only Ineos) and therefore the employment number will also be significantly lower.

Ineos's Grangemouth site produces jet fuel and this is used at Glasgow, Edinburgh and Prestwick airports. Employment at the Ineos Grangemouth site is approximately 1,650. However, the site also produces numerous other products so any notional allocation of employment numbers to jet fuel will be significantly lower than this.

It is assessed that there is insufficient data to quantify this segment of the landscape.

Aircraft and Ground Vehicle Owners / Operators

Activities included in the scope of this segment are:

- Passenger Airlines
- Offshore helicopter services
- Airport operations (incl. airport operators and ground operation contractors)
- Delivery/ Courier companies using aircraft
- NATS operations
- Emergency services

The SIC Codes that has some alignment with these activities are:

- 51101 - Scheduled passenger air transport (which includes transport of passengers by air over regular routes and on regular schedules and renting of air-transport equipment with operator for the purpose of scheduled passenger transportation)

- 51102 - Non-scheduled passenger air transport (which includes non-scheduled transport of passengers by air, scenic and sightseeing flights, regular charter flights for passengers and general aviation activities, such as: transport of passengers by aero clubs for instruction or pleasure)
- 51210 - Freight air transport (which includes transport freight by air over regular routes and on regular schedules, non-scheduled transport of freight by air and renting of air transport equipment with operator for the purpose of freight transportation)
- 52230 - Service activities incidental to air transportation (which includes activities related to air transport of passengers, animals or freight such as operation of terminal facilities such as airway terminals etc., airport and air-traffic-control activities, ground service activities on airfields etc. This class also includes firefighting and fire-prevention services at airports)
- 52242 - Cargo handling for air transport activities of division 51 (which includes loading and unloading of goods or passengers' luggage travelling via air transport)

The number of enterprises and level of employment in the above SIC Code, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Aviation activities in segment
51101	Scheduled passenger air transport	5	2,000	High
51102	Non-scheduled passenger air transport	10	1,000	High
51210	Freight air transport	5	100	High
52230	Service activities incidental to air transportation	50	4,500	High
52242	Cargo handling for air transport activities of division 51	10	500	High

Table 11: Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and aviation and aerospace activities covering craft/ground craft vehicle owners/operators (Scottish data)

Note that the SIC Code 52230, 'services activities incidental to air transportation', includes both air traffic control staff and firefighting services at airports. Information published by NATS states that there are around 700 NATS employees based at the Prestwick site, which provides air traffic control services to Scotland and beyond. In addition to this there are air traffic controllers located at airport control towers, responsible for safety of aircraft around the airfield and approach controllers, responsible for managing approaching and departing aircraft in a safe and efficient manner. SOC data identifies 1,900 employees in Scotland for SOC Code 3511, 'Air traffic controllers'. These employees will be included in the data for SIC Code 52230, 'Services incidental to air transportation'.

SOC Code data was also identified for SOC 3512, 'Aircraft pilots and flight engineers' highlighting 1900 employees with this occupation in Scotland. These employees will be part of the 3,000 employees in SIC Codes 51101, 'Scheduled passenger air transport' and 51102, 'Non-scheduled passenger air transport'.

Information published by airport operator, HIAL, states that they employ around 200 staff within their Airport Fire Service, covering 11 airports in the Highlands and Dundee. In addition to this there are private firefighting operations at Glasgow, Aberdeen and Edinburgh with an unspecified number of employees.

SIC Code data for this segment totals 80 enterprises and 8,100 employees. There is high alignment of the SIC Codes used to define this segment and the aviation and aerospace activities specified.

It should be noted that there will be no, or very low, need for new skills development with a significant proportion of employees in this segment. For example, cargo handing employees, included in SIC Code 52243, are unlikely to require additional skills as a result of decarbonisation.

It should be noted that firefighters from the Scottish Fire and Rescue Service can be called to provide supporting resources in the case of major incidents so there may be a wider need for skills development in this organisation, especially for crews nearest to major airports. A report on Organisational Statistics (2021-2022) from the Scottish Fire and Rescue Service identifies 5,600 staff scheduled to crew appliances. This number is not included in the estimate of employees for this segment.

It is therefore, assessed that 8,100 employees are active in this segment.

Aircraft and Ground Vehicle Maintenance, Repair and Overhaul

Activities included in the scope of this segment are:

- Maintenance, Repair & Overhaul of Craft
- Service, Repair & Maintenance of Delivery Drones
- Service, Repair & Maintenance of Ground Vehicles

The SIC Codes that has some alignment with these activities are:

- 33160 - Repair and maintenance of aircraft and spacecraft (which includes repair and maintenance of aircraft (except factory conversion, factory overhaul, factory rebuilding) and repair and maintenance of aircraft engines)

The number of enterprises and level of employment in the above SIC Code, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Aviation activities in segment
33160	Repair and maintenance of aircraft and spacecraft	80	2,000	High

Table 12: Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and aviation and aerospace activities covering craft/ground vehicle maintenance, repair and overhaul (Scottish data)

SIC Code data for this segment totals 80 enterprises and 2,000 employees. The SIC data has a high level of alignment with the activities defined for this segment, although repair and maintenance of ground vehicles is not included in the SIC Code data.

SOC Code data for SOC 5235, ‘Aircraft maintenance and related trades’, identifies Scottish employment in this occupation as 5,000. This is significantly higher than the SIC data of 2,000 employees. However, the SOC data has a +/- 2,300 confidence interval at the 95% level and also includes unspecified ‘related trades’.

Therefore, it is assessed that the employment in this segment is approximately 2,000. As stated earlier, this does not include repair and maintenance of airport ground vehicles.

End of Life / Circular Economy

Activities included in the scope of this segment are:

- Re-lifing / reusing, repurpose with modifications and down cycling

- Aircraft Decommissioning
- Ground Vehicle Dismantling/ Treatment

The SIC Codes that has some alignment with these activities are:

- 33160 - Repair and maintenance of aircraft and spacecraft (which includes repair and maintenance of aircraft (except factory conversion, factory overhaul, factory rebuilding) and repair and maintenance of aircraft engines)
- 38210 - Treatment and disposal of non-hazardous waste (which includes the disposal and treatment prior to disposal of solid or non-solid non-hazardous waste including operation of landfills for the disposal of non-hazardous waste, disposal of non-hazardous waste by combustion or incineration or other methods, with or without the resulting production of electricity or steam, compost, substitute fuels, biogas, ashes or other by-products for further use etc., treatment of organic waste for disposal)
- 38220 - Treatment and disposal of hazardous waste (which includes the disposal and treatment prior to disposal of solid or non-solid hazardous waste, including waste that is explosive, oxidising, flammable, toxic, irritant, carcinogenic, corrosive, infectious and other substances and preparations harmful to human health and the environment. This class includes operation of facilities for treatment of hazardous waste, treatment and disposal of toxic live or dead animals and other contaminated waste, incineration of hazardous waste, disposal of used goods such as refrigerators to eliminate harmful waste, treatment, disposal and storage of radioactive nuclear waste including treatment and disposal of transition radioactive waste, i.e. decaying within the period of transport, from hospitals and encapsulation, preparation and other treatment of nuclear waste for storage)
- 38310 - Dismantling of wrecks (which includes dismantling of wrecks of any type (automobiles, ships, computers, televisions and other equipment) for materials recovery. This class excludes disposal of used goods such as refrigerators to eliminate harmful waste and dismantling of automobiles, ships, computers, televisions and other equipment to obtain re-sell usable parts)
- 38320 - Recovery of sorted materials (which includes the processing of metal and non-metal waste and scrap and other articles into secondary raw materials, usually involving a mechanical or chemical transformation process. Also included is the recovery of materials from waste streams in the form of (1) separating and sorting recoverable materials from non-hazardous waste streams (i.e. garbage) or (2) the separating and sorting of mixed recoverable materials, such as paper, plastics, used beverage cans and metals, into distinct categories)

The number of enterprises and level of employment in the above SIC Code, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Aviation activities in segment
33160	Repair and maintenance of aircraft and spacecraft	80	2,000	High
38210	Treatment and disposal of non-hazardous waste	60	3,500	Low
38220	Treatment and disposal of hazardous waste	10	2,000	Low
38310	Dismantling of wrecks	5	30	Med
38320	Recovery of sorted materials	105	2,000	Low

Table 13: Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and aviation and aerospace activities covering end of life/ circular economy

Based on the SIC Codes, there are 260 enterprises and 9,530 employees in this segment. However, several of the segments have a low alignment between the SIC Code coverage and the aviation activities being investigated. Only the SIC Code 33160, repair and maintenance of aircraft and spaceraft, is assessed as having a high level of alignment, with 80 enterprises and 2,000 employees. It should be noted that there is duplication of SIC Code 33150, which is also used in the assessment of the maintenance, repair and overhaul segment. It is assessed that there is insufficient data to define an estimate of the number of employees in this segment.

Summary of Employment in the Scottish Aviation and Aerospace Landscape

Table 14 below provides a summary of the indicative levels of employment in the different aviation and aerospace segments in that are likely to require some additional skills when decarbonising.

Aviation and Aerospace Segment	Indicative total employment by segment
Design, development, testing of parts, components, systems and fuels	2,250
Design, development, testing and manufacture of craft and ground vehicles	<100
Charging/ refueling infrastructure developers/operators	Limited data
Craft/ ground vehicle owners/operators	8,100
Craft/ ground vehicle maintenance, repair and overhaul	2,000
End of life/Circular economy	Limited data

Table 14: Indicative number of employees in different segments of the aviation and aerospace landscape in Scotland

In some cases, the alignment between the aviation segment definition and SIC/SOC code data was low. In these circumstances no indicative estimates were able to be identified and therefore 'Limited data' was registered.

It should be noted that not all employees will require skills development as a result of the shift to decarbonisation. For example, of the 8,100 employees involved in craft/ground vehicle owners/operators, approximately 500 are baggage handlers, who are very unlikely to require additional skills as a result of decarbonisation beyond the operation of battery electric ground vehicles.

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