FAIR PROMOTES ELECTRIC AVIATION

ELECTRIC AVIATION 2021

TECHNOLOGY OVERVIEW

EUROPEAN UNION

Interreg Botnia-Atlantica

European Regional Development Fund

BIOFUEL REGION – FUELLING THE BIOECONOMY AND SUSTAINABLE TRANSPORTS

BioFuel Region is a member owned non-profit organization working for a well-developed bioeconomy and a low carbon vehicle fleet by initiating, coordinating, and collaborating on project. The aim is to develop the region; Sweden's four northernmost counties.

BioFuel Region is one of the FAIR project partners.

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PREFACE

Aviation is currently facing strong headwinds with COVID-related travel restrictions, environmental concerns and a challenging economic situation for regional airlines and airports. At the same time, promising developments in new technology could tackle at least some of the current challenges. Electric aviation is one of the up and coming sectors within aviation. With promises of lower noise levels, lower operation costs and lower CO_2 emissions, it could be one of several solutions leading to fossil-free aviation.

FAIR (Finding Innovations to Accelerate Implementation of Electric Regional Aviation) is a two-year project to support the early and efficient commercialization of electric regional flights in the Kvarken region. The Kvarken region consists the counties of Ostrobothnia, Southern Ostrobothnia and Central Ostrobothnia in Finland and the County of Västerbotten and the municipality of Örnsköldsvik in Sweden.

FAIR is preparing the Kvarken region for an early implementation of electric aviation. The project expands the knowledge base on electric aviation, investigates possibilities and surveys both needs and required technical investments. FAIR is one of several projects working in this new field.

Technological advancements in the fields of aviation and electrification are in a development phase, and there is a need to map the knowledge as a baseline for further studies that will be conducted in the FAIR project (market analysis, regional effects, action plan, financing solutions and innovation process).

2 AIM AND SCOPE

The aim of this report is to give an overview of the current status and future development of electric aviation. The report focuses on electric aircraft, energy carriers, regulations and airport infrastructure necessary for implementing electric aviation.

3 ELECTRIC AIRCRAFT

An electric aircraft is an aircraft powered by electric motors. The first electric aircraft (with solid wings) flew in 1973 for 14 minutes.[1] An electric aircraft can be either fully electric or hybrid electric. Two major types of energy storage technologies for electric airplanes dominate the field: battery electric and hydrogen fuel cell electric.

[1] Taylor, John W. R. (1974). *Jane's All the World's Aircraft 1974–75*. London: Jane's Yearbooks. p. 573.

The advantage of electric motors over combustion engines is that they are more efficient. The largest portion of potential energy that is available in the fuel used in both piston and turbine engines is converted into heat. Electrical engines only lose a fraction of their potential energy due to electric resistance. This means that an electrical aircraft can fly with more than 90% potential energy transference to the axis in the powertrain while a turboprop aircraft has a potential energy of 20–25% at low altitudes and up to 35% efficiency at high altitudes. A turbofan engine is rather effective but still not close to an electric engine.[2] Electrical engines also have a much faster acceleration from zero to maximum effect compared to both piston and turbine engines. Another upside is less maintenance since an electrical driveline has fewer moving parts that wear during operation compared to a fossil-fuel engine.

> "An electrical engine can transfer around 90% of the potential energy to the axis in the powertrain and has less maintenance as compared to a fossil fuel engine."

As noted in the introduction, electric aviation involves aircraft using a certain powertrain of battery, hybrid or hydrogen. *Electrical Vertical Take-off and Landing* (eVTOL) aircraft are closely related to this. In this technical overview of electric aviation, we will not go into depth regarding eVTOLs. This branch of electric aviation will only be briefly addressed. Another closely related development is called *more electrical aircraft* within the airline industry. This is related to electrification of different functions in an aircraft, such as de-icing, heating system, brakes, and rudder steering.[3] This development is an interesting technological shift, but it falls outside the framework of this overview and will not be addressed in this report.

3.1 Range

The range of an aircraft can be measured in three ways; theoretical range, actual range and commercial range. The theoretical range is how far an aircraft can fly at normal speed until the motors stops. Actual range is used by private aviation, for example. Commercial range includes needed reserves for flying to an alternative airport in case of bad weather, for example.[4] The websites of companies rarely indicate what type of range is being presented. This is also true for the website of *International Civil Aviation Organization (ICAO)*, which is a platform for innovation of electric and hybrid aircraft.[5] One company that clearly describes its commercial range is Pipistrel, which is the only company with a *European Union Aviation Safety Agency (EASA)* certification.

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[2] Fleckenstein, David and Platts, T.S. "Max" (2019). *Electric Aircraft Working Group Report*. Washington State Department of Transportation. p. 4.

[3] Trafikanalys (2020). *Rapport 2020:12 Elflyget – början på en spännande resa – redovisning av ett regeringsuppdrag*. p. 41.

[4] Trafikanalys (2020). *Elflyg – början på en spännande resa – redovisning av ett regeringsuppdrag. Rapport 2020:12*. p. 47.

[5] The International Civil Aviation Organization (2020-10-22). *Electric and Hybrid Aircraft Platform for Innovation (E-HAPI).* https://www.icao.int/environmental-protection/Pages/electric-aircraft.aspx

3.2 Battery Electric Aircraft

A battery electric aircraft is an electric aircraft that stores its energy in batteries. Different electric aircraft are described in this section and shown in Table 1.

Pipistrel aircraft Alpha Electro.
***Photo credit:** www.pipistrel-aircraft.com*

The Slovenian company *Pipistrel* has developed three electric aircraft. Pipistrel's *Taurus Electro* model was the first two-seat electric airplane in serial production available on the market in 2007. The airplane was powered by a 40 kW Li-based battery technology.[6] Today, the *Pipistrel Alpha Electro* is the world's first electric airplane intended for flight training. It has a flight time of 1 hour plus a 30-minute reserve. The theoretical range is 600 km. The electric motor is 60+ kW and weighs 20 kg. The 21 kWh battery pack can either be replaced in minutes or recharged in less than an hour.[7] The aircraft is certified in accordance with *Federal Aviation Administration (FAA)* regulations.[8] Pipistrel has a third model, the *Pipistrel Velis Electro*, which in June 2020 became the world's first EASA-type certified electric airplane. It is fully approved for pilot training. The Velis Electro has an entirely liquid-cooled powertrain, including the batteries. This is next generation technology that enables about a doubling of the powertrain lifetime. Flight training is the main purpose for the Velis Electro. The commercial range is around 100 km or 50 minutes.[9]

Pure flight is a Czech company that has developed the electric airplane *Phinix* or *ΦNIX*. Its first flight was in 2018, and the airplane is certified in accordance with *ELSA* (Experimental Light-Sport Aircraft) regulations.[10] The two-seat plane is powered by a 60 kW battery and the flight range is 2.5 hours.[11] In 2019, the company performed winter-climate test flights in northern Sweden.[12]

Bye Aerospace is an American company located in Denver. They started in 2014 to develop the *eFlyer 2* and *eFlyer 4*. The eFlyer 2 will be used for pilot training and is equipped with 90 kW electric power.[13] The eFlyer 2 had its first test flight in 2018, and the goal is FAA and EASA certified during 2021. Its flight time is three hours.[14] The eFlyer 4 is aiming for air taxi, cargo and advanced training uses. In April 2021, Bye Aerospace announced the eight-seat *eFlyer 800*. This electric aircraft will be equipped with two wing-mounted electric motors. The eFlyer 800 is powered by solid state lithium-sulphur batteries being developed by *Oxis Energy*, a U.K. startup. The power needed in the battery cells is 550 kWh/kg. The Li-sulphur batteries are 60% lighter than Li-ion batteries, because there is less shielding required to prevent thermal runaway when the cells are assembled into packs. Sulphur is effective as a fire retardant for the highly flammable lithium in the battery. The eFlyer 800 will have a maximum range of 930 km at a cruising speed of 520 km/h. According to Bye Aerospace, operating costs will be one fifth of conventional twin turboprop aircraft. Market introduction is planned for between 2024 and 2026.[15]

[6] https://www.pipistrel-aircraft.com/aircraft/electric-flight/taurus-electro/ Visited 13 October 2020.
[7] https://www.pipistrel-aircraft.com/aircraft/electric-flight/alpha-electro/ Visited 13 Oct. 2020.
[8] https://electrek.co/2018/04/27/all-electric-trainer-plane-airworthiness-certification-faa-us/ Visited 2 Feb. 2021.
[9] https://www.pipistrel-aircraft.com/aircraft/electric-flight/velis-electro-easa-tc/#tab-id-2 Visited 14 Oct. 2020.
[10] http://gofly.sportaviationcenter.com/airplane-light-sport-aircraft/airplane-light-sport-aircraft-lsa/airplane-e-lsa/ Visited 11 Nov. 2020.
[11] https://www.pure-flight.eu/Pure-Plane.html Visited 13 Oct. 2020.
[12] https://www.tv4.se/klipp/va/12514264/historiska-forsok-med-elflyg-i-sverige Visited 2 Dec. 2020.
[13] https://byeaerospace.com/electric-airplane/ Visited 28 Apr. 2021.
[14] https://www.greenbiz.com/article/6-electric-aviation-companies-watch Visited 13 Oct. 2020.
[15] https://www.forbes.com/sites/jeremybogaisky/2021/04/21/bye-eflyer-king-air-oxis-electric-turboprop/?sh=627d26881b8f Visited 28 Apr. 2021.

RX1E aircraft is China's first electrical two-seat aircraft developed by *Liaoning Ruixiang General Aircraft Manufacture Co., Ltd in 2016.*[16] It has a certificate from the *Civil Aviation Administration of China (CAAV)* and under the *American Society for Testing and Materials (ASTM)* standard. It has also a mass producer license. Its power is 30 kW. The RX1E is similar to Pipstrel Alpha Electro with six Kokam battery packs that can be removed for recharging.[17] Another two-seat model, the *Ruixiang Extended Range Electric Aircraft (RX1E-A)*, had its first test flight in 2018.[18]

Havilland Beaver retrofitted with the magni500. ***Photo credit:*** *MagniX Technologies.*

MagniX is a company founded in Australia in 2009 and now located in Seattle. It creates electrical motors designed to replace conventional engines.[19] The electrical motor magni250 produces 375 horsepower (280 kW) for smaller airplanes, such as the nine-seat Eviation Alice aircraft. The magni500 is a 750-horse-power (560 kW) electrical motor designed to fit in models like the *de Havilland Beaver, Cessna Caravan* and *Beechcraft King Air.* The range will be around 160 km.[20] In 2019, the Havilland Beaver, retrofitted with the magni500 system, made its first flight in Vancouver, Canada. It is operated by *Harbour Air* and is intended for short flights (30 minutes plus 30 minutes back-up) to the nearby villages from Vancouver. A certification process was started after the demonstration flight and will take around two years.[21] The first 30-minute test flight with a turboprop aircraft, the nine-seat *MagniX's 208B Cessna Grand Caravan*, took place in 2020 in partnership with *AeroTec.* The aircraft was equipped with the magni500 engine.[22] The MagniX electrical engines has a lifetime of around 30,000 hours, which is a lot more compared to conventional engines used today.[23]

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[16] http://www.rgac.net.cn/Ruixiang/Productshow/ERX1E.php Visited 14 Oct. 2020.

[17] http://sustainableskies.org/chinas-first-certified-electric-airplane-ready-for-mass-production/ Visited 14 Oct. 2020.

[18] http://www.rgac.net.cn/Ruixiang/Productshow/ERX1EA.php Visited 14 Oct. 2020.

[19] https://www.magnix.aero/products Visited 13 Oct. 2020.

[20] https://www.greenbiz.com/article/6-electric-aviation-companies-watch Visited 13 Oct. 2020.

[21] https://www.flightglobal.com/aerospace/harbour-air-to-resume-electric-powered-beaver-flights-as-certification-work-begins/136071.article Visited 14 Oct. 2020; https://www.magnix.aero/our-story Visited 14 Oct. 2020; https://www.harbourair.com/seaplanes-to-eplanes-a-2020-project-update/ Visited 3 Nov. 2020.

[22] https://www.businessinsider.com/magnix-all-electric-cessna-grand-caravan-takes-first-flight-2020-6?r=US&IR=T#history-was-made-on-thursday-according-to-magnix-ceo-roei-ganzarski-the-30-minute-first-flight-of-magnixs-cessna-grand-caravan-on-in-may-proved-that-large-turboprop-aircraft-could-be-powered-and-flown-electrically-1 Visited 13 Oct. 2020.

[23] Roei Ganzarski, CEO MagniX, personal correspondence 28 Jan. 2021.

Heart ES-19, Heart Aerospace aircraft under development. ***Photo credit:*** *Heart Aerospace.*

Heart Aerospace is a Swedish start-up developing a 19-seat electric aircraft, the *Heart ES-19*. Its range is 400 km, and it has a cruising speed of around 300 km/h for aluminium aircraft. The aircraft will be equipped with 4 engines of 400 kW each, which means a total power of around 1600 kW. The engines will be powered by 4 batteries of 180 kWh each.[24] The goal is to have the aircraft certified and ready for commercial flights in 2026. The plane should be able to use short runways, 750 m, and focuses on regional travel.[25] The company is working a lot with simulations to develop the aircraft. In late 2020, the electric propulsion system was ready, and real tests have started.[26]

Eviation is an Israeli start-up developing the electric aircraft *Alice*. It is a nine-seat plane (plus 2 crew) with a range of 1000 km, a cruising speed of 410 km/h and a Li-ion battery with usable 920 kWh.[27] The aircraft will use the electric motor from MagniX.[28] In 2019, the company announced that American-based *Cape Air* will include Alice in their 92 plane fleet. The goal is to be EASA and FAA certified in 2022, but the project might suffer from delays since the prototype caught on fire in January 2020.[29] However, the goal is to perform the first test flight in 2021.[30]

Wright Electric is an American company developing the aircraft model *Wright 1* in cooperation with *Easyjet*. Wright 1 has 186 seats and multiple electric propulsion systems under each wing. The plan is to be ready in 2030. The range will be 500 km to start with, but the goal is to attain a range of 1280 km.[31]

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[24] A. Forslund, Heart Aerospace. https://www.youtube.com/watch?v=9wJjXBiWWJQ Time 2:02.

[25] https://heartaerospace.com/ Visited 15 Oct. 2020.

[26] A. Forslund, personal comment. FAIR Webinar Heart Aerospace on the Technical Development of Electric Aviation, 1 Dec. 2020. https://www.youtube.com/watch?v=lJLN7ZAv4As&feature=youtu.be

[27] https://www.eviation.co/aircraft/#4 Visited 15 Oct. 2020.

[28] https://electrek.co/2019/06/18/eviation-electric-cape-air/ Visited 15 Oct. 2020.

[29] https://www.flightglobal.com/eviation-alice-prototype-damaged-by-electric-fire-in-arizona/136327.article Visited 15 Oct. 2020.

[30] https://www.geekwire.com/2020/electric-aircraft-motor-company-magnix-lands-deal-power-uk-startups-planned-300-plane-fleet/ Visited 11 Jan. 2021.

[31] https://weflywright.com/ Visited 19 Oct. 2020.

Table 1. Battery electric aircraft.[32]

MODEL	PASSENGERS	RETROFITTED OR WHOLE PLANE DEVELOPMENT	TEST FLIGHT	PLANNED MARKET INTRODUCTION	POWER (kW)	RANGE (KM)	FLIGHT TIME (MIN)	CRUISING SPEED (KM/H)
PIPISTREL ALPHA ELECTRO	2	Whole plane	2015, FAA cert.	Is on market	60+	140* (600)	60+30 backup	148
PIPISTREL VELIS ELECTRO	2	Whole plane	EASA cert.	2020	57.6	100*	n/a	167
PHINIX	2	Whole plane	2018	n/a	60	300	150	160-200
BYE AEROSPACE EFLYER2	2	Whole plane	2018	2021	90	n/a	180	n/a
BYE AEROSPACE EFLYER8	8	Whole plane	-	2024-2026	n/a	930	n/a	520
RX1E	2	Whole plane	2016, CAAV cert.	n/a	30	n/a	45-60	120
RX1E-A	2	Whole plane	2018	n/a	n/a	n/a	n/a	110
MAGNIX-HAVIL-LAND BEAVER	6	Retrofit	2019	n/a	560	160	30 +30 backup	n/a
MAGNIX-CESSNA CARAVAN	9	Retrofit	2020	n/a	560	n/a	n/a	n/a
HEART ES-19	19	Whole plane	-	2026	4x400	400	n/a	300
EVIATION ALICE	9+2 crew	Whole plane	-	2022	n/a	1000	n/a	410
WRIGHT 1	186	Whole plane	-	2030	n/a	500	n/a	n/a

*commercial range

3.3 Fuel Cell Electric Aircraft

Aircraft powered by fuel cells store their energy for the engines in the form of hydrogen, which is converted into electricity through the fuel cells. Table 2 shows different hydrogen-based aircraft under development.

ZeroAvia is located both in United Kingdom and the United States. In June 2020 ZeroAvia held the first test flight of the six-seat *Piper M-class* equipped with an electrical motor. In September 2020, the first test flight with the Piper M-class aircraft powered with hydrogen and fuel cells was done in Cranfield, UK.[33] It was equipped with a system from the Swedish company *Powercell*.[34] The next step is a 400 km zero emission flight. ZeroAvia is also working towards having a 19-seat aircraft that uses fuel cells instead of batteries ready for the market by 2023. It will have a range of 560 km and be equipped with a 600 kW hydrogen-electric powertrain.[35] The company also hopes to have an aircraft for 50 to 100 passengers in 2030 and for around 200 passengers in 2040.[36]

[32] For a complete and updated list, visit: *Electric and Hybrid Aircraft Platform for Innovation (E-HAPI).* https://www.icao.int/environmental-protection/Pages/electric-aircraft.aspx

[33] https://www.zeroavia.com/press-release-25-09-2020 Visited 15 Oct. 2020.

[34] Webinar on Hydrogen aviation, Per Ekdunge, Powercell. 2 Dec. 2020. https://www.youtube.com/watch?v=C4np5yxPsr0&feature=youtu.be

[35] https://www.zeroavia.com/press-release-hyflyer-2-grant Visited 28 Apr. 2021.

[36] https://www.zeroavia.com/press-release-23-06-2020 Visited 21 Oct. 2020.

H2FLY is a German spin-off from the *German Aerospace Center (DLR).* The company operates the *HY4*, which was developed by DLR, H2FLY, Pipistrel, Stuttgart Airport, Hydrogenics and the University of Ulm.[37] HY4 is a four-seat aircraft powered by a hydrogen fuel cell system with electrical propulsion. The 80 kW motor has a cruising speed of 145 km/h and a range of 750 to 1500 km. The HY4 has a special design with two fuselages, each with room for two passengers. In 2016, the HY4 made a successful test flight. A lithium battery was covering peak power loads during take-off and when climbing.[38] In November 2020, the HY4 made 35 take-offs, flying up to 2 hours per flight using a hydrogen powertrain within the EU project *Modular Approach to Hybrid-Electric Propulsion Architecture (MAHEPA).* H2FLY has also announced two additional aircraft: a six to 19 seater for 2027 and a 40 seater for 2030. The six to 19 seater will be powered by a 300 kW hydrogen propulsion system (peak power 425 kW). Range will be up to 1500 km and it will have a maximum cruise speed of 370 km/h. For the 40 seater, a 1.4 MW hydrogen power system (3 MW peak power) will enable a maximum range of 1850 km and a cruise speed of 520 km/h.[39]

Pipistrel not only works with battery electrical aircraft but also with a model called *Miniliner*, which has a hydrogen based propulsion system. It is a 19-seat aircraft, with a range of 200 to 1000 km and capable of operating quietly from runways shorter than 1 km, including grass airstrips at small aerodromes. The airplane is being developed within the EU-funded project *Community Friendly Miniliner (UNIFIER19)*, and the first step was announced in April 2021. Pipistrel aims for a market introduction in 2028 to 2030.[40]

The company *HES Energy Systems*, originally from Singapore, works together with *Aerospace Valley* in Toulouse. In 2018, the aircraft *Element One* was announced, which is designed to fly four passengers for 500 to 5000 km, depending on whether the hydrogen is stored in gaseous or liquid form. There is no more recent news on the development status of the aircraft.[41]

APUS is a German company working with two programmes: the *APUS i-5* flying testbed arena for hybrid electric aircraft together with *Rolls-Royce* and development of the hydrogen powered *APUS i-2* aircraft. The APUS i-2 is a four-seat aircraft with a range of 800 km that utilises the APUS TubeStruct technology, which permits up to 25% higher specific energy density compared with standard hydrogen fuel tanks.[42] According to the report by the consultant company *Roland Berger*, the project was announced in 2019.[43] There is no more recent information on the status of the project.

The American based *Universal Hydrogen* is working together with MagniX to retrofit a *De Havilland Canada DCH-8 Q300.* This is a 56-seat commonly used type of aircraft that will be powered by a fully electric fuel cell powertrain. Due to the large hydrogen modules, the aircraft will have a reduced capacity of 40 seats. The aircraft will be powered by a pair of two-megawatt Magnix electric motors. The hydrogen will act as a battery, producing electricity as it runs through the fuel cells. The range will be 740 km and the plane will be ready for market in 2024.[44]

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37 http://hy4.org/ Visited 5 Nov. 2020.

38 http://hy4.org/zero-emission-air-transport-first-flight-of-four-seat-passenger-aircraft-hy4 Visited 5 Nov. 2020.

39 https://h2fly.de/ Visited 9 Apr. 2021.

40 https://www.pipistrel-aircraft.com/unifier19-2/ Visited 10 May. 2021; https://www.pipistrel-aircraft.com/pipistrel-makes-significant-progress-with-miniliner-designs-for-a-new-generation-of-zero-emission-aerial-mobility/ Visited 10 May. 2021.

41 https://www.hes.sg/element-one Visited 5 Nov. 2020.

42 https://apus-aero.com/aeronautical-engineering/i-planes/i-2/ Visited 6 Nov. 2020.

43 Roland Berger (2020). *Hydrogen -A future fuel for aviation?* Downloaded 5 Nov. 2020. https://www.rolandberger.com/en/Publications/Hydrogen-A-future-fuel-of-aviation.html

44 https://interestingengineering.com/la-based-startup-collaborates-with-magnix-to-build-worlds-largest-hydrogen-plane Visited 19 Oct. 2020.

In addition to fuel cells, hydrogen can be directly utilized in engines through combustion. *Airbus* hopes to develop a zero-emission aircraft by 2035 based on a hybrid-hydrogen powertrain. Modified gas turbine engines are powered through hydrogen combustion. They work based on three concepts: *turbofan, turboprop* and *blended-wing body.* The turbofan concept uses two hybrid-hydrogen turbofan engines to power the plane. The turboprop concept is powered by two hybrid-hydrogen turboprop engines. In both cases, a liquid hydrogen storage and distribution system is used. The third concept, the blended-wing body, looks different from a traditional aircraft. The aircraft is powered by two hybrid-hydrogen turbofan engines and the liquid hydrogen storage is underneath the wings.[45] No additional technical information about the different aircraft has been found.

Table 2. Fuel cell electric aircraft.

MODEL	PASSENGERS	PLANNED MARKET INTRODUCTION	POWER (kW)	RANGE (KM)
ZEROAVIA PIPER M-CLASS	6	2020*/2023	n/a	n/a
ZEROAVIA	19	2023	600	560
HY4	4	2016*	80	750–1500
H2FLY	6–19	2027	300	1500
H2FLY	40	2030	1400	1850
PIPISTREL MINILINER	19	2028–2030	n/a	200–1000
HES ELEMENT ONE	4	n/a	n/a	500–5000
APUS I-2	4	n/a	n/a	n/a
DE HAVILLAND CANADA DCH-8 Q300	40	2024	n/a	740
ZEROAVIA	50–100	2030	n/a	n/a
ZEROAVIA	200	2040	n/a	n/a

*test flight

3.4 Hybrid Electric Aircraft

There are two types of hybrid electric aircraft: parallel hybrid and serial hybrid. A parallel hybrid is a plane with both an electrical engine and an internal combustion engine, which work in parallel to provide thrust for the aircraft. In a serial hybrid, the propellers are powered by one or several electrical motors and the electricity comes from batteries or fuel cells and from a generator powered by a turbine engine. Data for different hybrid electric aircraft are shown in Table 3.

Ampaire is an American company developing a hybrid electric aircraft called the *Electric EEL*. The aircraft is a converted conventional three-seat *Cessna 337 (Skymaster).* One of the two motors are powered by a pack of batteries. It has a range of 640 km. The first test flight in 2019 used both the conventional and the electric powertrains. Ampaire is working with *Mokulele Airlines* in Hawaii to demonstrate the benefits of electrical flying.[46] In November 2020, the Electric EEL aircraft had a 20-minute flight from Maui's Kahului Airport across the island to Hana and back on a single charge. It was the world's first demonstration

[45] https://www.airbus.com/innovation/zero-emission/hydrogen/zeroe.html Visited 22 Oct. 2020.
[46] https://www.ampaire.com/vehicles/electric-eel-aircraft Visited 15 Oct. 2020.

flight along an actual airline route.[47] Ampaire is also working on future projects, including rebuilding of a 19-seat *DHC6 (Twin Otter)* turboprop aircraft into the *Eco Otter SX*. The range of this hybrid electric plane will be 320+ km using a 1 MW power source. This project is in cooperation with *National Aeronautics and Space Administration (NASA)*.[48] The company aims to receive FAA certification in 2023, with passenger service commencing in 2024.[49]

American *Zunum Aero* is developing a hybrid electric aircraft intended for market introduction in 2023. This 12 seater will have a range of 1100 km and an engine that powers the electrical generator for the aircraft. This generator will supplement stored energy in the plane's batteries with a peak power of 500 kW during key stages of flight and over long ranges. The aircraft will be able to cruise and land on turbo-generator power alone, offering full redundancy.[50] Since late 2018, however, the company has suffered from financial problems and its future is uncertain.[51]

UK-based start-up *Faradair* is developing the 18-seat propeller-driven triplane *BEHA M1H*. The aim is to be ready for market in 2026 and to produce 300 planes by 2030.[52] At the end of 2020, the company announced a cooperation with MagniX for providing electrical motors for the aircraft. The aircraft is being built as a hybrid electric, with a biofuel-powered generator providing electricity to a pair of 750 horsepower MagniX motors.[53]

Boeing and NASA are collaborating on Subsonic Ultra Green Aircraft Research *(SUGAR)* to develop a hybrid electric aircraft *(Boeing Sugar VOLT hybrid)*.[54] Not much information is available from after 2017, other than it will have 135 seats and be ready for the market in 2030–2050.[55]

The *APUS i-5* is described in Section 3.3.

The British Electric Aviation Group (EAG) has designed a 70+ seat Hybrid Electric Regional Aircraft *(HERA)*, which will be ready for market in 2028. It will have a range of 1480 km, and the hybrid electric powertrain is designed to be able to switch to fully electric without requiring any mechanical retrofitting.[56]

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[47] Press release 9 Dec. 2020. https://fd46bca4-8fdb-4a60-bb5a-984ecb406747.filesusr.com/ugd/63e3b9_a86b919997d34a12a56727b0c110a651.pdf

[48] https://www.ampaire.com/projects/NASA-Project Visited 15 Oct. 2020.

[49] https://www.forbes.com/sites/jeremybogaisky/2021/02/18/hybrid-electric-aviation-pioneer-ampaire-to-be-acquired-by-surf-air/?sh=29e0a-4ba75a6 Visited 28 Apr. 2021.

[50] https://zunum.aero/aircraft/ Visited 15 Oct. 2020.

[51] https://www.greenbiz.com/article/6-electric-aviation-companies-watch Visited 15 Oct. 2020.

[52] https://www.faradair.com/ Visited 11 Jan. 2021.

[53] https://www.geekwire.com/2020/electric-aircraft-motor-company-magnix-lands-deal-power-uk-startups-planned-300-plane-fleet/ Visited 11 Jan. 2021.

[54] https://www.boeing.com/features/innovation-quarterly/aug2017/feature-technical-sugar.page Visited 19 Oct. 2020.

[55] https://www.icao.int/environmental-protection/Pages/electric-aircraft.aspx Visited 19 Oct. 2020.

[56] https://www.electricaviationgroup.com/electric-flight/ Visited 19 Oct. 2020.

Table 3. Hybrid electric aircraft.[57]

MODEL	PASSENGERS	PLANNED MARKET INTRODUCTION	POWER (kW)	RANGE (KM)
AMPAIRE CESSNA 337	3	2019*	n/a	640
AMPAIRE ECO OTTERN SX	19	2024	1000	320
ZUNUM AERO	12	2023	500	1100
FARADAIR BEHA M1H	18	2026	n/a	n/a
APUS I-5	n/a	n/a	n/a	n/a
BOEING SUGAR VOLT	135	2030-2050	n/a	n/a
EAG HERA	70+	2028	n/a	1480

*test flight

3.5 Electric Vertical Take-off and Landing

Electrical aviation is an exciting and innovative field, and the electrical vertical take-off and landing aircraft (eVTOL) are perhaps the most ground-breaking approach. The concept of eVTOLs is basically a merger between a helicopter/drone and an aircraft. eVTOLs can do vertical take-offs and landings, during transit are able to utilise the aerodynamic benefits of having wings in forward movement. As far as infrastructure goes, this gives the eVTOL a major advantage as it only requires a flat surface to land and take off from.

As interesting as eVTOLs are, they are a different type of electrical aircraft. Their estimated range are mostly around 30–35 km and usually designed to be able to carry two passengers together with luggage.[58] This makes them not an alternative for commercial flights but rather a new type of taxi transportation, independent of conventional roads. At this point in time, eVTOLs are primarily a future competitor to taxicabs. However, as development progresses, it seems like an eVTOL is closer to market introduction at this time than an electric aircraft for passenger transport.

4 ENERGY CARRIERS

In this chapter we will go through the two major types of energy carriers available for electric aircraft: battery electric and hydrogen fuel cell electric.

4.1 Batteries

The two most important factors affecting the development of the battery technology is battery capacity and cost.

There are different rechargeable batteries, and lithium-ion batteries (Li-ion) are offer some of the best advantages. Among Li-ion batteries, there are also different types that use different metals in the cathode (+) and anode (-). The most common type contains lithium cobalt oxide in the cathode and graphite in the anode and is used in mobile cell phones and laptops. In cars, it is most common to have lithium manganese

[57] For a complete and updated list, visit: *Electric and Hybrid Aircraft Platform for Innovation (E-HAPI).* https://www.icao.int/environmental-protection/Pages/electric-aircraft.aspx

[58] See for example Trafikanalys (2020). *Elflyg – början på en spännande resa – redovisning av ett regeringsuppdrag. Rapport 2020:12. p. 55.*

oxide in the cathode.[59] Li-ion batteries are very light weight in relation to size and energy density compared with other types of batteries.

Energy density is important in the field of battery technology. It describes how much energy a fuel or battery contains in relation to its weight in the unit watt-hours per kilogramme (Wh/kg). Today's jet fuel has an energy density of 11,000–12,000 Wh/kg.[60] Li-ion batteries have seen huge advancements in the last 20 years and today have a specific energy density of 100–265 Wh/kg.[61] The maximum energy density of 400–450 Wh/kg is assumed will be reached around 2025.[62] However, this is still a very low energy density compared with jet fuel. Probably, other types of batteries will be needed in the future of electrical flight. Today's battery research is on the verge of developing other types of Li-ion batteries that use solid state metal and using gases, like oxygen. These batteries are called Li-sulphur batteries and Li-air batteries. Both have a higher theoretical potential and are expected to have low manufacturing costs and be environmentally friendly.[63] Another type of battery in early stage of development is the Aluminium-ion battery, which is believed to reach 3–4 times the specific energy density of Li-ion batteries.[64]

In 2020, the next generation solid-state battery was tested using an UAV (unmanned aerial vehicle). This was a lithium-sulphur battery that contained 473 Wh/kg at cell level. It had around 70% more energy than the best Li-ion automotive batteries. This type of battery was used by the previously described eFlyer 800.[65]

It is important to distinguish between energy density at cell level and at pack level. For batteries used in vehicles, the cells are put together into packs consisting of the cells and some components used to hold the pack together. The weight of the components lower the energy density of the pack compared to cell level. Today, battery cells in electric cars have an energy density of 240–270 Wh/kg. At the pack level, the energy density decreases between 30 to 50% of the energy density at cell level.[66] A comparison of today's electric cars and jet fuel, where the degree of efficiency in small turbine engines gives a net content in jet fuel of around 3,700 Wh/kg means that jet fuel has about 20 times higher energy density.[67]

The relationship between the specific energy and the size of an aircraft in terms of number of passengers is summarized in Table 4 based on data from *NASA's Glenn Research Center.* Range is included to provide an idea of the possibilities and goals for developing electrical aviation.[68] As batteries are improved, ranges will be extended for the different aircraft sizes shown in Table 1. The expected improvements in battery technology, with a specific energy of 600 Wh/kg around 2030 (Figure 1), would make it technically possible to fly a 50 passenger fully electric aircraft for at least 300 km.

[59] https://www.cei.washington.edu/education/science-of-solar/battery-technology/ Visited 27 Oct. 2020.

[60] Swedish Energy Agency, 2017. https://www.energimyndigheten.se/statistik/branslen/varmevarden-och-emissionsfaktorer1/

[61] https://www.cei.washington.edu/education/science-of-solar/battery-technology/ Visited 27 Oct. 2020.

[62] Fleckenstein, David and Platts, T.S. "Max" (2019). *Electric Aircraft Working Group Report*. Washington State Department of Transportation. p. 8.

[63] J. Salomonsson and J. Jussila Hammes (2020). *Det kommersiella elflyget - verklighet eller dröm? VTI rapport 1039*. p. 20.

[64] J. Salomonsson and J. Jussila Hammes (2020). *Det kommersiella elflyget - verklighet eller dröm? VTI rapport 1039*. p. 22.

[65] https://www.forbes.com/sites/jeremybogaisky/2021/04/21/bye-eflyer-king-air-oxis-electric-turboprop/?sh=627d26881b8f Visited 28 Apr. 2021.

[66] https://omev.se/2020/05/18/energieffektivitet-batteristorlek-och-rackvidd-inte-alltid-en-linjar-historia/ Visited 9 Oct. 2020; https://ntrs.nasa.gov/citations/20180001539 Visited 2 Feb. 2021.

[67] Trafikanalys (2020). *Elflyg – början på en spännande resa – redovisning av ett regeringsuppdrag. Rapport 2020:12*. p. 42.

[68] https://ntrs.nasa.gov/citations/20180001539 Visited 2 Feb. 2021.

Table 4. The specific energy in lithium ion batteries on a cell and pack level in relation to the number of passengers and range of electric and hybrid electric aircraft.

TYPE	SPECIFIC ENERGY, CELL LEVEL, WH/KG	SPECIFIC ENERGY, PACK LEVEL, WH/KG	NUMBER OF PASSENGERS	RANGE, KM
FULLY ELECTRIC	250	150–170	2–3	330
	400	300	30	490
	600	400–500	50–70	490
HYBRID ELECTRIC	400	300	50–70	490
	600	400–500	100–150	490
	1000	>750	180	1450

The cost of batteries is improving favourably. Between 2010 and 2020, the price went down from USD 1200/kWh to USD 137/kWh. This is a price drop of nearly 90% in about ten years.[69] Figure 1 shows the different Li-ion batteries potential together with the assumed cost development through 2040.

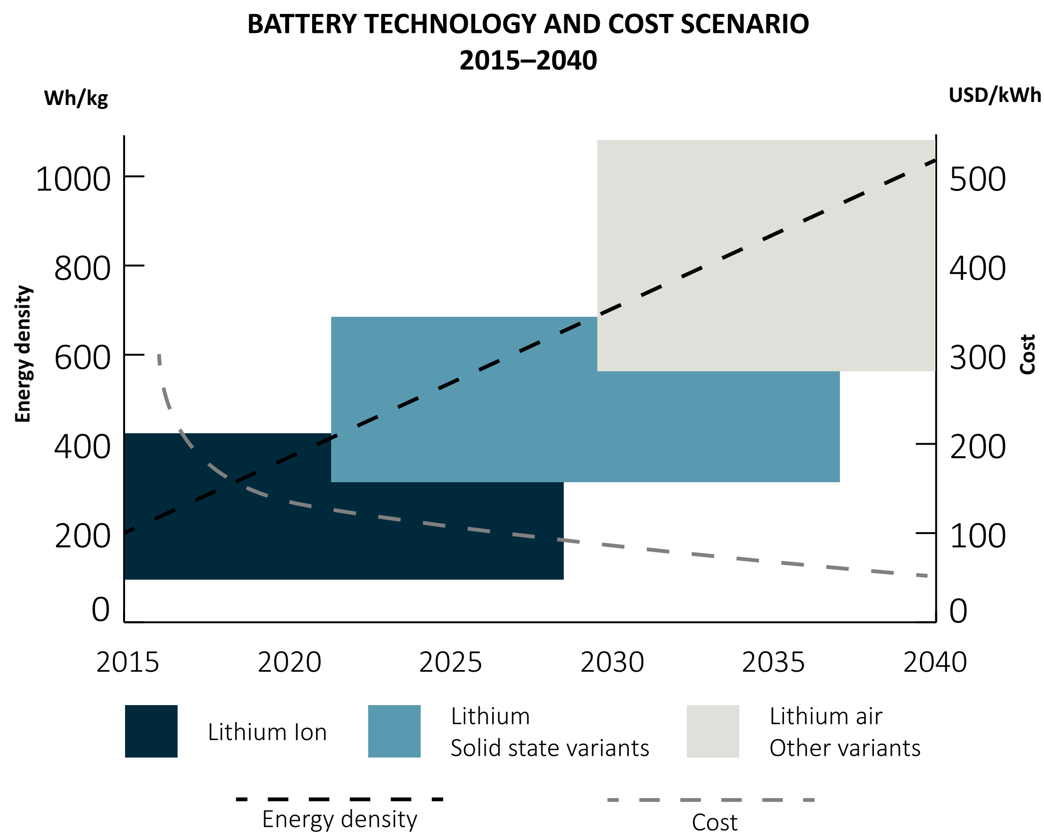

Figure 1. The assumed development of the energy density and cost for different types of lithium-ion batteries between 2015 and 2040.[70]

[69] C. Curry (2017) *Lithium-ion battery costs: squeezed margins and new business models.* Bloomberg New Energy Finance. https://www.bloomberg.com/news/articles/2020-12-17/this-is-the-dawning-of-the-age-of-the-battery?srnd=green Visited 5 Mar. 2021.

[70] JO Reimers (2018). *Introduction of Electric Aviation in Norway, Feasibility study by Green Future AS.* p. 20.

4.1.1 Battery life, mineral demand and re-cycling

Battery life will be determined by both the capacity and ability to deliver full power. Today, there are no standards for electric aviation, but it will probably be stricter compared with the car industry, where batteries are considered end of life at 75% to 80% reduced capacity.[71] The Swedish company Heart Aerospace is counting on between 1000–3000 recharging cycles for a battery before it will be replaced.[72] This is an interval between one to three years, depending on how many times a day the batteries are recharged.[73]

Mineral demand for key materials, such as cobalt and lithium, is often pointed to as a problem for expanding the use of electrical cars. These minerals often come from politically and economically instable countries. This is assumed to be a bottleneck for the expansion of the electric car industry in the next 15 years.[74] In an effort to address some of these problems, *the European Commission* has proposed modernised EU legislation aimed at steering the production of batteries to more sustainable solutions as part of a circular and climate-neutral economy.[75] This is part of the new *Circular Economy Action Plan.*[76] Batteries that are more sustainable throughout their life cycle are key for the goals of the *European Green Deal.*[77]

In terms of reuse and recycling of batteries, the trend in the car industry is on reusing old batteries as grid storage.[78] This could perhaps be a new sector. Batteries which are not suitable for cars and aircraft any longer, but nonetheless able to store relatively large amounts of energy, can yet be suitable to use in other solutions.[79] Another area for more sustainable batteries and extending the life of scarce minerals is recycling, something that *Northvolt* in Skellefteå is researching and developing.[80]

4.1.2 Safety and downsides with Li-Ion batteries

There are drawbacks with Li-ion batteries. They have a tendency to overheat, which in some cases can cause fires. Li-ion batteries require safety mechanisms to prevent high voltages and internal pressure. Another drawback is when the batteries age, they can lose capacity and frequently stop working. Moreover, Li-ion batteries are about 40% more expensive than Ni-Cd batteries.[81]

In 2018, a test flight with the two-seat *Siemens* and *Magnus' eFusion* caught fire and crashed in Hungary. Two people lost their lives. The motor installed in the prototype had a power output of 260 kW. It was also equipped with a bunch of Li-ion battery modules in the front of the aircraft.[82] The year before, a Siemens battery was used in an *Extra 330LE* prototype electric aerobatic plane that broke a new world record in speed for electrically powered aircraft.[83] We have been unable to find any more information after the accident.

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[71] Fleckenstein, David and Platts, T.S. "Max" (2019). *Electric Aircraft Working Group Report*. Washington State Department of Transportation's. p. 15.

[72] A. Forslund, personal correspondence 1 Dec. 2020.

[73] Trafikanalys (2020). *Elflyg – början på en spännande resa – redovisning av ett regeringsuppdrag. Rapport 2020:12.* p. 43.

[74] Fleckenstein, David and Platts, T.S. "Max" (2019). *Electric Aircraft Working Group Report*. Washington State Department of Transportation's. p. 15.

[75] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312 Visited 18 Mar. 2021.

[76] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_420 Visited 18 Mar. 2021.

[77] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en Visited 18 Mar. 2021.

[78] Fleckenstein, David and Platts, T.S. "Max" (2019). *Electric Aircraft Working Group Report*. Washington State Department of Transportation. p.16.

[79] ELISE/Grahn, Maria and Littorin, Henrik (2020). *Elresan: Elsystemets utveckling i samband med en introduktion av elektrisk luftfart*. p. 9.

[80] https://northvolt.com/loop Visited 18 Mar. 2021.

[81] https://www.cei.washington.edu/education/science-of-solar/battery-technology/ Visited 29 Sep. 2020.

[82] https://electrek.co/2018/06/04/siemens-electric-plane-prototype-fire-crash-death/ Visited 14 Oct. 2020.

[83] https://electrek.co/2017/04/04/all-electric-plane-record-top-speed/ Visited 14 Oct. 2020.

4.2 Hydrogen Fuel Cells

A fuel cell generates electrical energy through an electrochemical reaction. The process is similar to a battery, but with the difference that a battery needs to be recharged when the electrodes are consumed. A fuel cell produces electrical energy as long as it is fuelled by hydrogen and oxygen. Water is the only emission from a fuel cell, but at high altitudes this can impact the climate since it contributes to increased cloud formation.[84] The carbon footprint for fuel cell technology depends, however, on the manufacturing process used to make the hydrogen.

Hydrogen is in gaseous phase at room temperature and consists of two hydrogen molecules. It is the lightest element in the periodic table and has a high energy content. The energy content per kilogram is three times higher compared with jet fuel. But, per volume, it is low, which makes storage and transportation of hydrogen very space-intensive, requiring about 4 times more space than jet fuel with the same energy content. This can lead to less room for passengers and cargo or to larger aircraft.[85] As fuel cells are not able to produce enough power for lift-off, this type of solution must be complemented with a battery. There are challenges to solve for fuel cell technology and operation of 19-seat fuel cell powered airplanes may be a reality in about 10 years.[86] Similar to battery technology, the development of fuel cells is also driven by other sectors, such as the car, steel and concrete industries.[87]

According to a study by the consultancy Roland Berger, sustainable production of hydrogen together with distribution, storage and fuelling are the largest challenges for hydrogen technology becoming a reality for air traffic.[88]

HYDROGEN

Hydrogen is not naturally occurring. It can be produced in mainly three different ways:

- electrolysis where electricity is used to split water into hydrogen and oxygen
- reformation of natural gas or biogas through heating to high temperatures in a reactor
- gasification of carbon-rich material under high pressure.

Hydrogen is also a by-product from chemical industries.

5 INFRASTRUCTURAL REQUIREMENTS

For electrical and hydrogen based aviation, airport infrastructure must be adjusted in terms of charging stations and options for filling hydrogen tanks. A study on electric aviation in Norway found that regional electrical aircraft can operate at short field airports, which is defined by a runway of 800–1999 m.[89]

5.1 Charging Infrastructure

Charging infrastructure for electric aircraft needs to provide a plug that can be connected to the aircraft with a certain effect. In this early stage of electric aviation development and implementation, charging stations will probably be mobile and provided by the aircraft company. Today, almost all of the airports in the Kvarken region have power subscriptions with enough power needed for charging stations.

[84] Trafikanalys (2020). *Elflyg – början på en spännande resa – redovisning av ett regeringsuppdrag. Rapport 2020:12.* p. 44.
[85] Trafikanalys (2020). *Elflyg – början på en spännande resa – redovisning av ett regeringsuppdrag. Rapport 2020:12.* p. 44.
[86] https://www.fch.europa.eu/sites/default/files/FCH%20Docs/20200507_Hydrogen%20Powered%20Aviation%20report_FINAL%20web%20%28ID%208706035%29.pdf Visited 5 Nov. 2020.
[87] https://www.hybritdevelopment.se/ Visited 5 Nov. 2020.
[88] https://www.rolandberger.com/en/Publications/Hydrogen-A-future-fuel-of-aviation.html Visited 5 Nov. 2020.
[89] JO Reimers (2018). *Introduction of Electric Aviation in Norway, Feasibility study by Green Future AS.* p. 67.

Electrical demand depends on how the aircraft is operated. For a quick stop at an airport, fast charging is required, and for longer times on the ground, slow charging requiring a lower capacity is needed. Battery backups is another option for using slow charging systems for fast charging of an aircraft.

The time required for charging depends on battery capacity, state of charge and time available to charge. If the aircraft is capable of a battery swap, the depleted batteries could be charged at a slower rate.[90]

In May 2020, the first charging station in Sweden was inaugurated at *Dala Airport AB* in Borlänge. Dala Airport AB, *AB Dalaflyg* and *Fyrstads Flygplats AB* (Trollhättan-Vänersborg) had received financial support from *Klimatklivet*, which is a subvention from the *Swedish Environmental Protection Agency* for measures contributing to reduction of CO_2 emissions.[91] The charging stations are of the same type as fast chargers for electric cars and were installed by *Hybrida* in cooperation with the battery charging company *CTEK*.[92] *Skellefteå Airport* provides a power supply of 1 MW at airside. This will allow electric aircraft with their own charger to connect and charge. By providing a connection point, electric aircraft can use the airport even though there are no charging standard in place yet.

The Pipistrel Skycharger.
Photo credit: *www.pipistrel-aircraft.com*

Pipistrel has their own charging infrastructure that can be connected to the grid through a mobile charging station or through an installed fast charger able to charge two or four airplanes simultaneously. The charging station for two aircraft has a power of 2 x 20 kW. The time to fully charge a Pipistrel Alpha Electro (60 kW power) is one hour.[93] ByeAerospace aircraft eFlyer2 and 4 uses the same standard as fast chargers for electric cars.[94]

The Australian company *Electro.Aero* presented their mobile DC charger with a power of 30 kW in 2019. It is able to handle 300 to 1000 V depending on the infrastructure at the airport. The charger is constructed to connect to 3-phase 50 A and fit under the wings of most aircraft.[95] Their first customer was Ampaire, which is described more in the Section 3.4.

In Hawaii, the company Ampaire has started a one-month demonstration programme along a commercial air route. For the flight trials, the only change to ground equipment was the requirement to wire a Mokulele hangar with a 3-phase outlet. Ampaire has been working with *the Hawaii Department of Transportation* and *the Hawaiian Electric Company* to explore longer-term infrastructure solutions to support a fleet of hybrid or fully electric aircraft.[96]

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[90] Fleckenstein, David and Platts, T.S. "Max" (2019). *Electric Aircraft Working Group Report. Washington State Department of Transportation's.* p. 11

[91] https://www.naturvardsverket.se/Nyheter-och-pressmeddelanden/Satsning-pa-elektrifiering-genom-elflyg-och-elbussar-i-Klimatklivet—/ Visited 16 Nov. 2020.

[92] https://www.di.se/nyheter/forst-ut-i-sverige-har-kan-man-ladda-sitt-el-flygplan/ Visited 16 Nov. 2020.

[93] https://www.pipistrel-aircraft.com/aircraft/electric-flight/charging-infrastructure/ Visited 16 Nov. 2020.

[94] https://www.ostersund.se/download/18.1c9eb4ca16b237f846c52f73/1597991167355/2019.07.01_Rapport-Green-Flyway_v1-3_final.pdf Downloaded 16 Nov. 2020.

[95] https://www.electrive.com/2019/10/26/electro-aero-presents-dc-charging-solution-for-electric-aircraft/ Visited 18 Nov. 2020.

[96] Press release 9 Dec. 2020. https://fd46bca4-8fdb-4a60-bb5a-984ecb406747.filesusr.com/ugd/63e3b9_a86b919997d34a12a56727b0c110a651.pdf

5.1.1 Charging standard

There is currently no global standard for charging aircraft at airports. In fact, there are no global standards at all when it comes to heavy duty vehicles or aircraft. But there are organisations working towards establishing a global standard, the biggest of whom seems to be CharIn.[97] They started working on developing a standard under the name *High Power Charging for Commercial Vehicles* (HPCCV). This standard, according to CharIn, would handle up to more than 2 MW and be used for charging in the range of 200–1500 V and 0–3000 A. That should be enough to meet the needs of heavy-duty electric vehicles with battery pack as large as around 1 MWh.[98] In the autumn of 2020, the first prototypes were shown when the *National Renewable Energy Laboratory (NREL)*, in partnership with *CharIn* hosted an event for testing and evaluating high-power EV charging connectors currently under development by the industry. This is part of development by vehicle and equipment manufactures on HPCCV, which has been renamed *Megawatt Charging System (MCS)* and is based on t*he Combined Charging System (CCS)* standard. MCS are for outputs beyond 1 MW.[99]

Parallel to the work by CharIn, the standardisation organisation *SAE* is also working on high-power charging. There are, however, no concrete specifications related to electric aircraft.[100] So standardisation is still very much a work in progress. And as a consequence of this, today's solutions for electric aircraft in operations are to bring their own charger or use the same standard as for cars. In the future, there will probably be a global standard for charging between 750 and 2000 kW.[101] Additionally, it will probably be necessary to have a standard for docking technology since high power cables will be way too heavy to handle manually.

5.1.2 Electrical grid

The electrical grid has a pivotal role in the development of the transport sector. There are three different situations with electricity shortages.[102] Electricity shortage arise from power deficits, shortages in electrical energy or lack of capacity in the electrical grid. When demand for electricity at certain times is larger than supply, there will be a power deficit. This can happen on cold winter days with a high electricity use in combination with a low production because of, for example, bad weather conditions, production facilities off-line or a strong dependency of intermittent electricity production. Shortage of electrical energy is more of a long-time situation that can occur when the total supply of electricity is not expected to meet the total need for electrical energy over time. The probability for a shortage of electrical energy varies on a national level. Lack of capacity in the electricity grid happens when at a certain location, such as a city, does not have enough energy to meet its demand. This is due to limitations in the electrical grid and could be lack of cables, connections, or transformers able to use a certain power.[103] This is the type of problem that occurs in areas experiencing fast growth.

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[97] https://www.charinev.org/index.php?id=170

[98] https://insideevs.com/news/372749/charin-hpccv-over-2-mw-power/ Visited 18 Nov. 2020.

[99] https://insideevs.com/news/450499/megawatt-charging-system-connectors-test-nrel/ Visited 5 Mar. 2021.

[100] ELISE/Grahn, Maria and Littorin, Henrik (2020). *Elresan: Elsystemets utveckling i samband med en introduktion av elektrisk luftfart.* p. 10.

[101] Interview with Henrik Littorin 4 Sep. 2020.

[102] Region Norrbotten (2020). *Regional elnätsanalys – Norrbotten och norra Västerbotten.* p. 9. https://www.norrbotten.se/publika/lg/regio/2020/2020-09-03%20Regional%20eln%C3%A4tsanalys%20Norrbotten%20och%20norra%20V%C3%A4sterbotten.pdf

[103] https://www.ellevio.se/om-oss/Pressrum/newsroom/2019/mars/effektbrist-eller-kapacitetsbrist—eller-bade-och-vi-reder-ut-begreppen/ Visited 30 Nov. 2020.

5.2 Fuel cell infrastructure

Today, there is no hydrogen-based infrastructure in place at any airport, but there are some on-going studies on how to best fit such infrastructure into the regular electric system. Hydrogen might be a future option for larger aircraft, which will place additional requirements on infrastructure.[104] Hydrogen could be used in both gaseous and liquid phase. Theoretically, there is good potential for storage of hydrogen as an energy carrier at airports. However, safety aspects are important as well as regulations, which do not yet exist. Another interesting aspect is the integration of hydrogen in the overall system at airports, for example to integrate it with heating systems.

There are a lot of uncertainties when it comes to fuel cell infrastructure, and it will require more investigation and knowledge, a task that is outside the framework for this project.

6 RULES AND REGULATIONS

The process of certifying an aircraft is complex and largely guided by the European certification body *European Union Aviation Safety Agency (EASA)* and the U.S. equivalent, the *Federal Aviation Administration* (FAA). In addition to these organisations, there are also the *International Civil Aviation Organization* (ICAO), which is a part of the *United Nations* (UN) and supervises the Convention on International Civil Aviation (The Chicago Convention). Within ICAO, 193 member states and industry groups work towards reaching consensus on issues concerning civil aviation standards and recommended practices (SARPs). This work and policies are then used by the member states to ensure that their local civil aviation operations and regulations are in sync with global norms, which is the global foundation for a reliable, effective, safe, economically feasible and environmentally responsible civil aviation sector.[105]

6.1 Certification

The rules and regulations that governs certification of aircraft are a rather detailed and complex documentation which, in every possible way, seem to be reserved for experts. However, this does not mean that we can ignore the topic. A closer look at the supporting documentation and helpful explanations reveals that there appears to be a couple of sections that are more overarching and of relevance here. They are also reviewed and discussed in several different contexts, which makes them easier to understand, even for non-experts.

How an aircraft is certified depends on the Maximum Take Off Weight (MTOW) and number of passengers. And as this report primarily covers only electrical aircraft, we only present regulations that we understand as relevant. For us, this involves two standards: *Certification Standard 23* (CS23) and *Certification Standard 25* (CS25).

CS23 is applicable for aircraft with a MTOW of 8,618 kg and 19 passengers. CS23 is also known as "the Commuter category". For aircraft that exceed these limitations, there is CS25.[106]

CERTIFICATION STANDARDS CRITERIAS

PROPULSION	ALL	JET	PROPELLER
MAXIMUM TAKE OFF WEIGHT (MTOW)	8 618 kg or less	5 670 kg or greater	8 618 kg or greater
	AND	OR	OR
SEATS	19 seats or less	10 seats or more	19 seats or more
	=	=	=
	CS23	CS25	CS25

[104] ELISE/Grahn, Maria and Littorin, Henrik (2020). *Elresan: Elsystemets utveckling i samband med en introduktion av elektrisk luftfart*. p. 8.
[105] ICAO (2020). https://www.icao.int/about-icao/Pages/default.aspx Visited 23 sept. 2020.
[106] Reimers, Jan Otto (2018). *Introduction of electric aviation in Norway*. Feasibility study by Green Future AS. p. 16.

CS25 applies to the following type of aircraft: jets with 10 or more seats *or* a MTOW greater than 5,670 kg (12,500 pounds) *or* a propeller-driven aircraft with more than 19 seats *or* a MTOW greater than 8,618 kg (19,000 pounds).[107]

CS23 and CS25 have a similar structure. CS25, however, has a stricter system with more certification requirements and a more rigid review process from relevant authorities. As for the requirements put forth in CS23 and CS25, it seems that many of them could naturally be applied to electrical aircraft, e.g., flight characteristics, structure, systems, and documentation. However, there are no specific regiment (as of 2018 that is) regarding electric propulsion, storing and transferring of necessary amounts of electric energy. Given this, the logical conclusion seems to be that adequate requirements for electric aircraft must be formulated based on current regulations grounded in fossil fuelled propulsion or, in certain cases, formulating entirely new requirements.[108]

A Norwegian report from 2018 presents a draft of how a new set of regulations could be constructed. In broad strokes, the regulations for electric aircraft would be based on four sections:

I. existing certification requirements which will apply unchanged; and
II. existing certification requirements which will be adapted to electric propulsion; and
III. new certification requirements for electrical propulsion ("Special Conditions", "Certification Review Items"); and
IV. unique certification requirements for the specific project.[109]

The process of certifying an electric aircraft is both complicated and comprehensive. And when you want to certify new technology, it will be judged against already certified technology in a sense, something that may make it difficult to grasp and understand the process beforehand, e.g., what parts of the existing regulation may be applicable and what might demand new regulation. This transparency problem leads to a lot of uncertainties regarding the prerequisites for actors who want to certify new electrical aircraft.

6.2 Challenges with new technology

However, it is important to remember that electrical aircraft are still in a very early stage of development, both their technology and regulations. This can be seen in reports from the last couple of years, where it becomes clear how fast the development is taking place in both areas. Knowledge from three years ago might very well be outdated and something that was correct two or perhaps only one year ago may no longer be accurate. One prime example of this is that CS23 was recently [2019] rewritten to facilitate and to streamline the certification process, thus making it faster and perhaps lower the overall cost.[110] The effect of the new revisions is that rather than having to meet specified design requirements, manufactures must show that they can meet performance-based requirements based on aviation safety regulations and standards approved through consensus.

For those who want to certify electric aircraft, one big challenge is that they are not accustomed to the comprehensive certification process for aircraft and the interactions with certifying authorities. At the same time, the certifying authorities have a challenge in establishing new standards for new designs that are in parity and equal to current standards. And all of this within reasonable timeframes. At the moment, there are no standards for the kind of powerful batteries required or associated electronic components for electric propulsion of aircraft.

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[107] Fleckenstein, David and Platts, T.S. "Max" (2019). *Electric Aircraft Working Group Report*. Washington State Department of Transportation's. p. 6

[108] Reimers, Jan Otto (2018). *Introduction of electric aviation in Norway.* Feasibility study by Green Future AS. p. 16.

[109] Reimers, Jan Otto (2018). *Introduction of electric aviation in Norway.* Feasibility study by Green Future AS. p. 16.

[110] Fleckenstein, David and Platts, T.S. "Max" (2019). *Electric Aircraft Working Group Report*. Washington State Department of Transportation's. p. 6.

One challenge for manufacturers who want to become certified with the FAA is that they base their process for certification on a five-year program for aircraft intended for transportation from application and three years for other aircraft. But even the most experienced and mature companies have trouble keeping the proposed plan for certification and usually exceed the timeframe.

One concern that has been raised regarding future hybrid and electrical aircraft is that there might be significant differences in manufacturing processes compared to traditional aircraft. For example, will the construction for battery integration and optimal cooling systems present new challenges to manufactures/developers. Other aspects that might require unique manufacturing processes include the distribution of batteries, engines, higher voltages, aerodynamic considerations, the physical location of the electric systems and so on. Nobody really knows this beforehand and the only way to learn is by full-scale aircraft development programmes of new planes.[111]

A report on Norwegian infrastructure of shorter landing strips concluded that the regulations for aviation in all aspects are written primarily with a fossil-based engine system and aircraft in mind. And when new technology, new aircraft and new concepts for aviation emerge, it will undoubtedly affect the whole aviation system. This could affect such aspects as altered rules for safety, new certifications of parts and aircraft, alterations to current airport infrastructure, training and certification of pilots, and aviation regulations.[112]

The perspective you have on current regulations for electric propulsion can vary. However, there seems to be no uncertainty about the fact that regulations need updating or revising to some extent to be able to certify new technology. And when considering the pace of technology development, it becomes clear that it is of outmost importance that new rules and regulations need to be as "future-proof" as possible.

Basically, all aircraft with electric propulsion that are under development are designed to carry 19 passengers or less. The reason for this can be found in the certification rules that state that aircraft with more than 19 passengers also are required to have cabin crew, something that adds to costs for operators.

6.3 A paradigm shift

When it comes to rules and regulations regarding aircraft certification, it is apparent that there is an ongoing paradigm shift. The writings of the regulations are shifting towards a performance-based evaluation, where risk management and performance are the measure to live up to rather than fixed designs. The purpose of this shift is of course to make it easier to apply and integrate new technology and concepts to advance aircraft designs, given that the high standards of safety can be met. The general and "easy" explanation is that, as a manufacturer, you must be able to show that you are aware of and in control of risk factors and that the technical solutions proposed at a minimum meet the standard of current certified solutions.[113]

Introducing an electrical aircraft to aviation not only faces challenges regarding the certification of the planes and the design of associated infrastructure. When we look past this, we can see that there are also other rules and regulations for certifications that will be affected, e.g., training and certification of pilots and for technicians and maintenance.[114] According to the *Swedish Transport Analysis,* there is currently [2020] no specific regulation regarding permits for aircraft with electric propulsion, but they will be imposed.[115]

[111] Fleckenstein, David and Platts, T.S. "Max" (2019) *Electric Aircraft Working Group Report.* Washington State Department of Transportation's. p. 7.
[112] Avinor och Luftfartstilsynet (2020). *Forslag til program for introduksjon av elektrifieret fly i kommersiell luftfart.* p. 8.
[113] Avinor och Luftfartstilsynet (2020). *Forslag til program for introduksjon av elektrifieret fly i kommersiell luftfart.* p. 31.
[114] Avinor och Luftfartstilsynet (2020). *Forslag til program for introduksjon av elektrifieret fly i kommersiell luftfart.* p. 31.
[115] Trafikanalys (2020). *Rapport 2020:12 Elflyg – början på en spännande resa – redovisning av ett regeringsuppdrag.* p. 26.

7 DISCUSSION

Electrical and hybrid electrical aircraft and fuel cell-based aircraft are in a strong phase of development. At this point, there are no commercial air routes in the world using any of these types of techniques, but one three-seat hybrid electrical aircraft has flown a commercial route in Hawaii *(Cessna 337)* and another six-seat hybrid electrical aircraft is in the certification process in Vancouver *(MagniX-Havilland Beaver).* Certification is often a time-consuming process, and there is only one electrical aircraft that is used commercially for flight lessons; the two-seat *Pipistrel Velis electro.* The range for these models is around 30-minute flights, short distances over water or mountainous areas.

There are several promising projects currently being developed. The Sweden-based company Heart Aerospace is aiming to have a 19-seat fully electrical aircraft with a range of 400 km on the market in 2026. This type of aircraft will be a good option for regional travel. In this category of aircraft with up to 19 passengers, there are several hybrid and fully electrical aircraft that have been announced will be ready for the market before 2030. When it comes to large aircraft, the main focus will probably be on fuel cell-based aircraft, hybrid electrical aircraft and the development on bio-jet fuel as a drop-in fuel. From a technical perspective, it is realistic to believe that fully electric, hybrid electric or fuel cell-based aircraft will be available within ten years. It is hard to believe, however, that it will be on a large scale because of long delivery times, an uncertain market and difficult certification processes.

Battery development is in an exciting aspect, where the first aircraft equipped with a solid-state battery has been announced [2021]. This will enable an extended range and/or larger aircraft in the future. The use and development of Li-ion batteries will, however, probably continue to dominate in the near future. It is likely that the life of a battery for aircraft will be determined by charging cycles. The current life expectancy estimate for today's batteries is somewhere between 1 to 3 years, depending on the frequency of charging. If electric aviation is to be sustainable, there has to be a responsible way of dealing with batteries after they are deemed unfit for aircraft. This can be a new sector for new business models in the future.

There are some significant advantages with electrical aircraft that can be identified even at this early stage of development: they produce less noise, require shorter runways, are less expensive to operate due to a reduced amount of maintenance and cost for fuel, and haves lower CO_2 emissions. However, there are also barriers that have to be overcome to continue the progress, such as adopting and certifying the new technology and exploring and developing a partly new market.

Electric aviation currently has its greatest potential in short distances, 200–400 km and where the current alternative for travel involves prolonged actual distances. In these cases, the aircraft is a faster alternative compared with other options. And if people were to start flying shorter distances again, it is possible that the aviation sector will change from the current hub-model that shuttles people to large central airports. Electric aviation could change travel patterns and behaviours both on individual and society levels.

Fuel cell aviation has the greatest potential in mid-range distances, but on the longest distances drop-in bio-jet fuel will probably be the solution for achieving the goal of fossil-free aviation.

8 CONCLUSIONS

Travelling by electric aircraft within a five to ten years will most likely be possible, both technically and infrastructurally. The development of energy carriers will probably be enough for a 50-passenger aircraft with a range of 300 km. In this development phase of both electrical and fuel cell-based aircraft, it is not the technical challenges that will be the bottle-neck for the implementation on the aviation market.

As of today, only two-seat electrical aircraft have been certified, and the first larger hybrid and electrical aircraft are in different stages of the certification process. But the certification process is complicated and time-consuming even for aircraft with traditional fossil-based propulsion, and the new challenges of electrical propulsion may make it even more challenging.

The range of electric and hybrid electric aircraft is based on today's battery technology. The development of battery technology correlates with range and, in the future, the range of planes will be extended by using future battery technologies.

Efforts are currently underway for standardisation of charging infrastructure, which will likely facilitate implementation at airports. Several uncertainties remain, making it difficult for airports to foresee necessary development of ground infrastructure.

9 ABBREVIATIONS

ASTM	American Society for Testing and Materials
EAG	British Electric Aviation Group
CS23	Certification Standard 23
CS25	Certification Standard 25
CAAV	Civil Aviation Administration of China
CCS	Combined Charging System
EV	Electric Vehicle
eVTOL	Electrical Vertical Take-off and Landing
EASA	European Union Aviation Safety Agency
ELSA	Experimental Light-Sport Aircraft
FAA	Federal Aviation Administration
FAIR	Finding Innovations to Accelerate Implementation of Electric Regional Aviation
HERA	Hybrid Electric Regional Aircraft
ICAO	International Civil Aviation Organization
LI-ION	Lithium-ion batteries
MTOW	Maximum Take Off Weight
MCS	Megawatt Charging System
NASA	National Aeronautics and Space Administration
HPCCV	Power Charging for Commercial Vehicles
SARPS	Standards and Recommended Practices
SUGAR	Subsonic Ultra Green Aircraft Research
NREL	The National Renewable Energy Laboratory
UAV	Unmanned aerial vehicle

FINDING INNOVATIONS TO ACCELERATE THE IMPLEMENTATION OF ELECTRIC REGIONAL AVIATION

FAIR is to be seen as a first step of preparing the Kvarken region for an early implementation of electric aviation.

The project increases the knowledge base about electric aviation, investigates the possibilities and surveys both the needs and the required technical investments.

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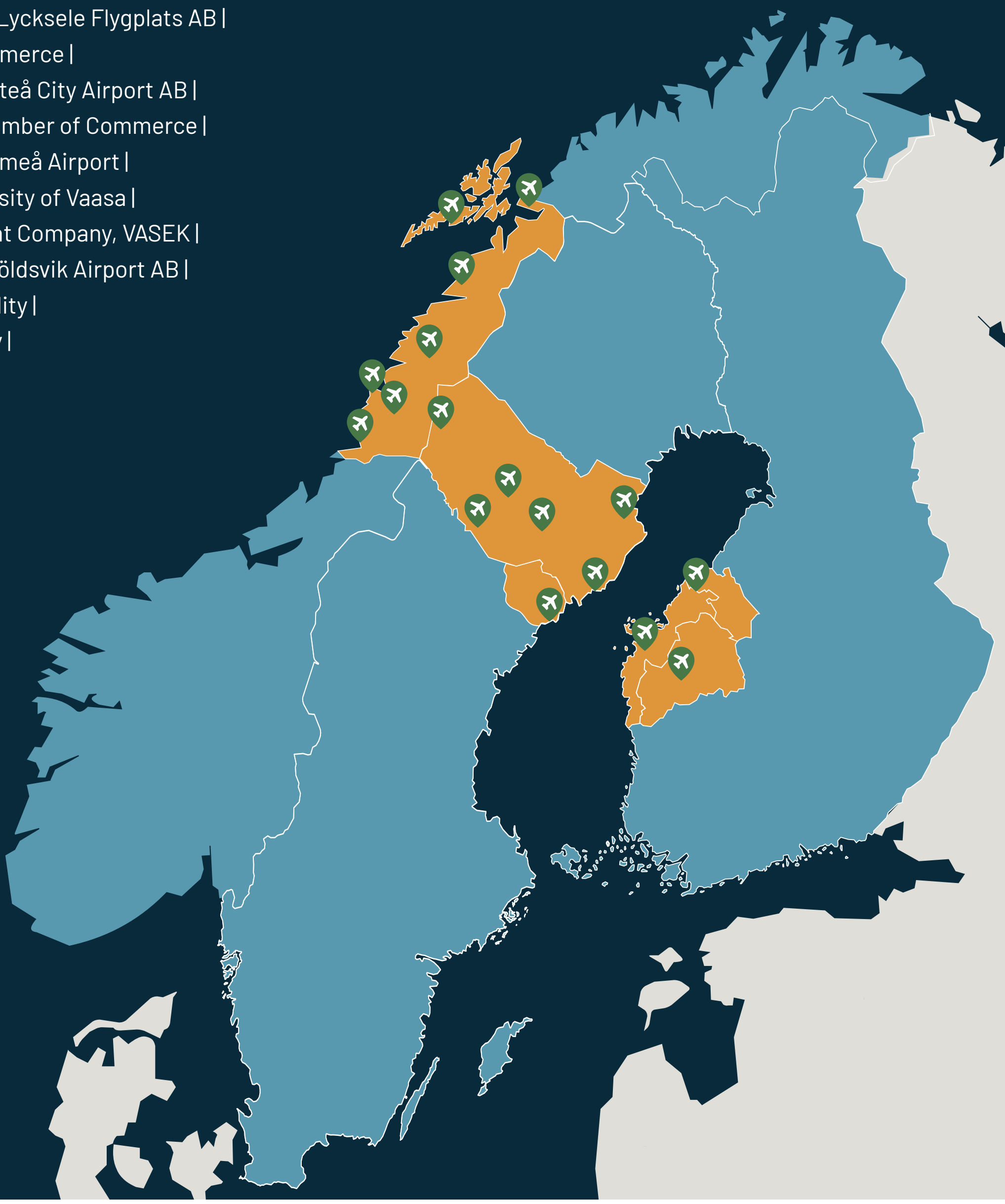

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