Opportunities for low-carbon emission aviation at Maastricht Aachen Airport

Final report

February 2022

A word of caution

This report analyses key sustainability developments in aviation and implications/opportunities for Maastricht Aachen Airport. Many sustainability technologies in aviation are still in their infancy. Therefore, quantitative analyses must be based on expert estimates or publicly announced specifications for in-development aircraft. These estimates or announced performance figures are unproven. Therefore, the analyses and recommendations from this study are our best *current* judgement. These results should be revalidated regularly in coming years when better estimates and proven performance figures will become available.

Executive summary

Preface

- This report contains the findings of a short engagement for the Province of Limburg with the overall objective to provide insights and supporting facts with regard to the development of low carbon operations at Maastricht Aachen Airport (MAA). The report extensively covers many general (non MAA-specific) aspects with the goal to improve understanding of the dynamics, the potential benefits but also the uncertainties and risks. Quantification of benefits and cost for these technologies requires a lot of assumptions. Applying these outcomes to develop a view on the market potential for a specific airport/region is even more challenging. However, using expert judgement based on a wide variety of inputs it is possible to define two development scenarios at MAA in the 2025 –2040 timeframe. Partly also for sake of feeding other assessment studies with tangible input, these scenarios were translated into traffic development, revenue, noise impact, required investments and local business opportunities. Despite the many uncertainties the project team is confident that the outcome provides a fair view on the potential development at MAA in the base-case scenario (as opposed to being a very optimistic view). The low-case scenario is, according to the project team, closer to a worst case-scenario than a lower-end base-case. It clearly is not a question whether this segment will develop but by when and by how much with timelines between a base-case and a low-case variating 5 years and a factor 2 in traffic volume

General technology development

- The aviation industry is widely known for its climate impact and has not been able to lower its emissions so far. However, a wide variety of innovations both related to fuel (SAF) as well as to aircraft technology (and ground service equipment) are being introduced. These technologies will not only make current aircraft operations more sustainable but will also enable new regional air services for passengers and cargo. Industry initiatives aiming to achieve net zero operations by 2050 expect that roughly 40% of CO_2 reduction will come from Sustainable Aviation Fuel and another 40% from new technologies using electric aircraft or hydrogen combustion
- A high-level comparison of all sustainable aviation technologies concludes that battery-electric aircraft is by far the most sustainable technology with strong additional benefits such as time-savings with improved regional connectivity (as a result of its lower cost), high energy efficiency/low lifecycle CO_2 and much lower particulate matter emission compared to cars (also electric cars) while noise levels are expected to be much lower than current aircraft. SAF will allow for less global warming impact and reduced contrails and local emissions . There is a lot potential for hydrogen in aviation especially for larger aircraft, but cost will initially be high with more complex logistics/infrastructure compared to electricity
- SAF covers a range of different fuel types both of bio- and non-biological origin that are expected to have a roughly equal share of total SAF volume by 2040. Key issues are high cost and production scaling. Over time, these will be overcome by increasing scale and rising fossil-fuel prices while regulations on minimum blending will ensure uptake towards ~10-15% in 2030 and 40-45% in 2050. For the time being, SAF distribution will mostly be through centralized blending. This means very limited investments at regional airports are needed
- New low/zero-emission aircraft covers several aircraft technologies including conventional landing and take-off as well as vertical landing and take-off. The first generations of new aircraft will use electric engines with power coming from batteries, a hydrogen-fuel cell or a hybrid-electric system using a turbogenerator. In the 2025-2030 timeframe many new aircraft are expected to enter the market. Despite their small size, cost of small aircraft will be competitive against today's 70-seater aircraft benefitting from lower energy and maintenance cost but also lower airport charges, no/lower taxes, etc. A key constraint, however, is the range of battery-electric aircraft. Before 2030 19-seaters will likely be limited to 200 - 250 km. Hybrid-electric aircraft technology will be able to achieve longer distances. Hydrogen-electric propulsion will also allow for longer distances but due will to its higher cost likely not be a key driver for unlocking new direct connections from regional airports

Potential development at Maastricht Aachen Airport

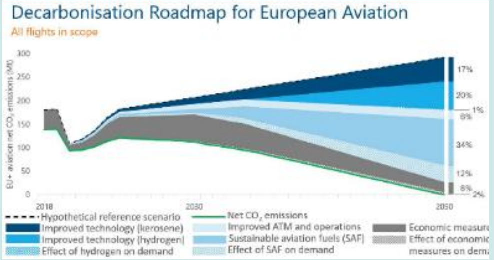
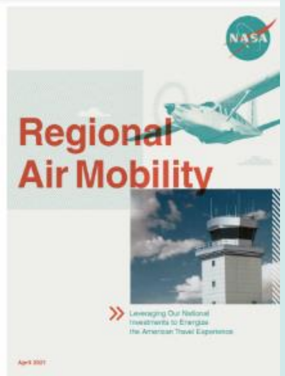
- In the context of a strong policy and regulatory framework increasing cost and limits to (growth of) fossil-fuel flights, the mobility demand to/from Zuid-Limburg and surrounding areas and the expected electric air services proposition in terms of cost and journey time vs. current travel options, a network development towards 10-15 destinations to key European cities in the 200– 750 km range can be expected to develop starting towards the end of this decade.
- Traffic potential in the base-case scenario suggests around 0.7m incremental passengers may travel to/from MAA in 2035 and about 1m by 2040 most of which are substituting car travel (to a large airport of to the final destination) with low/zero-emission air travel. In addition, a conservative estimate suggest up to 60 – 80 tons of cargo could be added through low/zero-emission cargo aircraft and drones enabling new efficient logistics solutions for short distances. The 2040 base-case traffic for these new traffic segments would be around 50-60k runway movements and another 50-70k vertical movements. This traffic is (almost) solely incremental traffic replacing mostly car travel and some truck transport. This includes passengers travelling by car or train to other airports today
- The base-case traffic would add around EUR 15m in annual revenue for MAA by around 2035 and EUR 25-30m in 2040.. A preliminary noise impact assessment indicate the noise contours will not change when only 9-seater electric aircraft will be used while introducing 19-50-seater electric aircraft will increase the noise contour slightly. This increase is expected to be easily offset by reducing large freighter aircraft movements as movements of electric aircraft are ramping up. Investments required to facilitate this traffic development towards 2040 are estimated to be in the range of EUR 12 – 14m which is mainly for electric infrastructure
- In a low-case scenario the development of new technology will face a delay of 5 years (vs. the base-case) and due to higher cost, a traffic reduction potential 50% lower than the base-case. This translates into a total of 0.4M passengers in 2035 and 30k flights and revenue of EUR 5-10m in 2040
- The introduction of new energy sources and new aircraft technologies will provide opportunities for a multitude of energy and aviation sector organisations in the MAA region. Through developing an ecosystem, MAA could position itself in the market to attract new service providers and technology companies.

Contents

Sustainable aviation is about making air travel more sustainable, but it also entails breakthrough technologies that can play an essential role in a sustainable, efficient and affordable future mobility system

🟩 Scope of this report

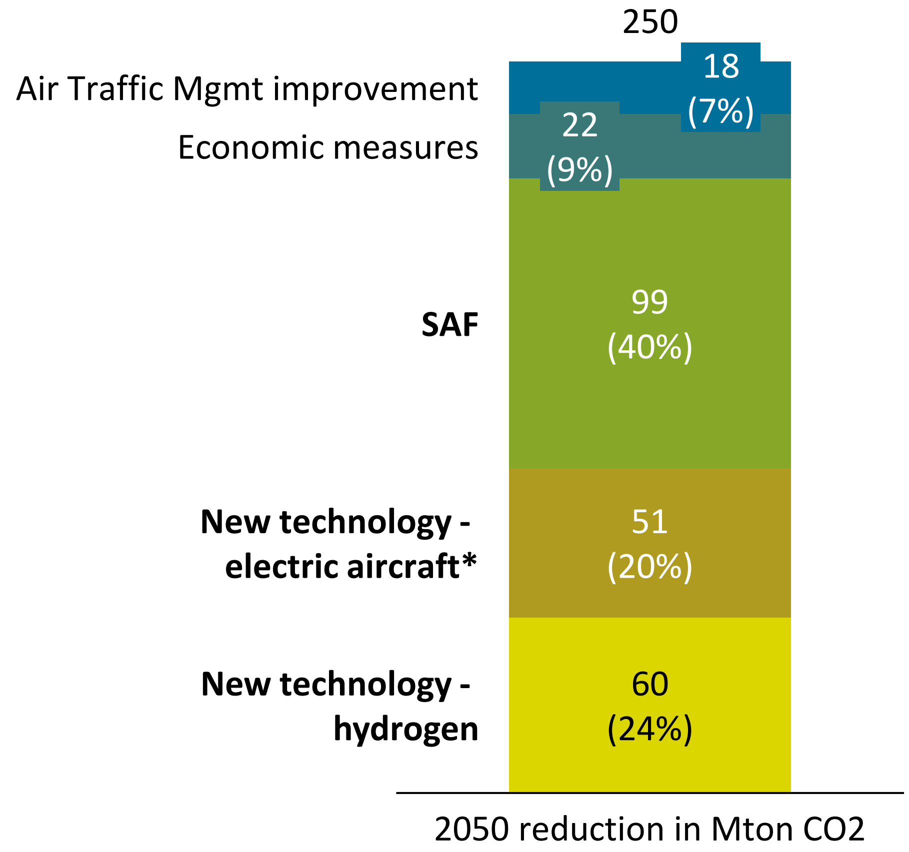
Sustainable Aviation

Aspect	**Key developments**	**Relevance to society**	**Industry initiatives** (example)
Making air travel more sustainable	• 🟩 **Sustainable Aviation Fuel** • Electrification of airport operations • New large aircraft • Pricing/fiscal measures	• Essential to drive down aviation emissions • No improvement in network • Higher cost (with likely reduced growth) • Gradually lower emissions per flight • Same stakeholders as today	
Leveraging new sustainable aircraft technology to improve *regional* connectivity	• 🟩 **New propulsion technologies** • 🟩 **New small scale aircraft** • **New ecosystem development** • Policy and regulatory context not yet adapted with potential bottlenecks in certification	• Massive expansion of regional networks • Much reduced cost for like-for-like A/C size • Much reduced travel times between regions • Reduction of road emissions, more efficient use of green energy and potentially avoidance of land-based infra investment • Much lower noise footprint • Positive commercial business case • Opportunities for new aerospace businesses	 NASA Regional Air Mobility Leveraging Our National Investments to Energize the American Travel Experience April 2021

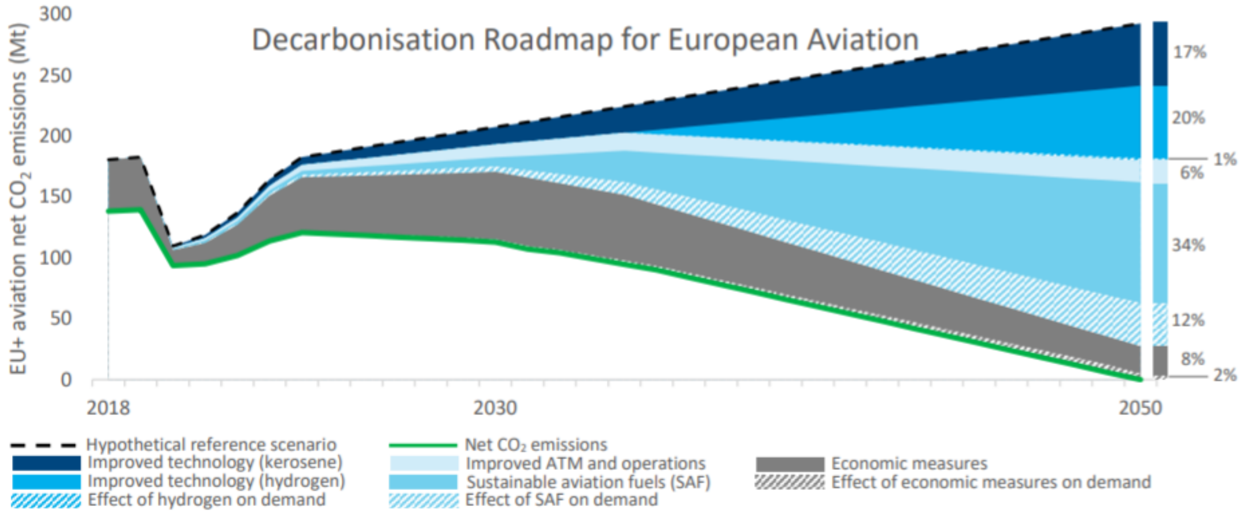
SAF and new low/zero-emission aircraft are expected to each contribute roughly 40% in the overall reduction of EU aviation emissions in 2050

Targeted sources of aviation emissions for flights departing/within EU countries

Sources of EU aviation emission reduction vs. business as usual in 2050 (excl. demand effects)



Estimated contribution of sources of emission reduction over time (incl. demand effects)



- CO_2 reduction measures addressing emission of current aviation operations are expected to reduce average annual passenger growth within/to/from EU countries from 2.0% to 1.4%
- This forecast does not include the increase in air travel from share capture from other modes of travel as a result of more efficient and lower cost aircraft technology (small electric aircraft and so-called electric air taxis)

Source: Destination 2050 (February 2021)

This report starts with assessing general technology and market developments which are subsequently translated into potential development at MAA building on insights in national and regional dynamics

	General technology and market developments	**Potential development of SAF and low/ zero-emission aircraft operations at MAA**
Sustainable Aviation Fuel (SAF) to make current aircraft operations	• Type of sustainable fuels • Availability over time • Logistics chains/local storage • Environmental aspects • Cost and airline economic aspects	• Quantity expected • Required infra • Local business opportunities

New small aircraft technologies mostly applied for new air services	• **General technology/market aspects**
	  • Propulsion technologies:
	    • Battery-electric
	    • Hydrogen-electric (with fuel cell)
	    • Hybrid-electric
	  • Type of aircraft
	  • Economics and use cases
	  • Environmental aspects and noise
	  • Required infrastructure
	• **Key players**
	  • OEMs
	  • Operators
		• **Demand dynamics**
		  • Local context dynamics
		  • Factors driving demand for new air services
		• **Potential traffic development**
		  • Routes
		  • Flights/passengers/cargo volume
		  • Impact on MAA revenue
		  • Impact on MAA noise volume
		• **Required investments to facilitate the demand**
		• **Local business opportunities**
		• Approach to developing low/zero-emission operations

Key abbreviations used for market segments

• **eCTOL**	• **C**onventional **T**ake-**O**ff and **L**anding-aircraft (requiring use of runway) with electric engines using battery-, hydrogen-fuel-cell- or hybrid-power trains
• **eVTOL**	• **V**ertical **T**ake-**O**ff and **L**anding-aircraft (requiring use of helipads/vertipads) with no more than 5 – 7 seats almost solely powered with a battery-electric power trains. Also known as air taxis/UAM
• **eCargo**	• Small to very small drones and aircraft for low volume cargo transport using either eCTOL, eSTOL or eVTOL (unmanned) aircraft technology
• **eGA**	• General Aviation operations with 4 to 9-seater CTOL aircraft for on-demand (business aviation) air services (excl. flight training and recreational use)

Note: eSTOL (**S**hort-**T**ake-**O**ff and **L**anding) not considered in this study as it will have little application at regional airports in the Netherlands

- Battery Electric and Hydrogen-Fuel Cell Electric aircraft are assumed to be **(near) zero emission** aircraft as there are no direct emissions (greenhouse gasses and pollutants)
- Through the use of SAF the direct emissions are not eliminated (they are reduced) but due to CO_2 recycling is can be argued that this is **low emission** aviation
- Combined battery electric and SAF operation at MAA are thus called **low/zero emission** aviation in this report

Contents

Topic

Sustainable aviation for conventional jet engines can be achieved through use of bio/synthetic kerosene or through the use of hydrogen as direct combustion fuel

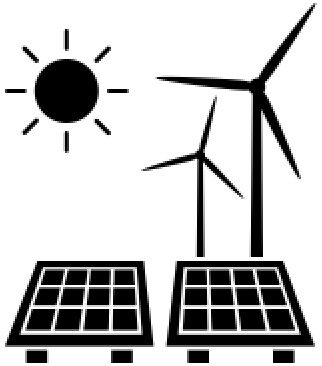
Overview of sustainable fuel technologies

SUSTAINABLE FUEL TECHNOLOGIES

Technology	State of tech development	Key market observations	
SAF	SAF made from renewable biomass and waste resources have the potential to deliver the performance of petroleum-based jet fuel but with a fraction of its carbon footprint, giving airlines solid footing for decoupling greenhouse gas (GHG) emissions from flight Longer term SAF can be made purely synthetic recycling actual CO_2	➢ Sustainable aviation fuels (advanced biofuels and electro-fuels) can significantly reduce aircraft emissions. However, this potential is largely untapped as such fuels represent only 0.05% of total jet fuel consumption ➢ Over 370,000 flights have been partly powered by SAF in the last decade proving the technology ➢ Currently up to 50% SAF is allowed to blended in but recently flights have successfully shown that 100% SAF is safe to use in commercial aircraft ➢ In order to reach full potential more production facilities are required and scaled up operations to drive costs down. Due to expected remaining cost differential with fossil fuel regulations/taxes are also required	  
HYDROGEN	Hydrogen can be used to power an existing combustion jet engine with only a few engine modifications Liquid hydrogen has about four times the volume for the same amount of energy of kerosene-based jet-fuel but only one third of the weight. In order to optimize the use new aircraft design are required	➢ Airbus is developing 3 separate zero emission aircraft that will be powered by liquid H_2. They expect to be commercially available by 2035 ➢ Boeing on the other hand does not expect H_2 to pay a role in fuelling jet aircraft before 2050. They are fully on the SAF track ➢ Hydrogen can be produced from water through a process called electrolysis, driven by renewable power, but this process is currently expensive and requires large amounts of energy. Only about 1% of hydrogen is produced this way at present.	 

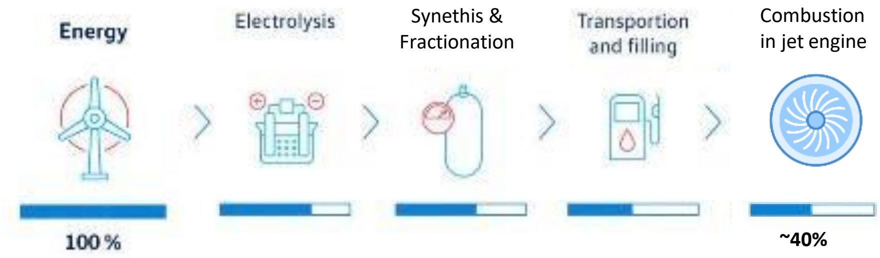
SAF and/or hydrogen offer benefits in the short term through their use in conventional jet engines

Comparison of (net) zero-emission propulsion technologies



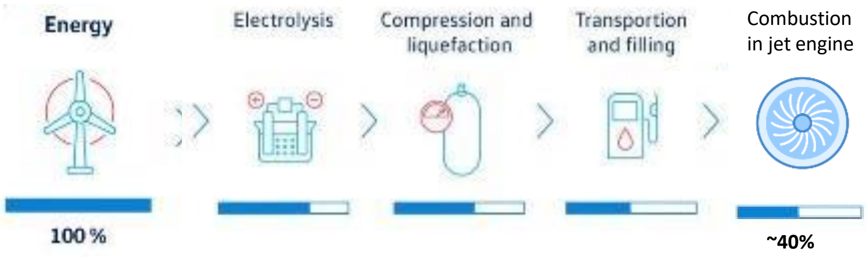
100% SAF (PtL) COMBUSTION

Currently SAF can be used blended with fossil kerosene up to 50% by volume. Tests have already demonstrated that 100% SAF is safe to use as jet fuel. Main drawbacks are limited production capacity and high costs. Benefits are the ability to use it in current aircraft engines



100% HYDROGEN COMBUSTION

Hydrogen is expected to be a promising technology for sustainable aviation, but mainly because of its high energy density. In terms of energy efficiency hydrogen-electric is less efficient. Hydrogen can be used in conventional jet engines with minor modifications



Although both technologies are still very much in testing phases (with SAF starting to be used commercially in small quantities) it would appear that the energy efficiency is roughly equal for both technologies. The main difference is that SAF is a net zero carbon emission technology while H_2 combustion is a real zero carbon emission technology

Sources: Roland Berger, M3 Desk research

Low/zero-emission aircraft are in the early stages of their development with good progress mainly in battery-electric and hybrid-electric technologies

Overview of the key low/no direct carbon emissions technologies

SUSTAINABLE PROPULSION TECHNOLOGIES

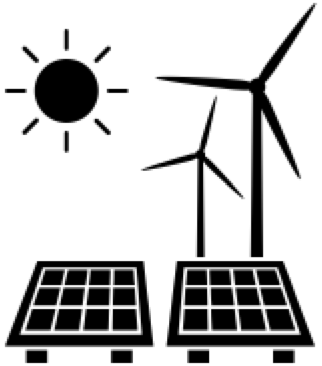
Technology	State of tech development	Key market observations	
BATTERY-ELECTRIC	- Car industry push for better batteries have resulted in energy-densities high enough to allow for first use cases in aviation - Many high potential developments of new battery-technics with a step-change in energy density and (ultimately) lower cost coming to the market between 2024 and 2030: lithium-metal; lithium-sulphur; solid-state - EASA has published its rules for certifying new battery-electric aircraft	- First fixed wing aircraft certified by EASA (2-seats, 100 km) and standards being set for electric propulsion within CS-23 - 10+ start-up OEMs have announced aircraft models with target entry into-service between 2024 and 2030 both for passenger and cargo operations - Operating commuter-class aircraft (9-19 seats) has only been demonstrated with retrofitted aircraft on 30-60min flights. Flying longer distances has not been demonstrated yet - Over 200 VTOL projects with several already in extensive testing mode achieving speeds op 200 mph and endurance of 150+ miles	 
HYDROGEN-ELECTRIC	- Hydrogen-electric is already in use for large trucks and can be applied in aircraft too - Current technology (pressurized hydrogen-gas with fuel cell to drive electric engine) can already allow for flights of 500+ km with further potential when using the more complex and costly super-cooled liquid-hydrogen - However, certification process not yet published and expected to be more difficult than battery-electric	- An increasing number of OEMs as well hydrogen-electric power train developers have been coming to the market - Main focus is on larger aircraft but initial application will be in the 19-50-seater aircraft - Technology demonstrated with a small passenger retrofit aircraft (6-seats) in a 10 min flight - In Feb 2021, the first established OEM announced the development of a new 19-seater (Pipistrel)	 
HYBRID-ELECTRIC	- Low risk with technology already existing for use in large aircraft (e.g., an A350 generator on SAF can be used for providing electricity for a 19-seater aircraft - Same A/C can be used to operate longer flights with no emission as batteries energy density improves - Concern is additional cost of dual power source	- Several hybrid-electric demonstrators already in development - Many initiatives targeting 19 up to 70-seaters	 

Battery-electric is (and is expected to remain) far more energy efficient than hydrogen-electric

Comparison of zero-emission propulsion technologies

100% BATTERY-ELECTRIC

Battery-electric seems preferred propulsion technology for short distance flights. The energy efficiency of batteries is higher than hydrogen-electric. It should be noted that battery-electric flights are limited to short distance only due to the low energy density/ heavy batteries



100% HYDROGEN-ELECTRIC

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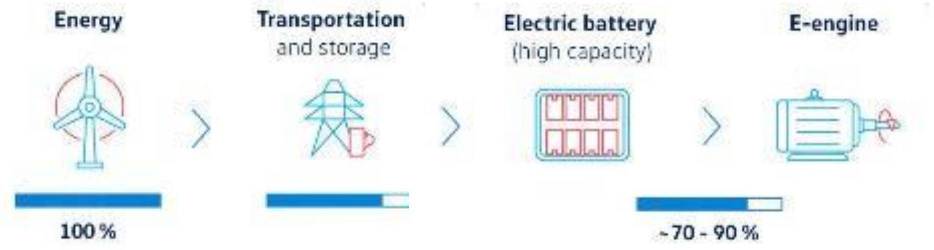
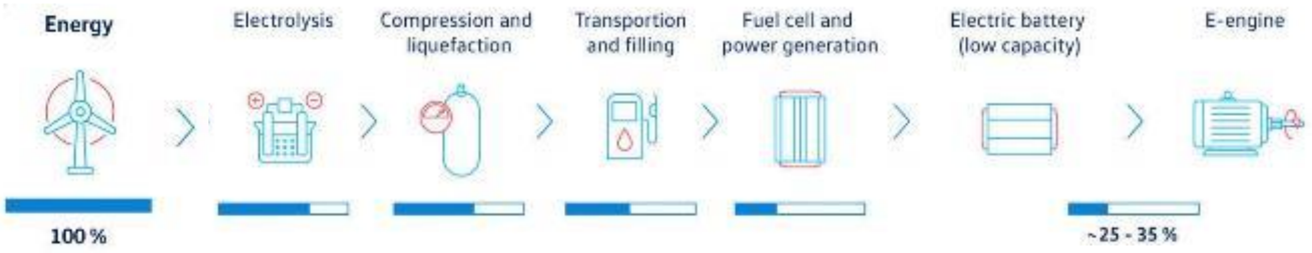




As a result, battery-electric flights will outcompete hydrogen-electric aircraft on thin routes that can be operated with electric aircraft but hydrogen-electric aircraft to be the dominant propulsion for large aircraft and/or longer distances (but with no significant cost advantage vs. fossil aircraft)

1) Aircraft Electrical Propulsion, Roland Berger; Futurebridge.com (link); Volkswagen Newsroom (link); M3 Desk research

New battery-electric aircraft are a breakthrough technology with many advantages resulting in significant environmental and health benefits both at global/national level as well as at regional/local level

Geographic scope	Societal impact	Technology advantages	Benefits vs. other transport options

• Global/ national	• Lifecycle CO_2	• No direct CO_2
		• High output in terms of seat-km per kg of body work (e.g., carbon fibre/thermoplastic) vs. car
		• Today still high CO_2 of battery production (~50-100 kg per kWh) but by 2030 CO_2 -neutral batteries available
			• Lifecycle CO_2 (early estimates) for a 400 km trip:
			  • *When travelling with alone*: 10-12x less than petrol car and 4 times less than EV
			  • *When travelling with 3 persons*: 4x less than petrol car; 1.5 x less than EV

	• Energy efficiency/ Use of scarce green electricity	• Improved glide ratio due to sleeker design but heavier; • No drag from road-friction/thinner air • More efficient propulsion (distributed, less power needed)	• Up to 10-20% fewer km needed for the same trip • Battery-electric air travel approx. 60 – 100 Wh/pkm at 300-400 km/h; EV ~ 200-220 Wh/km at 120 km/h; rail travel (average) 80 Wh/pkm at ~ 100-120 km/h
	• Usage of scarce minerals / social conditions at mining	• Currently high scarcity and social issues (e.g., cobalt mining). However, many new high energy density battery technologies don't require nickel, manganese, or cobalt • Battery recycling advancing quickly (at >90%)	• Initially negative impact but with a view on much reduced impact by around 2030;
	• Safety	• Better operational reliability due to more engines, more redundancies, fewer parts, etc. • Very high safety standards for batteries for use in aircraft; new battery-technologies much reduced risk/impact of fire	• Accident death rate of current generation commercial aviation 20 times lower than rail and 500 times lower than car travel; electric aircraft likely even better
• Regional/ local	• NO_{x}/ SO_x	• No direct emissions	• Significant benefit compared to fossil-fuel cars and aircraft
	• (ultra-) fine particles	• No fine particles emissions from electric engine;	• Early estimates suggest up to 10 times lower particulate matter emission per pkm compared to train and EV that emit due tire/wheel/break wear & tear

	• Noise	• Much reduced noise compared to current aircraft due to:
		  • Higher torque at low RPM > lower speed of propellor blade tips during take-off > shorter runway/steeper climb angle (at cost of cruise speed/range); blown-lift
		  • Less time/noise during start-up; less aerodynamic noise in cruise and landing (due to small size)
			• Very limited ground movement noise
			• Noise levels of aircraft near or below background noise outside of airport terrain. Early tests suggest 15 – 20 dB(A) noise reduction compared to small piston-engine aircraft

Source: extensive desk research and interviews with aircraft OEMs

Battery-electric aircraft and aircraft with green hydrogen fuel cells without water vapor emissions are truly zero-emission fully eliminating greenhouse gasses and air pollution from operations

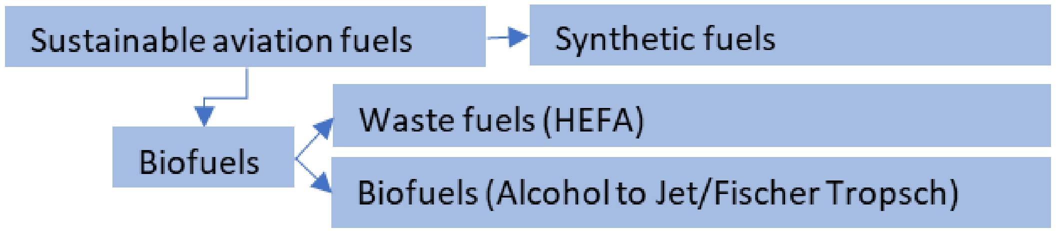
Indirect CO_2 is from manufacturing and operations and currently can only be offset; not entirely eliminated

Impact on GHG/pollution	Propulsion system/ energy source	Fossil Fuel (Kerosene)	Renewable Fuel SAF (Kerosene)	Hybrid Fossil/BE/FC	Green Hydrogen Fuel in jet engines	Green Hydrogen Fuel Cells with H_2O emissions	Green Hydrogen Fuel Cells no H_2O emissions	Battery-electric
◑	Indirect CO_2	◕	◕	◕	◕	◕	◕	◑ ↓
◑	Direct CO_2	●	●	◕	○	○	○	○
◑	Direct net NO_x	●	●	◕	◑	○	○	○
●	Direct Contrails	●	◑	◑	●	◑	○	○
◔	Direct Soot particulate radiation	●	◕	●	○	○	○	○
◑	Direct Soot particulate pollution (engines)	●	●	◕	○	○	○	○

Zero emissions

Contents

Bio or synthetic fuel is not new and does not require modifications to conventional engines but due to economic reasons will require legislation or voluntary green thinking to enjoy widespread usage



Sustainable aviation fuels

Synthetic fuels

Biofuels

Waste fuels (HEFA)

Biofuels (Alcohol to Jet/Fischer Tropsch)

- Biomass fuel is not new. It was first used in the 1850’s
- Currently much of the gasoline used (US and EU) contains ethanol which makes that gasoline a little bit more sustainable
- More than 370,000 flights have been made worldwide partially powered by SAF
- Currently SAF accounts for less than 0.1% of the aviation fuel market
- SAF at present is 2 to 6 times more expensive than fossil jet fuel
- SAF has been approved by the FAA in a mix with regular jet fuel of up to 50% SAF
- Demonstrations in 2021 have shown that aircraft (engines) can operate normally with 100% SAF
- Commitments have been made by oil producers that by 2030 10% of the jet fuel output will be SAF
- Dutch government blending mandate is 14% by 2030.

- **CO_2 reduction**
  - Up to 80% less CO_2 emissions compared to fossil jet fuel. Carbon used for SAF was previously emitted and absorbed from the atmosphere whereas the carbon from fossil fuels comes from millions of year-old reservoirs. SAF in effect recycles current CO_2
- **Improved local air quality**
  - An additional benefit of SAF is that it may reduce direct emissions of particle matter (PM) up to 90% and sulphur (SO_x) by 100% which are an extra benefit for the direct/local surroundings of airports
- **Improved fuel efficiency**
  - In studies SAF has appeared to have better fuel efficiency than fossil-based jet fuel due to it having a higher energy density. The improved fuel efficiency can be between 1.5% and 3%
- **Regional supply**
  - Regions can secure fuel availability and reduce price volatility by constructing SAF plants. This will stimulate local economics and create jobs

From the first commercial flight in 2008 some 370,000 flights have been made using a blend of sustainable aviation fuel with the latest proving 100% SAF is technically feasible and safely acceptable

Currently up to 50% SAF may be mixed in with regular jet fuel

2008

Virgin Atlantic becomes world's first airline to fly a plane on biofuel

London, 24/02/2008 - Virgin Atlantic, in partnership with Boeing, GE Aviation and Imperium Renewables, a leading biodiesel producer based in Seattle, Washington, successfully flight tested a Boeing 747 equipped with GE engines today using a 20% blend of a biojet fuel derived from babassu and coconut oil in one engine. No modifications were made to either the aircraft or its engines to enable the flight to take place.

2011

KLM Completes First Scheduled Service Flight Using Biofuel

Amsterdam, 29/06/2011 - The Dutch carrier KLM is the first airline in the world to move beyond the testing and promotion phase of using biofuels in one if its jets and is actually started using the stuff in service. The first flight occurred this week on a regularly scheduled flight from Amsterdam to Paris.

The Boeing 737-800 (similar to above) carried 171 passengers on June 29 burning a 50/50 blend of traditional jet fuel and used cooking oil. The company says it expects to be using the blend on more than 200 flights by September.

2021

First in-flight 100% sustainable-fuels emissions study of passenger jet shows early promise

Toulouse, 29/11/2021 - The ECLIF3 study, involving Airbus, Rolls-Royce, German research centre DLR and SAF producer Neste, marks the first time 100% SAF has been measured simultaneously on both engines of a commercial passenger aircraft – an Airbus A350 aircraft powered by Rolls-Royce Trent XWB engines.

United to Become First in Aviation History to Fly Aircraft Full of Passengers Using 100% Sustainable Fuel

Chicago, 01/12/2021 - The demonstration flight, which departed with more than 100 passengers from Chicago's O'Hare International Airport to Washington, D.C.'s Reagan National Airport, was on a new United 737 MAX 8. The aircraft used 500 gallons of SAF in one engine and the same amount of conventional jet fuel in the other engine to further prove there are no operational differences between the two and to set the stage for more scalable uses of SAF by all airlines in the future.

London Heathrow becomes first airport to incorporate SAF into fuel supply

London, 04/06/2021 - Heathrow has successfully incorporated sustainable aviation fuel (SAF) into its operation, ahead of the G7 Summit.

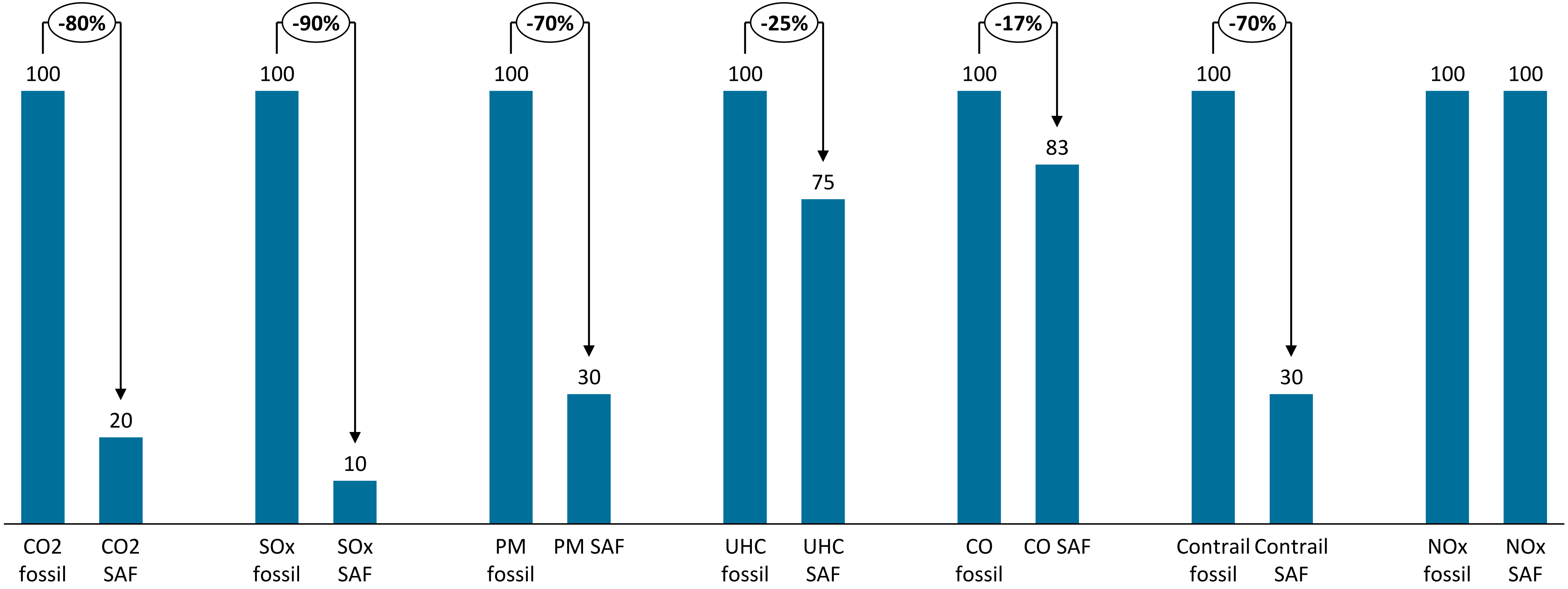
Heathrow will work alongside Vitol Aviation and Neste MY Sustainable Aviation Fuel™ where the fuel will be incorporated into the airport's main fuel supply today and blended to use across flights operating at Heathrow over the next few days.

Sources: United Airlines newsroom, Airbus newsroom, wired.com, renewable-carbon.com, IATA SAF

In addition to reducing fossil CO_2 emissions SAF also has additional benefits in reducing other pollutants with the exception of NO_x which appears to remain at the same level

SAF general

Potential and indicative lifecycle emissions % reductions utilizing 100% SAF



Depending on technology used the reduction could be as high as 100%

90% reduction for FT GTL an 100% reduction for HEFA/FT

Test on petrol cars also show that NO_x is not reduced using synthetic fuel

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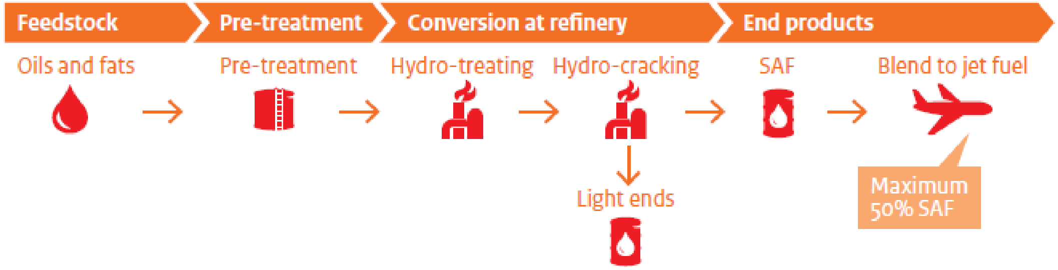
1) Sources: Euronews.green, What are sustainable aviation fuels and could they change the future of flying? , Booz Allen Hamilton: Alternative Jet Fuels Emissions, NASA for contrails, transportenvironment.org

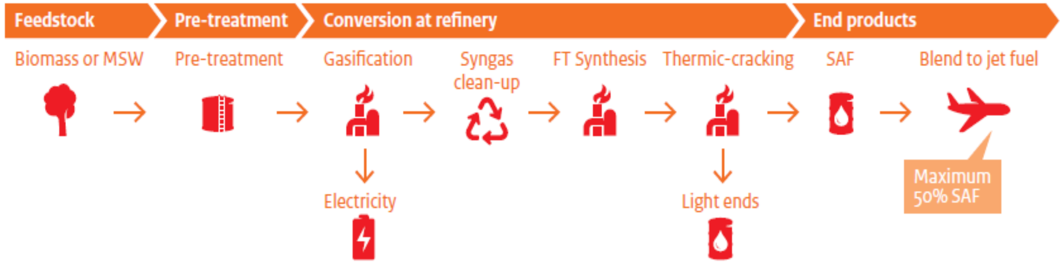
4 main technologies exist for creating SAF of which HEFA is currently already in use commercially (1)

HEFA (Hydro-processed Esters and Fatty Acids)



- Only technology for SAF currently proven on a commercial scale with 100,000 tonnes produced per year
- HEFA converts oils and fats to hydrocarbons via deoxygenation with hydrogen and cracking.
- Common feedstocks include vegetable oils, waste oils as used cooking oil
- and (inedible) animal fats
- 2 main players at present World Energy in California and Neste in Europe
- HEFA currently mainly used for road transport as renewable diesel, but it is approved for commercial aviation since 2011 and in use since then on a very small scale

Fischer-Tropsch (FT)

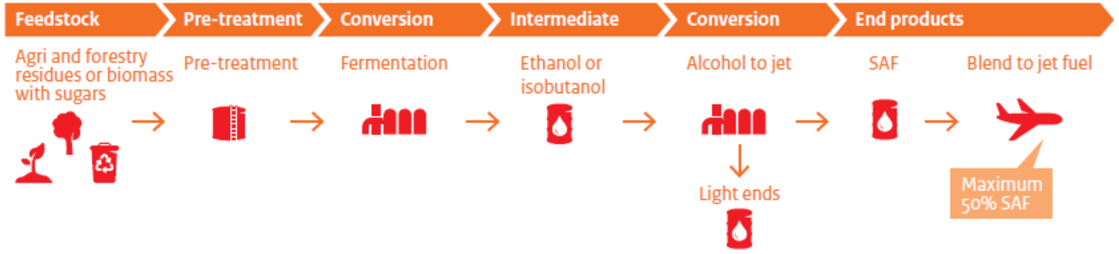


- Fischer-Tropsch (FT) is a proven technology for producing jet fuel from fossil-based feedstocks. Sasol has been producing FT-based fuel since 1955 from coal, while Shell uses FT in its Pearl GTL plant in Qatar based on natural gas.
- The technology converts any carbon-rich material into syngas which is then catalytically converted into fuel. The potential of FT is significant. The feedstock options comprise almost any carbon-rich material. Specifically, biomass, municipal solid waste, industrial gasses, biogas and landfill gas are interesting feedstocks for producing SAF. Especially from a sustainability point of view when these feedstocks are combined with renewable hydrogen to produce SAF.
- Given that FT is already proven and at scale commercially speaking, its deployment for SAF production with advanced (carbon and hydrogen) feedstock is considered feasible in this decade.

Source: Dutch Sustainable Aviation Table working group on sustainable fuels

4 main technologies exist for creating SAF of which HEFA is currently already in use commercially (2)

Alcohol-to-Jet (AtJ)



Feedstock → Pre-treatment → Conversion → Intermediate → Conversion → End products

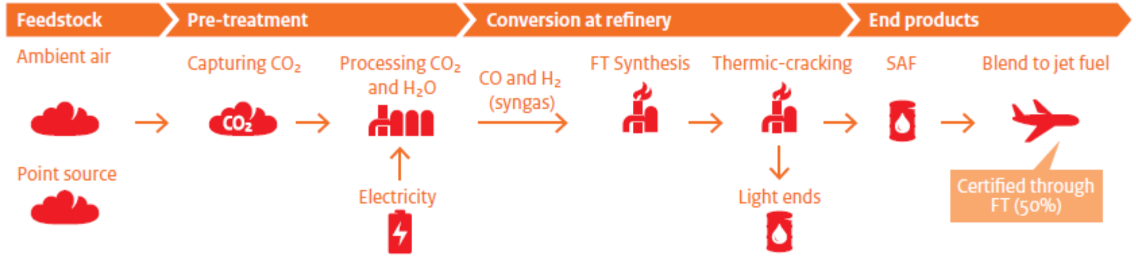
Agri and forestry residues or biomass with sugars → Pre-treatment → Fermentation → Ethanol or isobutanol → Alcohol to jet → SAF → Blend to jet fuel

Alcohol to jet ↓ Light ends

Maximum 50% SAF

- The Alcohol-to-Jet (AtJ) technology has been in development for more than a decade.
- The technology has been proven on a demonstration scale. Two small commercial plants are in development. Gevo plans to upgrade its existing facility and LanzaTech is developing a small commercial facility. Production of cellulosic ethanol by fermentation or gas fermentation has been proven on a commercial scale.
- AtJ converts sugars (from cellulosic materials or syngas) to jet through an alcohol intermediate. The feedstock options include organic waste, agriculture residues, municipal solid waste and industrial gases. Developing the AtJ technology through favourable policy is therefore also a key measure in diversifying the SAF feedstock options and scaling up production.

Power to Liquid (PtL)



Feedstock → Pre-treatment → Conversion at refinery → End products

Ambient air / Point source → Capturing CO_2 → Processing CO_2 and H_2O → CO and H_2 (syngas) → FT Synthesis → Thermic-cracking → SAF → Blend to jet fuel

Electricity ↑ Processing CO_2 and H_2O

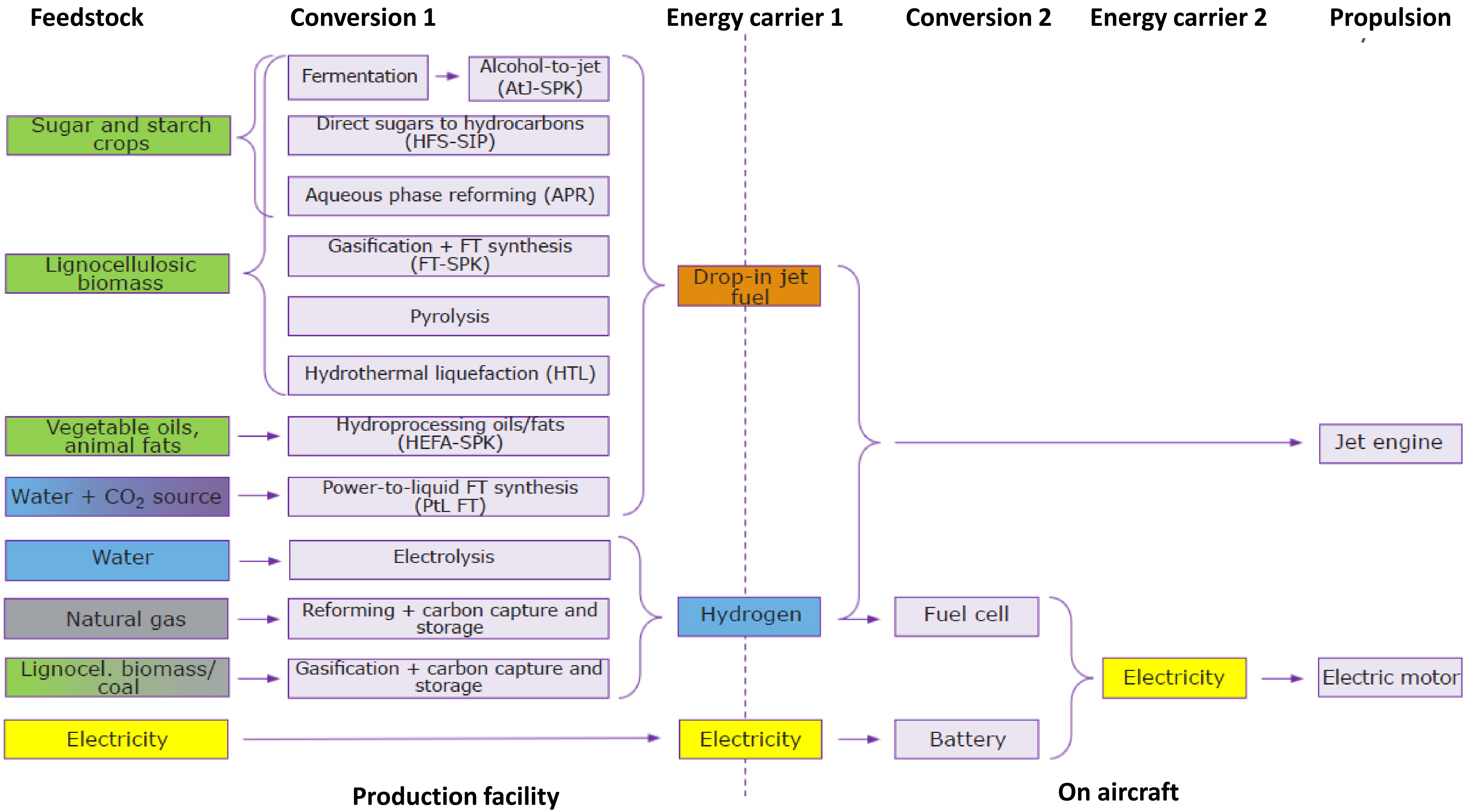
Thermic-cracking ↓ Light ends

Certified through FT (50%)

- A promising, but not yet mature, technology is Power-to-Liquid (PtL). This pathway has
- gained significant attention over the past years. One of the key advantages of this pathway is the fact that CO_2 can be used as a feedstock. With this pathway CO_2 is converted into CO, which together with hydrogen forms a very pure and clean syngas which can consequently be upgraded by means of FT to jet fuel. Although the scaling possibilities are endless when developing PtL on CO_2 from Direct Air Capture (DAC), there are significant challenges in respect of the electricity needed for this pathway and the currently limited technology readiness level.
- For PtL to succeed, there is a need for an abundance of (continuous/full load) sustainable electricity at very competitive prices (<30 EUR /MWh), which is not expected in North-Western Europe for the next decade. Also, the technology is not yet mature and needs significant scaling before commercial plants can be developed for PtL. At the same time, PtL is essential to reach 100% SAF uptake by 2050. There is therefor a need and role for favourable policies around pilot/demonstration projects to develop this pathway parallel to more commercial pathways.

Source: Dutch Sustainable Aviation Table working group on sustainable fuels

Overview of sustainable fuels and propulsion technologies from source to aircraft engine



Source: Johnson Matthey Technol. Rev., 2020 Sustainable Aviation Fuels

Dutch aviation sector short to medium term aims with regards to SAF have been defined and should get NL on track for its ambitious (higher than EU) SAF usage goals

2021-2024 (Short term)

- Production of 200,000 tonnes of SAF produced in the Netherlands via the HEFA technology in 2024.
- The first Alcohol-to-Jet (AtJ) SAF demonstration plant in the Netherlands under development.
- The first Power to Liquid (PtL) demonstration plant in the Netherlands, based on CO_2 Direct Air Capture (DAC) and/or industrial point sources, under development.
- Other feedstock opportunities for the HEFA pathway explored
- **New:** Blending mandate for Bio-SAF in the Coalition agreement

2024-2028 (Medium term)

- Production of at least 500,000 tonnes of SAF produced in the Netherlands via the HEFA technology in 2026.
- To have the first AtJ facility up and running in the Netherlands with additional R&D incentives in place to create a solid business case for these first demo facilities.
- Support international R&D challenges of the SAF sector. i.e. exploring the non-CO_2 effects of aviation and SAF in particular, ensuring that ASTM (technical certification scheme) allows for 100% SAF in the engine of a plane, ensuring the ASTM certification of new SAF technology pathways.
- Have a commercial PtL plant under construction or up and running before 2028.
- EU blending mandate of 2% by 2025

2028 onwards (Long term)

- Production of at least 640,000 tonnes SAF in the Netherlands annually to enable the 2030 SAF target of 14%.
- The WDB will work hard to further commercialise DAC or industrial point source technologies for SAF. The aim is to have at least two commercial PtL plants up and running before 2035.
- The aim is to have the first commercial AtJ facility up and running before 2030.
- The aim is to have replaced all fossil kerosene with SAF from 2050 onwards.

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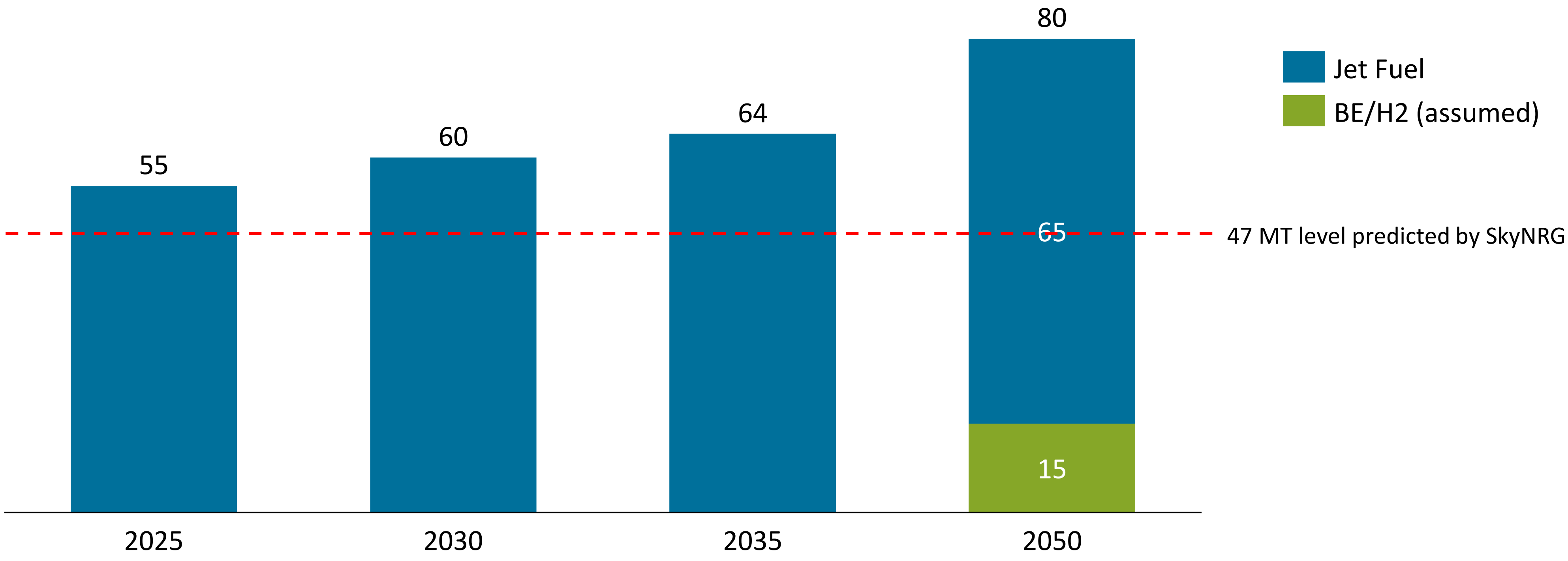
1) Ministerie van Infrastructuur en Waterstaat. (2021). WDB Action programme. The Hague: Ministerie van Infrastructuur en Waterstaat.

Although some studies expect a flat demand for jet fuel from 2025 until 2050 this is not considered realistic even taking into account use of some H_2 from 2040 onwards

Jet fuel (equivalent) demand EU (million ton)



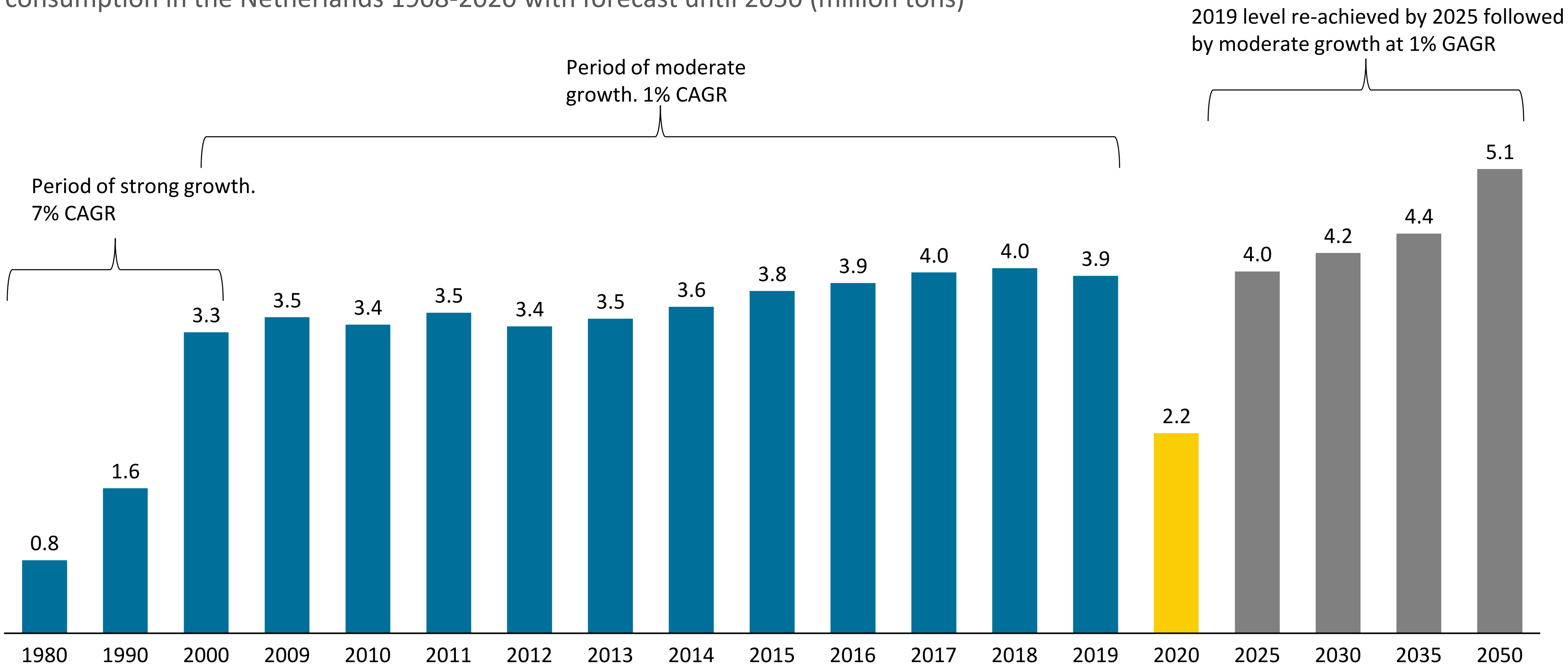
2019 level excl. UK

Note: Conservative real growth estimate of 1.5% per year for jet fuel (equivalent) demand

By 2030 the Netherlands will need to have up to 0.6 million metric ton of SAF available for internal use which will need to be ramped up in 2050 to up to 5.1 million metric ton (SAF/H_2 jet fuel equivalents)

SAF demand

Jet fuel consumption in the Netherlands 1908-2020 with forecast until 2050 (million tons)

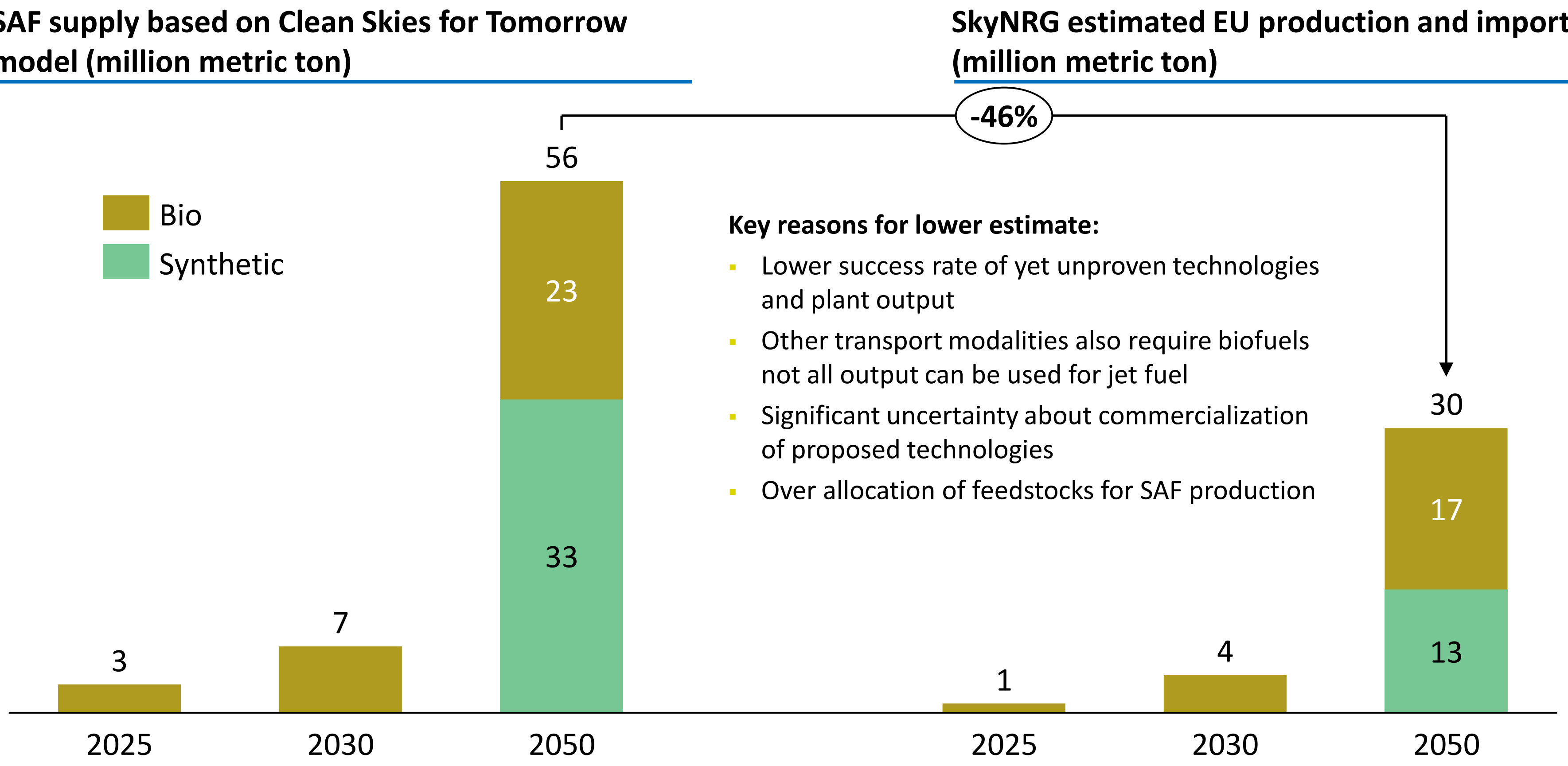


	2025	2030	2035	2050
EU SAF proposal	0.08	0.21	0.88	3.23
NL SAF proposal		0.59		5.10

Neste is investing EUR 190m in SAF refinery in Rotterdam that should produce 0.5 MT SAF by 2023

Meeting the required SAF demand in Europe looks achievable in 2030 but really challenging for 2050 based on review of the clean skies for tomorrow initiative done by SkyNRG

Global SAF production in 2020 was 0.1 MT



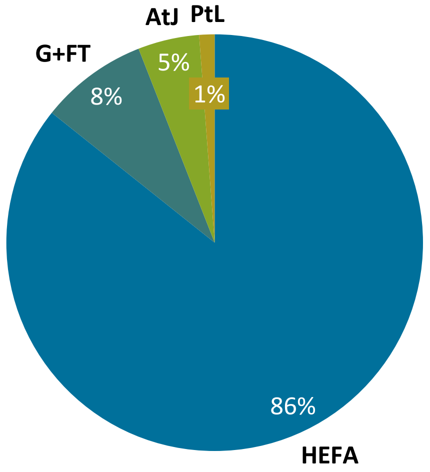
Key reasons for lower estimate:

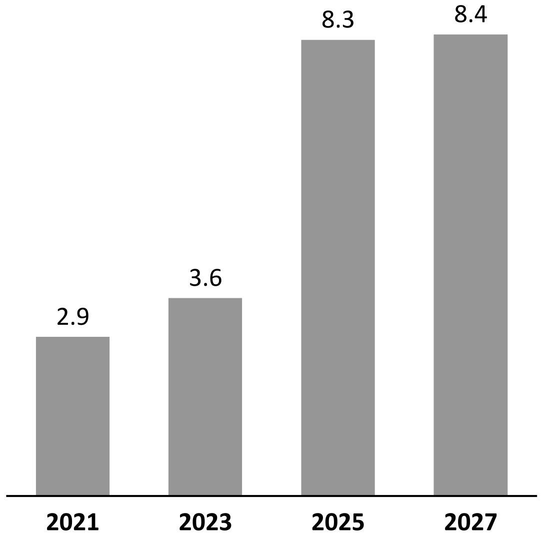
- Lower success rate of yet unproven technologies and plant output
- Other transport modalities also require biofuels not all output can be used for jet fuel
- Significant uncertainty about commercialization of proposed technologies
- Over allocation of feedstocks for SAF production

	2025	2030	2050	2025	2030	2050
% of fuel demand covered by SAF	5%	12%	70-86%	2%	7%	38-46%

Current and planned sustainable fuel initiatives in Europe are in large majority HEFA and plan to reach production capacity of 8.4 million metric tons by 2027

Supplier	Country	Technology	Start	Capacity (million MT/yr)
Neste	Finland	HEFA	-	0.4
Neste	Netherlands	HEFA	-	1.3
UPM	Finland	HEFA	-	0.1
Total Energies	France	HEFA	-	0.5
Cepsa	Spain	HEFA	-	0.1
Repsol	Spain	HEFA	2023	0.2
ENI	Italy	HEFA	2024	0.4
Preem	Sweden	HEFA	2025	1
Enerkem	Netherlands	G+FT	2021	<0.1
Colabitol	Sweden	HEFA	2022*	0.5
ENI	Italy	HEFA	2021	0.5
ST1	Sweden	HEFA	2022	0.2
Kaidi	Finland	G+FT	2022	<0.1
SkyNRG	Netherlands	HEFA	2023	0.1
Sunfire	Norway	PtL	2023	<0.1
Caphenia	Germany	PtL	2023	<0.1
Total Energies	France	HEFA	2024	0.2
SkyNRG/LanzaTech	TBD	AtJ	2024	0
Preem	Sweden	HEFA	2024	0.7
Neste	Netherlands	HEFA	2025	1
Velocys	UK	G+FT	2025	0.1
LanzaTech	UK	AtJ	2025	0.4
UPM	Finland	G+FT	2025	0.5
Fulcrum	UK	G+FT	2025	0.1
Synkero	Netherlands	PtL	2027	0.1
Engie/Safran/Airbus/AF-KLM	France	PtL	?	<0.1
				8.4





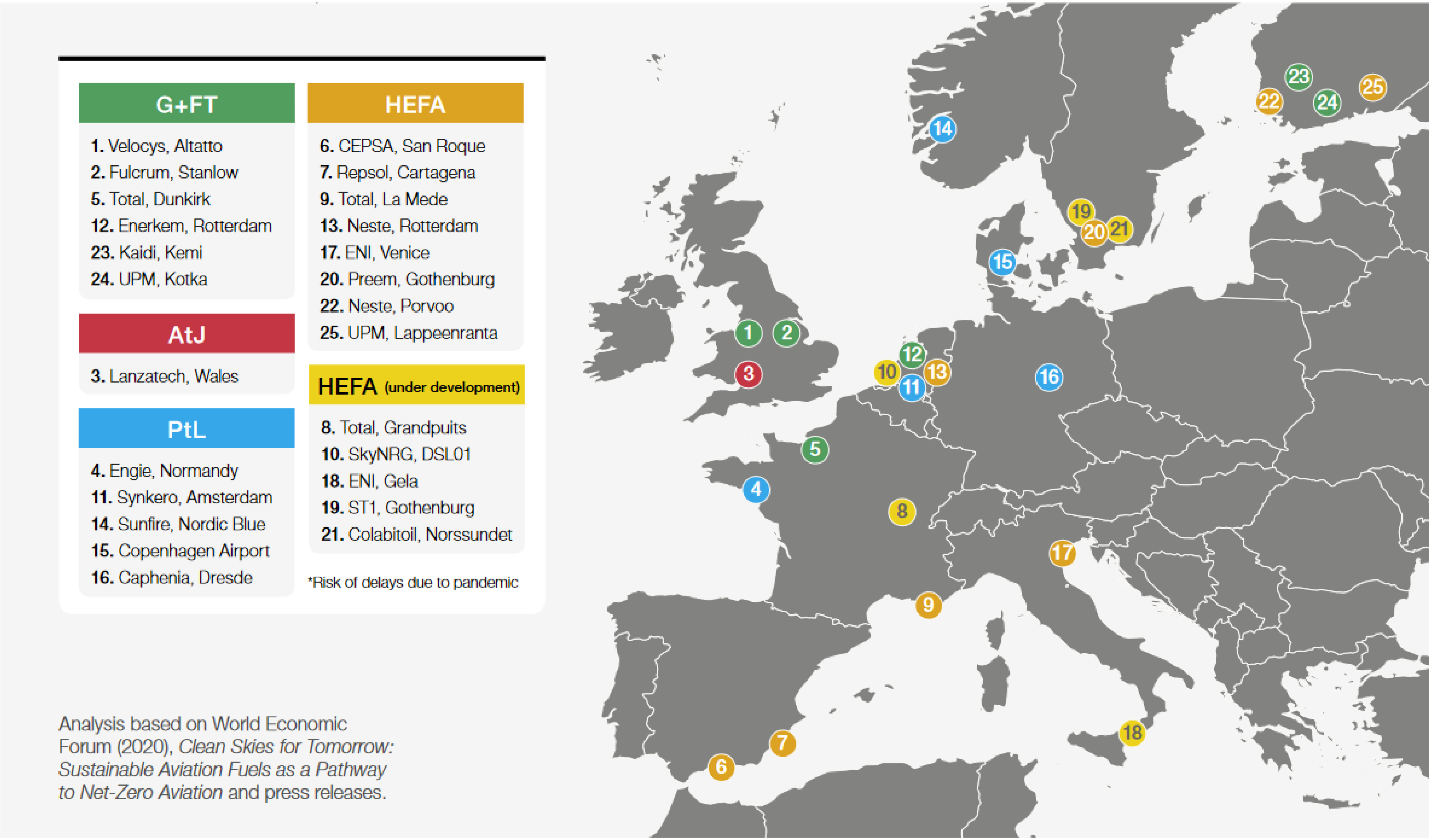
Entries in red are pilot/demonstration plants and have not been taken into account for the total capacity

* Production was planned for 2021 but more realistic is 2022

Source: WEF: Guidelines for a Sustainable Aviation Fuel Blending Mandate in Europe

Many initiatives have been announced for sustainable fuel production and several are already in a (pilot) production stage but not all output can be considered to be for aviation

SAF supply



G+FT

- **1.** Velocys, Altatto
- **2.** Fulcrum, Stanlow
- **5.** Total, Dunkirk
- **12.** Enerkem, Rotterdam
- **23.** Kaidi, Kemi
- **24.** UPM, Kotka

AtJ

- **3.** Lanzatech, Wales

PtL

- **4.** Engie, Normandy
- **11.** Synkero, Amsterdam
- **14.** Sunfire, Nordic Blue
- **15.** Copenhagen Airport
- **16.** Caphenia, Dresde

HEFA

- **6.** CEPSA, San Roque
- **7.** Repsol, Cartagena
- **9.** Total, La Mede
- **13.** Neste, Rotterdam
- **17.** ENI, Venice
- **20.** Preem, Gothenburg
- **22.** Neste, Porvoo
- **25.** UPM, Lappeenranta

HEFA (under development)

- **8.** Total, Grandpuits
- **10.** SkyNRG, DSL01
- **18.** ENI, Gela
- **19.** ST1, Gothenburg
- **21.** Colabitoil, Norssundet

*Risk of delays due to pandemic

Analysis based on World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation* and press releases.

- 4 of the initiatives are planned/located in the Netherlands with total theoretical output in 2027 of 1.6 million tons in 2027 which equates to 41% of the 2019 Dutch kerosene usage of 2019 (3.9 million metric tons)
- However, kerosene was only 27% of total fuel usage (including petrol and diesel)
- Current theoretical output is 2.4 million tons per year
- Total output by 2027 (assuming no delays/setbacks) based on the initiatives listed could be up to 8.4 million metric tons per year (excluding pilot plants)

To date 9 methods have been approved for SAF production with various blend in ratios

In order to be used in commercial flights, a sustainable aviation fuel (SAF) has to comply with ASTM D4054. As of October 2021, 9 conversion processes have been approved for SAF production.
In order to be eligible for use within the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), SAF must also meet a set of sustainability criteria

ASTM reference	Conversion process	Abbreviation	Possible Feedstocks	Blending ratio by volume	Commercialization proposals / Projects
ASTM D7566 Annex 1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT	Coal, natural gas, biomass	50%	Fulcrum Bioenergy, Red Rock Biofuels, SG Preston, Kaidi, Sasol, Shell, Syntroleum
ASTM D7566 Annex 2	Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids	HEFA	Bio-oils, animal fat, recycled oils	50%	World Energy, Honeywell UOP, Neste Oil, Dynamic Fuels, EERC
ASTM D7566 Annex 3	Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%	Amyris, Total
ASTM D7566 Annex 4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	FT-SKA	Coal, natural gas, biomass	50%	Sasol
ASTM D7566 Annex 5	Alcohol to jet synthetic paraffinic kerosene	ATJ-SPK	Biomass from ethanol or isobutanol production	50%	Gevo, Cobalt, Honeywell UOP, Lanzatech, Swedish Biofuels, Byogy
ASTM D7566 Annex 6	Catalytic hydrothermolysis jet fuel	CHJ	Triglycerides such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil	50%	Applied Research Associates (ARA)
ASTM D7566 Annex 7	Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10%	IHI Corporation
ASTM D1655 Annex A1	FOG Co-processing		Fats, oils, and greases (FOG) from petroleum refining	5%	
ASTM D1655 Annex A1	FT Co-processing		Fischer-Tropsch (FT) biocrude as an allowable feedstock for petroleum co-processing	5%	Fulcrum

Source: ICAO / Environmental Protection / GFAAF / Conversion processes

Proposed EU SAF ramp-up starts slow in 2025 but has the ambition to reach 63% by 2050 which would cover the alternative fuel requirement

SAF blending	2025	2030	2035	2040	2045	2050
SAF total	**2%**	**5%**	**20%**	**32%**	**38%**	**63%**
Bio fuels	2%	4.3%	15%	24%	27%	35%
Renewable Fuels of Non-Biological Origin (RFNBOs)	-	0.7%	5%	8%	11%	28%

The Netherlands aims to use 14% SAF in 2030 and 100% SAF in 2050

Pricing EUR /MT	2025	2030	2035	2040	2045	2050
Kerosene no taxes	**514**	**588**	**636**	**688**	**743**	**802**
Kerosene with taxes	909	983	1,100	1,200	1,300	1,400
Bio-fuels	1,150	1,650	1,950	2,000	2,000	2,000
Renewable Fuels of Non-Biological Origin (RFNBOs)	2,950	2,900	2,800	2,500	2,300	1,900
SAF cost as per EU mix	1,150	1,825	2,163	2,125	2,086	1,955
Fuel price no kerosene taxes	527	650	941	1,148	1,253	1,528
Increase over base kerosene	2%	11%	48%	69%	69%	91%
Fuel price with kerosene taxes	527	1,041	1,312	1,496	1,599	1,750
Increase over kerosene with tax	2%	4%	19%	25%	23%	25%

In additional to potential fuel taxes EU can impose penalties of up to 2x the fossil fuel price for each MT of SAF that was not used

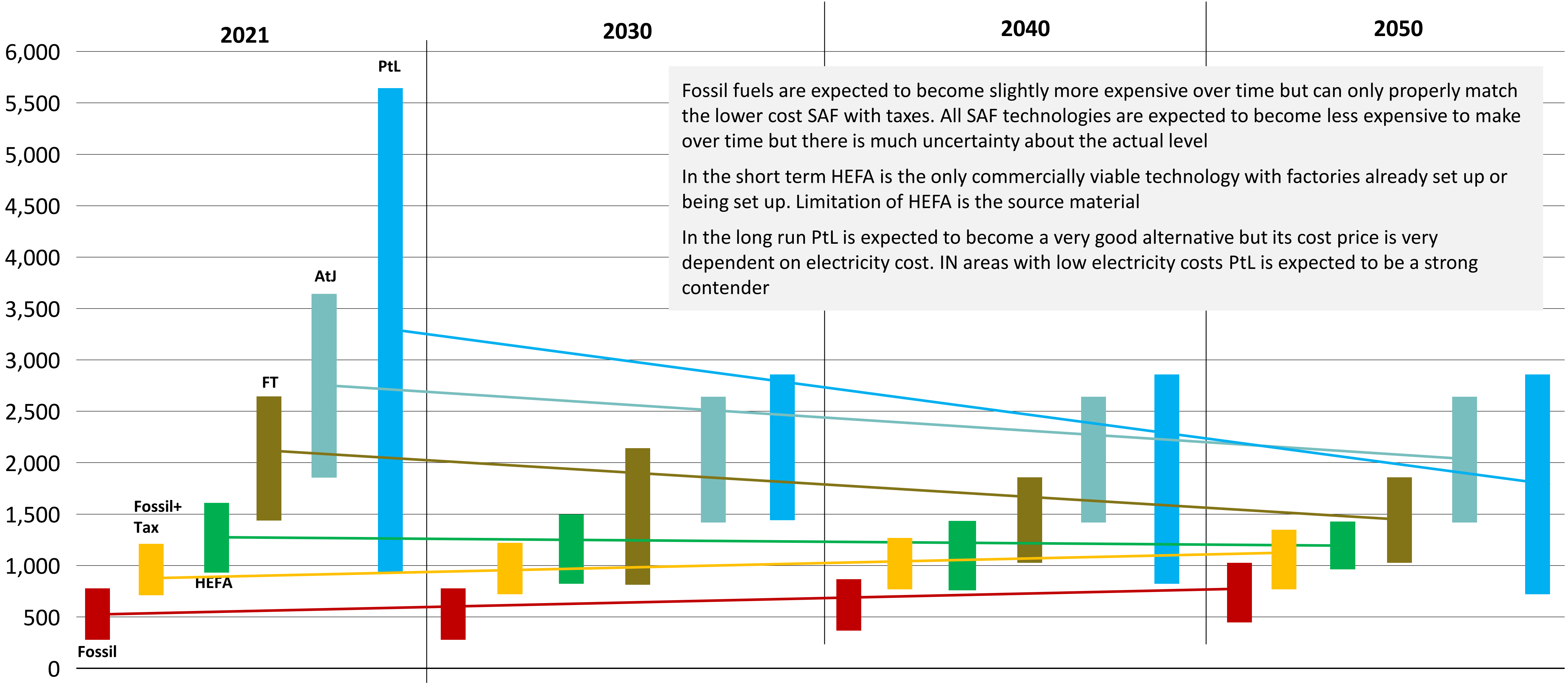
Indicative pricing based on literature review and team analysis

Proposed taxes in EU are 395 Euro/ton 2023-2033

Sources: SAF blending is based on EU ReFuelEU Aviation initiative. Assumed SAF pricing is based on sources from EU, McKinsey and the International Council on Clean Transportation

While there is significant uncertainty about SAF prices in the short term HEFA is the only viable current technology while after 2030 MSW/Gas FT could also become viable and PtL from 2040 onwards

Indicative cost prices for various jet fuels in EUR /metric ton over time



Fossil fuels are expected to become slightly more expensive over time but can only properly match the lower cost SAF with taxes. All SAF technologies are expected to become less expensive to make over time but there is much uncertainty about the actual level

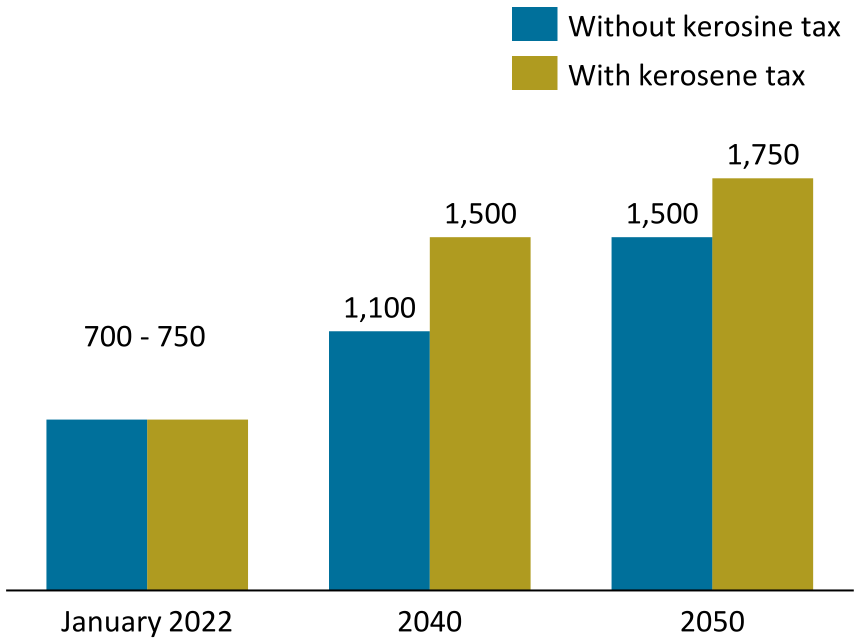
In the short term HEFA is the only commercially viable technology with factories already set up or being set up. Limitation of HEFA is the source material

In the long run PtL is expected to become a very good alternative but its cost price is very dependent on electricity cost. IN areas with low electricity costs PtL is expected to be a strong contender

Sources: LEK, WEF/McKinsey, ICCT, EU, German Environmental Agency

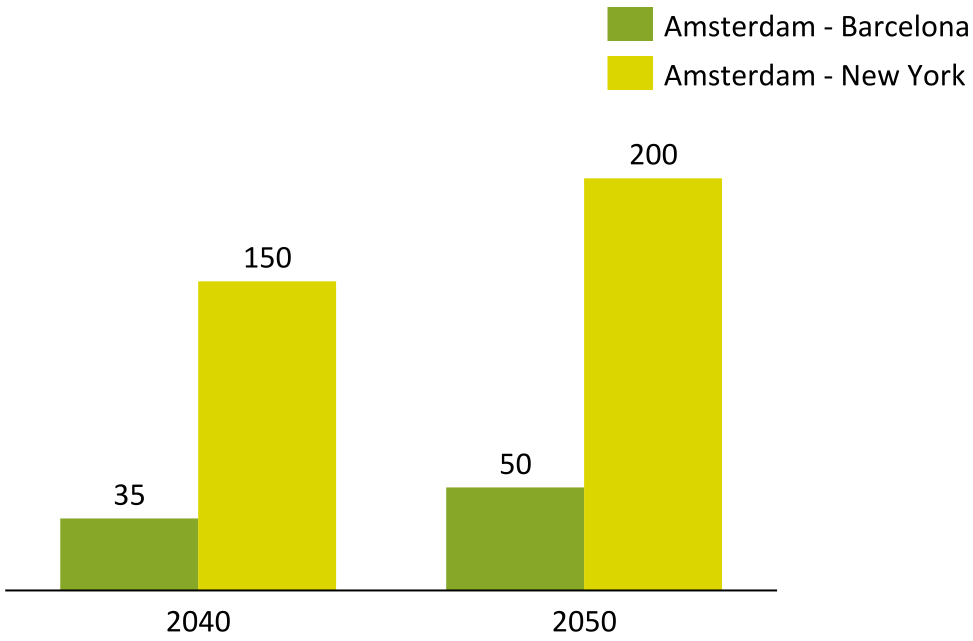
With increasing fuel prices, flying with current generation aircraft will become significantly more costly in the future which will increase the potential for operations with new propulsion technologies

Estimated total fuel cost (incl. SAF)
in EUR per metric ton



- Assumptions on blending SAF (high end estimate):
  - 2040: 30%
  - 2050: 60%
- Kerosene tax 2023-2033 EUR 395 per MT and EUR 600 by 2050

Estimated additional fuel cost per passenger vs. Jan 2022
In EUR per return trip (note: high end estimate on blending)



- Assumptions on fuel consumption (in jet fuel per p.p. return:
  - AMS-BCN ~ 60 litre (A320 NEO performance)
  - AMS-JFK ~ 260 litre (B787-900 performance)
- Actual consumption will likely be lower with more fuel efficient aircraft available by 2040/2050

Sources: SAF blending is based on EU ReFuelEU Aviation initiative. Assumed SAF pricing is based on sources from EU, McKinsey and the International Council on Clean Transportation; fuel burn per passenger per route based on Atmosfair.de

Contents

Topic

There are three relevant new aerospace technologies being introduced in the next 5 – 10 years

Electric aircraft (eCTOL)
Conventional **T**ake-**O**ff and **L**anding with battery-, hydrogen- or hybrid-electric propulsion

- General aviation 2/4-seaters initially mostly operator by flight training schools (2021)
- Battery-electric electric aircraft initially with 9-19 seats (2025-2030) at ranges up to 500-750 km; after 2030 also up to 1,000 km and possibly more seats
- Hydrogen-electric aircraft may have as early as 50 seats 500-750 km between 2025-2030
- Hybrid aircraft possible with 70 seats from 2028

Air taxi's/Urban Air Mobility (eVTOL)
Vertical (or **S**hort) **T**ake-Off and **L**anding almost solely with battery-electric propulsion

- "Air taxis" (Urban Air Mobility) with electric drive and "Vertical Take-Off and Landing" (VTOL) with 2 - 7 passengers at distances of 25 - 200 km
- Initially with pilot; but unmanned is already being tested in China

Cargo aircraft/cargo drones (eCargo)
Wide range of technologies for very short and long distances; soon autonomous

- Urban package services initially with medicines / medical transport as a first use case; but also for parcel delivery
- Medium-distance air cargo drones and cargo aircraft for 250 – 4,000 kg
- Longer range aircraft on hybrid-electric technologies

It is expected that first commercial operations for low/zero-emission technologies in the Netherlands will take place in the 2026 – 2030-time window with rapid scaling up in the years following

	2022 - 2025	2026 - 2030	2031 - 2035	2036 - 2040
General Aviation	• Commissioning of the first electric aircraft for training flights	• Large-scale rollout; decrease in noise nuisance from flight training • First private aircraft	• Start of phasing out of fossil fuel flight training aircraft or retrofitted with electric engines	• 80+% flights with electric planes
Passenger aircraft	• Test flights (electric/hybrid first; hydrogen-electric later)	• 4, 9- to 19-seater aircraft; by 2030 possibly larger hydrogen-electric; • First commercial flights (dom+int'l) around 2026/2027 from regional airports • New on-demand business models	• Range small aircraft >500 km with networks of 10-15 destinations from reg. airports • Larger hydrogen-powered aircraft (~50-70 seats) to replace current flights	• Volume increases significantly by more substitution of car traffic • Larger (150+ seats) hydrogen aircraft to replace current flights • Noise levels at airports decrease sharply/smaller noise contours
Cargo drones/ aircraft	• Partly unmanned test flights (mainly battery-electric)	• First commercial services, e.g., to Wadden Islands; medical use; parcel delivery drones from regional airports	• Start feeder networks with electric aircraft and drones for dedicated shipments	• Costs quickly lower and higher capacity > air freight will gain market share from road traffic
eVTOLs/air taxis	• Some first test flights	• First air taxi services in 2028-2029 with routes up to 100 km, especially from regional airports • First vertiports are being developed	• Start of scheduled air taxi services between major cities (150+ km) and on-demand offer • Introduction to unmanned air taxis	• Network of eVTOL services between large cities with a maximum travel time of one hour; more and more provincial towns have their own vertiport

Different design configurations have been published by OEMs to enable zero-emission flights in both urban- and regional air mobility

Aircraft Types

Passenger

Key UAM technologies

	URBAN AIR MOBILITY (UAM)				REGIONAL AIR MOBILITY (RAM)
Design configuration	**eVTOL**			**eSTOL**	**eCTOL**
	Wingless	***Lift + Cruise***	***Vectored trust***		
Examples					
Description	Thrusters only for lift, cruise via rotor pitch	Independent thrusters used for cruise as for lift	Thrusters used for both lift and cruise	Horizontal thrust; Interaction of wing, flaps and distributed propellors enables short take-off and landing distance	Horizontal thrust; independent battery- or hydrogen-electric propulsion system
***Stated* range (km)**	• Ca. 35 km	• 100-500 km	• 95-240 km	• Up to 400 - 600 km	• Up to 500 - 750 km
Speed (km/hrs)	• 100-130 km/h	• 180-270* km/h	• 240-320 km/h	• Up to 320 km/h	• 300-520 km/h
Payload (pax)	• 200-220 kg	• 180-2700* kg	• 410-700 kg	• Up to 1000 kg	• 700-2,100 kg
Runway length (m)	• 0 (Helipad)	• 0 (Helipad)	• 0 (Helipad)	• Around 100 m	• Up to 800 m
Examples (seats) (autonomous)	• VoloCity (2) (A) • EHang 216 (2) (A)	• VoloConnect (4) • Beta ALIA* (2) • Wisk Aero (2) (A) • Ehang VT-30 (2)	• Joby Aviation S4 (5) • Lillium Jet (6) • Vertical Aerospace VX-4 (4) • Archer Aviation (5) • Hyundai SA-1 (4)	• Airflow 100 (4) • Airflow 200 (9) • Electra Aero (7) (hybrid) • Dufour Aerospace Aero-3 (8)	• Eviation Alice (9) • Bye Aerospace eFlyer 800 (9) • Heart Aerospace ES19 • Tecnam P-Volt

**Only limited information available*

1) Performance data based on OEM-published information

A multitude of technologies (eVTOL, eSTOL and eCTOL) for manned- and unmanned cargo aircraft is coming to the market which will unlock new logistics chains/same-day services

	eVTOL (fully autonomous)		**eSTOL** (initially piloted)	**eCTOL** (pilot and autonomous)	**Fossil-fuel cargo drones**
	Last mile delivery	***Small shipments***	***Feeder remote locations***	***Feeder flows***	***Cargo hub-to-hub flows***
					
Runway/space required	~5 x ~5 meter	~30 x ~30 meter	~100 – 150 meter	Up to 800m	Up to 2000 m
Typical range	-20 – 50 km	500+ km	500 – 700 km	500 - 750 km	>5000 km
Examples (payload/ range)	• VoloDrone (200 kg/40km) • Flyingbasket (100 kg) • Xi'anSupersonic Aviation (100 kg)	• Pipistrel Nuuva V300 (hybrid-electric, 460 kg/typical range 300 km) • Elroy Air Chapparal (226 kg/482 km) • Sabrewing Rhaegal RG-1 (450 kg/580 km)	• Airflow (900 kg/800 km) • Dufour Aero 3	• Eviation Alice Cargo • Xwing (retrofit Cessna Caravan 206) • Hydrogen cargo conversion of large turboprop aircraft	• Natilus (up to 100 tonnes; transpacific capabilities) > 50% lower trip cost compared to Boeing 747 Freighter but 2-3 times longer trip time
Expected entry into service	• First commercial services started	• 2022 - 2024	• 2023 - 2025	• 2023 - 2027	• 2025+

With today's aircraft technology the cost for air cargo is 8 – 10 times higher than for road cargo. In addition, cargo is relatively less time-sensitive. However, these new technologies, especially when autonomous and with high energy-dense battery-electric propulsion may narrow that can to a factor of 1.5 to 3 towards 2035/2040. With less risk of congestion and issues with truck-driver shortages, this segment will likely to become a relevant option for current logistics flows as well as trigger new logistics flows

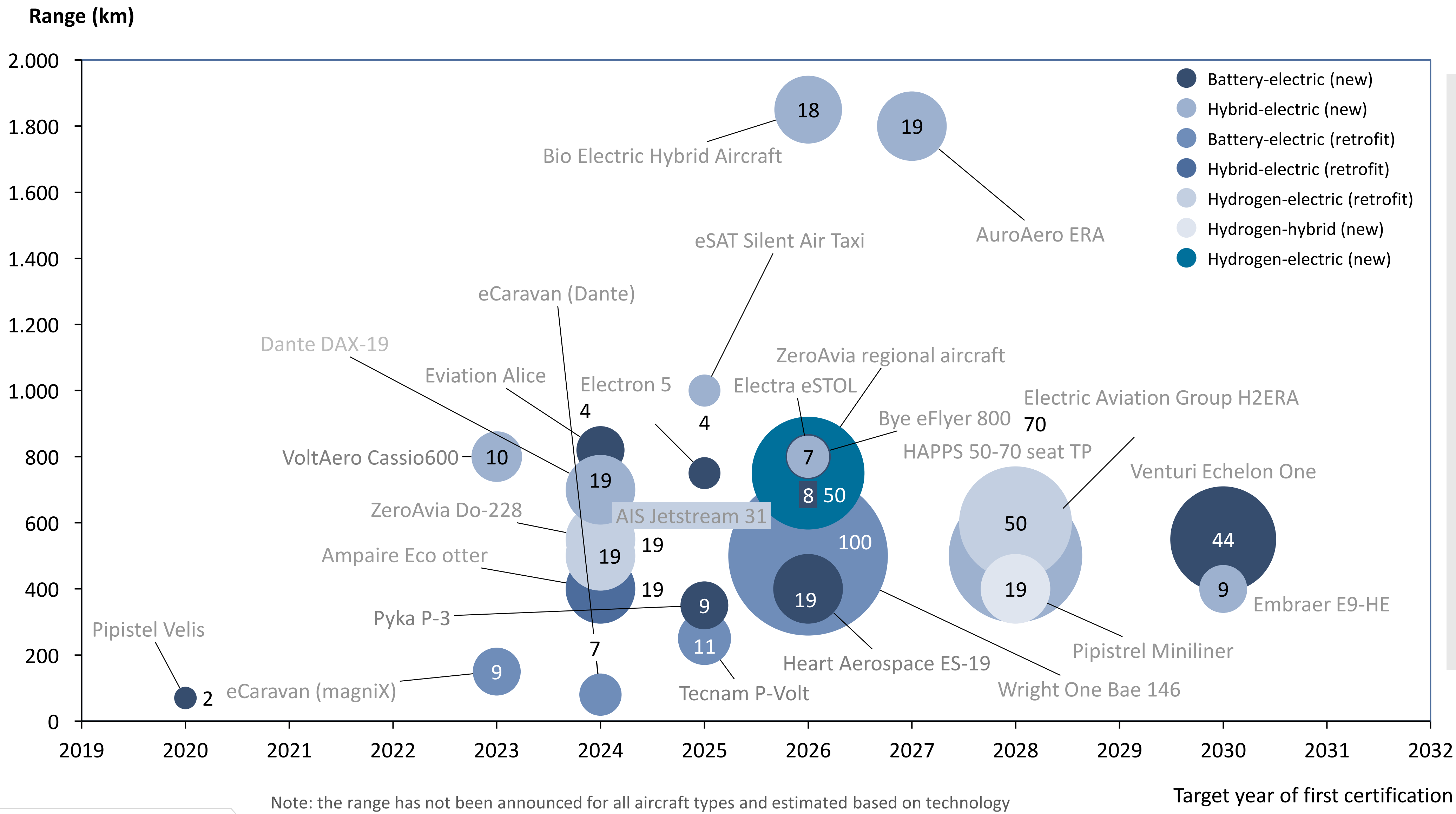
Source: OEM websites

Contents

Topic

There are currently nearly 25 eCTOL aircraft in development with the majority being targeted for certification in the 2023 – 2028-time window — timing and expected performance are (very) ambitious

Selection of announced new and retrofitted zero-emission and hybrid-electric aircraft by target year of certification (not exhaustive)



- Independent aeronautical engineers consider timelines and expected performance as very optimistic. Not all OEMs will make it through to certification (e.g., due to lack of financing)
- However, timelines may likely slip by no more than 2 to 4 years; a reduced performance may well still have market relevance and performance with potential battery-breakthroughs
- Note: hybrid-electric aircraft can operate short-distance routes on battery-energy only and switch to full-battery when battery-performance improves

Note: the range has not been announced for all aircraft types and estimated based on technology
Source: M3 desk research; expert interviews

Hybrid-electric aircraft can cover longer distances with battery-power only while ranges of up to 1500 – 1800 km are possible with significantly lower carbon emission than today's technology

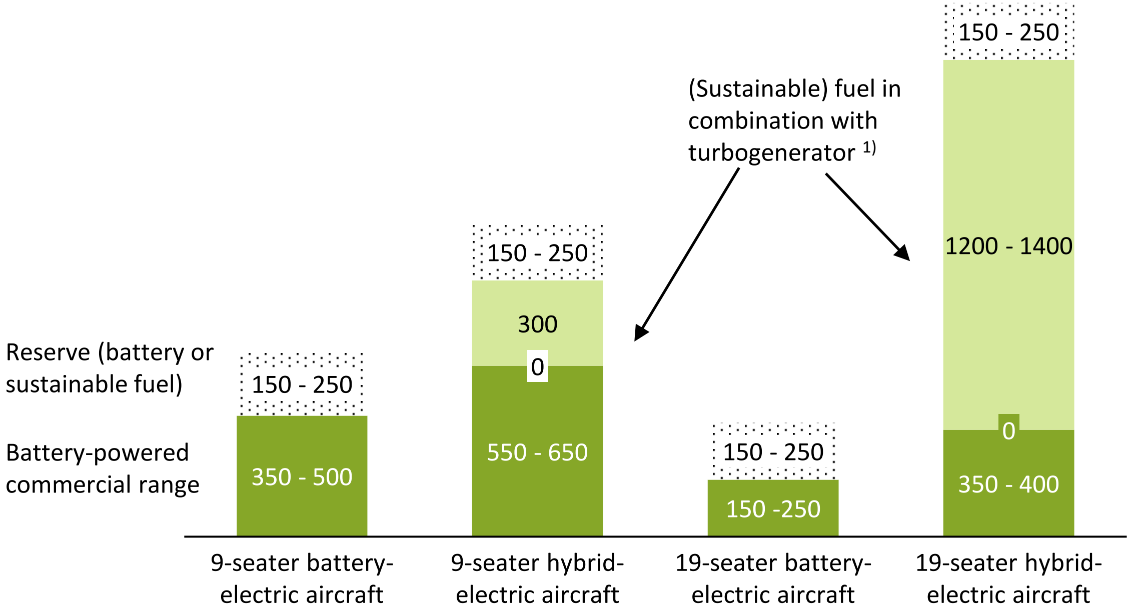
Performance

eCTOL

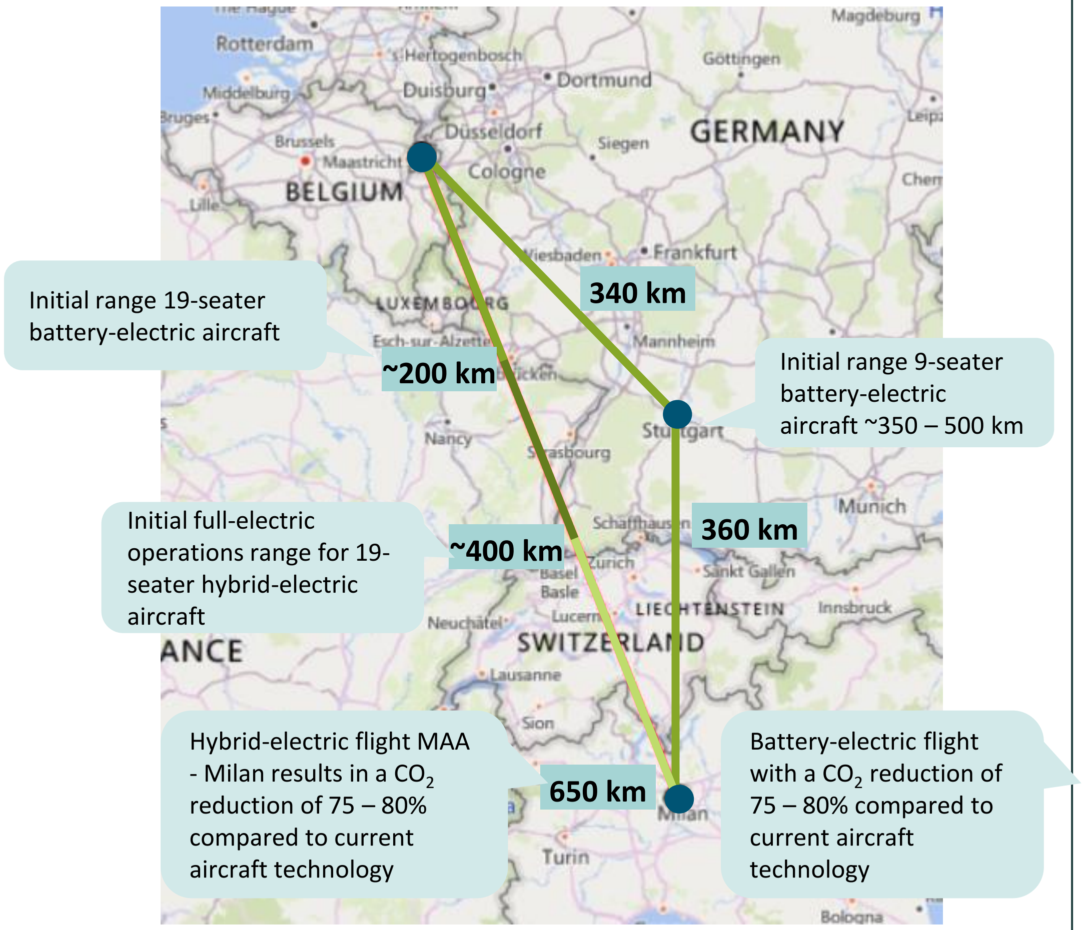
While battery-electric aircraft can only use part of its battery energy for scheduling routes, hybrid electric aircraft can take full benefit of its battery while covering the reserve (+ extra range) with fuel…

Estimated range of a 9 and 19-seater battery-electric and 19-seater hybrid-electric aircraft with battery pack energy density of ~ 220 – 240 Wh/kg in kilometre

- Commercial aircraft are required to plan for 45 min IFR reserve plus distance to alternate airport
- For a battery-electric aircraft this means only 50% of the usable battery-energy (80% of maximum energy) can be used to schedule routes resulting in a range of 300 – 400 for a 9-seater and 150 - 250 for a 19-seater aircraft
- A hybrid-electric aircraft can cover to required energy for the reserve with (sustainable) fuel powering a 300 – 400 kW turbogenerator and extend the range available to schedule routes. This allows for flights to have 100% reduction in CO2 up to 400 km, approx. 75% reduction for 700 km flights and 50% reduction for 900 km flights with a maximum range of 1500 – 1800 km



… which allows for direct flights with a 19-seater to destinations such as Milan achieving still a 75+% reduction in CO2 emissions (or more when sustainable fuel is used)



Initial range 19-seater battery-electric aircraft

Initial range 9-seater battery-electric aircraft ~350 – 500 km

Initial full-electric operations range for 19-seater hybrid-electric aircraft

Hybrid-electric flight MAA - Milan results in a CO_2 reduction of 75 – 80% compared to current aircraft technology

Battery-electric flight with a CO_2 reduction of 75 – 80% compared to current aircraft technology

[1] Range with regular/sustainable fuel can vary significantly depending on aircraft design

Source: M3/GH Consulting analysis based on extensive OEM and technology assessments

The maximum range available using 100% battery-power will increase significantly over time as new battery-technologies with (much) higher energy-density levels become commercially available

Performance

eCTOL

Estimate maximum range for scheduling routes ***using 100% power from batteries***

Battery-technology (examples only)

Lithium – Ion

Lithium – Sulphur[1]

Lithium – Silicon nanofiber

← - - ? - - - Solid-state

← - - ? - - - Metal-air flow (e.g. Aluminium)

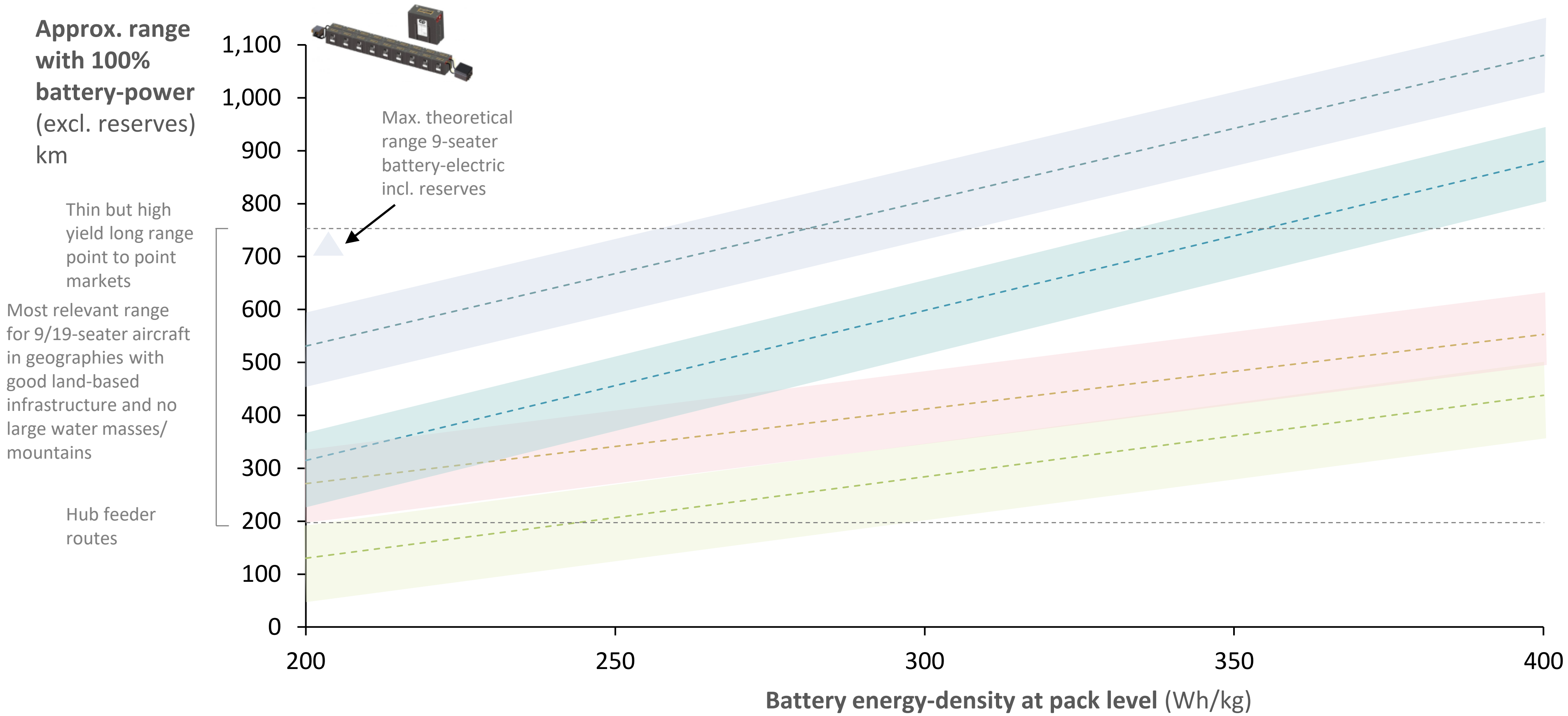
Potential timeline

Available today (205 Wh/kg)

2025

~2030

2030+



9-seater hybrid-electric

9-seater battery-electric

19-seater hybrid-electric

19-seater battery-electric

---

[1] Cycle life will be lower for Li-Sulphur but with an expected much lower cost per kWh could still be an attractive business case for electric aviation

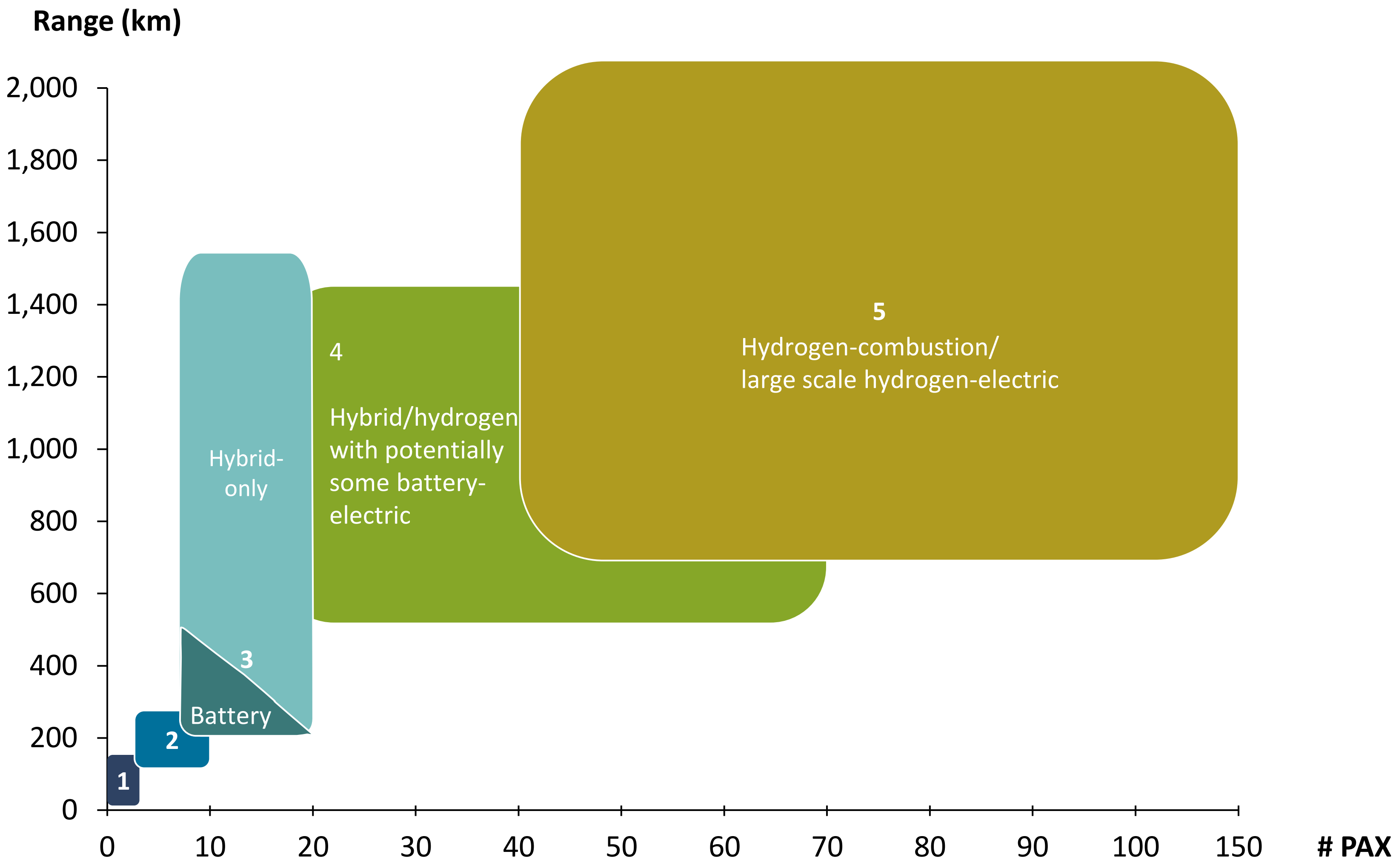
Source: M3/GH Consulting analysis based on extensive OEM and battery technology assessments

Zero-emission aircraft are expected to reach maturity in 5 distinct stages towards 2040

Performance

eCTOL

Development of range and size of zero-emission aircraft



- **1** **Current status:** several battery-electric and hydrogen-electric test flights, and 2-seater aircraft certified
- **2** **2024-2026**: first retrofitted small aircraft (up to 19-seats)
- **3** **2026-2030**: first new-design battery-electric and hybrid-electric aircraft up to 19-seats; towards end of period possibly larger retrofitted hydrogen-electric 30 -50 seater aircraft
- **4** **2030-2035**: 2e generation new battery-electric (up to max 30-40 seats; hybrid-/hydrogen electric up to 50-70 seats
- **5** **2035-2040**: large 100+ seater hydrogen electric aircraft and longer range small battery-electric aircraft (750+ km)

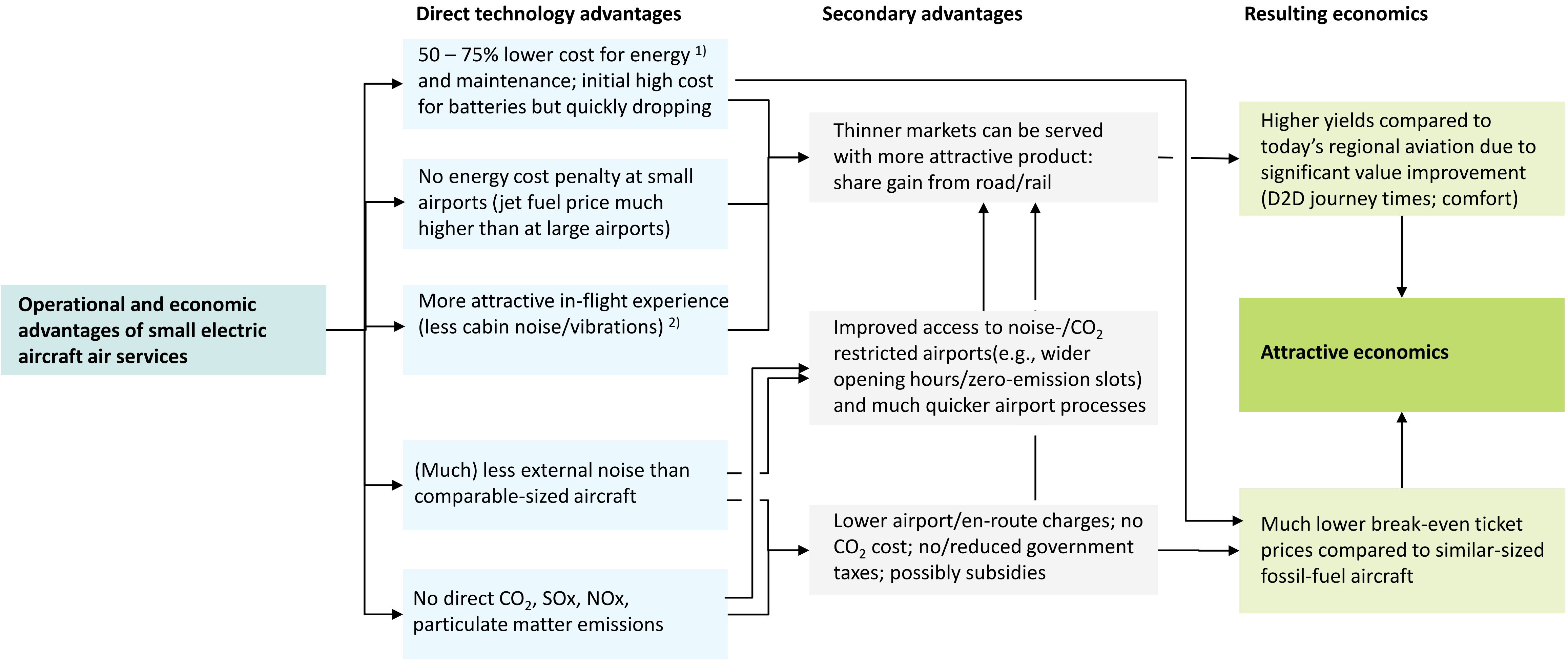
Source(s): M3/PEN EM expert judgement based on extensive OEM and technology assessments

The attractive economics of electric regional air services are driven by improvements in direct cost, comfort and emissions which will enhance market access and yields compared to today's regional air services

Economics

eCTOL

OVERVIEW OF ELECTRIC AVIATION ECONOMICS VIS-À-VIS CURRENT TECHNOLOGY



Direct technology advantages

Secondary advantages

Resulting economics

Operational and economic advantages of small electric aircraft air services

50 – 75% lower cost for energy 1) and maintenance; initial high cost for batteries but quickly dropping

No energy cost penalty at small airports (jet fuel price much higher than at large airports)

More attractive in-flight experience (less cabin noise/vibrations) 2)

(Much) less external noise than comparable-sized aircraft

No direct CO_2, SOx, NOx, particulate matter emissions

Thinner markets can be served with more attractive product: share gain from road/rail

Improved access to noise-/CO_2 restricted airports(e.g., wider opening hours/zero-emission slots) and much quicker airport processes

Lower airport/en-route charges; no CO_2 cost; no/reduced government taxes; possibly subsidies

Higher yields compared to today's regional aviation due to significant value improvement (D2D journey times; comfort)

Attractive economics

Much lower break-even ticket prices compared to similar-sized fossil-fuel aircraft

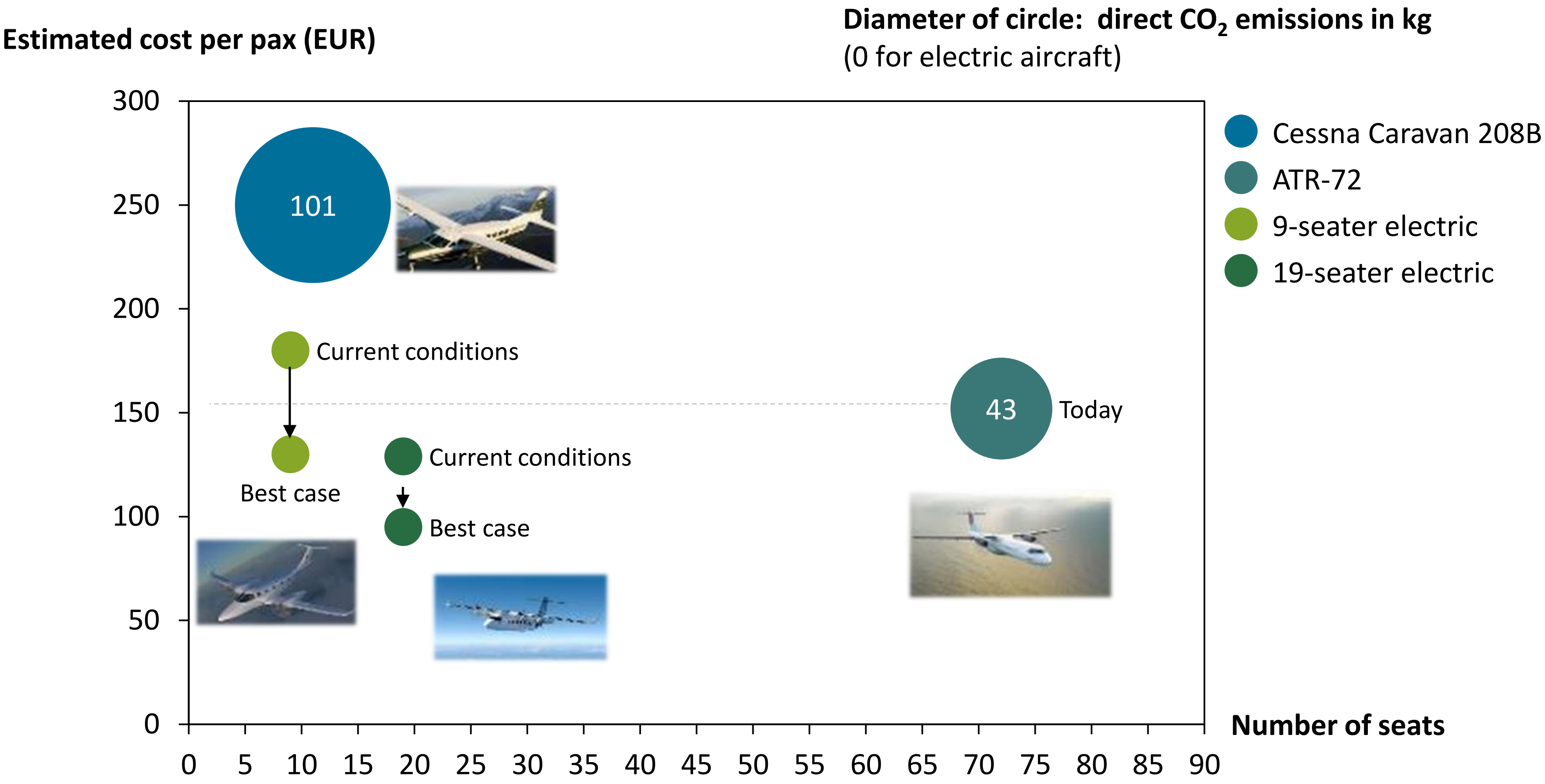
---

1) Energy cost advantage strongest for battery-electric aircraft and hybrid-electric aircraft. Hydrogen energy cost will be higher than fossil fuel cost today for the foreseeable future

2) Non-pressurized aircraft such as a retrofitted Cessna Caravan will be less comfortable

Battery-electric aircraft are expected to achieve a cost level at or below a 70-seater fossil-fuel aircraft but requiring far fewer passengers to fill a flight making thin routes much more viable

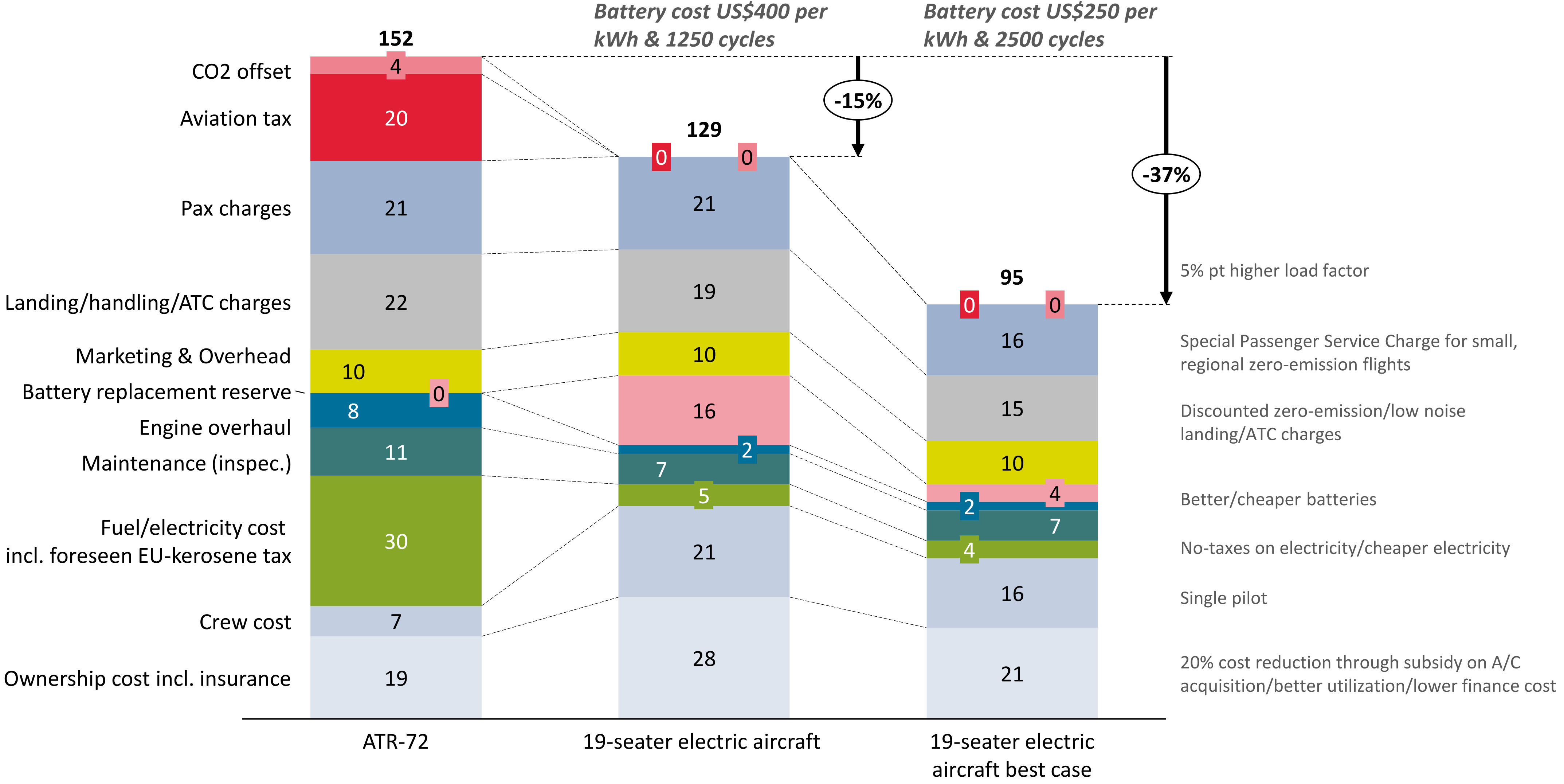
Cost in EUR incl. all taxes (excl. airline profit margin) per passenger and CO_2 for a 400 km flight (based on Jan 2022 energy cost)



Source: M3 analysis based on extensive bottom-up modelling of cost, travel time, energy consumption and emissions

An electric 19-seater has relatively high ownership and crew cost compared to a 70-seater fossil aircraft but compensates this with significant savings on energy, maintenance, airport cost as well as reduced taxes

Bottom-up estimate of one-way trip cost per passenger in EUR for a 400 km route from the Netherlands (assuming new aviation tax level not applied for electric aircraft)



Note: jet fuel cost at regional airports typically much higher than at large airports making fossil-fuel operations less profitable. With electricity no such differences exist

Source: M3 analysis based on extensive bottom-up modelling of cost, travel time, energy consumption and emissions using January 2022 data and Maastricht/Groningen airport charges

While economics of hydrogen-powered aircraft are difficult to estimate, it appears that this technology will mainly be replacing current medium haul operations with no demand/network effects

Synthesis of hydrogen-powered aircraft economics

- The operational cost of zero-emission hydrogen-power aircraft are challenging to predict with wide ranges of costs both for hydrogen itself, the required ground infrastructure including service delivery model as well as in-flight technology
- Other reports such as the 2020 study “Hydrogen-powered aviation: A fact-based study of hydrogen technology, economics, and climate impact by 2050” prepared by McKinsey & Company for the Clean Sky 2 JU and Fuel Cells and Hydrogen 2 JU do provide some guidance what to expect
- Key insights is that hydrogen-electric is expected to result in more or less similar cost to similar-size fossil-fuel small aircraft and with 10-30% higher cost for larger aircraft
- As such, we assume the introduction of such will be driven by increasing cost of fossil-flights and not lead to demand generation and/or new routes (unlike small-scale battery electric aircraft) and for regional airports with thin flows not competitive against battery-electric options

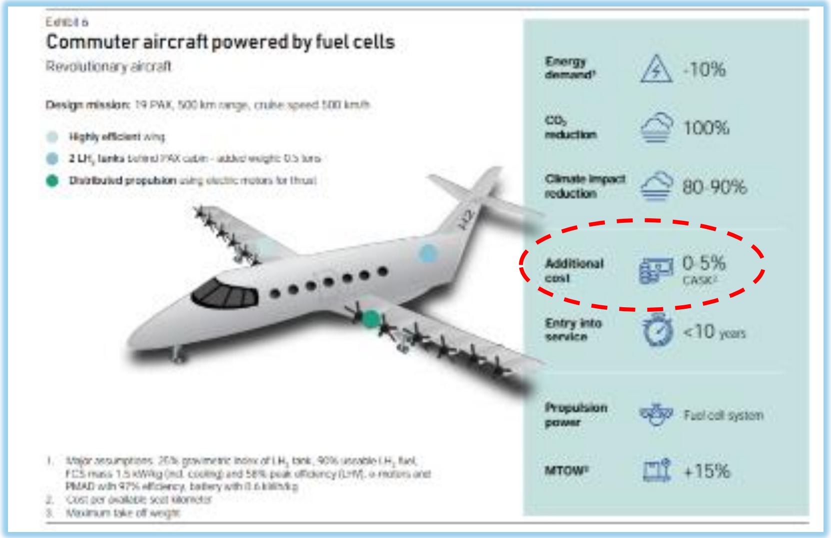


Exhibit 6

Commuter aircraft powered by fuel cells

Revolutionary aircraft

Design mission: 19 PAX, 500 km range, cruise speed 500 km/h

- **Highly efficient** wing
- **2 LH_2 tanks** behind PAX cabin - added weight: 0.5 tons
- **Distributed propulsion** using electric motors for thrust

Energy demand[1]	-10%
CO_2 reduction	100%
Climate impact reduction	80-90%
Additional cost	0-5% CASK[2]
Entry into service	<10 years
Propulsion power	Fuel cell system
MTOW[3]	+15%

1. Major assumptions: 25% gravimetric index of LH_2 tank, 90% useable LH_2 fuel, FCS mass 1.5 kW/kg (incl. cooling) and 58% peak efficiency (LHV), e-motors and PMAD with 97% efficiency, battery with 0.6 kWh/kg
2. Cost per available seat kilometer
3. Maximum take off weight

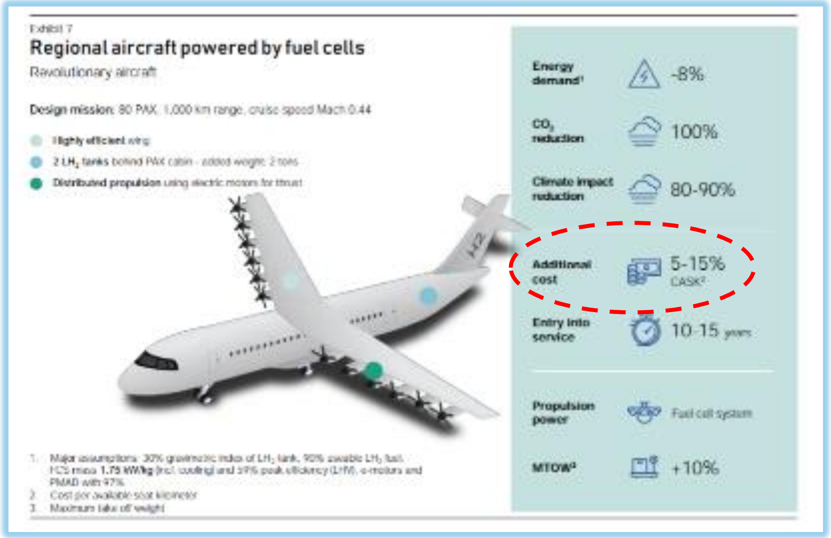


Exhibit 7

Regional aircraft powered by fuel cells

Revolutionary aircraft

Design mission: 80 PAX, 1,000 km range, cruise speed Mach 0.44

- **Highly efficient** wing
- **2 LH_2 tanks** behind PAX cabin - added weight: 2 tons
- **Distributed propulsion** using electric motors for thrust

Energy demand[1]	-8%
CO_2 reduction	100%
Climate impact reduction	80-90%
Additional cost	5-15% CASK[2]
Entry into service	10-15 years
Propulsion power	Fuel cell system
MTOW[3]	+10%

1. Major assumptions: 30% gravimetric index of LH_2 tank, 90% usable LH_2 fuel, FCS mass **1.75 kW/kg** (incl. cooling) and 59% peak efficiency (LHV), e-motors and PMAD with 97%
2. Cost per available seat kilometer
3. Maximum take off weight

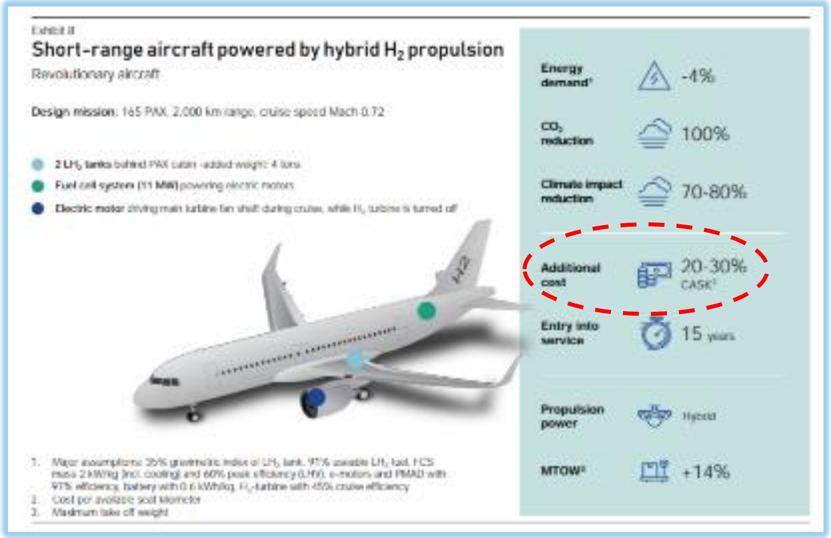


Exhibit 8

Short-range aircraft powered by hybrid H_2 propulsion

Revolutionary aircraft

Design mission: 165 PAX, 2,000 km range, cruise speed Mach 0.72

- **2 LH_2 tanks** behind PAX cabin - added weight: 4 tons
- **Fuel cell system (11 MW)** powering electric motors
- **Electric motor** driving main turbine fan shaft during cruise, while H_2 turbine is turned off

Energy demand[1]	-4%
CO_2 reduction	100%
Climate impact reduction	70-80%
Additional cost	20-30% CASK[1]
Entry into service	15 years
Propulsion power	Hybrid
MTOW[3]	+14%

1. Major assumptions: 35% gravimetric index of LH_2 tank, 97% usable LH_2 fuel, FCS mass 2 kW/kg (incl. cooling) and 60% peak efficiency (LHV), e-motors and PMAD with 97% efficiency, battery with 0.6 kWh/kg, H_2-turbine with 45% cruise efficiency
2. Cost per available seat kilometer
3. Maximum take off weight

Source: Hydrogen-powered aviation: A fact-based study of hydrogen technology, economics, and climate impact by 2050” prepared by McKinsey & Company for the Clean Sky 2 JU and Fuel Cells and Hydrogen 2 JU

Electric aviation is expected to be most relevant in regional-to-regional and regional-to-big city with a limited role in hub-routes to nearby (domestic cities)

Market relevance

eCTOL

DEEMED RELEVANCE OF (INITIAL) ELECTRIC FLIGHTS BY TYPE OF ROUTE BASED ON MARKET DEMAND AND CURRENT OFFERING

5	Very relevant
1	Not relevant

Domestic routes in OD-matrix (AMS = only city/hub)

	Local	Regional	Big city	Hub
Local	3	4	3	4
Regional	4	5	3	5
Big city	3	3	n/a	n/a
Hub	2	5	n/a	n/a

Domestic flights are most relevant between local and regional airports and local/regional to hub

- Local and regional origins are typically not well connected by current travel options and have thin flows that could well be served by small and fast electric aircraft
- Markets between local/regional cities and Amsterdam as the main big city are well connected by current travel options (both rail and road)
- However, connections from local and regional cities to the hub with onward connectivity would be highly relevant

International routes in OD-matrix

	Local	Regional	Big city	Hub
Local	2	4	4	2
Regional	4	5	5	4
Big city	4	5	3	2
Hub	2	4	2	1

International flights are most relevant from local and regional airports to big city destinations

- Main interests in international markets is expected to be between regional airports and big cities that are not well connection by current travel options
- International routes to/from local cities are expected to have to little traffic to be relevant
- Dense routes like hub-to-hub or hub-to-big city are served by large aircraft with low unit cost that small electric aircraft can't compete against

1) M3 Analysis

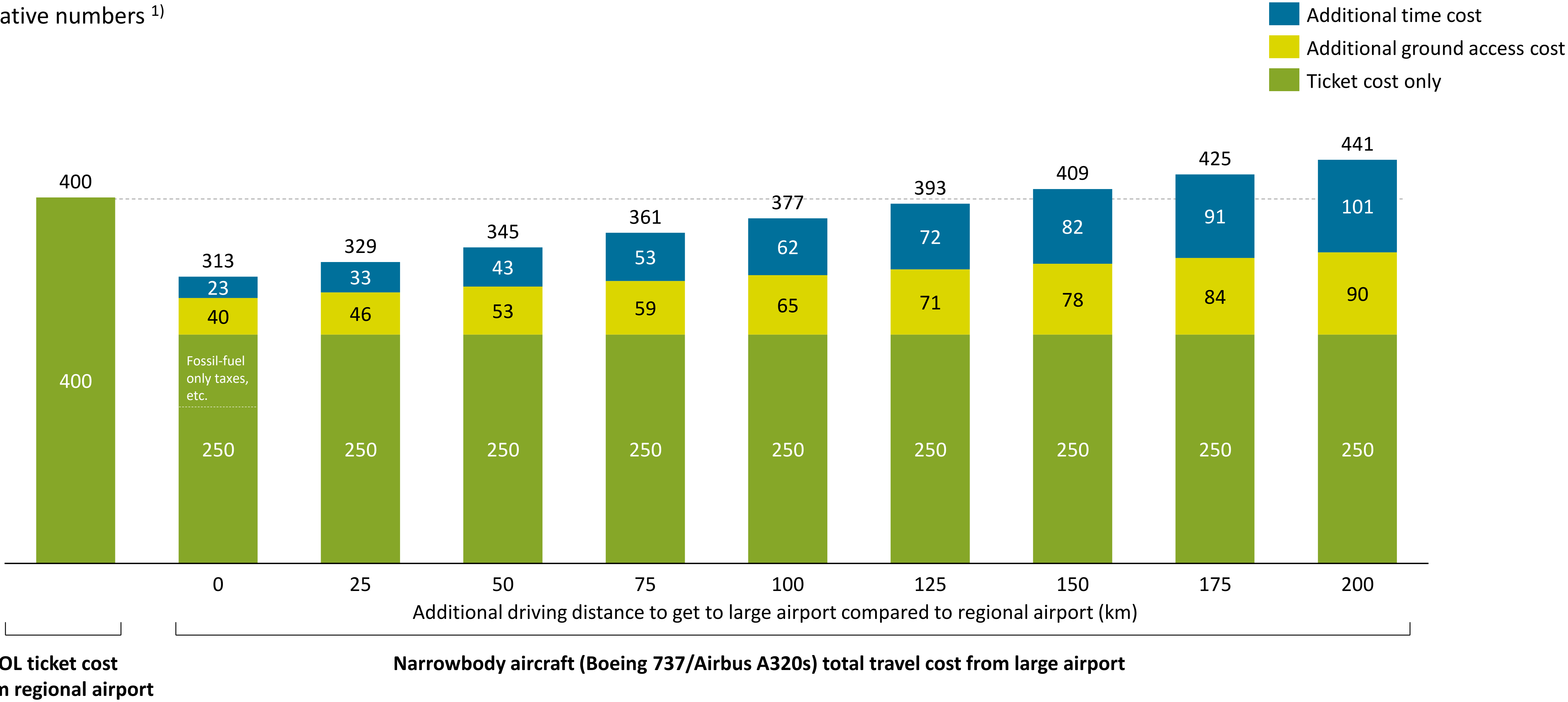
The competitiveness of high(-er) price eCTOL flights from regional airports strongly improves the further away passengers have to travel to a large airport to catch a lower price narrowbody flight

Market relevance

eCTOL

Differences in total journey cost by additional distance to get to a large airport compared to flying from nearby regional airport , EUR

Illustrative numbers 1)



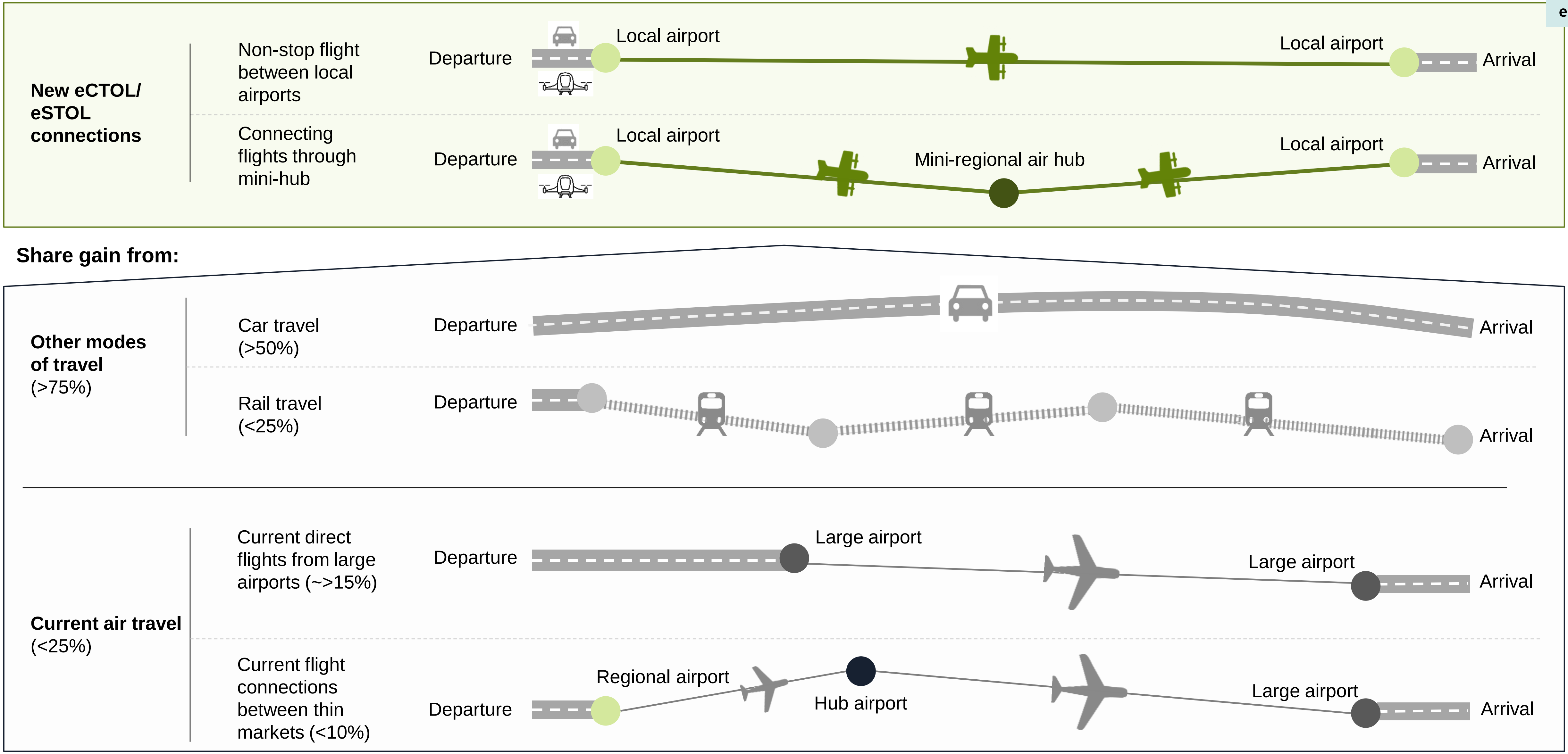
1) Assuming value of time of EUR 35 per hour; 30 min additional flying time for eCTOL compared to narrowbody; EUR 40 difference in cost for 2-day parking at large airport vs. regional airport; road access average speed of 90 km/h and EUR 0.25 variable cost per km. Airport time with eCTOL: 20 min; narrowbody 90 minutes

Sources:

‘eCTOL’-routes, whether non-stop or connecting at a regional mini-hub, are expected to take share mostly from current land-based travel as well some from current direct flights and connecting flights

Market relevance

eCTOL



New eCTOL/ eSTOL connections

Non-stop flight between local airports

Connecting flights through mini-hub

Share gain from:

Other modes of travel (>75%)

Car travel (>50%)

Rail travel (<25%)

Current air travel (<25%)

Current direct flights from large airports (~>15%)

Current flight connections between thin markets (<10%)

There are already many airlines who have either pre-ordered, expressed interest and very actively exploring low/zero-emission aircraft technology in the Netherlands and surrounding countries

Non-exhaustive list of announced interest in low/zero-emission aircraft technology (including flight training and electric Short Take-Off and Landing aircraft)

Country	Airline/operator	Airline/operator
Netherlands	AIS Airlines	• Retrofitting a 19-seat Jetstream-31 with a hydrogen-electric powertrain targeting entry-into-service in 2024
	E	• First full battery-electric flight training school started in 2021; collaboration with KLM Flight Academy
	KLM flight academy	• Announced intend to acquire 14 eFlyer 2 and eFlyer 4 battery-electric flight training aircraft
Scandinavia	widerøe	• Established a dedicated zero-emission unit: Wideroe Zero; Partnered up with Rolls Royce and Tecnam in the launch of the all-electric 12-seater P-Volt in 2026; also evaluating hybrid-electric aircraft and eVTOls (partnership with Eve)
	FINNAIR	• Signed a LoI for 20 19-seater aircraft from Heart Aerospace. They plan to introduce these aircraft on short thin routes within their current network from 2026 onwards
	BRA	• Actively exploring opportunities for new routes starting with services between Gotland and Smaland in Sweden. Various electric aircraft currently evaluated
	SAS	• Collaborating with Ampaire in the 2ZERO emission program and exploring 19-seater electric aircraft
United Kingdom	BRITISH AIRWAYS	• Co-invested in hydrogen-powertrain OEM ZeroAvia targeting a 50+ seater aircraft to be introduced around 2030
	LOGANAIR SCOTLAND'S AIRLINE	• Partnering in Project Fresson targeting a 19-seat BN-2 Islander retrofitted by hydrogen-electric retrofit to be introduced by 2024 with a range of ~ 250 km. Also evaluating new design battery-electric aircraft
	easyJet	• Evaluating both hydrogen and battery-electric; collaboration with Wright Electric targeting a 186-seater all electric aircraft by 2030 for short sector routes and Airbus to introduce its Zero-E aircraft in 2035 for longer distance flights
Other Europe	flyv	• Ordered 100 7-seater Electra eSTOL aircraft for its on-demand business model
	Lufthansa	• Will be the launch partner of the Airbus ZEROe program with first aircraft targeted for 2035
	DHL	• Ordered 12 Eviation Alice cargo aircraft and plan to operate those from 2024 onwards (initial use in USA)

Source: extensive desk research

The interest in electric aircraft is not limited to Europe with different types of operators already taken first steps towards securing low/zero-emission aircraft

Non-exhaustive list of announced interest in low/zero-emission aircraft technology (including flight training and electric Short Take-Off and Landing aircraft)

United and Mesa Airlines jointly (pre-)ordered 200 ES-19 aircraft from Heart Aerospace, placed a conditional order of 100 powertrains with Zero Avia and pre-ordered 200 eVTOLs from Archer

New Zealand-based regional airline signed a LoI for three aircraft with Heart Aerospace. It plans to use these aircraft from 2026 onwards on their current routes as part of their goal to be net-zero in 2030

US-based regional airlines that will be the launch partner for Eviation Alice. It plans to replace their current aircraft for short and thin routes

US-based virtual on-demand airline acquires hybrid-electric power train/aircraft OEM Ampaire and agreed a deal with Cessna to acquire 150 Cessna Caravan's to be retrofitted with hybrid-electric power trains

Latin-American On-demand air charter service provider agreed deal for 20 MagniX electric aircraft engines to retrofit Cessna Caravans targeting operations in 2024

Bristow group ordered 50 eSTOL vehicles from Electra and 25 eVTOLs from Vertical Aerospace planning to use these new technologies to enter new markets in Europe.

Australia-based airline mainly performing short flights working with Dante Aerospace to retrofit their aircraft with battery-electric drive trains. It aims to have its first electric aircraft operational in 2024

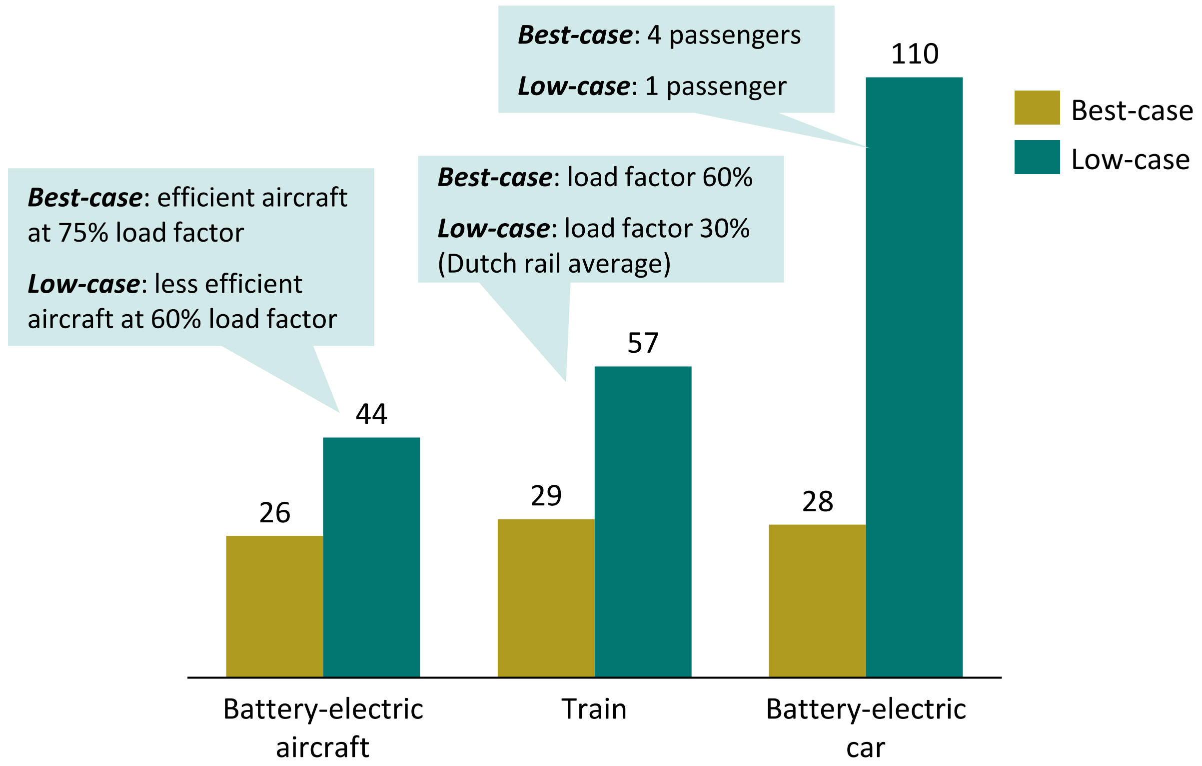
Source: extensive desk research

Each type of operator has a different approach to sustainable aviation with regional and start-up airlines and helicopter operators being the most ambitious in terms of quickly launching low/zero-emission flights

Type of operator	Typical approach to sustainable aviation	Example
Network airlines/	• Neary fully focused on SAF but starting to explore electric aircraft opportunities. Focus on projects that aim to develop 50/100+ near-zero emission aircraft with a range of 500 km	SAS
Low-cost carriers	• Focus on projects that aim to develop larger near-zero emission aircraft with a range of at least 400/500 km	easyJet
Regional airlines	• Very focused on zero-emission technology; partly to replace current operations; partly for opening new markets • Very experienced in RAM segment; working on new ground operations processes	LOGANAIR SCOTLAND'S AIRLINE
Helicopter operators entering non-VTOL	• Focus on smaller (pax 4-7) short take-off (eSTOL) vehicles to replace current vehicles but also to explore new business opportunities	Bristow
Business jet operators	• Exploring options to introduce new aircraft technologies initially with a view to expand and partly to replace	ALS
Start-up airlines	• Several start-ups with high ambitions to enter the market either as virtual airline or by partnering with an existing AOC-holder with an on-demand model	LUCY
Express/cargo-airlines	• Want to make current operations more sustainable and faster. They are mainly focusing on smaller vehicles with low operational cost.	DHL
Flight academies	• Planning to replace a large pat of their fleet by full-electric 2/4-seater aircraft	KLM flight academy E

Electricity consumption of battery-electric flying is at or below electric car and train consumption levels (depending on utilization) while door-to-door travel times for a 400 km can be 4 to 6 hours shorter

Electricity consumption per passenger for 400 km trip, in kWh
(adjusted for average detour)



Best-case: efficient aircraft at 75% load factor

Low-case: less efficient aircraft at 60% load factor

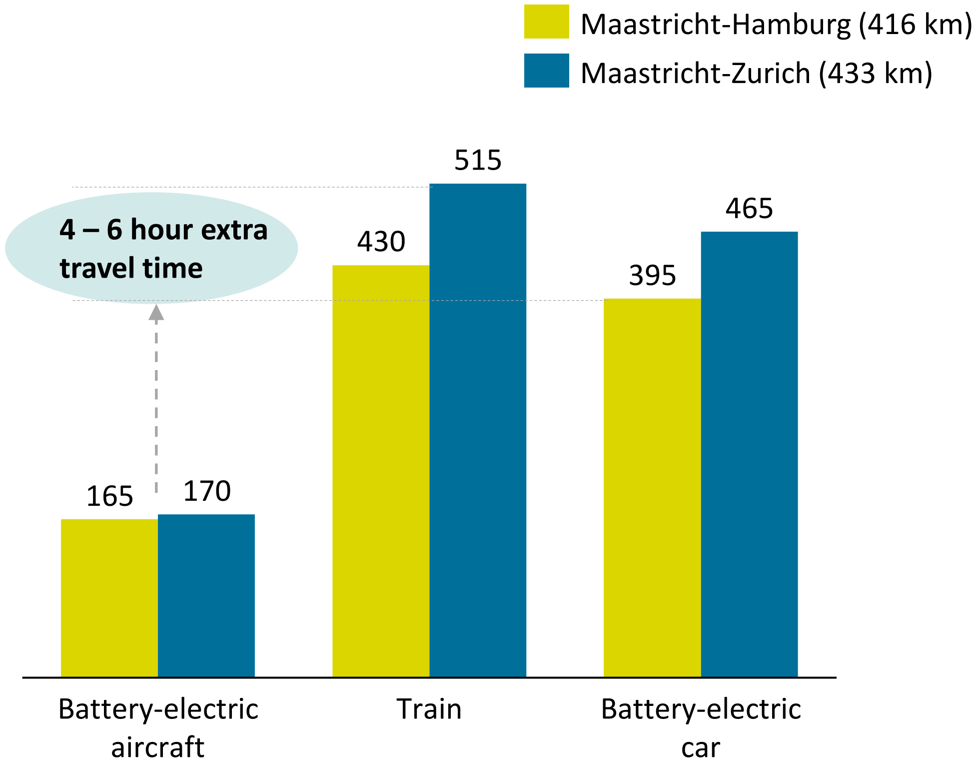
Best-case: load factor 60%

Low-case: load factor 30% (Dutch rail average)

Best-case: 4 passengers

Low-case: 1 passenger

Door-to-door travel times, in minutes
(incl. breaks/time buffer, see append.)



4 – 6 hour extra travel time

Battery-electric aircraft (estimates): best case: 4/9-seats very efficient electric aircraft (60 Wh/pkm); low case: 19-seats electric aircraft (100 Wh/pkm)
Battery-electric car: Tesla Model 3 average year-round electricity consumption at 120 km/h (230 Wh/km)
Rail: electricity consumption for long-distance high-speed trains 33 Wh/seat km (Source: Energy Consumption of Rail Baltica Project: Regional Aspects of Environmental Impact (2019) Olga Piterina.
Adjusted for real km needed (detour factor vs. as the crow flies distance): air +10%; road +20%; rail +30% travelled to cover 400 km: Electric car: 471 km, Electric aircraft: 434 km, Train 549 km

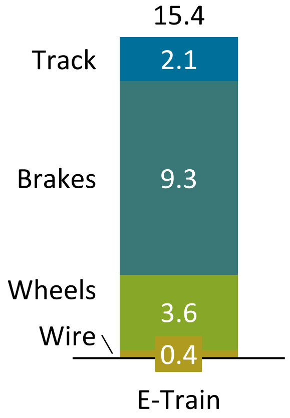
Particulate matter emission of electric aircraft will be substantially lower compared to emissions of (electric) car and rail due to the high wear on road, tire/wheels and brakes

Environmental impact

eCTOL

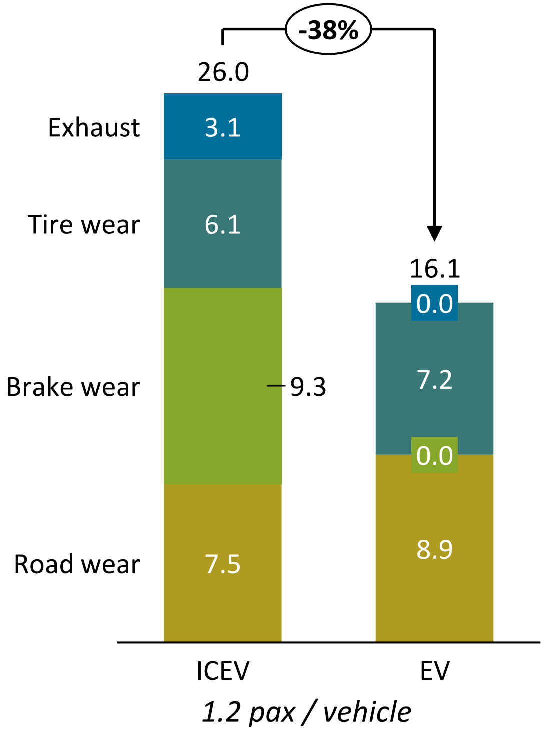
Train

PM10 emissions of electric train (mg/pkm)



Car

PM10 emissions of electric vs. gasoline vehicles (mg/vkm)



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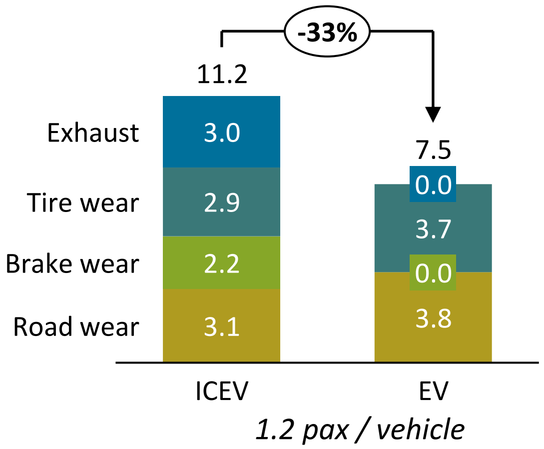
PM2.5 emissions of electric vs. gasoline vehicles (mg/vkm)



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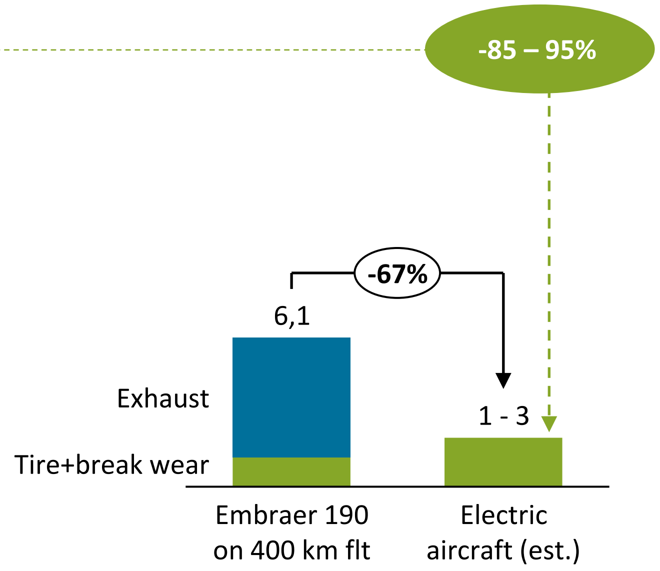
Total PM for EV: 19.7 mg/pkm

Aircraft (early estimates)

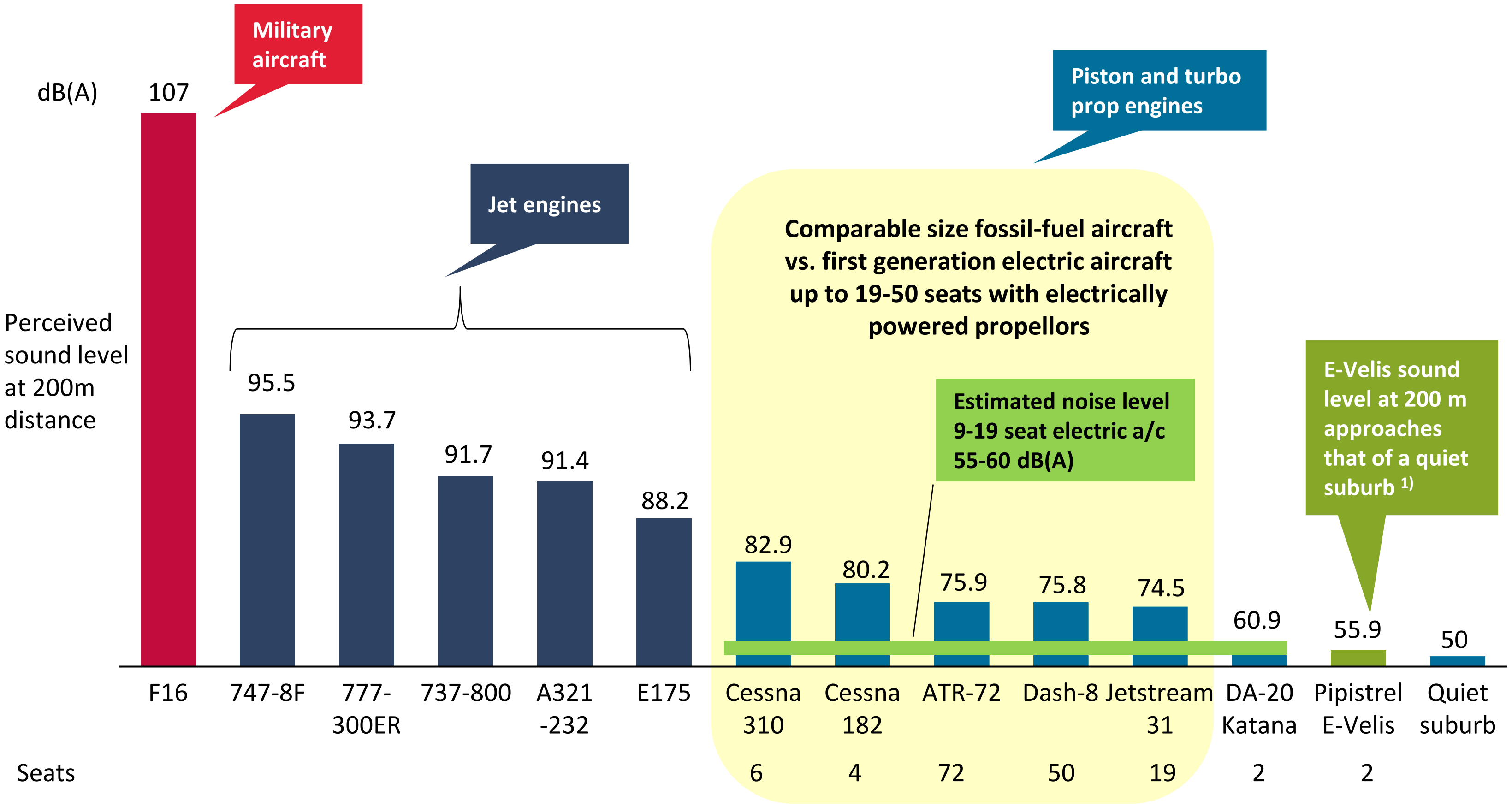
Total PM emissions for a 400 km flight fossil-fuel A/C vs. electric A/C (mg/pkm)



Note: Diesel and gasoline vehicles are very similar in terms of PM10 and PM2.5 which is why only gasoline emissions are shown
PM10 are Particulate Matter with a diameter of less than 10 micrometers and PM2.5 are particles with a diameter of less than 2.5 micrometers
Vkm = vehicle kilometer which takes into account the number of wheels/tires & brakes

Source: https://www.greencarcongress.com/2016/04/20160418-pm10.html / University of Edinburgh (for car data); 2011- Delft - Comparison of various transport modes on a EU scale with the STREAM database (for train data); https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-a-aviation-1/view; https://ce.nl/wp-content/uploads/2021/03/CE_Delft_190325_STREAM_Goedervervoer_2020_DEF_Versie2.pdf

New electrically powered small aircraft are expected to have significantly smaller noise footprint than comparable current conventional aircraft as has already been demonstrated by the Pipistrel E-Velis



Sources of noise emission:

- Speed of propellor tip (higher means more noise)
- Aerodynamic noise du to weight of the aircraft (more weight is more noise)
- Combustion (engine) noise (while limited it is a factor at short distance to the noise)

The perception of the noise is then due to the following factors:

- Altitude / Distance to the observer
- Engine power / Stage of the flight e.g., take-off, cruise or landing

Current understanding and explanation why electric aircraft will be (significantly) quieter than their current counterparts is due to a number of reasons

- Electric engines have high torque even at low speeds meaning lower propellor speeds are possible thus reducing noise
- Due to the higher torque available electric aircraft can, depending on design, climb faster putting more distance to observer faster
- Electric engines are smaller and weigh less so more engines (and propellors are possible) distributing the required power and enable blown lift
- Electric engines do not require gearboxes and have less moving parts and thus less noise

1) The noise level of a Pipistrl Velis is still relatively high for an electric aircraft as its propellor still runs at 2500 RPM while new generation drive trains allowing more/larger blades allow for a much lower RPM of around1300 – 1500 which significantly reduced noise levels. Blown-lift designs as foresees for the Venturi Echelon 01 will allow for even greater noise reductions

Source: NLR Appendices van de voorschriften voor de berekening van de geluidbelasting in Lden voor de overige burgerluchthavens bedoeld in artikel 8.1 van de Wet luchtvaart

Geluidsniveaus, prestatiegegevens en indeling naar categorie Versie 13.3

dB(A) value at 200m for Thrust setting 2 or in the case of jet engines or turbo prop second highest power setting

Current electric aircraft in development claim to have very low noise signature which could result in halving or more of sound levels compared to conventional aircraft

Noise impact

eCTOL

Current thinking is that electric aircraft can have noise signature that is 10-15 dB(A) less than conventional aircraft. This is half as noisy

Pipistrel Velis Electro – 2 seats - **60 dB(A)**

Lilium's eVTOL – 5 seats – **65-70dB(A)** at 100m claimed

Magnus eFusion – 2 seats – **60 dB(A)**

Cessna 174 – 4 seats – **86dB(A)** inside & **89 dB(A)** at 100m at take-off

Electric Aviation Group HERA – 70 seats – “whisper quiet” **(65% less noise)**

Kitty Hawk Heaviside **40 dB(a)** at 1500 ft overhead

NASA SCEPTOR X-Plane **15 dB** lower community noise

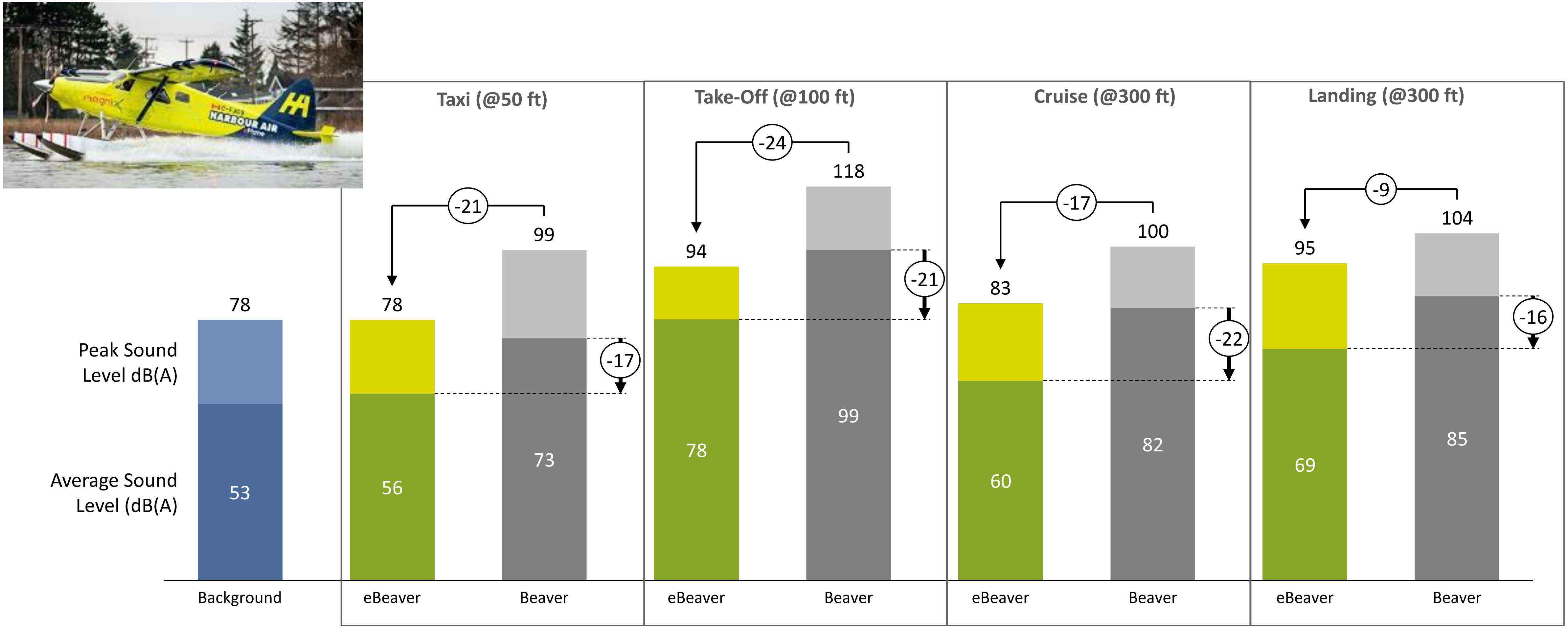
Sources: Company websites and various other sources

Recent test shows 16-22 dB(A) average sound level reduction across various flight segments when using an electric engine compared to a convention engine using a Harbour Air / Magnix DHC-2 Beaver

Noise impact

eCTOL

20 dB(A) reduction is equivalent to 100 times lower noise energy and 4 times quieter perceived sound level by humans



Taxi and cruise sound levels for the eBeaver are similar to normal background noise levels

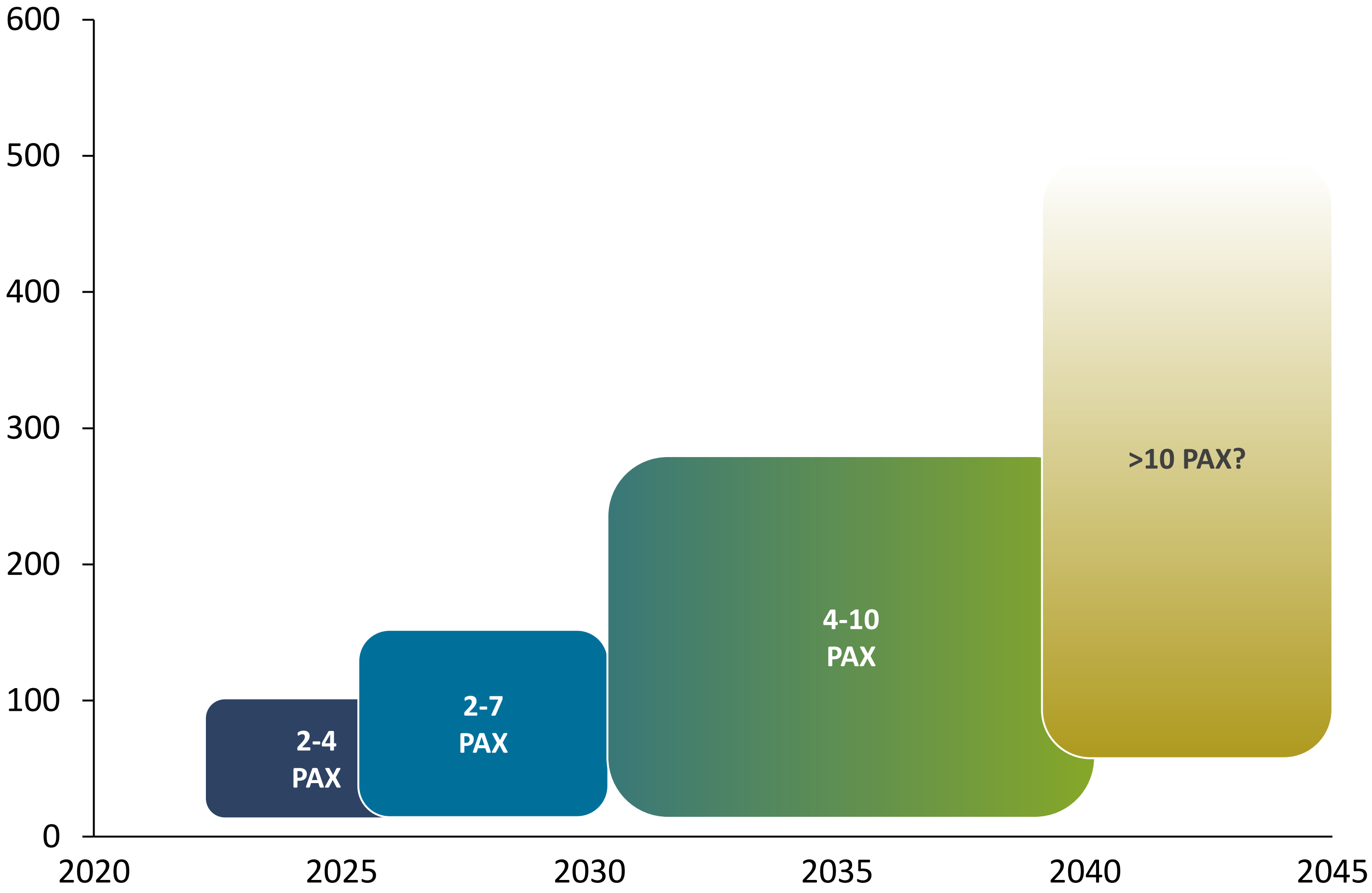
Source: https://transportup.com/headlines-breaking-news/vehicles-manufactures/truth-in-data-magnix-testing-shows-considerable-noise-reduction-in-electric-aircraft/

Contents

Topic

We expect eVTOL flights to develop in steps starting with flights below 100 km with 2 – 4 passengers but gradually increasing towards up to 10 passengers in the next decade

Potential development of UAM sector



0 **Current status**: eVTOL OEMs launching certification phase for 1st generation eVTOL aircraft. Battery-electric aviation can only be practiced with certified 2-seater aircraft (Pipistrel)

1 **2022-2027**: 1st generation eVTOL aircraft the market with flight performances below what is currently announced (range: <100km , capacity: 2-4 seats)

2 **2025-2030**: 2nd generation eVTOL aircraft entering market with flight performances matching specifications as initial promised (range: <150km , capacity: 2-7 seats). Construction of first Vertiports potentially starting

3 **2030-2035**: 3d generation eVTOL aircraft entering market with improved flight performances characteristics (range: <200-250km , capacity: 4-10 seats). Number of operated Vertiports potentially increasing

4 **>2035**: UAM market becoming more mature as UAM network becomes more dense and its service increases in popularity

5 **>2040**: if technology allows new generation eVTOLS with increased capacity and longer flight distance might potentially be developed and enter the market

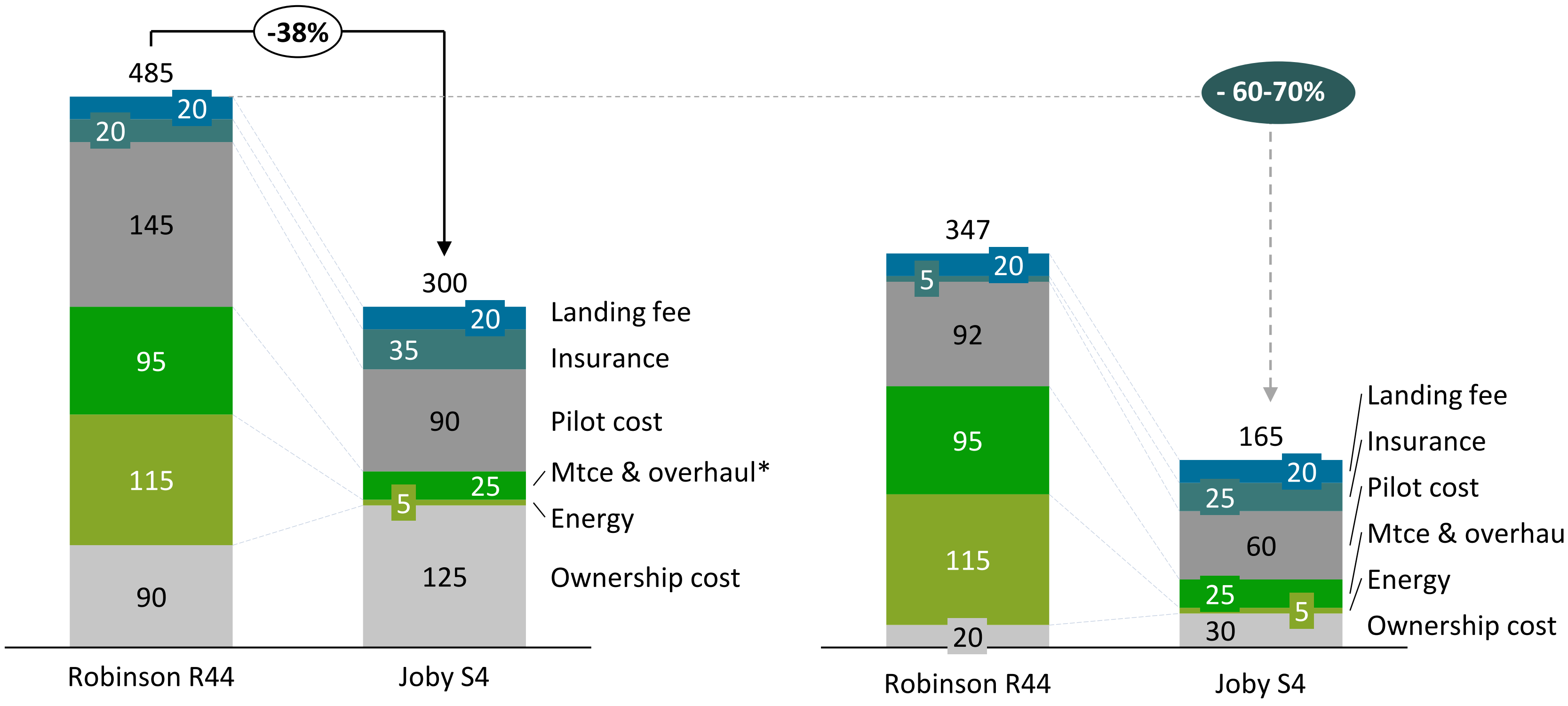
1) Source(s): M3 Desk research

An eVTOL with high utilization is by 2030 expected to have a cost advantage of ~60 to 70% compared to today's helicopter cost but even with comparable utilization will still be ~ 40 % lower in cost

Estimated trip operating cost for a 150 km trip excluding variable passenger charges and overhead cost in EUR with aircraft and battery cost by ~2028 - 2030

At current typical helicopter utilization rates

At projected eVTOL utilization



	Robinson R44	Joby S4	Robinson R44	Joby S4
Flight time (min.)	49	35	49	35

- Utilization (BH/year)
- Pilot productivity (BH/year)

- 450
- 450

- 2,000
- 700

Joby business plan 2026: 2.600 BH/year

Cost sensitivities:

- Electricity price 3 times higher: EUR 5 – 10
- Battery life cycle 50% lower: EUR 10
- Pilot productivity 25% lower: EUR 15 higher

* Includes battery reserve cost

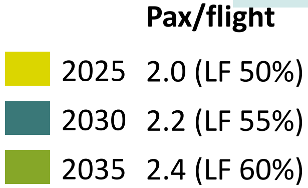
Sources: M3/PEN EM analysis

eVTOL costs are very expensive on a per passenger kilometre basis but dropping quickly with longer distances — over time cost are expected to drop by 60 – 70%

In 2021 EUR

Estimated price
per passenger km

Estimated cost
per vehicle km,
excl. airport taxes)



- With high one-off cost per passenger/flight and low variable operating cost, longer trips become much more attractive on a per km basis than short trips
- With the expected 2030 technology the cost of passenger km will be below EUR 2 for trips of 100 km but more than double for trips of just 20 km
- The above suggests that intra-city UAM services will be an (ultra) niche market while longer range eVTOL services will at one point be an relevant option for a much wider audience

Source: M3/PEN EM analyses

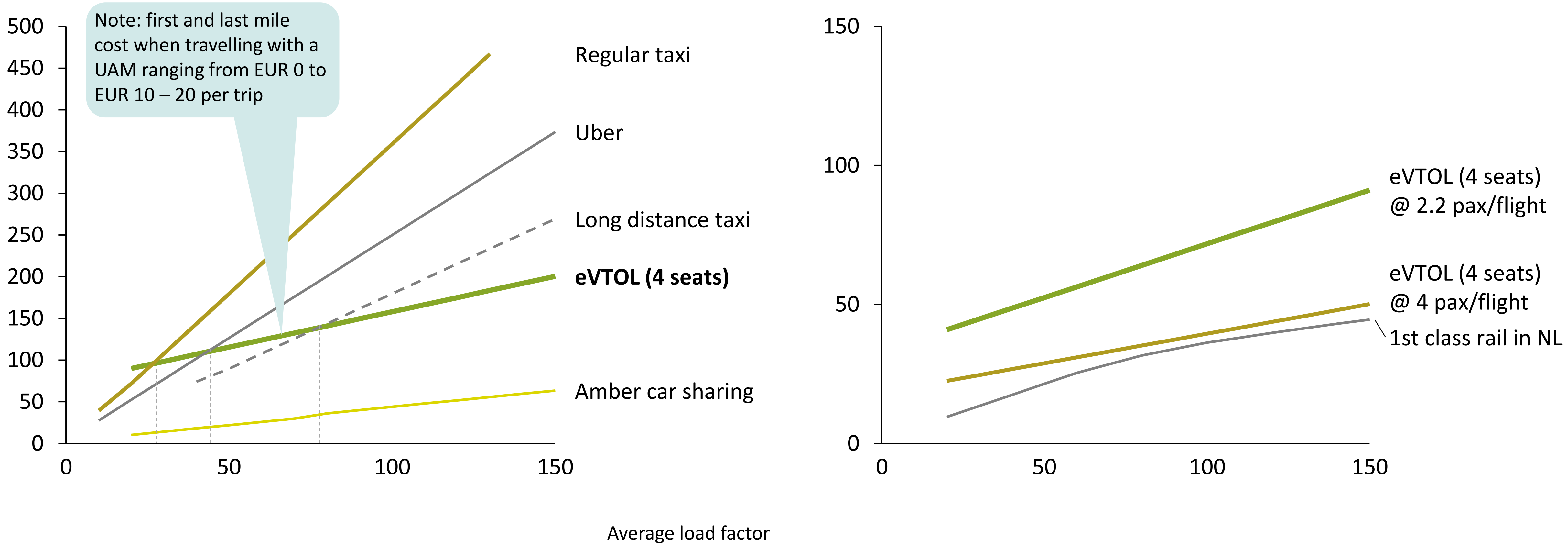
Given the low variable price per km, vehicle trip cost for a UAM service is expected to beat taxi services from around 30 – 50 km while on a per passenger basis is ~ twice as expensive as first-class rail

Economics

eVTOL

Estimated *vehicle trip cost* in 2030 expressed in 2021 EUR for different modes

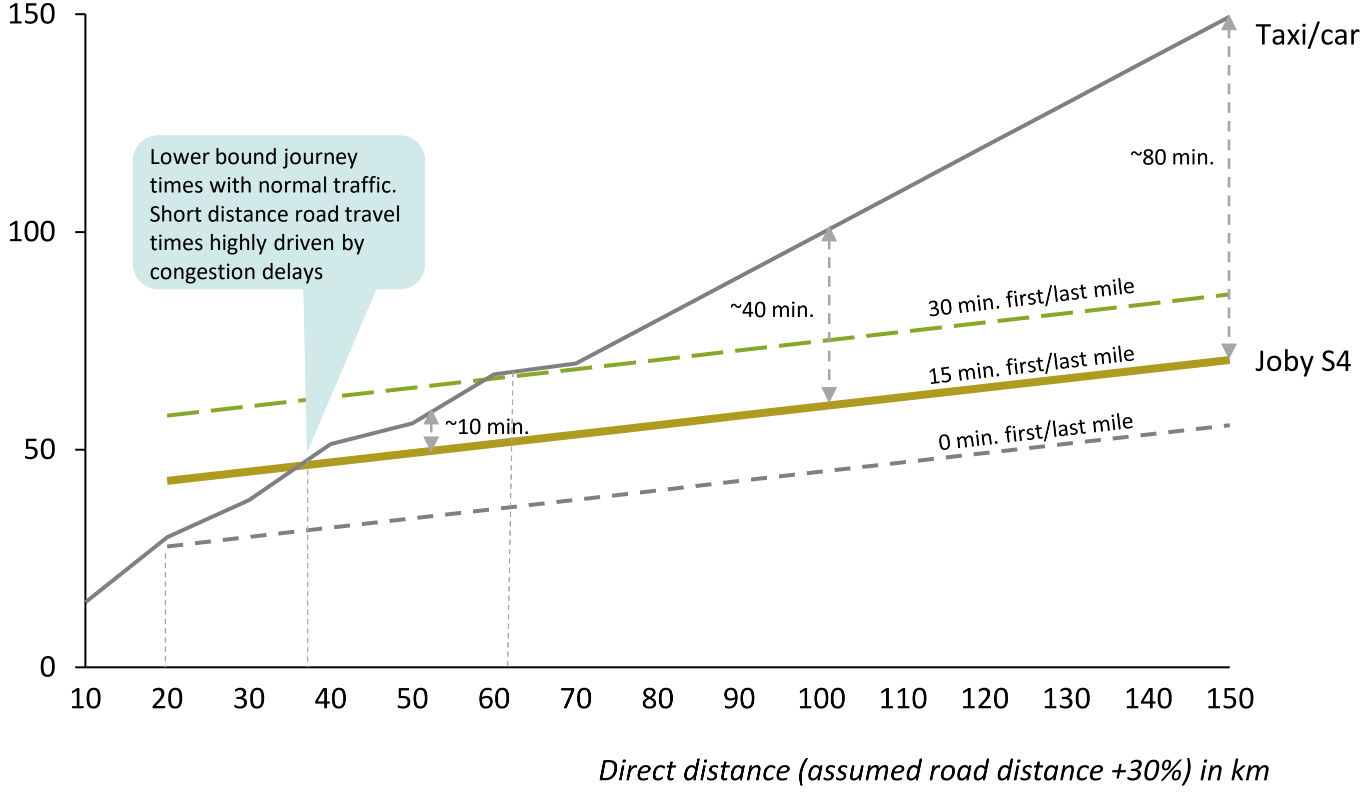
Estimated *passenger trip cost* in 2030 expressed in 2021 EUR for different modes



Note: first and last mile cost when travelling with a UAM ranging from EUR 0 to EUR 10 – 20 per trip

Source: M3 UAM cost model

In terms of journey times, UAM can be competitive against a taxi from around 20 km when origin and destination are both UAM-bases and from 60 km if both origin and destination are a 15 min drive away



Lower bound journey times with normal traffic. Short distance road travel times highly driven by congestion delays

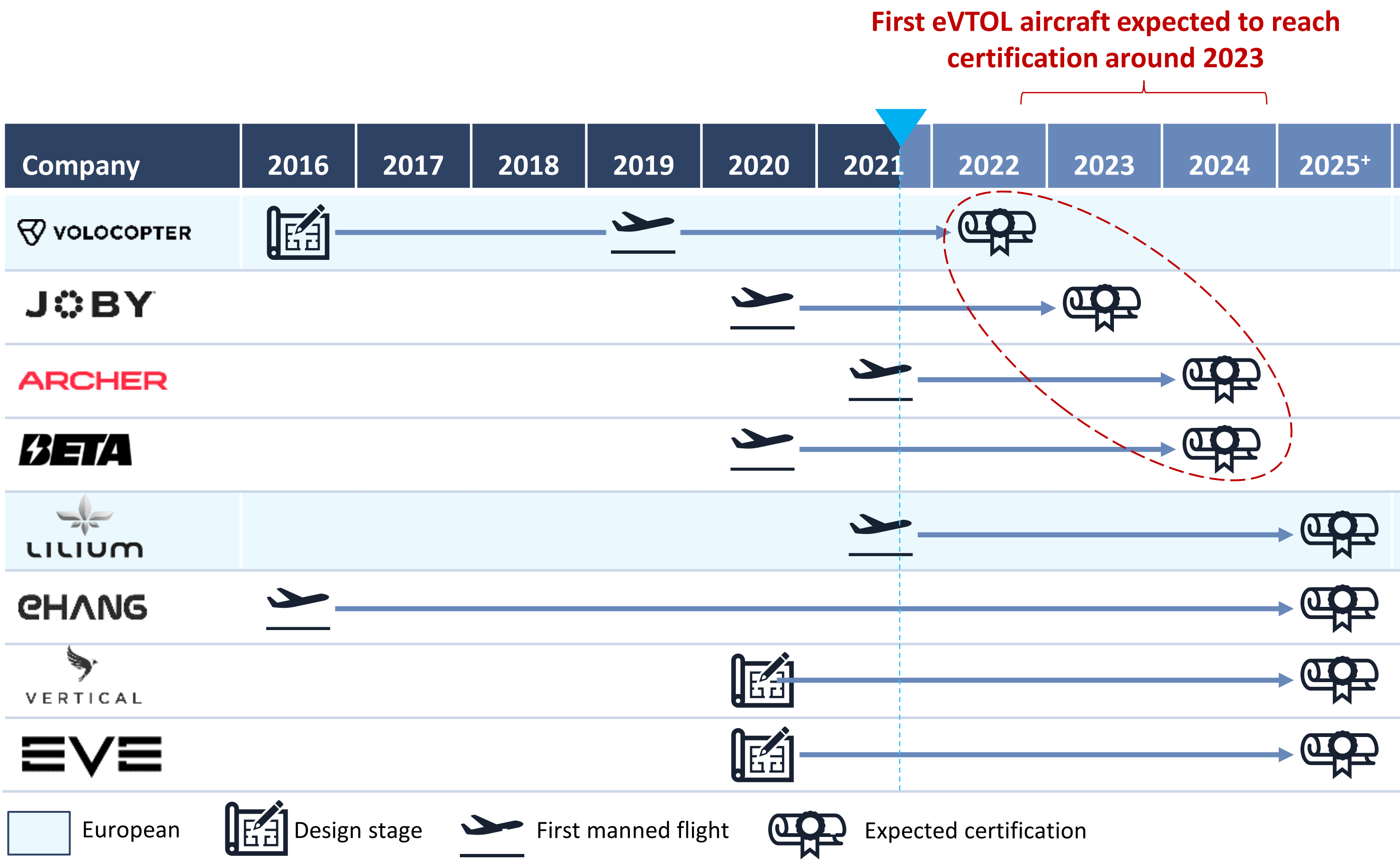
Assumed journey time for UAM

Trip-element	Remote to remote	Remote to Center	Center to Center
First mile	15	15	-
Pre-boarding	10	10	10
Boarding	5	5	5
Hovering	4	4	4
Deboarding	5	5	5
Last mile	15	-	-
Total time excl. cruise-flight	**54**	**39**	**24**
Example routes	Gieten - Zeewolde	Uithuizen - GAE	Eemshaven - GAE

Source(s): M3/PEN EM analyses

Certification of eVTOL aircraft is in the process of being launched, resulting in the first certified aircraft for UAM near the end of 2022 at earliest

Targeted certification timeline as announced by eVTOL OEMs



First eVTOL aircraft expected to reach certification around 2023

Company	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025+	Public announcements
Volocopter ▢	✎			✈			📜				- First manned test flight in USA in July 2021 - Commitment to launch Air Taxi services in Singapore
Joby					✈			📜			- n/a
Archer						✈			📜		- n/a
Beta					✈				📜		- n/a
Lilium ▢						✈				📜	- First manned test flight in Cologne and Dusseldorf planned for 2025
EHang	✈									📜	- Test flights planned for 2021 in Linz, Seville and Lliria
Vertical					✎					📜	- n/a
Eve					✎					📜	- n/a

▢ European ✎ Design stage ✈ First manned flight 📜 Expected certification

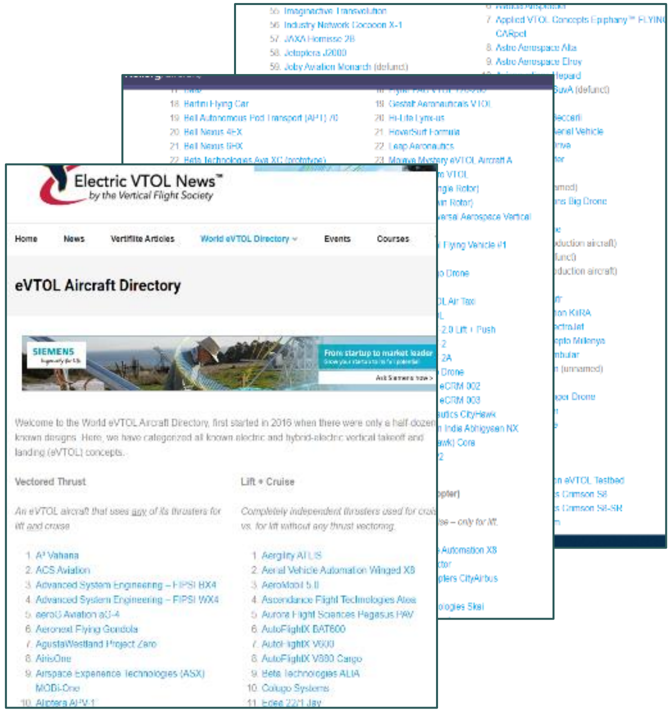
eVTOL aircraft use a blend of available FAA/ EASA certifications that cover about 67% of certification requirements. Additional certification considerations are being addressed with the FAA/ EASA by means of issue papers. Close cooperation between OEM and FAA/EASA is then required to develop special condition VTOL (SC VTOL) and complete eVTOL aircraft certification

1) Source(s): Study on the societal acceptance of Urban Air Mobility in Europe, EASA report; eVTOL Certification: Where Are They Now and the Challenges that Still Lie Ahead, aviationtoday.com

eVTOL developers that are able to breach the investment hurdle for certification are expected to be among the first to bring eVTOL aircraft to market

Overview of leading eVTOL developers

There are hundreds of eVTOL initiative across the globe..



Electric VTOL News™
by the Vertical Flight Society

Home | News | Vertiflite Articles | World eVTOL Directory | Events | Courses

eVTOL Aircraft Directory

Welcome to the World eVTOL Aircraft Directory, first started in 2016 when there were only a half dozen known designs. Here, we have categorized all known electric and hybrid-electric vertical takeoff and landing (eVTOL) concepts.

Vectored Thrust

An eVTOL aircraft that uses any of its thrusters for lift and cruise

1. A³ Vahana
2. ACS Aviation
3. Advanced System Engineering – FIPSI BX4
4. Advanced System Engineering – FIPSI WX4
5. aeroG Aviation aG-4
6. Aeronext Flying Gondola
7. AgustaWestland Project Zero
8. AirisOne
9. Airspace Experience Technologies (ASX) MOBi-One
10. Alptera APV-1

Lift + Cruise

Completely independent thrusters used for cruise vs. for lift without any thrust vectoring.

1. Aergility ATLIS
2. Aerial Vehicle Automation Winged X8
3. AeroMobil 5.0
4. Ascendance Flight Technologies Atea
5. Aurora Flight Sciences Pegasus PAV
6. AutoFlightX BAT600
7. AutoFlightX V600
8. AutoFlightX V800 Cargo
9. Beta Technologies ALIA
10. Colugo Systems
11. Edea 221 Jay

.. but only a handful have secured sufficient funding to finance the lengthy and costly certification process

Company	Prior Funds ($m)	SPAC/ alt	Cash + PIPE ($m)	Total Funds ($m)	Valuation ($m)	Orders
Archer	62	ACIC	1100	**1,162**	3800	United (250)
Beta	511	-	-	**511**	1400	Blade (150), UPS (202)
EHang	132	[IPO]	-	**n/a**	2200	Private (130)
Eve	*private*	ZNTE*	n/a	**n/a**	2000*	Halo (200), Helisul (50)
Joby	820	RTP	1600	**2,420**	6600	-
Lilium	392	QELL	830	**1,222**	3300	Azul (220)
Vertical	80	BSN	394	**474**	2200	American (350), Avalon (500), Virgin (150)
Volocopter	377	-	-	**377**	620	-
NOTES	-	-	-	*Post-SPAC*	-	*incl. options*

**under negotiation*

While some OEMs have managed to secure a large amount of funding, there is a considerable risk of a bubble burst when timelines are not being met or first production vehicle performance falls significantly short of currently projected performance with a snowball effect on other investments

1) Source(s): Turning Point, Electric VTOL News (evtol.news/news/turning-point)

eVTOL use cases are partly related to replacing current helicopter operations but for the most part related to new mobility options for passenger transport

🟩 Use case with highest potential in the Netherlands (from ~2030)

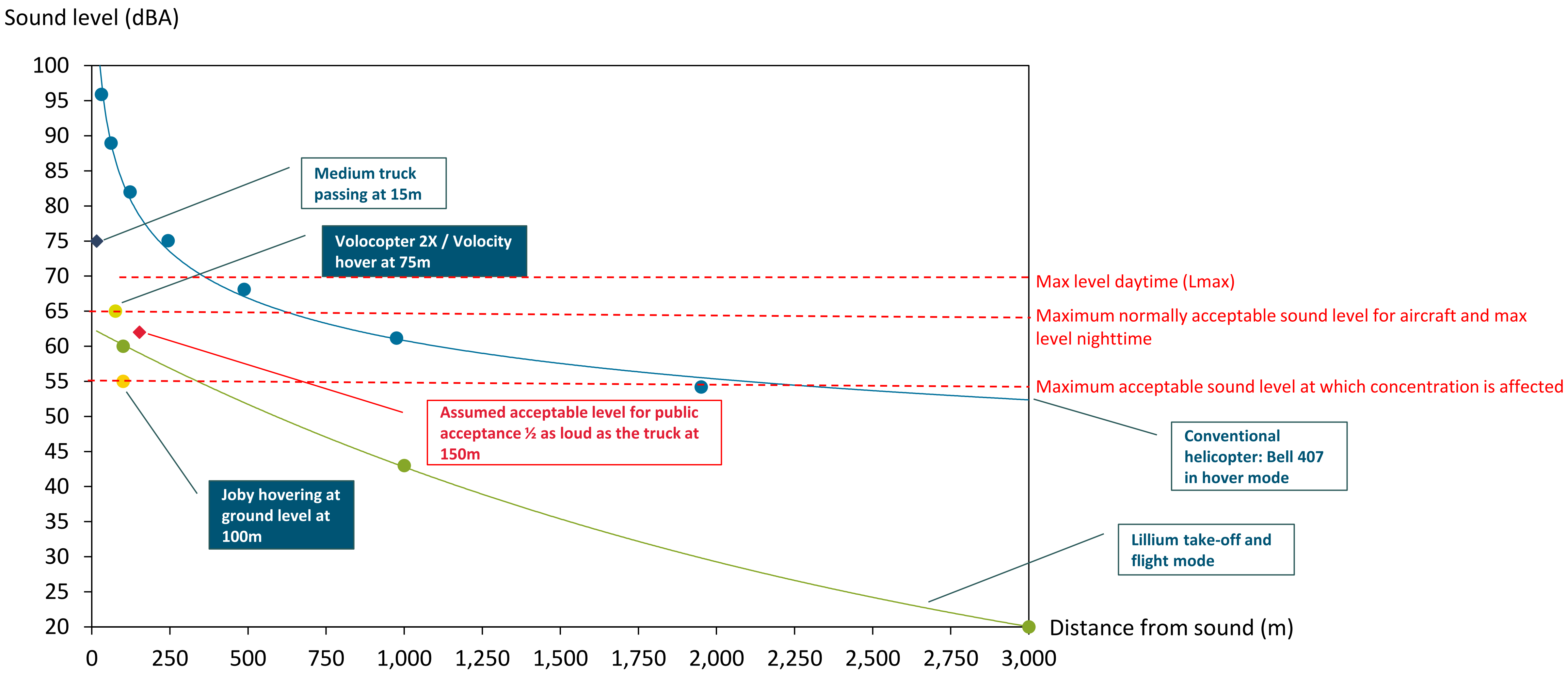
Potential for eVTOL operations in North Netherlands

		Use cases
Replacement of VTOL current operations	Emergency response	▪ Medical team helicopter services and ambulance flights
	Maintenance	▪ Inspection and maintenance of wind farms (but range a constraint)
	Passenger transport	▪ Transport of technicians and staff to offshore facilities or large ships
	Recreation	▪ Sight seeing
New VTOL operations (new use cases)	Emergency response	🟩 ▪ Expansion of ambulance flights directly from/to regional hospitals 🟩 ▪ Police helicopters; fire fighting
	Regular passenger transport	▪ Intra-city (up to 30 km) 🟩 ▪ Airport shuttle from mid-sized towns directly to the airport as a landside (or in some cases) air side connection 🟩 ▪ Intercity flights (50 – 150+ km) connecting major cities especially where no direct train connection exist and/or with frequent heavy traffic congestion 🟩 ▪ Island-connections from major cities to cross to large lakes/see offering significant time savings over land transport
	Special needs	▪ On demand services for special transport of persons or cargo that requires human supervision

Source: M3 analysis

The noise levels as indicated by the eVTOL OEMs of the currently flying versions is quite impressive with noise at 75-100m distance of around 55 – 65 dBA

All 3 UAMs reviewed claim to meet normally acceptable criteria for aircraft sound levels even at very short distances



Sources: Lillium, Joby and Volocopter company info and Sound levels of helicopters used for administrative purposes at Grand Canyon National Park, NPS Report No. GRCA-07-05 for Bell 407 data. 62 dBA level is from Urban Air Mobility: History, Ecosystem, Market Potential, and Challenges, University of Berkely

Joby has demonstrated how quite it is compared to small helicopters and fixed wing aircraft flying at 100 knots at 1570 feet high

Cirrus SR22

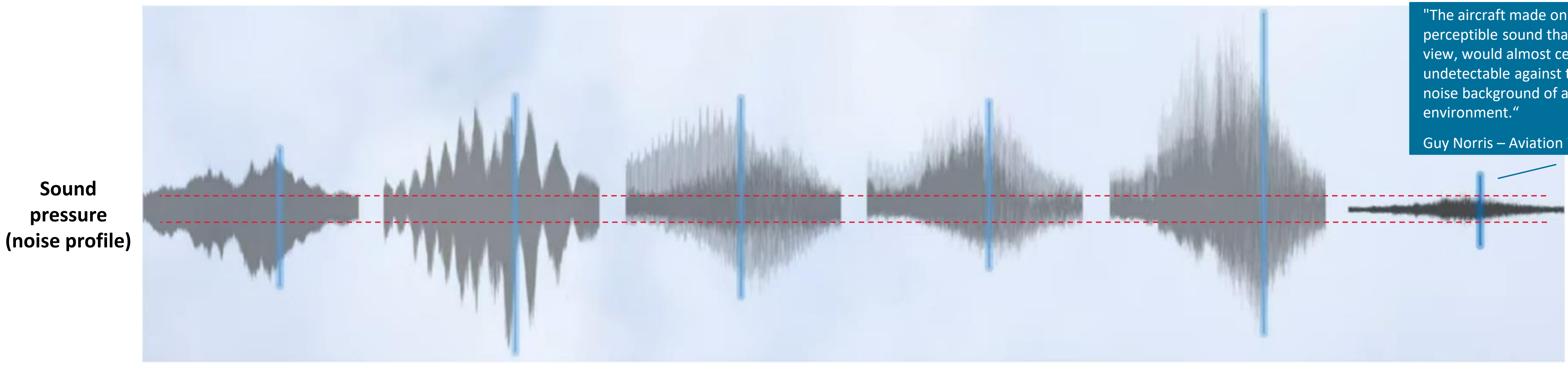
Beechcraft Baron BE-55

Robinson R44

Bell 106

Leonardo AW109

Joby



> "The aircraft made only a partially perceptible sound that, in this editor's view, would almost certainly be undetectable against the everyday noise background of an urban environment."
>
> Guy Norris – Aviation Week

- Small diameter propellor
- Fast tip speed
- Intense high frequency pressure waves

- Large diameter rotor
- Medium tip speed
- Rotor wake interaction
- Impulsive very low frequency pressure waves

- Large diameter propellor
- Slow tip speed
- Low intensity, low frequency pressure waves

Source(s): Joby Aviation

Contents

Topic

Required infrastructure investments are expected to be relatively modest for battery-electric applications, while hydrogen infra technology is less mature and requires more significant investments

Overview of infrastructure options for operations with battery- vs. hydrogen-electric aircraft

REQUIRED INFRASTRUCTURE

State of technology	Infrastructure options	Description	
BATTERY-ELECTRIC Existing technology. Required infrastructure for commercialization expected to be available/ can be copied from applications in automotive industry relatively easy	➢ Ground Power Units (GPU)	➢ Although most airport already have GPU’s in place, capacity and power are both relatively low resulting in long recharging times	
	➢ Portable battery system	➢ Battery energy storage systems (stored in a sea container) can recharge at ~200 kW with a capacity of ~500 kWh and can easily be moved around on airside for recharging purposes.[1]	
	➢ Recharging network	➢ Installed recharging network with next generation fast chargers can be installed and connected to local grid (midden-hoogspanningsnet). E.g., recharging network for electric busses at Schiphol is delivering 13 MW to 100 busses[2]	
HYDROGEN-ELECTRIC Required infrastructure technology under development. Commercialization will require creating a whole new hydrogen infrastructure	➢ On-site electrolysis	➢ Requires local supply and/or production of electricity and electrolyser to convert electricity into hydrogen	+
	➢ Off-site + truck	➢ Requires transportation from off-site production location to the airport. Required transport capacity depends on scale of operations	+
	➢ Off-site + pipeline	➢ Requires large infrastructural investments for the construction of a hydrogen distribution network. From off-site production location to airport	+

In all three cases, on-site storage and refuelling systems are required to accommodate H_2-aircraft

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1) Solar deals (link

2) BOV Eindhoven (link))

The potential network for eVTOL operations can be larger and denser compared to eSTOL & eCTOL aircraft as eVTOL aircraft will use existing heliports and future vertiports in addition to existing airports

Infra Requirement

Theoretically available infrastructure per aircraft configuration

		Heli/verti-pad/-port	Local & military airports	Regional airports	Large airports
Description		Heliports typically serving business travellers, emergency- and military operations with conventional helicopters at the moment	Typically serving general aviation (GA), aeronautics and military operations; too small/ exclusive (military) for commercial transport; some military airports potentially opening up for civil co-use	Serving commercial point-to-point and feeder destinations in Europe; only some activity related to GA, emergency- and/or military operations	European hubs, typically serving commercial point-to-point and intercontinental destinations; only some activity related to GA, emergency- and/or military operations
Examples in N-NL region		Eemshaven, Amsterdam, Borkum	Ameland, Drachten, Hoogeveen, Borkum, Emden	Lelystad, Groningen, Twente	Schiphol
Typical vs. required runway length/ platform size		15m x 15 m – 35m x 35 m	720 – 1,300 m	1,800 – 3,000 m	3,300 – 3,800 m
eVTOL	~30m x ~30 m	☑	☑*	☑*	☑*
eSTOL	100 m	☒	☑	☑	☑
eCTOL	800 m	☒	☑	☑	☑

**Operations with eVTOL only possible in case of available heliport infrastructure*

Required power for testing phase with battery-electric flights expected to be limited, while commercial operations (at larger scale) quickly require a fully installed recharging network

Estimation of required peak Power for different scales of operation (MW)

AIRCRAFT PERFORMANCE ACCORDING TO OEM

Eviation Alice

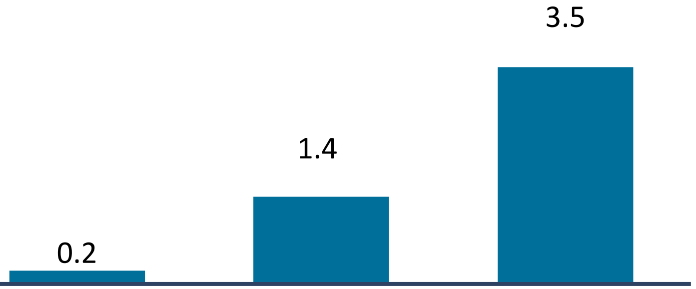
Dry Operating Mass	2,010 kg
Battery Mass	3,540 kg
Payload	800 kg
Max Take-Off Mass	6,350 kg

	SECENARIOS		
	Testing	**First Operator**	**Multiple Operators**
No. aircraft (#)	1	5	15
No. flights p day (#)	4	6	6
Average range p flight (km)	160	250	450
Charge time per flight (min)	120	30	30
# of aircraft charged in parallel	1	2	4

REQUIRED INFRASTRUCTURE

- Portable battery systems would be well suited for facilitating electric flights in testing phase, and potentially also start of operations/ first operator. Because recharging power is relatively low (~200 kW) and results in long recharging times, this option becomes less attractive for commercial operations
- A fully Installed recharging network would provide direct access to energy supplies but requires significant investments. Therefore, this option should be considered in a later stage of the development roadmap, and after the potential of a positive business model for the airport (and operator) is proven in testing/ first operator phase

Estimated peak Power (MW)



TO PUT NUMBERS INTO PERSPECTIVE

- Peak power capacity of a departing train (intercity, ICM-0) ~1.25 MW
- Annual electricity consumption Eindhoven Airport ~7 MW
- Recharging station for electric busses at Schiphol Airport delivering ~13 MW

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1) M3 Analysis

Required hydrogen supplies expected to be relatively low for all stages of operations; even at large scale of operations transportation by truck expected to be feasible and economically most viable option

Infra Requirement

Estimation of required hydrogen supplies for different scales of operation (Litres p day, x10^3)

AIRCRAFT PERFORMANCE MODELING

Eviation Alice

Dry Operating Mass	2,010 kg
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Payload	800 kg
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SECENARIOS

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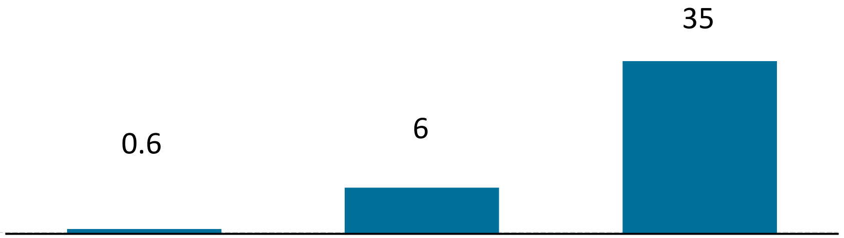
Cryogenic H_2 volume (Litres p day, x10^3)



	Testing	First Operator	Multiple Operators
Weight (kg)	42	420	2,500
Required transport capacity (no. truck loads)	X 0.01	X 0.15	X 0.7

Assuming LH_2 truck with total capacity of 50.000L[1]

REQUIRED INFRASTRUCTURE

- Transportation by truck expected to be most cost effective method for the amount of hydrogen required and when transport distances remain below a few hundred km
- On site H_2-production could be an alternative for operations at sale, removing the need for transportation and enabling economies of scale in a single large storage tank, but still requires the need for transporting hydrogen from a central reservoir to the aircraft
- Installation of branched pipeline seems unlikely. Due to the highly branched/distribution nature of airports, and relatively low flow rate through each branch, which must be held at cryogenic temperatures, required investments are expected to be very significant[2]

1) Mahytec (link); NPROXX (link); Cryoworld (link); M3 Analysis 2) Hydrogen MIT study (2019)

Required hydrogen supplies expected to be relatively low for all stages of operations; even at large scale of operations transportation by truck expected to be feasible and economically most viable option

Infra Requirement

Estimation of required hydrogen supplies for different scales of operation (Litres p day, x10^3)

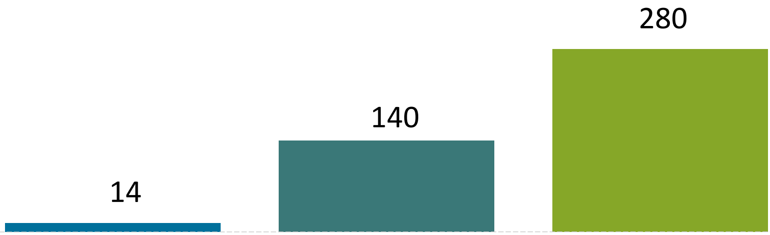
AIRCRAFT PERFORMANCE MODELING

Retrofit ATR 72[3]

Dry Operating Mass	31,265 kg
Propulsion system Mass	8,146 kg
Payload	16,645 kg
Max Take-Off Mass	38,870 kg

SECENARIOS

	Testing	First Operator	Multiple Operators
No. aircraft (#)	1	5	15
No. flights p day (#)	1	10	30
Average range p flight (km)	900	900	900
Cryogenic H_2 volume (Litres p day, x10^3)	14	140	280
Weight (kg)	1,000	10,000	20,000
Required transport capacity (no. truck loads)	X 0.28	X 2.80	X 5.60



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- **ZeroAvia and Universal Hydrogen has made a deal with ASL to retrofit ATR72 aircraft. (link)*

---

1) Mahytec (link); NPROXX (link); Cryoworld (link); M3 Analysis

2) Hydrogen MIT study (2019)

3) Preliminary Propulsion System Sizing Methods for PEM Fuel Cell Aircraft (link)

State-of-the-art charging infra already allows for recharging aircraft in ≤1.5 hours and likely to further develop in the next 5 years, enabling short and competitive turnaround times for electric aircraft

🟩 <45 min
🟨 45 min - 1.5 hrs
🟧 1.5 - 3 hrs
🟥 > 3 hrs

Equals energy required to fly ~400 km with 19-seater and ~800km with 9- seater.

	RECHARGING TIME			
Energy required (kWh)	**Mobile (250 kW)**	**Next Gen (350 kW)**	**Fast (600 kW)**	***Mega (1,200 kW)***
50	🟩 00:12	🟩 00:09	🟩 00:05	🟩 *00:03*
100	🟩 00:24	🟩 00:17	🟩 00:10	🟩 *00:05*
150	🟩 00:36	🟩 00:26	🟩 00:15	🟩 *00:08*
250	🟨 01:00	🟩 00:43	🟩 00:25	🟩 *00:13*
500	🟧 02:00	🟨 01:26	🟩 00:50	🟩 *00:25*
750	🟧 03:00	🟧 02:09	🟨 01:15	🟩 *00:38*
900	🟥 03:36	🟧 02:34	🟨 01:30	🟩 *00:45*
Description of charging technology	Mobile charger, potentially interesting option for a PoC when infrastructure is not yet in place	Next generation charging stations for automotive passenger transportation vehicles, available in short term	Rapid charger for heavy-duty battery electric vehicles (BEV) already in use	*Next generation of rapid chargers for heavy-duty battery electric vehicles (BEV). First such chargers installed in 2021*
Feasibility	**Considered to be feasible options for application before 2030. For 19-seater aircraft such as the Heart ES-19 a dual charge system is said to be used**			*Readiness of battery tech. expected to be insufficient and uncertain for future applications in aviation in next 10 yrs*

- Current charging infrastructure for BEVs allows for flights ~400 km with 19-seater and ~800 km with a 9=seater while keeping recharging time ≤. hrs
- Development of mega chargers will further reduce recharging time to ≤45 min, depending on distance of flight
- Future outlook for charging infrastructure looks promising, allowing for even shorter turn around times (TAT) that can be competitive with TAT of conventional aircraft
- Key will be to make efficient use of lower cost, slower chargers for overnight (150-350 kW sufficient) and fast chargers for charging between flights

Daimler Builds First Public Megawatt-Level EV Truck Charging Site

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1) Comparison of hydrogen and battery electric trucks, Transport & Environment; M3 desk research

Contents

Topic

A base-case and low-case potential network and demand of low/zero-emission aviation at MAA can be developed based on expert judgement using a wide-variety of inputs

General developments (Section I)

Technical feasibility
- Range/capacity
- Timing (certification/production)

Economic feasibility
- Cost per seat/passenger (by range)
- Battery development assessment

General SAF market developments
- % of total fuel
- Fuel distribution dynamics

Other market reports
- Potential interest (e.g., EASA study)
- Market size/growth
- Timing

European and Netherlands-specific context dynamics (next slide)

(Expected) Dutch policy context
- Tax on fossil-fuel flights vs. low/zero-emission aircraft
- Slot availability for low/zero-emission and low-noise aircraft
- Airport charges/facilities for low/zero-emission aircraft
- Road taxing; subsidies; Investment in other infra

Limburg-specific market dynamics

DLR Small Aircraft Tool
- Current demand by mode
- Potential market share small aircraft
- Potential routes

MAA market analysis
- Local demand by route
- Connecting traffic potential

Historic demand for regional connections
- MAA – AMS route
- Other Dutch regional routes

CBS ODiN data
- Current demand
- Prosperity

Current offering to/from region
- Current demand
- Prosperity

Potential development of low/zero emission aviation at MAA in terms of network and volume

Approach to estimating potential development of new low/zero-emission aviation operations at MAA:
- Given the many uncertainties such as timing and economics and the fact that new low/zero-emission aircraft will likely take share from other modes of travel, there is no exact way to determine the network and volume of new zero-emission aircraft operations. Availability of aircraft will be the main constraint for development in the first 10 years of operation
- However, based on the many data points/insights as described above, an expert judgement can be made to develop a base-case scenario and a low-case scenario:
    - ***Base-case***: timeline of first flights at MAA 3 – 4 years after OEM-stated target year of introduction (see assumptions page for more detail)
    - ***Low-case***: assumes significant delay in certification/production upscaling and higher cost: timing +5 years of base case timeline; traffic -50% of (already 5 year later) operations
- While routes/volumes may well turn out differently, these scenarios will allow for an assessment of the expected societal costs and benefits

The transition to sustainable aircraft and airport operations at MAA is not option but a necessity as a result of a wide range of international and national policies, regulations and industry agreements

International regulations & policies regarding sustainable aviation

Net-zero carbon emissions by 2050

- **Policies**:
  - EU Fit for 55
  - EU Green Deal
  - Paris Agreement
  - ETS/CO_2 reduction of free allocation of rights
- **Rules/regulation/taxation in preparation**
  - Potential introduction of kerosine tax (excise duty)
  - Mandatory SAF mixing
  - EASA aircraft certification rules for new technologies
- **Industry agreements**:
  - IATA goal: Net Zero carbon aviation sector by 2050.
  - European aviation sector: Destination 2050
  - ICAO: CORSIA

MAASTRICHT AACHEN AIRPORT

National policies regarding sustainability, livability and connectivity

- **Policies**:
  - Luchtvaartnota 2020-2050/ Klimaatakkoord Luchtvaart:
    - 2030 carbon neutral airport operation
    - Mandatory blending SAF 2030 14%, 2050 100%
    - Dutch airport system: MAA is an element in Dutch air accessibility
    - Growth of airports only allowed in combination with reduction of annual noise levels and when it contributes to regional development
- **Rules/regulation/taxation in preparation**
  - Increase in aviation tax from EUR 7.85 to ~ EUR 20 per passenger (likely not for low/zero-emission aircraft)
  - CO_2 cap at airport level (incl. aircraft emissions)

Verantwoord vliegen naar 2050

Ontwerp-Luchtvaartnota 2020-2050

There are many reasons why small electric aircraft are expected to generate significant demand

Demand drivers for low/zero-emission aviation at MAA	Explanation
Significant time savings	• Time savings travelling to/from Zuid-Limburg are significant due to short airport processes (max. 20-30 min ahead of time at airport) and short flight times. Door-to-door travel time savings for domestic services to e.g., Groningen already 2 – 2.5 hours; international destinations in the 400 – 500 km range 3 to 5 hours • Regional airports closer to home/final destination; arriving at hub airport results in significant time saving
Cost levels (increasingly) competitive against other options	• Ticket prices for small electric aircraft will be relatively high compared to current large aircraft ticket prices but: • Cost of electric aircraft will come down significantly over time while cost of fossil-fuel flights quicky rising with Aviation tax going towards EUR 20 on average and need to use Sustainable Aviation Fuel • Introduction of road pricing will make driving relatively less attractive
Much more pleasant way of travelling	• Short journey to/from airports in the region (for many inhabitants MAA is also as easy/more easily to reach than an intercity rail station) • Much quicker processes at the airport requiring to arrive only 20-30 min ahead of the flight vs. 60-120 min for large aircraft operations • Inflight experience much better due to lower cabin noise and less vibrations
Demand is out there but not accommodated today for various reasons that will likely not apply to new low-zero emission aircraft	• DLR SAT modelling results in a (preliminary) estimate of total unconstrained market potential at around 1.5M passenger (2012 traffic data) • Concerns about climate impact refrains both passengers flying short distances; ‘Flying zero-e’ (and low noise) will have a totally different image • Jet fuel cost at regional airlines make flying from regional airports relatively more expensive. With electricity there is no such cost difference • Businesses express strong demand for more direct connections in particular to hubs but also to other important destinations • Hub feeder routes have shown to have sufficient demand (MAA > Schiphol 50 – 80k passenger per year but stopped due to higher value of use of scarce peak hour slots by larger aircraft for other routes. Also, point-to-point routes like Rotterdam-Groningen have proven to work but failed ultimately due to high cost and undesirability (emissions/noise) • Through the use of Pricing and Revenue Management tools airlines can offer tickets extracting high value from the premium segment and be able to offer low prices for price-sensitive customer segments
Airlines/operators are already seeing the opportunity	• While many existing large airlines have not yet looked into the opportunity of electric aircraft operations, operators’ interest is increasing quickly: • Several large airlines have already announced a Letter of Intent (e.g. United Airlines) • Many start-up airlines and regional airlines (also in NL) have expressed their ambition to acquire these new aircraft (see Section II)
Airports likely very much welcome low/zero emission and low-noise aircraft	• Large airports have typically seen a lot of small aircraft operations seen being reduced and operational integrations has some challengers but: • (Hub) airports such as Schiphol face considerable environmental pressure with tightening caps on noise and on emissions. Low noise, new aircraft will not take up much/any such of the noise or emission budget • Separate slots for low-zero-emission aircraft might be introduced so it may not affect its ability to accommodate large aircraft • Less operational restrictions might be applied to very low-noise aircraft (other opening hours) but integration of more (small aircraft) movements in peak hours will encounter some significant challenges

Contents

Topic

Base-case vs. low-case scenarios: general view and key assumptions

Base-case

- The base-case is assumes a slow relatively slow ramp up with battery-electric aircraft and some hybrid-electric aircraft with the growth towards 19-seaters only by around 2031/2032 growing to around 50 departures per day in 2035/200
- eVTOL will grow from2 locally based eVTOLs to 8 in 2035 and 6 in 2040 (as more downtown vertiports become available
- eGA assumptions are very conservative (15 dep/day in 2035; 25 in 2040) as this segment may well grow significantly through new on-demand air services as early as 2026. Such an extra growth would go partly at the cost of scheduled eCTOL operations
- eCargo traffic are similarly very conservative(10 dep/day in 2035; 25 in 2040 with small 2-5 ton aircraft). There is moderate to high change demand will be much higher and come more quickly with new logistics networks emerging e.g. hospitals optimizing medicines, isotopes, general stock; patients between locations allowing for better care and lower cost. But also large hydrogen aircraft with 20 ton capacity may well be starting services to MAA

Low-case

- In the low-case, the introduction of new technologies will be strongly delayed due to challenges with certification and scaling up production. As a result, cost will be higher than expected which will reduce potential demand
- The chance that by 2035 there will be no traffic is consider close to 0.

Aspect	Key assumptions	Key assumptions
Traffic segments segments in scenario	• eCTOL (using runway) passengers and flights on domestic and international routes. Traffic is mostly point-to-point traffic but for hub-destinations it includes also connecting passengers • eVTOL (using vertipads): total operations (based on number of eVTOLs and number of trip per eVTOL per day); initial range up to around 2030 max. 100 km; towards 2035 max range 200 km. • eCargo (using runway or vertipad) small aircraft operations both with CTOL and VTOL technologies • eGA (using runway): small 4-9-seater electric aircraft (only movements)	• All timelines +5 years • Traffic potential -50% vs. 5 year earlier in base case (due to higher cost)
Aircraft-related assumptions	• General: introduction of new aircraft approx. 4 – 5+ years after target certification year currently announced; e.g. • 9-seater: target certification year 2024; assumed introduction at MAA 2028 • 19-seater: target certification year (Heart Aerospace ES-19): 2026; assumed introduction at MAA 2031 • 44+-seater: target: 2028-2032; assumed introduction at MAA: 2033-2035 (due to initial high cost of hydrogen; the first of these aircraft are most likely used for replacing current operations as opposed to unlocking new routes from MAA • NB: 4-seater small eCTOL aircraft for air taxi use are part of eGA traffic • Routes: up to 2030 max. 400 - 500 km; 2030-2040 max range 750 • Propulsion technology: mix of battery-electric and hybrid-electric in first 5-7 years or operation; hydrogen-electric from 2030-2035)	• All timelines +5 years
Operations (detailed by route for eCTOL operations)	• Air: Travel time to MAA: 20 min; minimum reporting time at airport 20-25 min.; average aircraft speed ~ 250-300 km/h (depending on trip distance. Average domestic fares (including 9% VAT) estimated to be EUR 0.40-0.45 cents/pkm in 2030; EUR 0.37/pkm in 2035 and EUR 0.34 /pkm in 2040. For international trips no VAT is assumed • Road: driving time (Google maps); breaks (from 15 min to 90 min) and buffer time (15 to 45 min) to cover for potential delays • Rail: fastest connection available with 10 min travel time to and 10 min from rail station	• Like base-case
MAA revenue (passenger fee, landing fee; handling fee)	• eCTOL: EUR 20 per departing domestic passenger and EUR 30 for international (Groningen Airport Eelde had ~ EUR 32/pax in 2019) • eVTOL: EUR 20 per passenger • eCargo: EUR 125/metric ton in 2030; EUR 100/metric ton in 2040 (larger aircraft) • eGA: EUR 250 per movement	• Like base-case

Based on the characteristics of new technologies likely users can be identified but with varying level of uncertainties and thus confidence in the traffic development

Market segment	Expected users	Key uncertainties	Level of confidence with regard to base-case scenario

• **eCTOL**	• Point-to-point (travellers from/to MAA)
	  • Large corporates with multiple locations (in NL and abroad)
	  • Professional services companies/selected academia
	  • Professional sports teams (charter)
	  • High income families(for short holiday trips or family visits
	• Connecting at hub-destination (in addition to the above)
	  • Small/Medium-sized businesses
	  • Mid income tourists/ family visits
	• Connecting at MAA
	  • Travellers who make a journey combining 2 flights through a connection at MAA
		• Battery technology development
		• Certification timing
		• Production scaling
		• Acceptance of autonomous flight (no pilot)
		• Reduction in business travel
			• Medium to high: potential demand is not the key constraint; supply side is. In case batteries don't improve quickly, there will more use of hybrid-electric and hydrogen-electric. With the higher cost, it may limit the market size

• **eVTOL**	• Airport transfer
	  • To connect at point of destination (e.g., Brussels/Dusseldorf)
	  • Flying from regional cities to MAA for connection on longer flight
	• High end corporates (e.g., Maastricht-Arnhem)
	• High income groups
		• Number of landing sites
		• Global scale of production
		• Air space integration
		• Cost
		• Vertiports near Maastricht (competing with MAA)
			• Medium to low: base-case is optimistic in cost and global vertiport development but assumes a local vertiport in/very close to Maastricht City Center won't be operational well into the 2030s

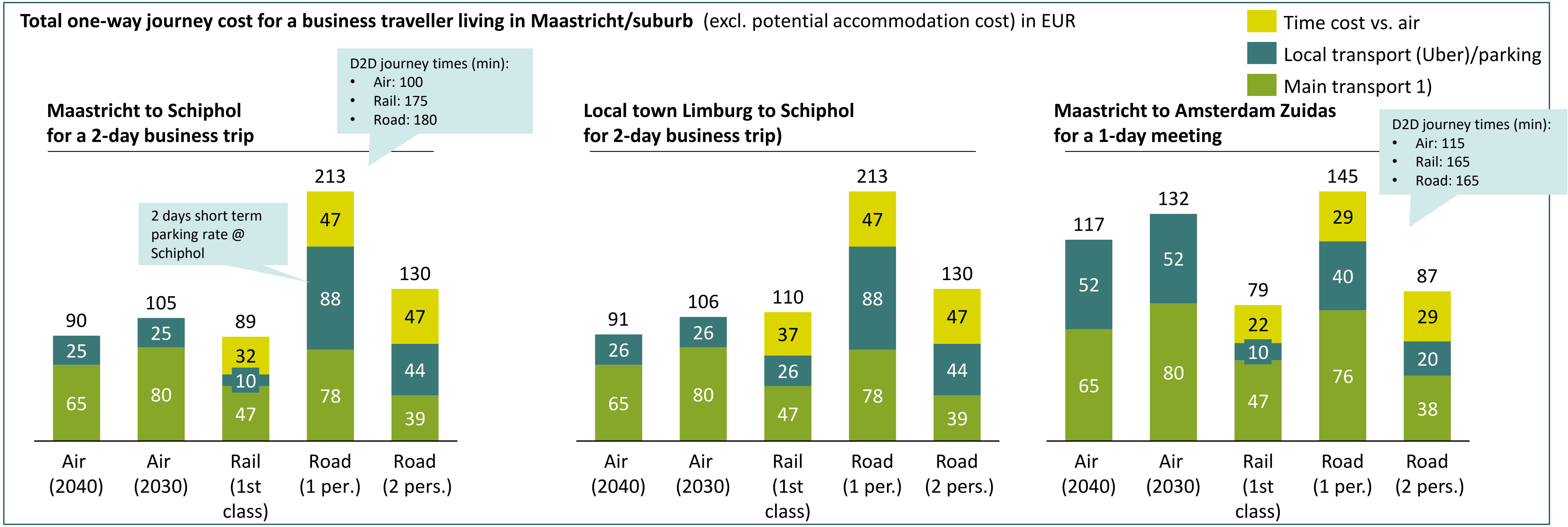
• **eCargo**	• Express operators (e.g., DHL, UPS) • Air cargo forwarding/local operators for fast delivery of selected shipments • Longer term wider range of medical supplies, higher value goods for rush deliveries	• Speed of introduction of autonomous flight • Number and location of cargo eVTOL landing sites e.g., at industrial parks	• Low: base-case is relatively conservative as cost difference between eCargo and road transport will narrow by a lot compared to today's cost difference between short haul air cargo vs. road freight. New technologies will trigger new logistics patterns.
• **eGA**	• Executives; senior management; very high income individuals; but also groups chartering a plane (larger customer base than today's business aviation due to lower cost/clean)	• Scale (higher scale makes real on-demand models feasible)	• Medium-high: economics are attractive compared to today's offering. A high growth of this segment will go at the cost of eCTOL

Case example Maastricht – Schiphol/Amsterdam Zuidas: flying to Schiphol is an attractive option when connecting to onward flights especially for those not living close to an intercity rail station

Case example Maastricht – Schiphol/Amsterdam Zuidas

- A hub-feeder flight to Schiphol would save travellers approx. 1h15 in time compared to travelling by train or car to Schiphol. It would also be more convenient especially when the flight will be handled at the main terminal. For people living close the Maastricht rail station, rail will initially have a lower cost. But for people requiring as much time to get to MAA as to the station, an air connection is already lower cost. For some business travellers an eCTOL flight might also be an option for a trip to Amsterdam Zuidas
- In the years 2000 – 2005 the Maastricht – Schiphol route had an average annual passenger volume of 68k passengers. By 2020,the market size would be around 105k passengers and a 2.5% growth in 2020-2040, it would be approx. 175k passengers in 2040. In the base-case scenario, it is assumed that in 2035/2040, the routes would have an average of 6 daily departures with a 50-seater aircraft adding up to around 85k passenger per year, well below estimated market size

Total one-way journey cost for a business traveller living in Maastricht/suburb (excl. potential accommodation cost) in EUR



2 days short term parking rate @ Schiphol

D2D journey times (min):
- Air: 100
- Rail: 175
- Road: 180

D2D journey times (min):
- Air: 115
- Rail: 165
- Road: 165

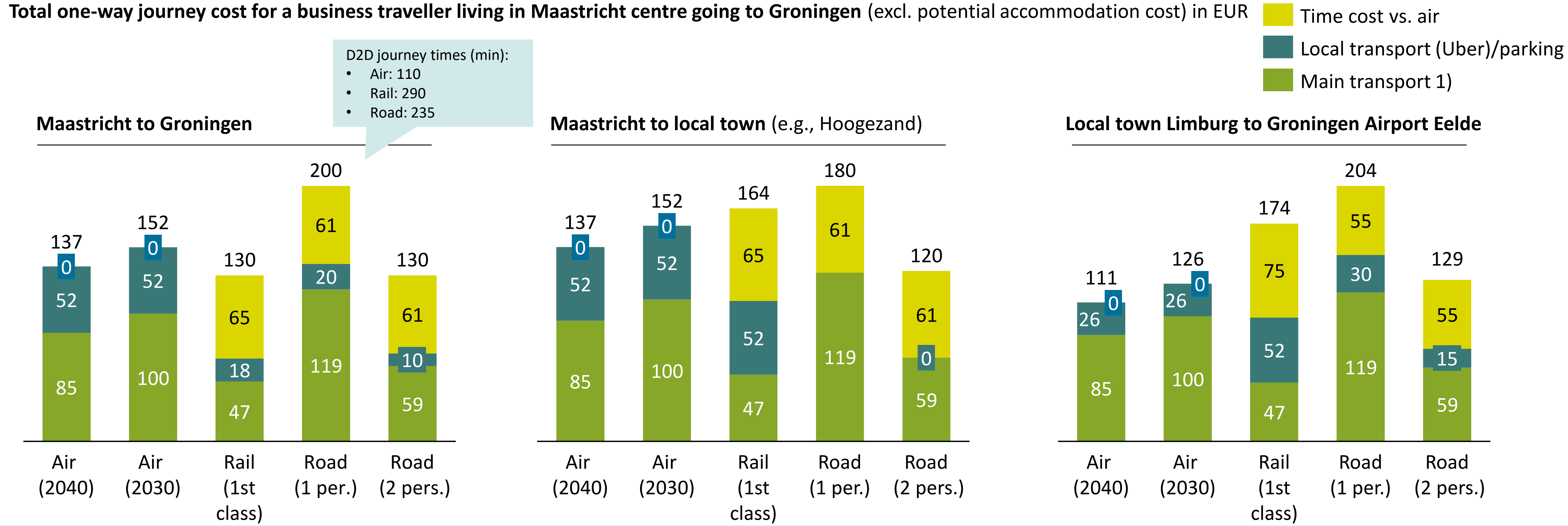
Air travel prices include airline profit margin and 9% VAT and EUR 15 in passenger/security fees; road price is EUR 0.23 + 0.07 road pricing; rail is max day fare 1st class in 2022. Local transport cost based on Uber-like fare (EUR 1.75 per km) . Value of time rail travel ~EUR 25; car travel ~EUR 35. While currently there are very few peak hour slots available at Schiphol, new ATC processes and technologies and the fact that these aircraft will be significantly lower noise would likely enable more flights to be handled.

Source: DLR SAT tool; NIBUD; NS.nl; Google Maps; M3 analysis

Case example Maastricht – Groningen: illustrates the value proposition of eCTOL vs. road and rail for business travellers/high-income travellers justifying the 5 - 10% modal share in the base-case traffic scenario

Case example Maastricht – Central Groningen/North Drenthe

- Total annual traffic Maastricht catchment area to central province Groningen in 2030 ~ 170k passengers (~ 135k by road and 35k by rail). With North Drenthe included this is well over 250k. Approximately 15% is travelling for business purposes and/or is high income group (~ 35-40k travellers)
- For business travellers, the total cost for air travel is slightly higher than rail and lower than road when travelling alone in the city centre to city-centre market but for trips from city centre to suburb or at/close to the Groningen Airport Eelde; total cost for travel by air is a lot lower (see below). If the cost for an extra night stay are to be included – a day trip would mean 8 hours of travel on 1 day when travelling by road or rail – the air travel option will become even more attractive
- The base-case scenario assumes 9k passengers in 2030 and 22k in 2040 which represents approx. 5% and 9% of the total market in 2030 and 2040 respectively



Total one-way journey cost for a business traveller living in Maastricht centre going to Groningen (excl. potential accommodation cost) in EUR

D2D journey times (min):
- Air: 110
- Rail: 290
- Road: 235

1) Air travel prices include airline profit margin and 9% VAT and EUR 15 in passenger/security fees; road price is EUR 0.23 + 0.07 road pricing; rail is max day fare 1st class in 2022. Local transport cost based on Uber-like fare (EUR 1.75 per km) . Assumed value of time rail travel EUR 25; car travel EUR 35

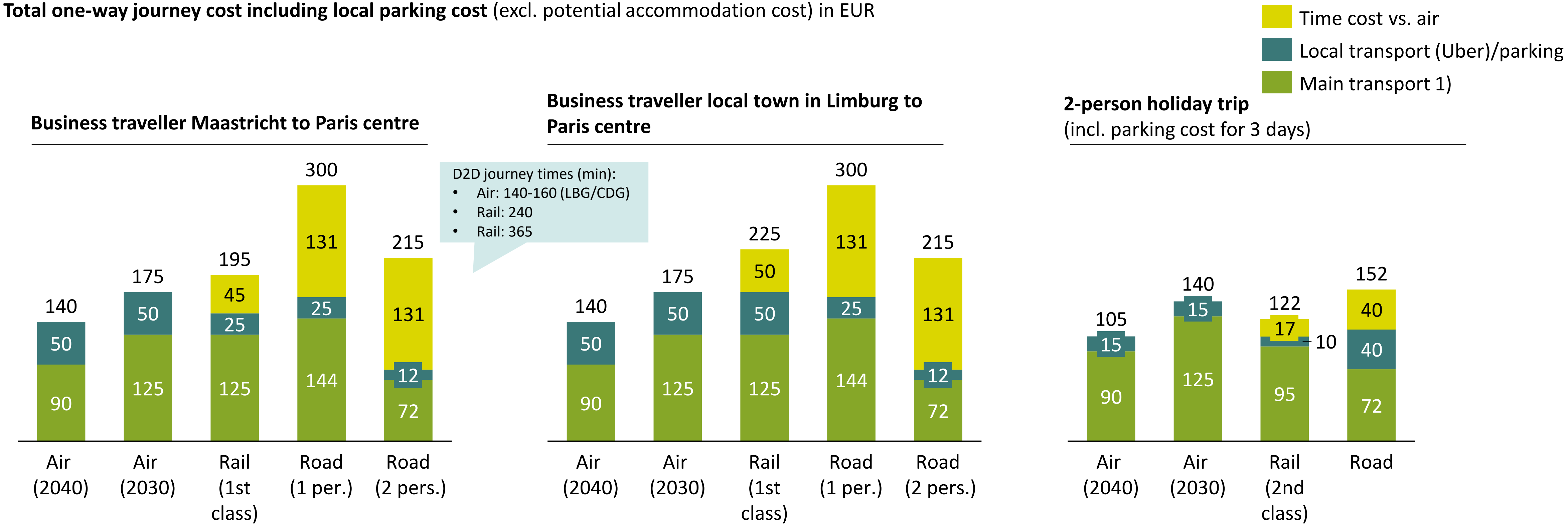
Source: DLR SAT tool; NIBUD; NS.nl; Google Maps; M3 analysis

Case example Maastricht – Paris: eCTOL already competitive for business travellers in 2030 and by 2040 also for leisure travellers

Case example Maastricht – Paris

- A flight to Paris would both offer travellers that need/want to be in Paris as well as connecting passengers e.g., those travelling to destinations not served from Schiphol a significant time saving of about 1h30-2h00 hours vs. rail and more than 3h30 vs. road. An air service to Le Bourget (already one the busiest business aviation airport in Europe) would likely be possible with new low noise small aircraft but the main airports Orly or Charles de Gaulle could also be an option
- eCTOL total journey cost for a business travel would already be lower by 2030 and significantly lower by 2040 compared rail and road options. By 2040 the ticket price for air would already be comparable to today's ticket price for rail. Including a EUR 10 value of time, the total journey cost would be considerably lower.
- The DLT SAT model estimates a market size of around 65k passengers based on 2012 data translation into around 80k in 2020 and 130 in 2040. Base-case scenario 2040: 60k

Total one-way journey cost including local parking cost (excl. potential accommodation cost) in EUR



D2D journey times (min):
- Air: 140-160 (LBG/CDG)
- Rail: 240
- Rail: 365

1) Air travel prices include airline profit margin and EUR 15 in passenger/security fees; road price is EUR 0.23 + 0.07 road pricing; rail is one-way price as available for Feb 2022. Local transport cost based on Uber-like fare (EUR 1.75 per km) . Assumed value of time rail travel EUR 25; car travel EUR 35

2) Rail is currently indirectly subsided with approx. EUR 0.10 per pkm (due to rail infra cost being mostly paid by the government)

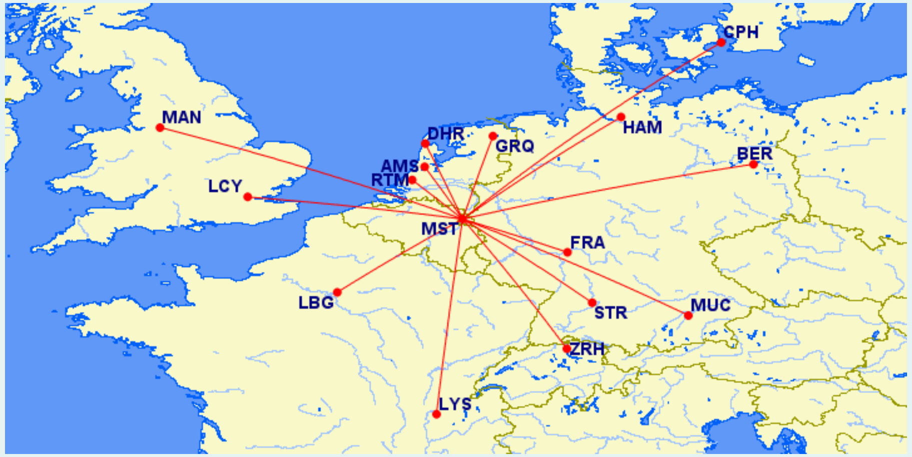
Source: DLR SAT tool; NIBUD; NS.nl; Google Maps; M3 analysis

In the base case, the *eCTOL segment* could grow from an initial 5 – 7 destinations around 2030 to ~ 15 destinations in the second stage of its development growing towards 1 million passengers by 2040

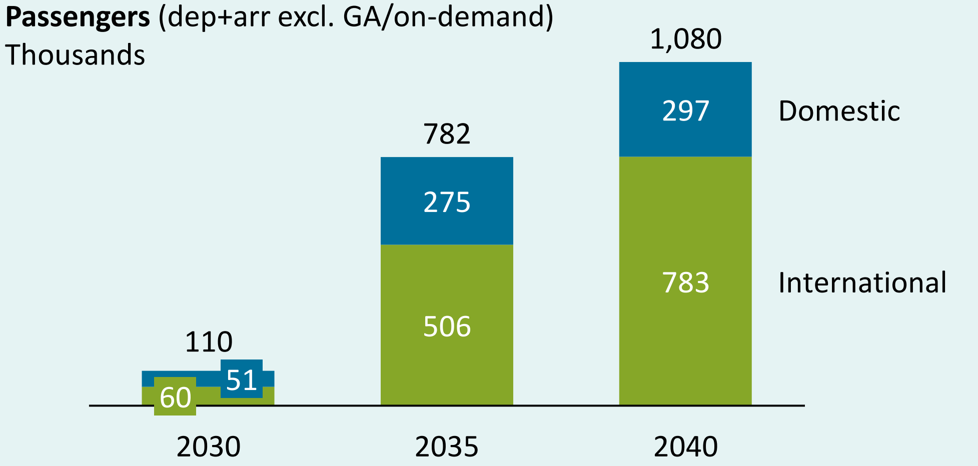
Base-case scheduled eCTOL network development

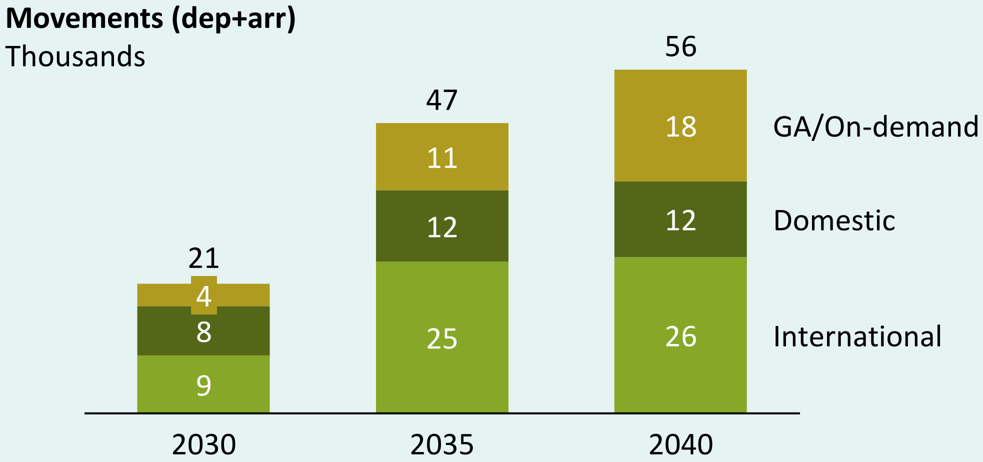
Initial stage
(max range
400-500 km)

Second stage network
(max range
700-800 km)



Potential MAA eCTOL traffic development (incl. eGA for movements)





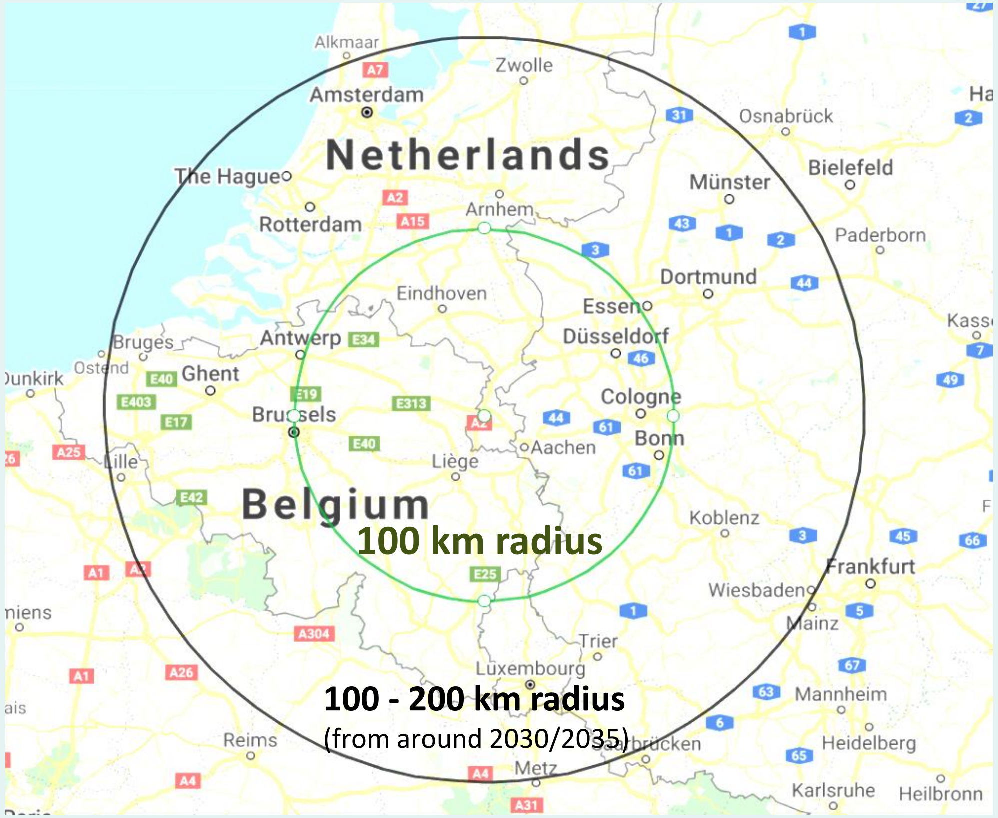
Note: this network development is constrained by availability of aircraft; total potential market size is larger

In the base case, the *eVTOL segment* will see a small start around 2030 but may well grow to around 100-150 thousands passengers by year towards 2040

***Examples* of potential eVTOL destinations initial** stage (2030-2035) **and later stage** (2035-2040)

Initial stage: Dusseldorf; Antwerp; Brussels; Cologne/Bonn; Eindhoven; Venlo

Second stage: Breda, The Hague; Amsterdam; Zwolle; Enschede; Arnhem; Lelystad; Ghent; Luxembourg; Dortmund; Munster

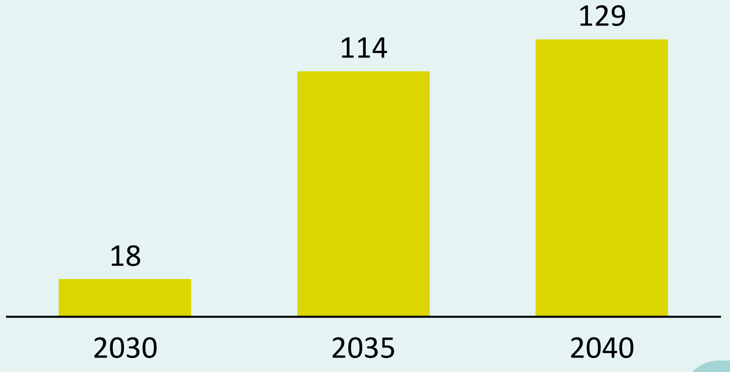


100 km radius

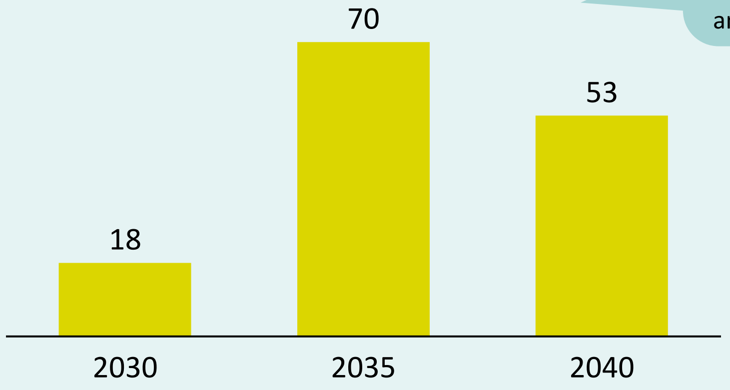
100 - 200 km radius
(from around 2030/2035)

Potential MAA eVTOL traffic development

Passengers (dep+arr)
Thousands



Movements (dep+arr)
Thousands



As more vertiports will become available closer to/in cities, the network at airports will focus more on longer range and larger eVTOLs

Note: this network development is constrained by availability of eVTOLs; vertiport network development and global scale (unit price of eVTOLs)

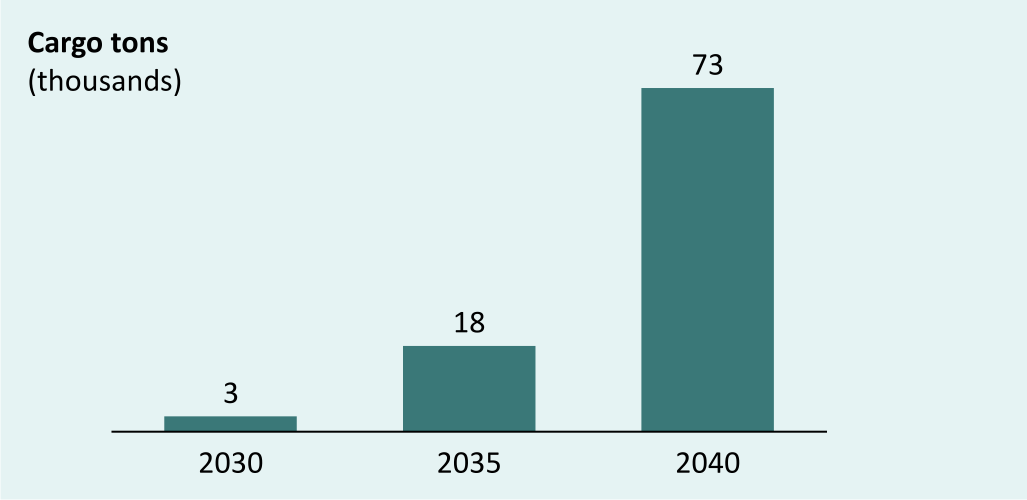
In the (very conservative) base-case, the *eCargo segment* will see a network development towards 10-15 destinations with up to 10-15 thousands flights and about 70 thousands tons of cargo

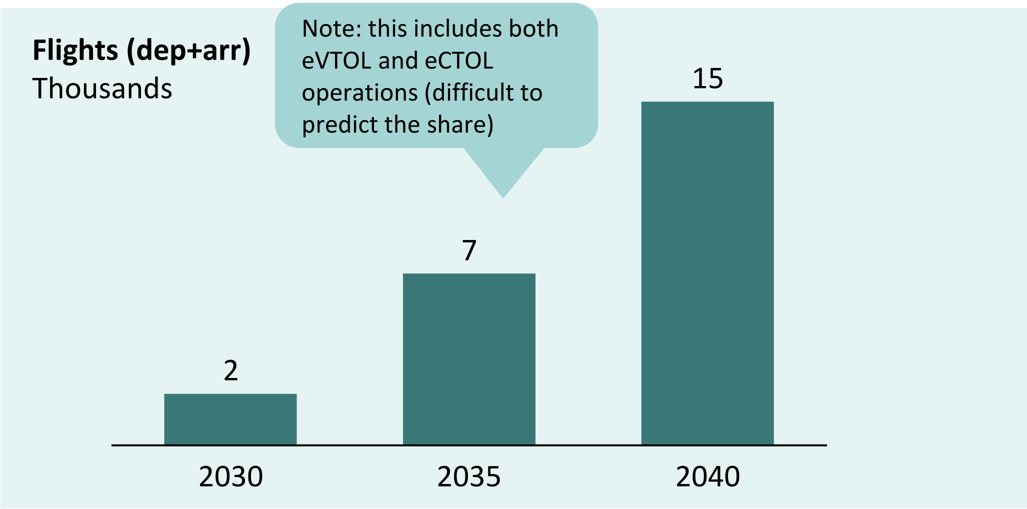
Example eCargo network (both eCTOL and eVTOL)

Note:

- Forecasting eCargo forecast is very challenging with much more significant cost advantage compared ePassenger aviation (e.g., higher share of cost are fuel, maintenance) and more likely/earlier adoption of autonomous flight and with a lack of data on short-haul logistics flows
- Moreover, an eVTOL logistics network may well be development from large logistics parks (away from the airport). However, given the locational synergies of combining eCTOL and eVTOL cargo operations, MAA is still likely to see a considerable amount of traffic

Potential eCargo traffic development

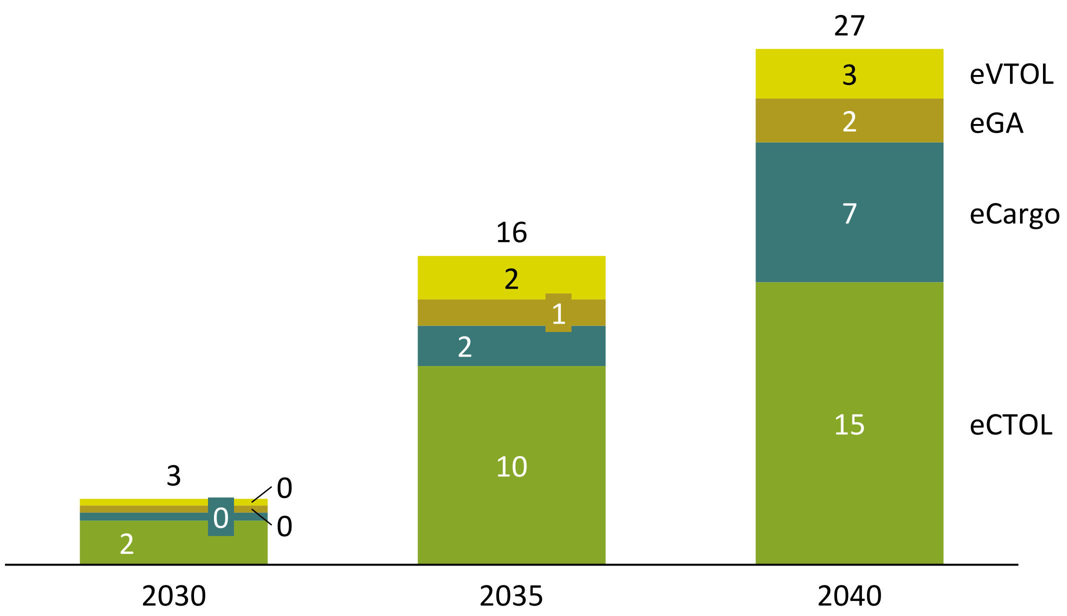




Note: this includes both eVTOL and eCTOL operations (difficult to predict the share)

Base-case summary - revenue: low/zero-emission aircraft technology might add around EUR 15 million in 2035 and over EUR 25-30 million by 2040 to MAA's revenue with around 100 thousand (low noise) movements

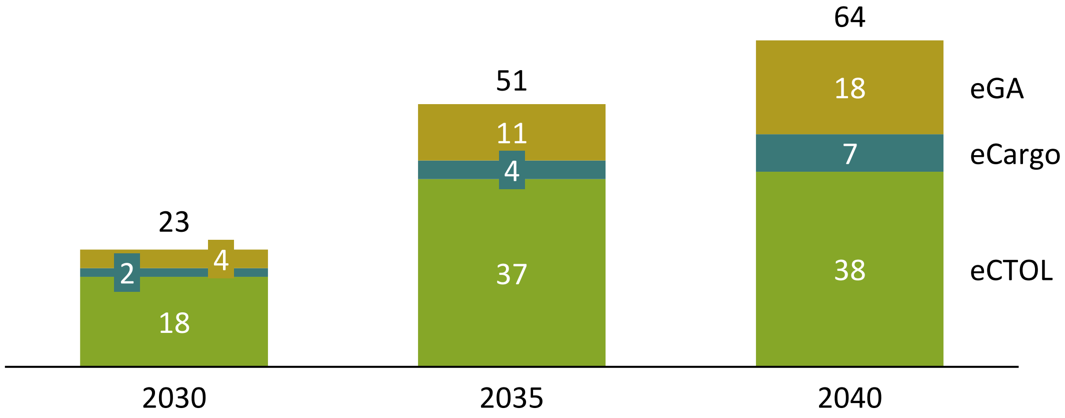
Base case revenue development (incremental) with low/zero-emission aircraft
EUR millions (gross revenue excl. cost/investments)



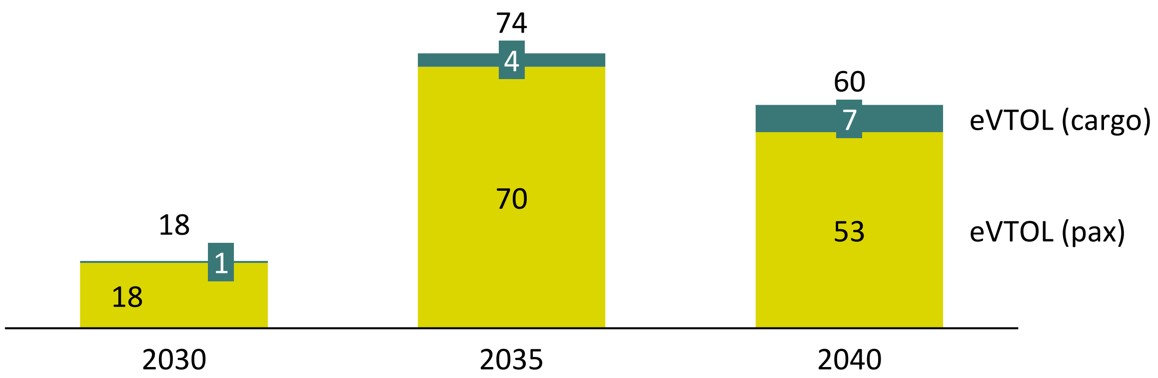
Note: no estimate of traffic-driven operational cost was made as this is highly dependent on the levels of existing traffic segments. In general, cost for this segment will be lower as a result of:

- Higher ground staff productivity (incl. security, ground handling) due to more equal distribution of passengers over the day (now only 1-2 flights/day)
- Less extensive fire brigade for small aircraft (different approach to be defined)
- Lower maintenance cost of e.g. runway (due to lower weight)
- Less m2 per passenger needed in terminal due to much reduced avg dwelling time
- Most passengers likely to travel with hand luggage only
- Potentially/likely different security regime for small aircraft intra Schengen/EU flights (already today 9-zieater flights in Scotland operated without security check)

Total eCTOL movements
Thousands

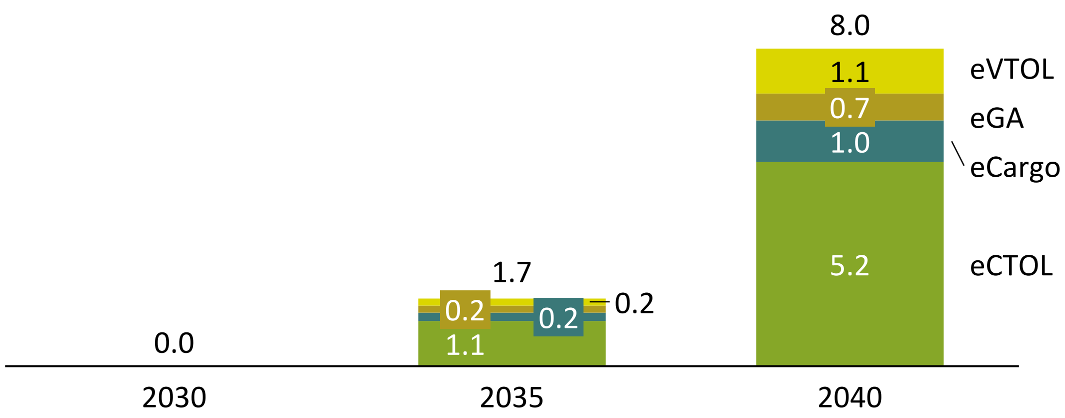


Total eVTOL movements
Thousands



Low-case summary - revenue : in the low-case scenario, low/zero-emission aviation could add around EUR 1 -2 million in 2035 and around EUR 7 - 9 million per year by 2040 to MAA's revenue

Base case revenue development (incremental) with low/zero-emission aircraft
EUR millions (gross revenue excl. cost/investments)



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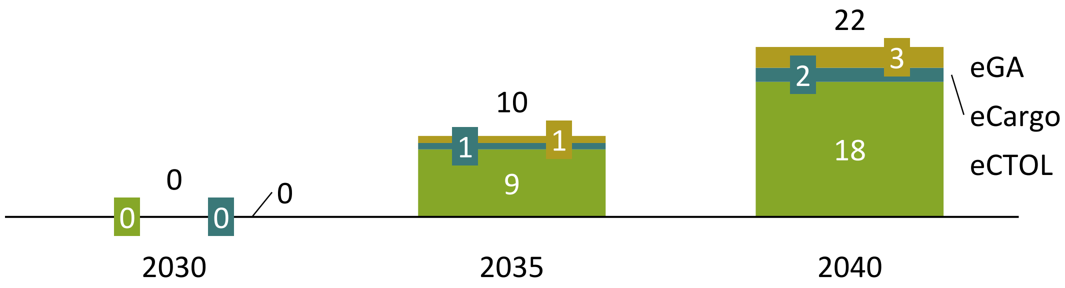
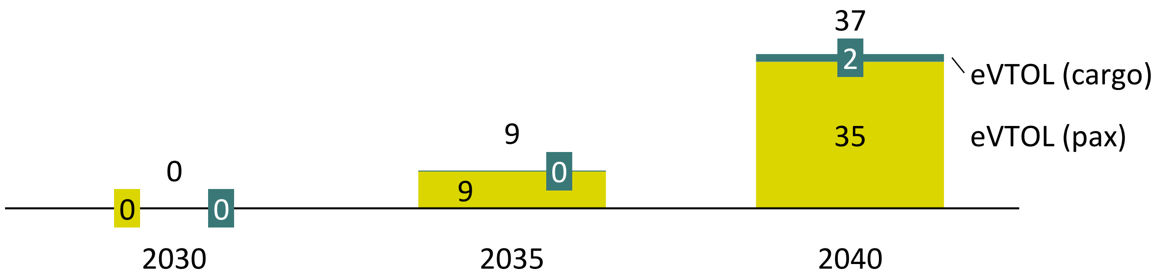
- Less m2 per passenger needed in terminal due to much reduced avg dwelling time
- Most passengers likely to travel with hand luggage only
- Potentially/likely different security regime for small aircraft intra Schengen/EU flights (already today 9-zieater flights in Scotland operated without security check)

Total eCTOL movements
Thousands



Total eVTOL movements
Thousands



Base case summary – noise: when adding the base-scenario traffic levels on top of the 2019 traffic volume the noise contours which can be compensated by a small reduction in current large aircraft operations

Approach to assessing noise impact of large number of small eCTOL operations

- To assess the noise impact of large number of low/zero-emission aircraft movements, 48 dB(A) Lden noise contours have been calculated for the base-case traffic development
- Since there are no certified noise levels, the noise level of existing aircraft has been used for comparable-sized current aircraft adjusted for lower noise

Scenario assumptions

0. **2019 traffic**

I. **2030 scenario**:.
  - 2019 traffic
  - 22.813 9-seater eCTOL with noise profile of a Catania DV20/Pipistrel Velis Electro

II. **2035 base-case scenario**:
  - 2019 traffic
  - 16,060 9-seater eCTOL with noise profile of a Catania DV20/Pipistrel Velis Electro
  - 24,090 19-seater eCTOL with noise profile of a Jetstream 31 with 65% lower noise
  - 10.950 50-seater eCTOL with noise profile of a Dash 8 with 65% lower noise

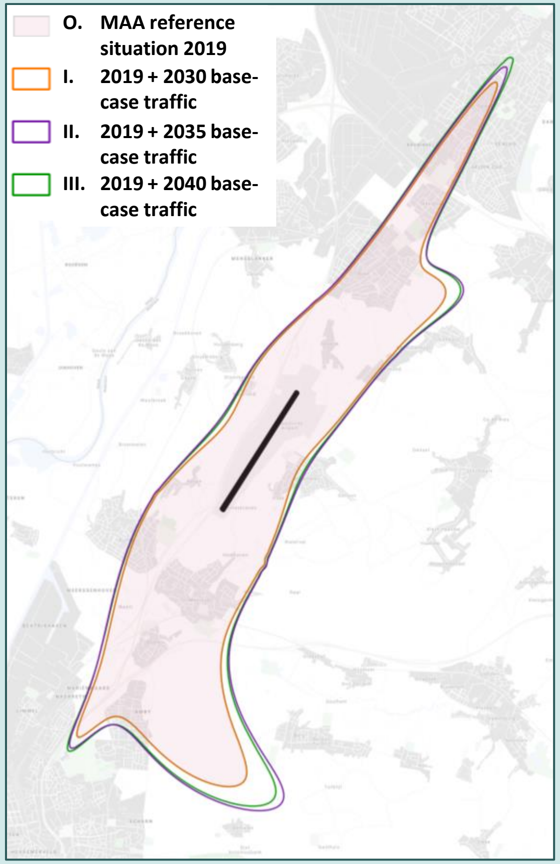
III. **2040 base-case scenario**:
  - 2019 traffic
  - 21,900 9-seater eCTOL with noise profile of a Catania DV20/Pipistrel Velis Electro
  - 16,790 19-seater eCTOL with noise profile of a Jetstream 31 with 65% lower noise
  - 24,820 50-seater eCTOL with noise profile of a Dash 8D with 65% lower noise

Notes:

- The 65% noise reduction is (amongst others) derived from statements from Embraer with regard to their recently announced low/zero-emission regional aircraft Energia Family
- eVTOL movements not calculated as their nearly vertical climb-out and low noise levels will not be heard outside of the airport perimeter
- The 2019 noise contour has been used as a reference point to assess the relative impact of additional movements. In reality, the noise contour will decline over time but unclear as to how much by when which is why 2019 was used as the only certain reference point

Impact on noise contours at MAA

48 dB(A) Lden contours for various traffic scenarios



Key insights:

- Substantial numbers of 9-seater aircraft movements do not/hardly impact noise contours
- The 19- and 50-seat aircraft do slightly enlarge the 48 db(A) Lden area
- However, a small reduction in B747/B777 movements will likely be enough to compensate for this small increase
- As a result, it can be concluded that even 50 – 60 thousand eCTOL movements per year can realistically be fitted from a noise constraint profile (assuming a small reduction in heavy freighters movement will be implemented by around 2035)
- Furthermore, it can be concluded that an eAviation-only traffic scenario would have very small noise contours. However, as larger aircraft on SAF or hydrogen combustion will still produce noise and such flows continue to be needed, it is not deemed realistic to produce noise contours of only eAviation
- As a reference, the inner-Londen London City Airport can accommodate 110 thousands movements with a single runway use

Source: To70 analysis; including input from https://netzero.aero/2021/11/17/embraer-shows-roadmap-to-net-zero-emissions-project-energia/

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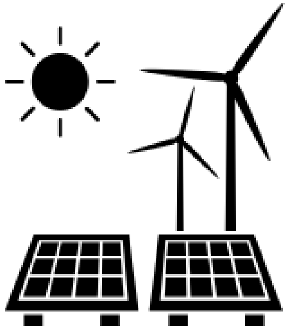
Topic

Accommodating low/zero-emission aircraft operations requires investments in energy systems, terminal & handling infra and apron & runway adjustments

Investment aspect	Infrastructure requirements	Key investment drivers
Energy systems - _Electric infra/ Battery systems_ - _Hydrogen-infra_ - _Sustainable fuel infra_	Electricity generation (solar) Storage (batteries, tanks) Grid Logistics facilities (cables/pipelines) Charging/loading equipment	Number of aircraft to be charged the same time Pre-mixing/local-mixing of SAF Type of hydrogen Pre-mixing/local-mixing of SAF Number of passengers in peak hours
Terminal & handling	Terminal facilities (desk/bag drop (dedicated passenger handling process: max 20-30 min ahead of departure) eCTOL/eVTOL handling facilities for passenger and cargo •	Number of passengers in peak hours (eCTOL operations will be pax 400-500 pax in peak hour; eVTOL 100- 150 pax) Number of aircraft to be handled at same time
Apron & runway	Apron-space including demarcation Taxiways Runways	Number of aircraft on the ground at the same time

Facility	Current situation at MAA	Base-case scenario solution assumed
Peak power	Max power today 1.75 MW	Max power required for all e-aircraft: ~ 2MW in 2030 and 4 MW in 2040
Storage	No local electricity storage	Stationary battery required with decharge power of 400 KW and total storage of 600 kWh
Grid	Basic electricity grid	SMART grid investment to optimize electricity flows around the airport
Fuel tanks	One fuel tank for each major fuel type (Jet-A; AVGAS)	No local blending of SAF before 2035/2040 as volumes (~55k litres in 2035) will not make dedicated 100% SAF fuel storage viable
Chargers	No electric aircraft charging	GA charger needed this year; high power chargers needed by 2025/2030 (250/350+ kW)
GA terminal facility	GA terminal has sufficient capacity (XX pax in peak?) but requires basis check-in	Upgrading of GA terminal to accommodate eVTOL operations; if dedicated terminal required most likely to be developed by 3rd party
Main terminal facility	Main terminal has sufficient capacity	No investment needed (possibly some replacement investment in passenger screening)
Handling facilities	No/limited handling equipment/ infrastructure available for small passenger and cargo aircraft	Investment needed in handling infra for both passenger and cargo (eCTOL+eVTOL)
Apron surface	Sufficient apron surface available to accommodate 5-7 eCTOL and 10 eVTOL at the same time but no demarcation	Demarcation of aircraft positions for eCTOL, eVTOL and eCargo
Runway	Runway length and width: 2,750 by 45 meters	Expectation Runway length and width: 1,500 by 45 meters

MAA currently has several facilities/utilities in place for the transition and has several projects ongoing to expand on them



Energy generation and use

Current Infrastructure

- Electricity requirement: 4,000 MWh/year (airside only 2,500 MWh
- Connection with regional grid: 1.75 MW,
- Solar panels: 0.6 MWp (Freight building)

Planned Infrastructure

- 2023 upgrade grid connection to 6 MW.
- Future solar panels: 0.8 MWp by ‘22 + 6,5 MWp by ’24
- Continued energy efficiency improvements (LED, Aircon, operations)

Sustainable mobility

Current Infrastructure

- 2 eGPUs (140 kVA) and 1 electric preconditioned air unit
- Warehouse vehicles all electric

Planned Infrastructure

- Electrification of airport vehicles where possible, and installing charging infrastructure (’22-’29)
- Autonomisation of airside and freight vehicles
- HVO (bio) fuel for heavy airport vehicles (from ‘22 onward)

Current (research) projects to expand facilities for sustainable operations

- Future hydrogen use at airport
- Green hydrogen production or smart grid for peak production storage
- Development Smart Electricity Grid with use of all available battery (carparking/busses/airport vehicles etc.), storage battery etc

Looking at some of the major aspects of different technologies makes it clear that MAA's priority should be on investing in battery-electric infrastructure in combination with SAF readiness

	Technology relevance				Technology costs				
	Technical readiness	**Passengers /flight**	**Short term 10 yrs envr. impact**	**long term 30 yrs envr. Impact***	**Develop. & production costs**	**Airport infra investment costs**	**Aircraft development costs**	**Total cost perspective**	**Comments**
Battery Electric	◕ ~2026	9-19	High per passenger but low for total industry	High per passenger 2-5% impact industry	€	€€	€€€	**€€**	• Technology is ready and first commercial a/c are almost ready. With limited airport investments required this is the prime technology to focus on for regional airports
SAF combustion	● 2022	Same as current aircraft	Theoretically high but practically low	High, decrease 30%-65% current emissions	€€€	€	€	**€€**	• Regulation is currently driving this technology and adaptation is therefore limited by it. Production is ramping up but airports are not in the driver's seat. Readiness is however needed
(Liq.) H_2 Fuel Cell Electric	◑ ~2030	~20 - 100	Low due to few aircraft	Decrease up to 20% of current emissions	€€€	€/€€€	€€€€	**€€€**	• Development and piloting will be ongoing for the next 5-8 years. Research into safety, operations and infrastructure is being developed at airports that want to lead in hydrogen aviation, although large scale refueling is not expected until after 2030.
Liq. H_2 combustion	◔ ~2035	Up to 200	Nihil due to little to no aircraft	Decrease 10%-20% of current emissions	€€€€	€€€€	€€€	**€€€€**	• Research & Development will be ongoing for the next 10 years. Too early to decide definitively on local infrastructure

Lowest cost alternative with high environmental impact (also vs.EVs) but limited application

Solution for current large passenger a/c. Environmental impact depends on SAF availability/usage

Certification, Fuel availability, airport modifications and aircraft developments make this less likely in the short/medium term. OEMs can provide local solutions (pods/small truck if needed)

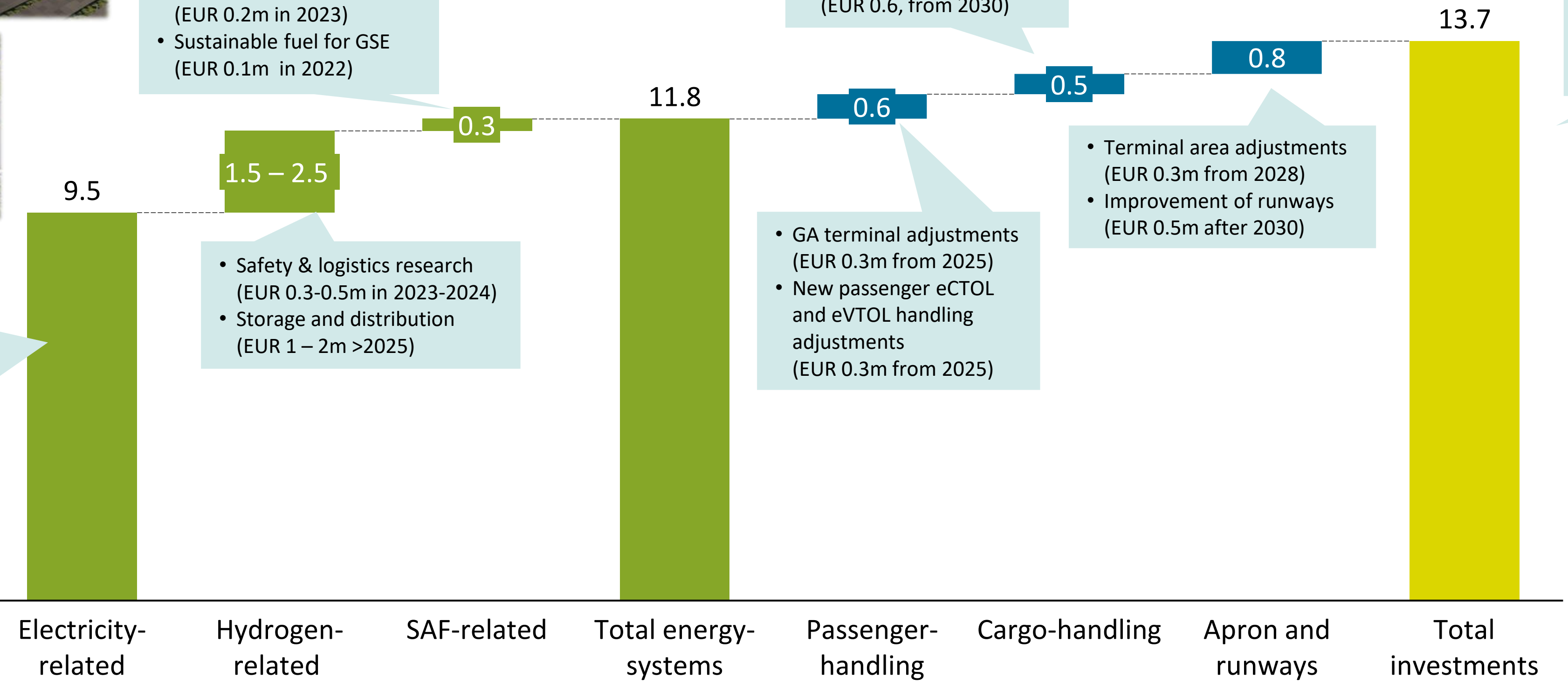
Initial investments are relatively low due to trucking possibilities. Scale-up will require larger investments

Fuel availability and airport/aircraft modifications make this less likely in the short/medium term

* Based on Sector reports, including Destination 2050, ATAG Waypoint 2050 and IATA Fly Net Zero plan

The overall investment required to accommodate the demand for new low/zero-emission aircraft operations is estimated to be around EUR 14m in the 2022 – 2035 time window

Total estimated investment required to facilitate base-case eCTOL, eVTOL, eCargo and eGA traffic up to 2035/2040 in EUR million



- SMART Grid (software + hardware (EUR 3.7m)
- Aircraft charges (EUR 2.2m)
- Solar panels (EUR 1.7m)
- Stationary battery (EUR 1.3m)
- Energy efficiency inv. (EUR 0.6m) (all investment spread with peak in the 2025 – 2030-time window)

- Safety & logistics research (EUR 0.3-0.5m in 2023-2024)
- Storage and distribution (EUR 1 – 2m >2025)

- Sustainable fuel for aircraft (EUR 0.2m in 2023)
- Sustainable fuel for GSE (EUR 0.1m in 2022)

- GA terminal adjustments (EUR 0.3m from 2025)
- New passenger eCTOL and eVTOL handling adjustments (EUR 0.3m from 2025)

- Adaptation small cargo aircraft (eCTOL & eVTOL) (EUR 0.6, from 2030)

- Terminal area adjustments (EUR 0.3m from 2028)
- Improvement of runways (EUR 0.5m after 2030)

- Potential runway adjust to 1,400 m (after 2040) would cost approx. EUR 4.5m (not included in total)

Note: Investment cost such as eVTOL terminal and hydrogen-facilities may also be covered by service providers paying a concession fee to MAA (but this would go at the cost of MAA revenue per passenger)

Source: MAA; To70 analysis

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Topic

Low/zero-emission aviation is new ecosystem that will be shaped in the next 2 to 4 years providing opportunities for many new entrants, also from outside the aviation industry. Regional airports are the centre

Mobility providers	Mobility-as-a-Service	Virtual airlines			
Owner/Operator	Private individuals	Fractional ownership	Air taxi operators	(Regional) airlines	
Infrastructure operators	Airports	Vertiports			
Services	Aircraft trader	MRO Part 145	Advisory services (e.g. certification)	Financial services (leasing)	
Energy providers	Local H_2 production	Energy storage	Charging infrastructure		
Aerospace/tech industry	Aircraft OEMs	Powertrain			
	Battery (pack)	(hydrogen)-fuel cell	Electric engine	Inverter	Cables
Regulatory/policy making	Policy makers	Authority			

Regional partners in sustainable aviation development for MAA – *Energy-related organizations*

Energy source	Regional partner	Possible connections
Sustainable aviation fuels	Coval Energy & FlyGaft – SAF production	Supply of sustainable aviation fuel
	Feunix – Circular technology company upcycling waste fuels	Circular economy at the airport
Electric	RWTH Aachen University – CELLFAB in the Electromobility Laboratory	Battery improvement & development
	Enexis – Partner for smart grid	Smart Grids
Hydrogen	FUREC – Waste to hydrogen application set up by RWE in collaboration with Brightlands	Hydrogen production Energy storage in Ammonia
	NPROXX – develops high pressure hydrogen storage and transport for all types of applications.	Hydrogen operations and logistics

Regional partners in sustainable aviation development for MAA – *Aviation service providers*

Services	Regional partner	Possible connections
OEM-aftersales/ Maintenance	SAMCO Aircraft maintenance	Already focuses on regional aircraft and is well positioned to move into new small aircraft; could move into component maintenance (batteries)
	MAAS Aviation	There will be a significant inflow of new small aircraft. When an OEM decides to locate at/near MAA it is well positioned to be the paint provider. Later also for repainting
	Collins Aerospace	Collins claims to be the leader in aircraft electric systems and has a high ambition to be a key supplier for new electric aircraft OEMs
Education	Aviation Competence Center VISTA college	Provides training for mechanics etc which will also be needed to serve these new small aircraft operations

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Given the opportunities and their relevancy and the wider context of an industry quickly taking shape, MAA/Province of Limburg should start building a local ecosystem and clearly communicate its ambition

Synthesis of the current situation

Insights from feasibility study

- Low/zero-emission aircraft operations will become technically and economically feasible within 4 – 6 years with further performance improvements soon following
- There is market relevance for all segments (eCTOL, eVTOL, eCargo and eGA at MAA
- The traffic will be almost entirely incremental strongly improving the revenue base of MAA while no more than EUR 14M in investment is needed for the 2022 – 2035 time frame
- These operations will not add any significant amount of noise disturbance and no local emissions. It will lead to much improved connectivity

Wider context

- Zero-emission regional air mobility truly is a revolution in short haul travel. Its success, however, does depend on the national and international policy and regulatory framework
- There are dozens of OEMs working on the early design/concepts and first testing of their technology. Many will need to pick a location for further expansion, testing, producing and maintaining their aircraft. It is believed that in the next 2 to 4 years ecosystem will develop quicky with chances for new entrants after that period diminishing quickly
- There are potential synergies to be captured with other eMobility opportunities such as Rivian (who also will attach high value to MAA for staff and logistics

Proposed next steps

- Actions at local level
  - ***Develop an ecosystem/coalition*** of local organisations who all see opportunities arising from the development of these new traffic segments. Brand and communicate the ambition clearly in order to attract potential new organisations at/around MAA and funding
  - ***Execute the energy-management research and action plan*** already developed and ***secure GA-aircraft charging equipment*** to ensure any sudden visits/business opportunities can be accommodated
  - ***Update the Masterplan*** with locations for handling small eCTOL, eVTOL and eCargo aircraft. Interact with start-up zero-emission aircraft operators and eVTOL operators on functional requirements
- Actions at (inter-) national level
  - ***For MAA, share findings with other regional airports*** in the Netherlands and ***continue contribution to Power Up*** with targeting a range of different demonstrator aircraft as early as 2022 to drive operational preparation and first eCTOL commercial passenger operations from 2026 /2027
  - **For the Province, team up with other provinces** to voice towards national policy makers the value to the new low/zero-emission networks to regions and secure policy-adjustments that stimulate the segment and financial support to (co-)finance required investments. If funding is a constraint reach out to the private investment community. There is a growing interest to invest in regional airports given the new opportunities that will arise

Final considerations: role of low/zero-emission aviation in future socioeconomic regional development and mobility & logistics networks

- While this reports has shown in great level detail the general and MAA-specific opportunities, required investments and business opportunities, there are a number of important policy implications that need to kept in mind in this development. While the scope of the consulting assignment did not include a view on this, the consulting project team considers these implications as too important not to mention them. These are:

1. **Step-change network development will have an important impact on the wider socio-economic development of a region**
    - Historically, small regional airports with mostly only outbound leisure have had a limited impact in driving regional economic growth (but bringing employment). With the emerging new regional networks of 10 – 15 business destinations and hub connections, that will change significantly. Businesses/organisation but also students and workers are much more likely to choose to work, study and life in a region that is well-connected
    - Having or not-having a local regional airport (with such networks) will be a much more important differentiator between regions than it is today.
    - Many other regions/regional airports are very ambitious in developing this segment (e.g. Groningen Airport Eelde/Prov Groningen; Rotterdam The Hague Airport, Teuge Airport, Twente Airport)
2. **The role of regional airports will change towards mobility and energy hubs**
    - The new connection will attract new type of passengers (business; high-income tourists).
    - With both intra-regional/national connections with eVTOL and longer range national/international services with eCTOL co-located at the airport, regional airports will develop into mobility hubs with a clear market place attraction for businesses (meeting facilities; hotels; offices). This will in turn raise the land value/rent level at/around the airport
    - Similarly, regional airports with their large surface are well positioned for solar panels and will over time develop facilities for storage and supply for a wide variety of energy types. Airports will become regional energy hubs that can also serve landside demand
3. **New low/zero-emission aviation investments should be compared against other sustainable mobility investment options**
    - As this report has shown, new low/zero-emission aviation can create significant societal value (in terms of CO_2, particulate matter and travel time reduction) while noise levels are very low and require only low levels of investments. This is in sharp contrast with, for example, the EUR 1 or 5bn investments required for time-savings of respectively 17 min and 30 min for the upgrade of Eindhoven – Aachen-link and the Lelylijn (which is not expected to result in a modal shift from car to rail). Rail investments generally have been negative business cases (as the EUR 2bn annual rail infra cost coverage shows)
    - It is, therefore, advisable for regional and national policy makers to not consider an airport investment as a stand alone decisions but to trade a decision off against other sustainable mobility investment options

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Appendix

MAA needs to select one or more investments to facilitate battery-electric applications: Ground Power Units, Portable battery-systems and/or recharging network

Electric Infra

Overview of infrastructure options for operations with battery- electric aircraft

REQUIRED INFRASTRUCTURE

State of technology	Infrastructure options	Description
BATTERY-ELECTRIC Existing technology. Required infrastructure for commercialization expected to be available/ can be copied from applications in automotive industry relatively easy	➢ Ground Power Units (GPU)	➢ Although most airport already have GPU's in place, capacity and power are both relatively low resulting in long recharging times
	➢ Portable battery system	➢ Battery energy storage systems (stored in a sea container) can recharge at ~200 kW with a capacity of ~500 kWh and can easily be moved around on airside for recharging purposes.[1]
	➢ Recharging network	➢ Installed recharging network with next generation fast chargers can be installed and connected to local grid.

SMART AIRPORT GRID

- A Smart grid is a soft and hardware tool that measure and connects 24/7 energy generation, energy storage and energy use. Increased electric aircraft, electric busses and other vehicles and building electrification together with increased local energy production will require a better understanding and control of energy flows.
- Examples of how a smart grid helps are by connecting car batteries as energy storage, assessing peak loading times for future aircraft and airport equipment, and distributing electricity to 3rd party stakeholders.
- A Smart Grid can provide future revenue streams, including the distribution network over which the airport can control ownership and the energy generation that airports can provide over their network to all connected third parties.

REQUIRED BATTERY INFRASTRUCTURE

- Portable battery systems would be well suited for facilitating electric flights in testing phase, and potentially also start of operations/ first operator. Because recharging power is relatively low (~200 kW) and results in long recharging times, this option becomes less attractive for commercial operations
- A fully Installed recharging network would provide direct access to energy supplies but requires significant investments. Therefore, this option should be considered in a later stage of the development roadmap, and after the potential of a positive business model for the airport (and operator) is proven in testing/ first operator phase

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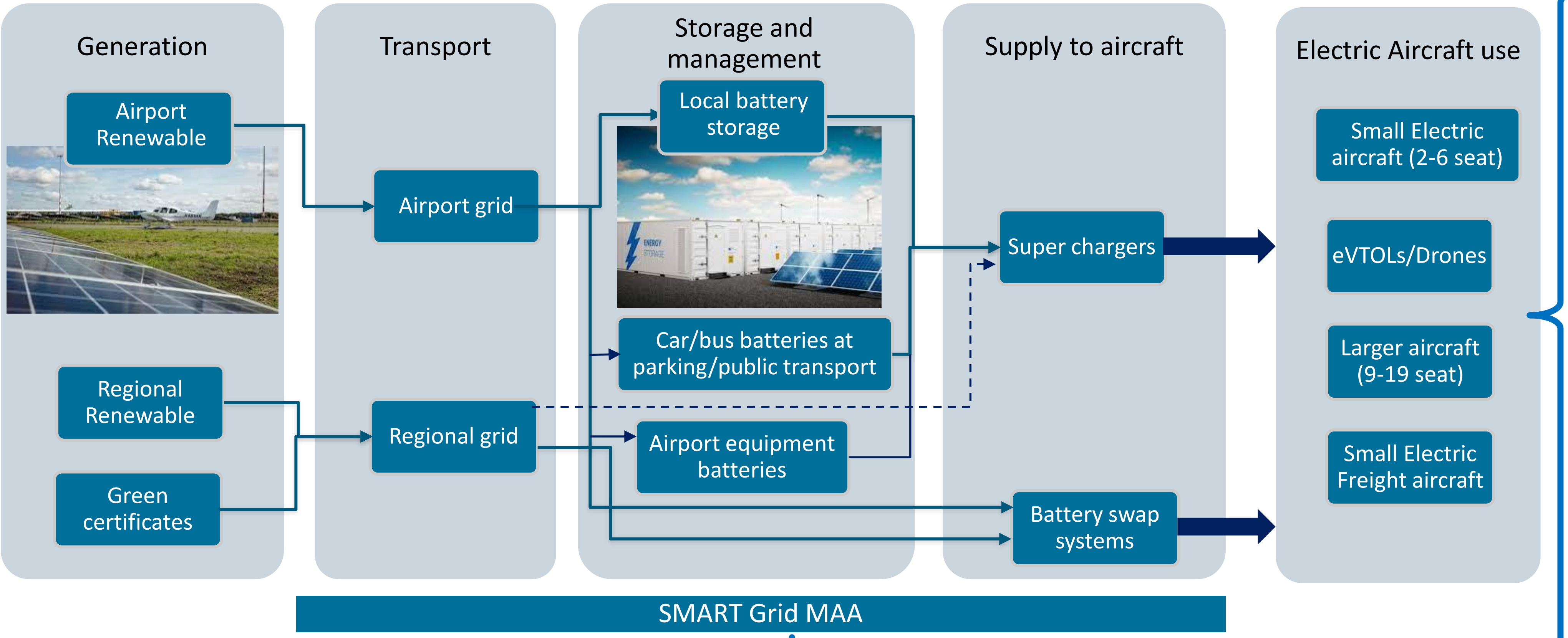
1) Solar deals (link

2) BOV Eindhoven (link))

Electric Airport infrastructure value chain MAA – 2035



Generation

Airport Renewable

Regional Renewable

Green certificates

Transport

Airport grid

Regional grid

Storage and management

Local battery storage

Car/bus batteries at parking/public transport

Airport equipment batteries

Supply to aircraft

Super chargers

Battery swap systems

Electric Aircraft use

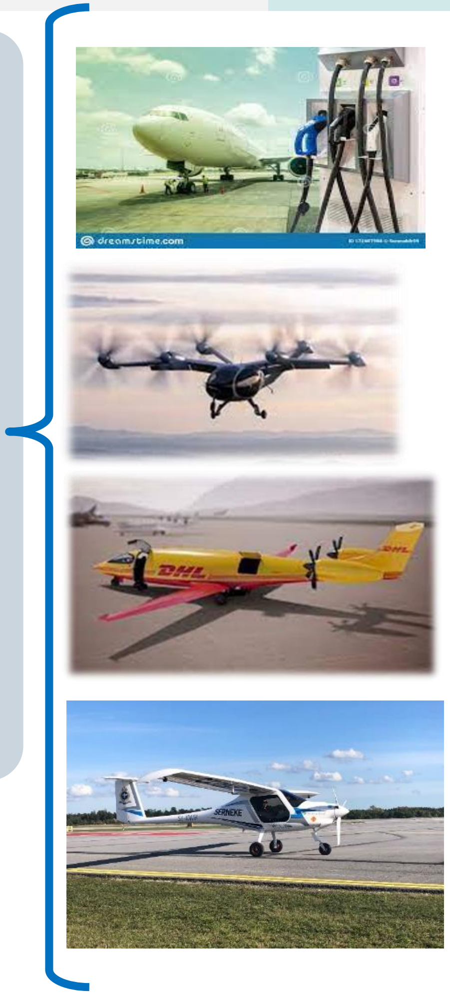
Small Electric aircraft (2-6 seat)

eVTOLs/Drones

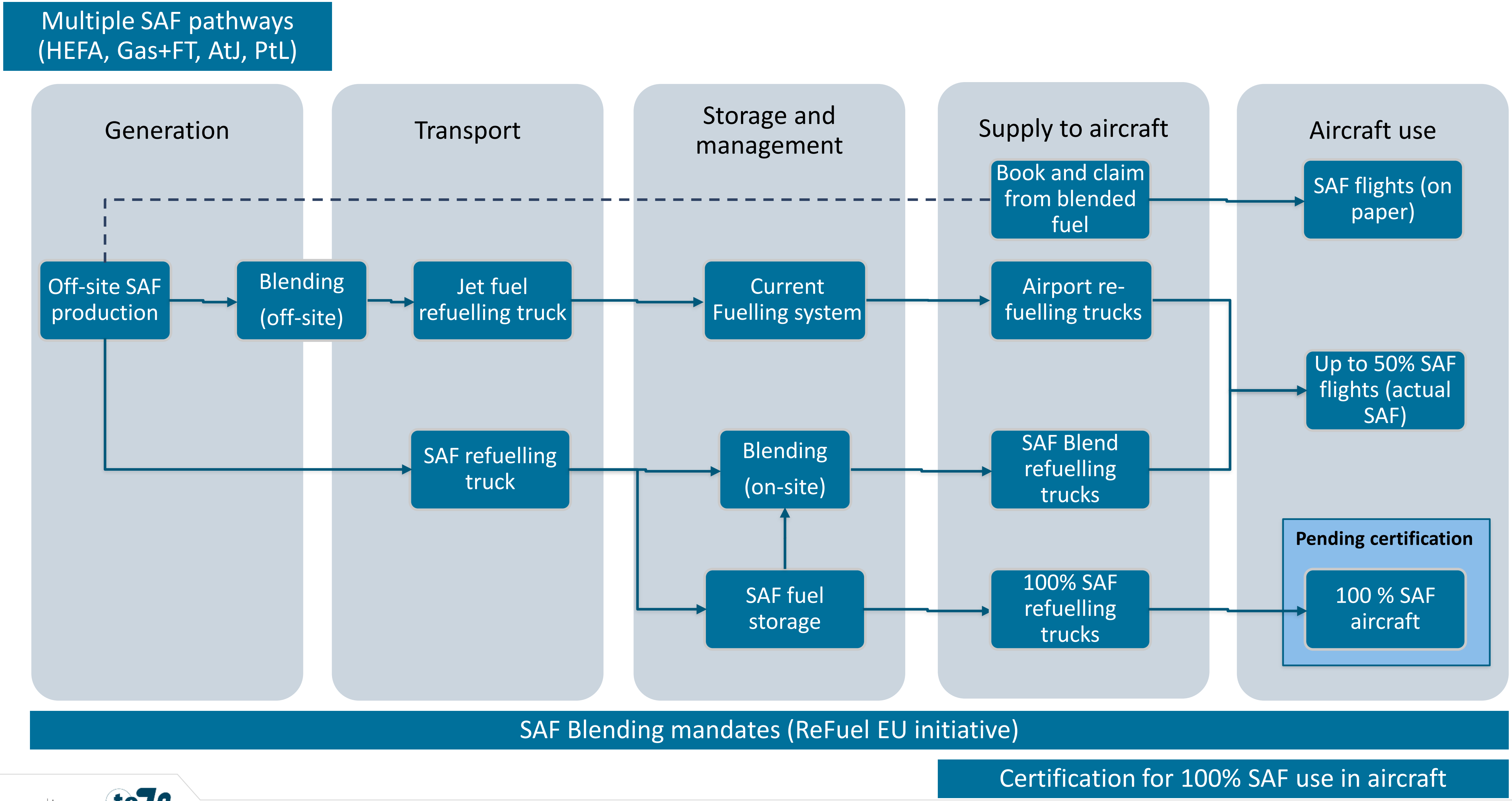
Larger aircraft (9-19 seat)

Small Electric Freight aircraft

SMART Grid MAA



SAF Airport infrastructure value chain



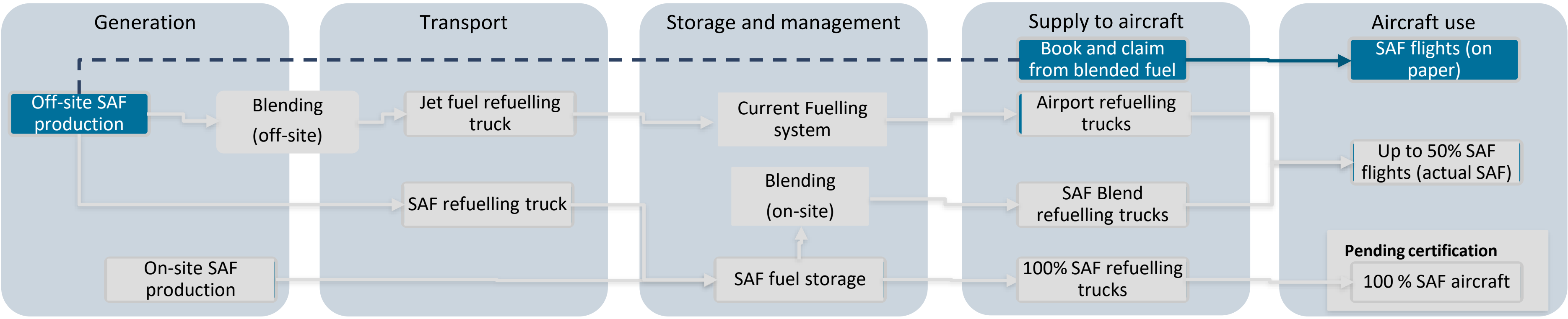
Sustainable aviation for conventional jet engines can be achieved through use of Waste, Bio or Synthetic kerosene

SAF Infra

REQUIRED SAF INFRASTRUCTURE

Method | **Infrastructure value chain**

Book and Claim[1]



Generation
Off-site SAF production
On-site SAF production

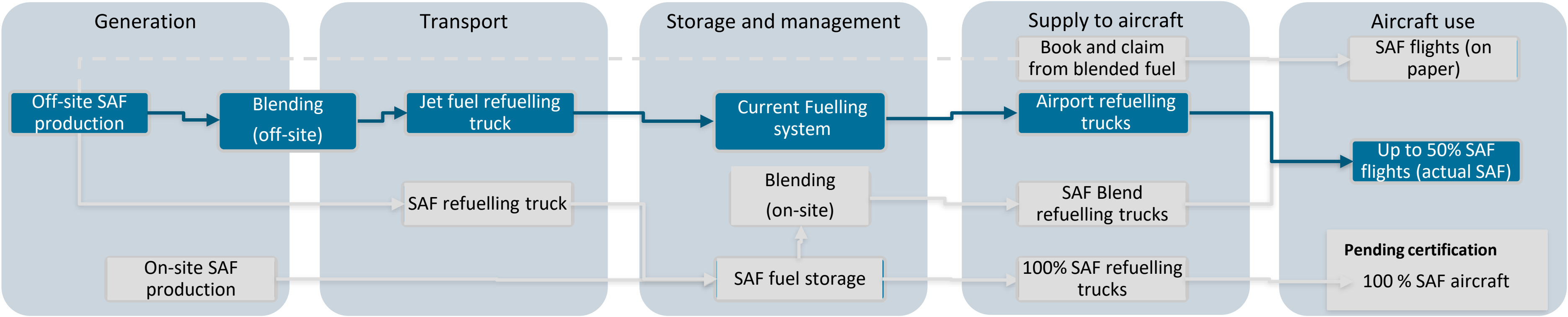
Transport
Blending (off-site)
Jet fuel refuelling truck
SAF refuelling truck

Storage and management
Current Fuelling system
Blending (on-site)
SAF fuel storage

Supply to aircraft
Book and claim from blended fuel
Airport refuelling trucks
SAF Blend refuelling trucks
100% SAF refuelling trucks

Aircraft use
SAF flights (on paper)
Up to 50% SAF flights (actual SAF)
Pending certification
100 % SAF aircraft

Off-site production & blending



Generation
Off-site SAF production
On-site SAF production

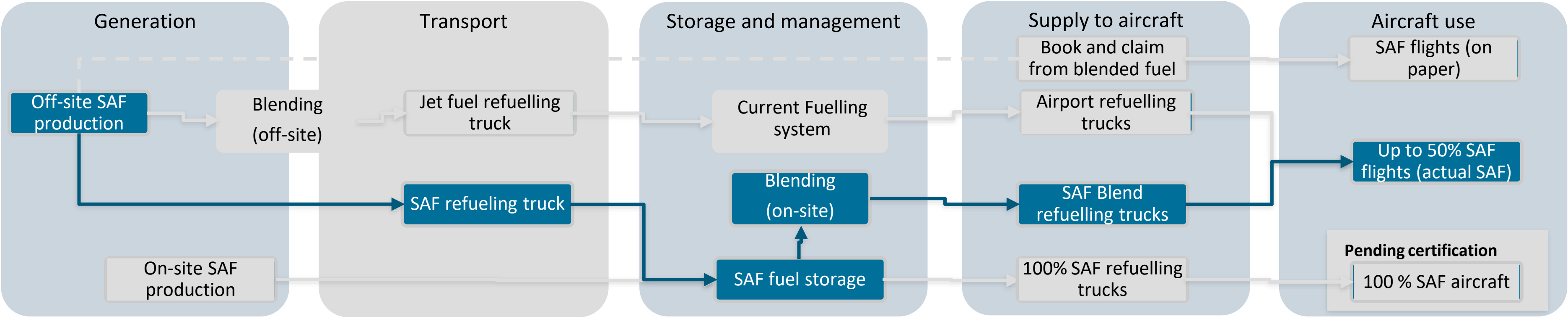
Transport
Blending (off-site)
Jet fuel refuelling truck
SAF refuelling truck

Storage and management
Current Fuelling system
Blending (on-site)
SAF fuel storage

Supply to aircraft
Book and claim from blended fuel
Airport refuelling trucks
SAF Blend refuelling trucks
100% SAF refuelling trucks

Aircraft use
SAF flights (on paper)
Up to 50% SAF flights (actual SAF)
Pending certification
100 % SAF aircraft

Off-site production, on-site blending



Generation
Off-site SAF production
On-site SAF production

Transport
Blending (off-site)
Jet fuel refuelling truck
SAF refueling truck

Storage and management
Current Fuelling system
Blending (on-site)
SAF fuel storage

Supply to aircraft
Book and claim from blended fuel
Airport refuelling trucks
SAF Blend refuelling trucks
100% SAF refuelling trucks

Aircraft use
SAF flights (on paper)
Up to 50% SAF flights (actual SAF)
Pending certification
100 % SAF aircraft

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1) Pechstein, J., Bullerdiek, N., & Kaltschmitt, M. (2020). A “book and Claim”-Approach to account for sustainable aviation fuels in the EU-ETS–Development of a basic concept. *Energy policy*, *136*, 111014.

Sustainable aviation for conventional jet engines can be achieved through use of Waste, Bio or Synthetic kerosene

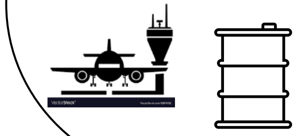
Integration at MAA airport

SAF Infra

Most applicable to MAA

Applicable if SAF can be developed with partner

REQUIRED SAF INFRASTRUCTURE



SAF fuel costs can be calculated into fuel price for airlines, so that only minor infrastructure adaptations remain

Method | **Expected investments**

Book and Claim

- Most simple for airport, no infrastructure required
- SAF production must be connected to airline payment. Does not matter where SAF is delivered.

Infrastructure	2025	2030	2035	2040
Book & Claim platform development	0.3m	0.6m	na	na
Extra cost of SAF fuel (See appendix for more detail)	1m	3-4m	10m	na

Off-site production & blending

- Relatively simple for airport, no infrastructure required
- Airport must connect with fuel supplier to ensure blended fuel is received.
- Either all airlines must tank SAF (at higher price), or there are 2 types of fuel available

Infrastructure	2025	2030	2035	2040
Coordination of SAF tanking	0.2m	1m	na	na
Extra cost of SAF fuel (See appendix for more detail)	1m	3-4m	10m	na

Off-site production, on-site blending

- Most complicated for airport, blending infrastructure required.
- Two types of fuel must be delivered to airport
- Airlines can choose what blend they would like.

Infrastructure	2025	2030	2035	2040
On-site blending	0.5m	1m	na	na
Coordination of SAF tanking	0.5m	1m	na	na
Extra cost of SAF fuel (See appendix for more detail)	1m	3-4m	10m	na

Costs shown in EUR

Expected SAF consumption MAA, in line with EU/NL blending mandates

	2019	2021	2025	2030	2035
SAF % as dictated by EU/NL guidelines	na	na	2%/na	5%/14%	20%/na
Total (expected) fuel consumption MAA (million litre/year)	54	72	75	100	100
SAF requirement MAA(million litre per year)	na	na	1.5	5/14	20
SAF requirement MAA (metric ton per year)	na	na	1,226	4,085/11,438	16,340
Relative amount of total current biofuel production that would be required for SAF	na	na	0.1%	0.3%/0.8%	1.0%
Total fuel requirement MAA (litres/day)	147,945	197,260	205,479	273,973	273,973
Total fuel trucks per day (truck capacity: 43 m3)	3.44	4.59	4.78	6.37	6.37
SAF requirement MAA (litres/day)	na	na	4,110	13,699	54,795
SAF trucks per day (in case of on-site blending)	na	na	0.10	0.32	1.27

Onsite blending not expected to be viable option

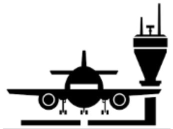
Based on extrapolation of fuel used in 2019 and 2019 flights versus current maximum levels (without significant investments) of 700,000 pax and 200,000 ton per year which is capped in 2030

Although hydrogen infra technology is less mature it is expected to require significantly more investments than for battery-electric applications

H_2 Infra

Overview of infrastructure options for operations hydrogen-electric aircraft vs. hydrogen combustion aircraft

REQUIRED INFRASTRUCTURE



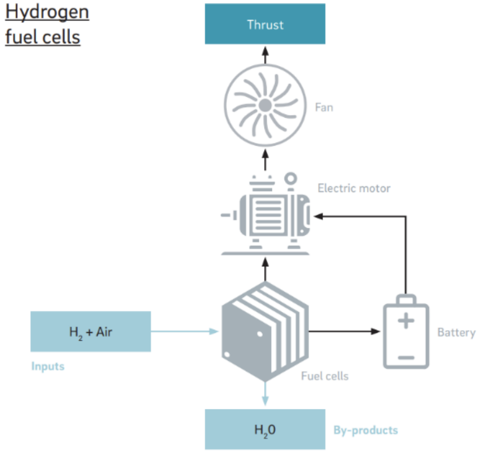
State of technology	Infrastructure options	Description
HYDROGEN H_2 Required infrastructure technology under development. Commercialization will require creating a whole new hydrogen infrastructure	➢ On-site electrolysis	➢ Requires local supply and/or production of electricity and electrolyser to convert electricity into hydrogen
	➢ Off-site + truck	➢ Requires transportation from off-site production location to the airport. Required transport capacity depends on scale of operations
	➢ Off-site + pipeline	➢ Requires large infrastructural investments for the construction of a hydrogen distribution network. From off-site production location to airport

In all three cases, on-site storage and refuelling systems are required to accommodate H_2-aircraft

Hydrogen-electric fuel cell

Hydrogen fuel cells

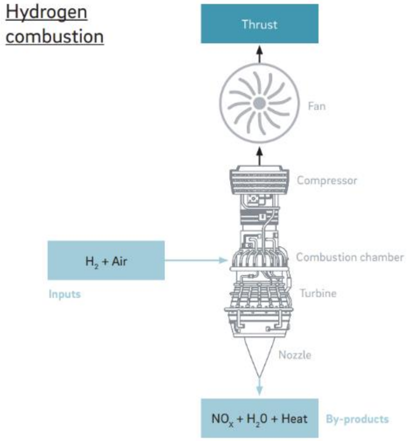
Hydrogen can be used to power a fuel cell that produces electricity. While the conversion rate of a fuel cell is higher than a combustion engine, fuel cell technology is less developed, and the overall system is relatively heavy. These types of power trains are currently being developed by research teams and start-ups such as Universal hydrogen, H2Fly, ZeroAvia and H3 Dynamics.



Hydrogen combustion Jet engine

Hydrogen combustion

Hydrogen can be used to power a combustion engine that works similarly to a current kerosine engine. The technology is currently being developed by OEMs such as GKN, GE, Rolls Royce, Airbus and Embraer.



Source: Roland Berger

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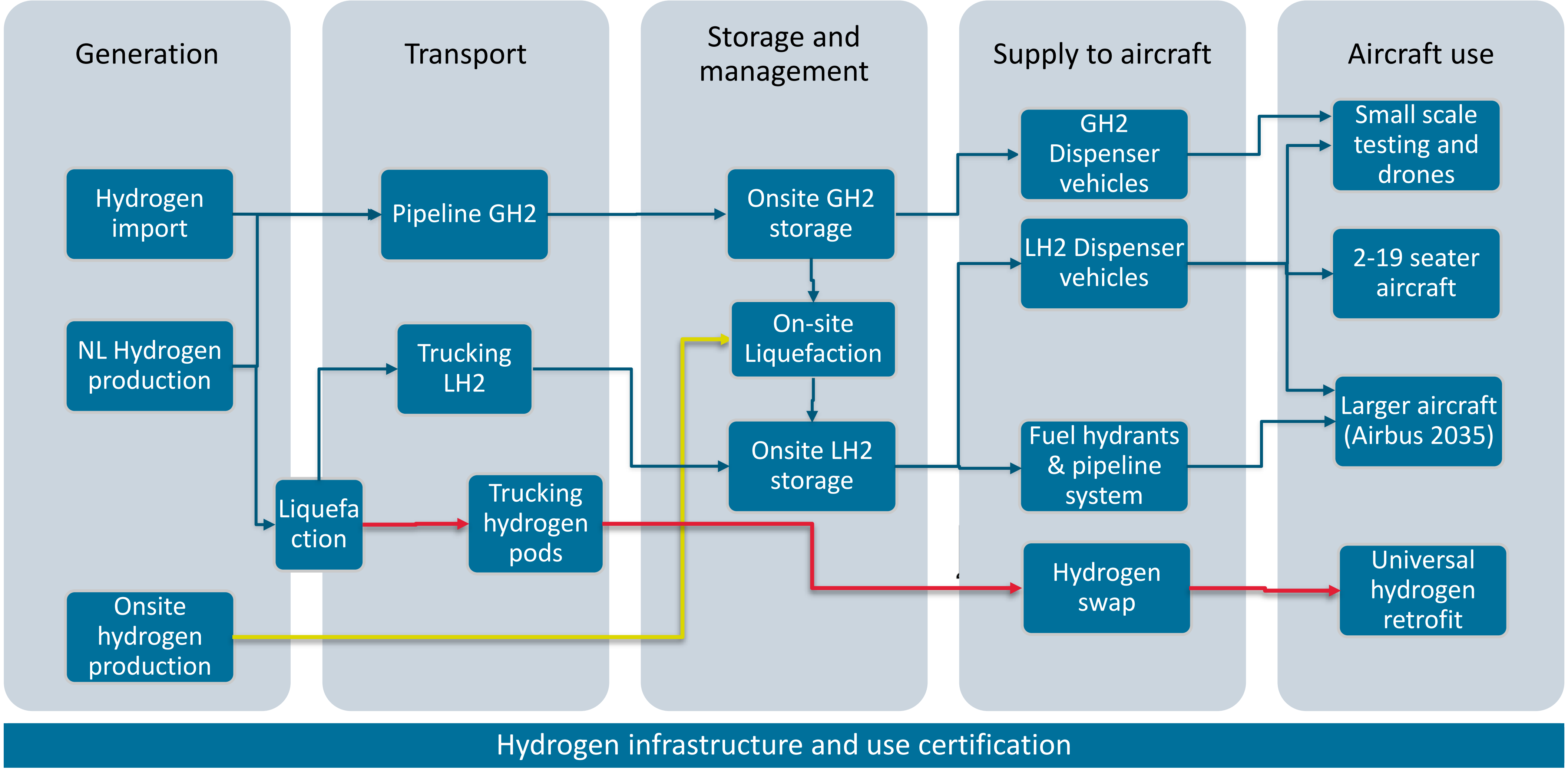
1) Solar deals (link

2) BOV Eindhoven (link))

3 main options can be used for hydrogen airport infrastructure from generation to use in aircraft

REQUIRED HYDROGEN INFRASTRUCTURE



Generation

Transport

Storage and management

Supply to aircraft

Aircraft use

Hydrogen import

NL Hydrogen production

Onsite hydrogen production

Pipeline GH2

Trucking LH2

Liquefaction

Trucking hydrogen pods

Onsite GH2 storage

On-site Liquefaction

Onsite LH2 storage

GH2 Dispenser vehicles

LH2 Dispenser vehicles

Fuel hydrants & pipeline system

Hydrogen swap

Small scale testing and drones

2-19 seater aircraft

Larger aircraft (Airbus 2035)

Universal hydrogen retrofit

Hydrogen infrastructure and use certification

→ On-site Hydrogen production
→ Modular refueling
→ Traditional refueling

1) Own analysis of data

Hydrogen & hydrogen-electric aviation infrastructure – 2025 to 2035

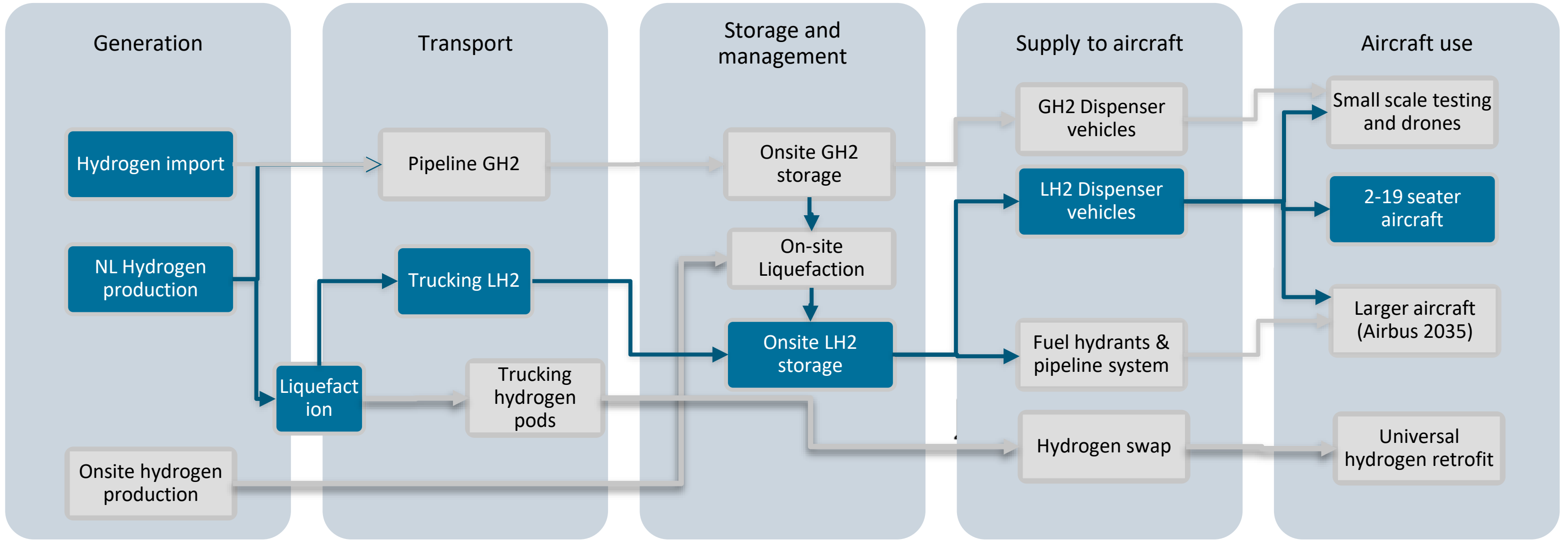
H_2 Infra

REQUIRED HYDROGEN INFRASTRUCTURE

2025-2035

Method | **Infrastructure value chain**

➢ Off-site + truck



Generation
- Hydrogen import
- NL Hydrogen production
- Liquefaction
- Onsite hydrogen production

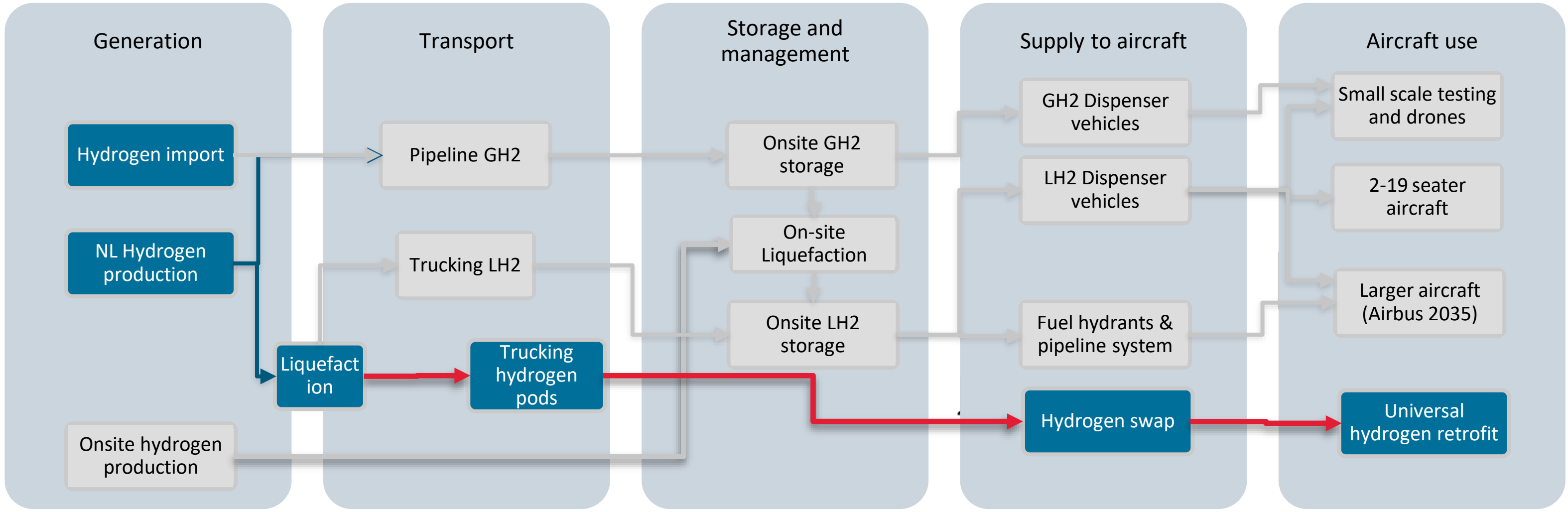
Transport
- Pipeline GH2
- Trucking LH2
- Trucking hydrogen pods

Storage and management
- Onsite GH2 storage
- On-site Liquefaction
- Onsite LH2 storage

Supply to aircraft
- GH2 Dispenser vehicles
- LH2 Dispenser vehicles
- Fuel hydrants & pipeline system
- Hydrogen swap

Aircraft use
- Small scale testing and drones
- 2-19 seater aircraft
- Larger aircraft (Airbus 2035)
- Universal hydrogen retrofit

➢ Off-site + modular refuelling pods



Generation
- Hydrogen import
- NL Hydrogen production
- Liquefaction
- Onsite hydrogen production

Transport
- Pipeline GH2
- Trucking LH2
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Storage and management
- Onsite GH2 storage
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- GH2 Dispenser vehicles
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Aircraft use
- Small scale testing and drones
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- Larger aircraft (Airbus 2035)
- Universal hydrogen retrofit

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1) Solar deals (link
2) BOV Eindhoven (link))

Hydrogen & hydrogen-electric aviation infrastructure – 2025 to 2035

H_2 Infra

REQUIRED HYDROGEN INFRASTRUCTURE

2025-2035

Method | **Required investment** | **Integration at MAA airport**

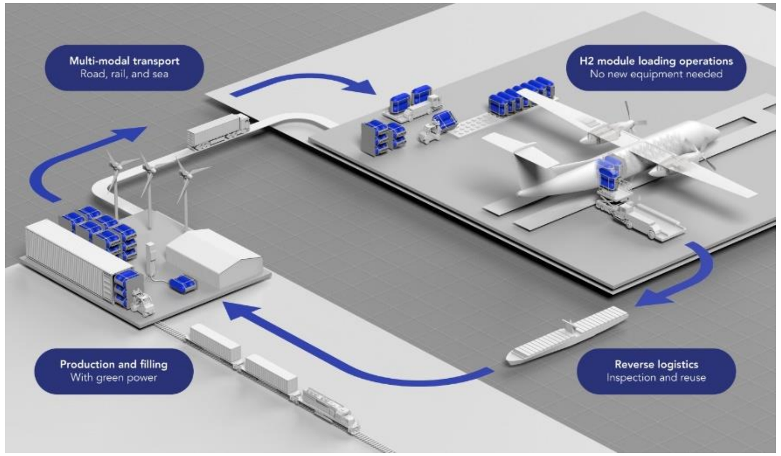
➢ Off-site + truck

Infrastructure	2025	2030	2035	2040
LH2 safety research (BRZO)	0.2m	0.4m	0	0
LH2 operations research	0.2m	0.4m	0	0
LH2 logistics (trucks, refuelling)	0.5m	1m	na	na
LH2 storage systems *	2m	2m	na	na

*RLD_01_K19004_15_Hydrogen_Fuel_Tech_Broschuere_RZ_VIEW_tcm17-610582.pdf (linde-gas.com)

➢ Off-site + modular refueling pods

Infrastructure	2025	2030	2035	2040
LH2 safety research (BRZO)	0.2m	0.4m	0	0
LH2 operations research	0.2m	0.4m	0	0
LH2 logistics (Pod refilling and transport)	0.5m	1m	na	na
LH2 storage systems (in pods)	0.2m	0.2m	na	na



1) Solar deals (link
2) BOV Eindhoven (link))

Costs shown in EUR

Hydrogen & hydrogen-electric aviation infrastructure – 2035+

H_2 Infra

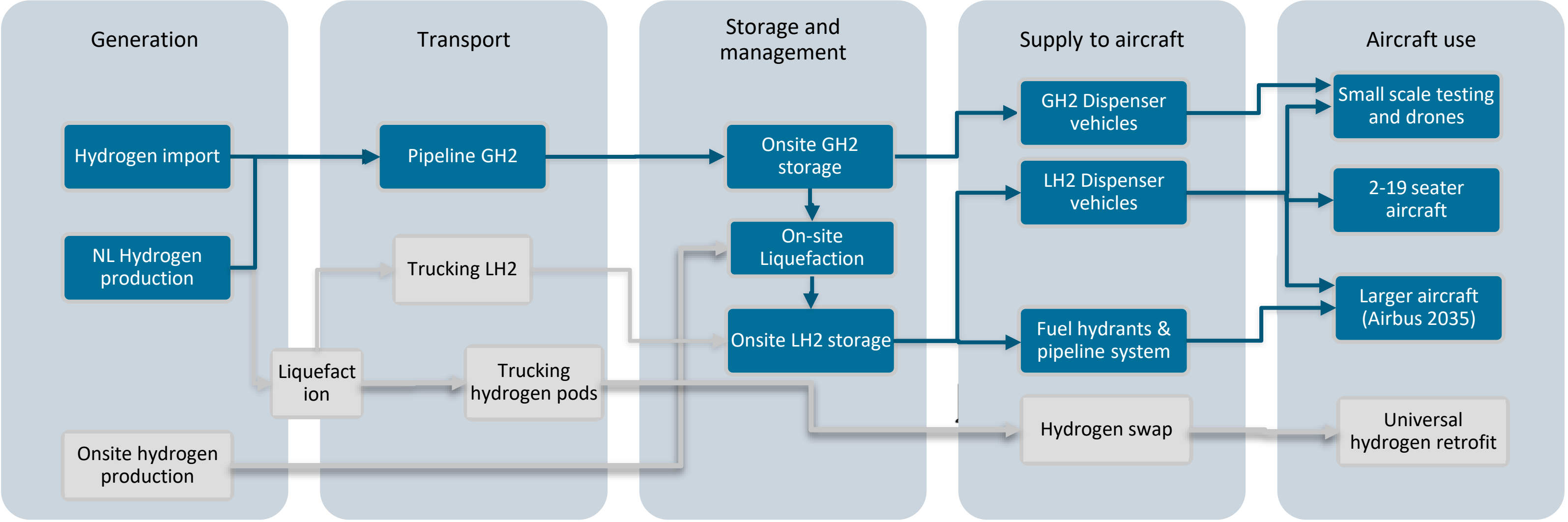
Method

Infrastructure value chain

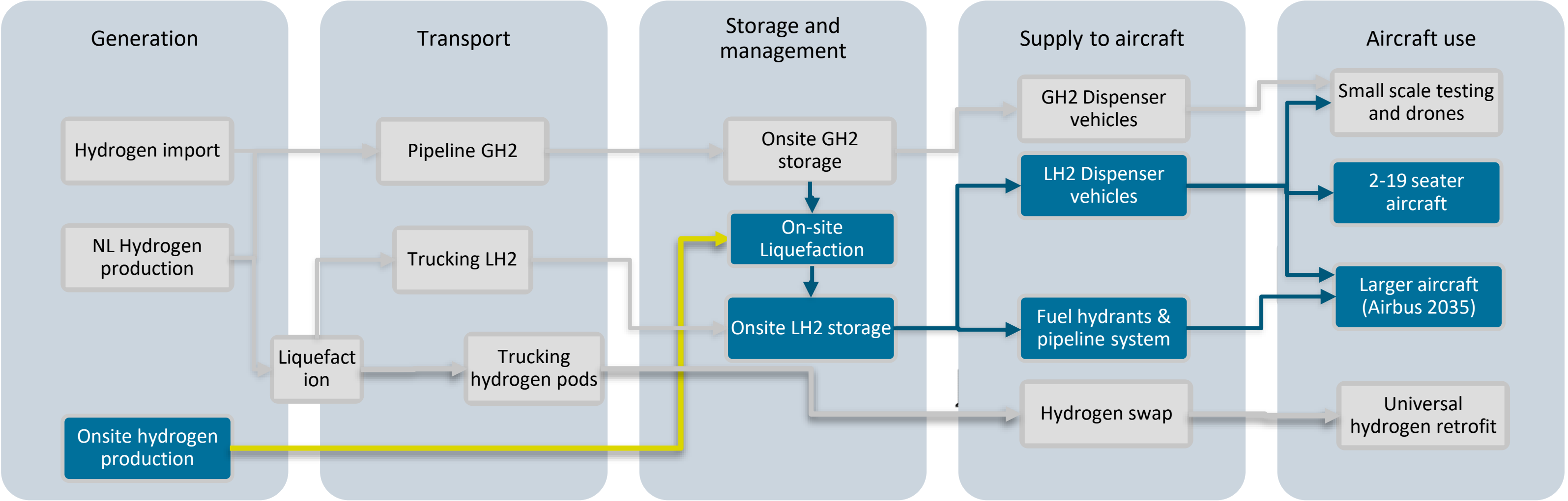
REQUIRED HYDROGEN INFRASTRUCTURE

2035 +

- **Off-site + pipeline**



- **On-site + electrolysis**



1) Solar deals (link)
2) BOV Eindhoven (link))

Hydrogen & hydrogen-electric aviation infrastructure – 2035+

REQUIRED HYDROGEN INFRASTRUCTURE

2035 +

Method | **Expected investments** | **Integration at MAA airport**

- **Off-site + pipeline**

Infrastructure	2025	2030	2035	2040
LH2 safety research (BRZO)	Not available	0.5m	0	0
LH2 operations research	Not available	2m	0	0
LH2 logistics (pipeline and supply)	Not available	5m	10m	na
LH2 storage systems	Not available	2m	2m	na

- **On-site + electrolysis**

Infrastructure	2025	2030	2035	2040
LH2 safety research (BRZO)	Not available	0.5m	1m	0
LH2 operations research	Not available	2m	2m	0
Hydrogen production	Not available	5m	10m	na
LH2 logistics (Refuelling)	Not available	1m	2m	na
LH2 storage systems	Not available	2m	2m	na

1) Solar deals (link

2) BOV Eindhoven (link))

Costs shown in EUR

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Appendix

Assumed door-to-door journey times by mode of transport

Journey times from Maastricht (town)

		Rotterdam	Schiphol	Zuid-As	Den Helder	Groningen	Frankfurt	Paris LBG	Stuttgart	Hamburg	Zurich	Munich	Berlin
	Air time savings vs. road	0:55	1:15	0:50	1:55	1:50	1:55	3:45	3:35	3:50	4:55	6:00	5:40
	Air time savings vs. rail	1:05	1:16	0:53	2:15	2:45	1:25	1:45	2:25	4:25	5:45	4:25	4:10
Air	Pure Block time flight	40	45	45	60	60	55	70	75	90	90	110	115
	Ground travel to MAA	20	20	20	20	20	20	20	20	20	20	20	20
	Airport time	25	25	25	25	25	25	25	25	25	25	25	25
	Arr apt time	10	10	10	10	5	10	10	10	10	5	5	5
	Ground travel to destination	15	0	15	10	15	20	15	20	20	30	30	30
	Total door-to-door time	**110**	**100**	**115**	**125**	**125**	**130**	**140**	**150**	**165**	**170**	**190**	**195**
Road	Pure driving time	140	145	140	205	200	195	300	300	330	400	435	420
	Total breaks	5	5	5	15	15	15	30	30	30	30	60	60
	Buffer for traffic congestion	15	15	15	15	15	30	30	30	30	30	45	45
	Parking	5	10	5	5	5	5	5	5	5	5	10	10
		165	**175**	**165**	**240**	**235**	**245**	**365**	**365**	**395**	**465**	**550**	**535**
Rail	Pure station to station	140	151	143	235	250	180	210	260	395	480	420	410
	Travel to station	10	10	10	10	15	10	10	10	10	10	10	10
	Time buffer ahead of train dep	10	10	10	10	10	10	10	10	10	10	10	10
	Station exit time	5	5	5	5	5	5	5	5	5	5	5	5
	Travel to final destination	10	0	0	0	10	10	10	10	10	10	10	10
	Total door-to-door time	**175**	**176**	**168**	**260**	**290**	**215**	**245**	**295**	**430**	**515**	**455**	**445**

Source: NS.nl; Google Maps; M3 analysis

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There are many OEMs working working on electric eCTOL and eSTOL aircraft with varying credibility, technological feasibility and timeline credibility (1/2)

	Type of Aircraft	Model developed	Company maturity	Technological feasibility (by 2030)	Credibility timeline	
VOLTAERO	• eCTOL • Hybrid- electric • New design	Cassio480 6-8 seater Cassio600 10-12 seater	◕	●	◕	The team has a lot of experience in the field of aerospace and they assume reasonable battery performance and range. They have a credible timeline using experiences of smaller models. Already have a demonstrator flying.
ELECTRA.AERO	• eSTOL • Hybrid-electric • New design	Electra eSTOL 5-seater	◕	◕	◑	The team has a lot of experience also in eVTOL sector. Reasonable battery performance and but range is overestimated. The timeline is quite optimistic due to new elements in design
Heart Aerospace	• eCTOL • New design • Battery -electric	ES-19 19-seater	●	◕	◑	Large team and raised a lot of funding recently. They assumed reasonable battery performance but an optimistic range. They don't have a demonstrator flying yet and have an optimistic timeline.
EVIATION	• eCTOL • New design • Battery -electric	Alice 9-seater	●	◑	◑	Raised a lot of funding and have a large experienced team. Range and battery performance characteristics are optimistic. Redesign has taken place recently which makes timeline optimistic.
ZEROAVIA	• eCTOL • New design • Hydrogen - electric	HyFlyer II 19-seater Regional Aircraft 50-seater	●	◕	◑	Raised a lot of funding and a large team with very experienced staff both in OEM and start-up business. Had a small demonstrator, however, timeline is very optimistic mainly due to certification. Operations will be very costly at start of operation.
AURA AERO	• eCTOL • New design • Hybrid- electric	Integral 2-seater ERA 9-seater	◑	◕	◕	Have a lot of experienced employees from Airbus and Boeing but do have limited funding and ordered aircraft. Assume optimistic battery performance but have a reasonable timeline.
BYE AEROSPACE	• eCTOL • New design • Battery-electric	eFlyer2 2-seater eFlyer4 4-seater eFlyer800 8-seater	◕	◕	◔	Dedicated electric aircraft OEM with many years experience starting with 2/ and 4-seater aircraft for flight training/private pilots. eFlyer 800 performance based on unrealistic battery assumptions and timeline unlikely
EMBRAER	• eCTOL • Retrofit • Battery/Hybrid–electric		●	●	●	Has introduced a wide-range of new aircraft (Energia family) in December 2021. Very credible company, performance and timeline
PYKA	• eCTOL • New design • Battery-electric	Pyka P3 9-seater	◑	◕	◑	Already have deals from their agriculture planes and raised a lot of funding. Not much deals for P3 model. They have optimistic battery performance estimation and already a lot of inhouse experience. Timeline for P3 is optimistic.

There are many OEMs working working on electric eCTOL and eSTOL aircraft with varying credibility, technological feasibility and timeline credibility (2/2)

	Type of Aircraft	Model developed	Company maturity	Technological feasibility (by 2030)	Credibility timeline	
QUALITY AIRCRAFT SINCE 1948 TECNAM	• eCTOL • Battery - electric • Retrofit	P-Volt 11-seater	●	◕	◑	Partnerships with Wideroe and Rolls Royce. Very credible OEM with realistic assumptions. However, the P2012 platform used for the P-Volt has a poor glide ratio making range very limited
AMPAIRE	• eCTOL • Hybrid-electric • Retrofit	Eco Otter SX 19-seater	◕	◕	◑	Secured funding and has large team. Performance characteristics are achievable with initial retrofit projects (e.g., Eco Otter) will have low range using battery-power only
faradair	• eCTOL • Hybrid- electric • New design	Bio Electric Hybrid Aircraft 18-seater	◑	◑	◑	Still completing current funding round. Hybrid-technology has high potential, but tri-wing design induces performance uncertainty and longer/uncertain certification process.
ELECTRON	• eCTOL • Battery - electric • New design	Electron5 4-seater	◑	◕	◑	Company already has a 2-seater demonstrator but few employees. It already does have first letters of interest. Optimistic performance characteristics but timeline might be met given the characteristics
VENTURI	• eCTOL • Battery - electric • New design	Echelon 1 44-seater	◑	◔	◔	Very ambitious project in terms of engineering challenges and timeline; small team so far but high relevancy of aircraft size/range combination
PIPISTREL	• eCTOL • Battery/Hybrid – electric • New design	Velis electro 2-seater Pipistrel Miniliner 20-seater	●	◑	◔	Certified first all-electric aircraft and have a lot of experienced employees. Assumptions for Miniliner are reasonable but timeline is very optimistic.
DA	• eCTOL • Retrofit • Battery/Hybrid–electric	eCaravan 9- seater DAX-19 19-seater	◑	◕	◔	Dante Aeronautical likely first to have certified battery-electric retrofit in Australia; working on various hydrogen-electric retrofits and new design with European airlines

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Appendix

2. Benchmarking future fuel (SAF, H_2 & BE) initiatives at European airports

Appendix

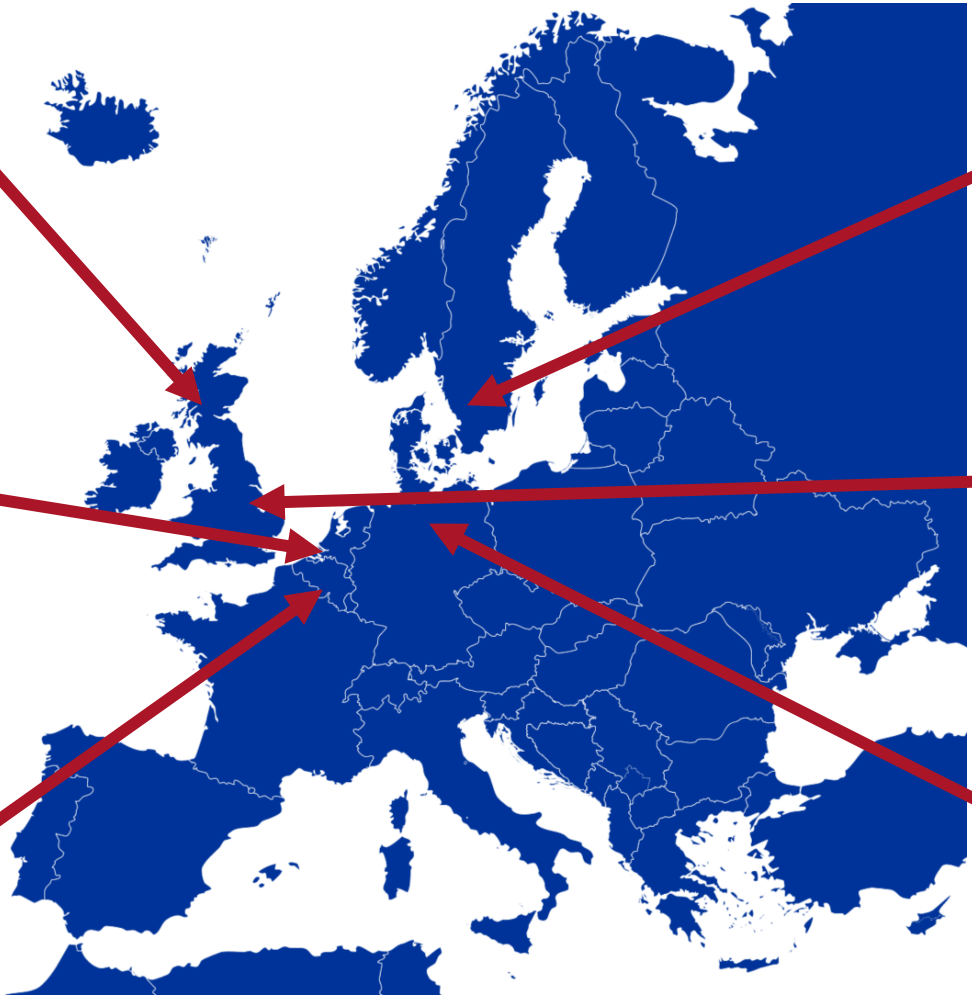
Edinburgh Airport partners with Orsted in hydrogen and SAF production

Rotterdam The Hague airport sets up Zenid consortium for synthetic fuels.

zenid JET FUEL FROM AIR

EU Green Deal Stargate project includes pilots in on-site SAF blending & electric / H_2 GSE.

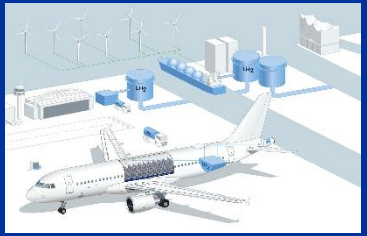
Stargate within EU Green Deal



Visby airport of Swedeavia installs first electric aircraft charging stations

London Heathrow becomes first airport to incorporate SAF into fuel supply

Hamburg airport in collaboration with Lufthansa and DLR



* More information on these initiatives can be found in the appendix

2. Benchmarking future fuel (SAF, H_2 & BE) initiatives at European airports

Edinburgh Airport partners with Orsted in hydrogen and SAF production

Edinburgh - 22/10/21

The Edinburgh Airport project will see electricity sourced from offshore wind farms and the renewable hydrogen will then be combined with sustainably sourced carbon to produce 250,000 tons of e-kerosene and e-methanol per year when fully scaled up. Ørsted will draw on the experiences of this project and work with Edinburgh Airport to implement an array of ambitious initiatives that will rapidly accelerate the shift to sustainable air travel.

Rotterdam The Hague airport sets up Zenid consortium for synthetic fuels.

zenid JET FUEL FROM AIR

Rotterdam - 08/02/21

Rotterdam The Hague Airport (part of Royal Schiphol Group), SkyNRG and Climeworks take a next step in realizing Zenid. Zenid is a demonstration plant producing fully circular sustainable aviation fuel directly from air. The current production ambition is still on a research phase. However, the technology can be shared within the partners and will enable the airport to stimulate SAF uptake from airlines.

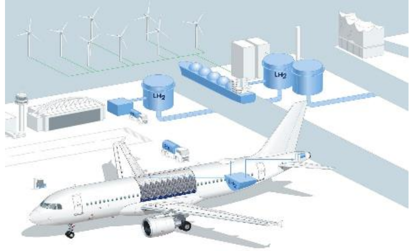
EU Green Deal Stargate project inculdes pilots in on-site SAF blending

Stargate within EU Green Deal

Brussels - 24/11/21

Stargate is a European funded research program set up by a consortium of 4 European airports. Research within the project includes the development of biofuel blending installation at the airport, electric ground handling material and testing quiet engine innovations. The project aims to increase the sharing between airports and ensures that European airports can share their innovations.

Hamburg airport in collaboration with Lufthansa and DLR



Hamburg - 24/11/21

In a two-year research project from DLR, Hamburg airport and Lufthansa, a decommissioned Airbus A320 aircraft will be converted into a stationary, fully functional field laboratory equipped with LH2 infrastructure. This will take place at Lufthansa Technik's base at Hamburg airport. In the first phase the partners will identify areas for developing and elaborate the concept for subsequent testing. The aim is to jointly implement a pioneering demonstrator that is operational by 2022.

Visby airport of Swedeavia installs first electric aircraft charging stations

Visby - 05/10/21

Swedavia has provided funding for the electric aircraft charging stations in collaboration with Region Gotland and GEAB. Climate Leap (Klimatklivet), the Swedish Environmental Agency's program for local and regional investment support to reduce greenhouse gas emissions, provided additional funding for the installation. The infrastructure consists of three charging stations for electric aircraft, located at two different sites at Visby Airport. Two charging stations are set up on the airport's main apron for aircraft while the third is located at the Gotland Flying Club, in the southern part of the airport.

London Heathrow becomes first airport to incorporate SAF into fuel supply

London - 04/06/2021

Heathrow has successfully incorporated sustainable aviation fuel (SAF) into its operation, ahead of the G7 Summit. Heathrow will work alongside Vitol Aviation and Neste MY Sustainable Aviation Fuel™ where the fuel will be incorporated into the airport's main fuel supply today, and blended to use across flights operating at Heathrow over the next few days.

Sources: United Airlines newsroom, Airbus newsroom, wired.com, renewable-carbon.com, IATA SAF