Market opportunities and business planning for eRAM

Workshop
'Electrification & battery developments for electric flying'-event

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VENTURI

Content of this workshop

- **Key drivers for market relevance: performance, timing and economics**
- OEM timelines regarding introduction
- Our expert judgement on potential timelines
- Implications for business planning

Market relevance of eRAM services is determined by three aspects: performance, economics and environmental footprint

Aspect	Key market relevance-drivers
• **Performance**	• Battery-electric vs. hybrid vs. hydrogen-electric • Battery-density and power • Aircraft design (retrofit vs. new design (L/D)
• **Economics**	• Battery-cost and cycle life • Aircraft price • Pilot (dual/single/autonomous) • Airport charges • Applicable government taxes • Subsidies?
• **Environmental footprint**	• Direct CO2/ Lifecycle CO2 • Nitrogen • Particulate matter • Energy efficiency • Noise levels

Trade-offs

Discussion:

What is the market looking for in terms of eRAM aircraft technology?

Technological development of batteries along 8 axes is crucial for the success of battery-electric flights

8 CHARACTERISTICS

Drive the performance of batteries for battery-electric flights

1. Total energy density (100%-0%)
2. Usable energy density (e.g. 95-5%)
3. Energy power density
4. Maximum charge & discharge rates
5. Internal resistance
6. Cell-to-pack ratio
7. Battery life (no. charge cycles)
8. Battery cost per kWh per flight

Critical characteristic for vertical take-off and landing capability

IMPROVING ALL SIMULTANEOUSLY

Makes the development of batteries challenging

Energy density ⬆	~	Battery lifespan ⬇	E.g. new Li-S technologies currently still have a limited lifespan
Power density ⬆	~	Battery lifespan ⬇	High discharging capability (~2C range) required during take-off and high charging capability required to realise short TATs
Charge & discharge rates ⬆	~	Battery lifespan ⬇	The more power you draw, the faster internal resistance deteriorates which affects battery lifespan
Cell-to-pack ratio ⬆	~	Battery lifespan ⬇	E.g. solid state batteries are expected to improve cell-to-pack ratio but currently have reduced maximum no. cycles
Battery cost per kWh per flight ⬆	~	➢ Production cost ⬆ ➢ Battery life ⬇ ➢ Second life yield ⬇	New technologies like Li-S currently increase production costs, reduce battery life and reduce 2nd-hand value

1) Source: DLR expert interview; M3 analysis

Battery-electric flights with eVTOL aircraft are expected to become feasible as battery performance characteristics improve over time

Forecast of expected battery performance and cost and resulting flight range

8 CHARACTERISTICS
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Critical characteristic for vertical take-off capability

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***INDICATIVE* OUTLOOK**
How battery technology *could* develop

	now	2025	2030 target[1)]
Density (Wh/kg at pack level)	200	300	450 - 600
Usable Density (Wh/kg)	160	240	360 - 500
Power density (Wh/kg)	800	1,200	2,000
Charge rates	1/1C	2/1C	3/1C
Cell/Pack	65%	75%	80%
Life span (no. cycles)	500	1,000	3,000 [2)]
Costs (€/kWh at pack level) [3)]	*500+*	*300+*	*200-300*

All parameters are interrelated and cannot be improved at the same time!

Discussion:

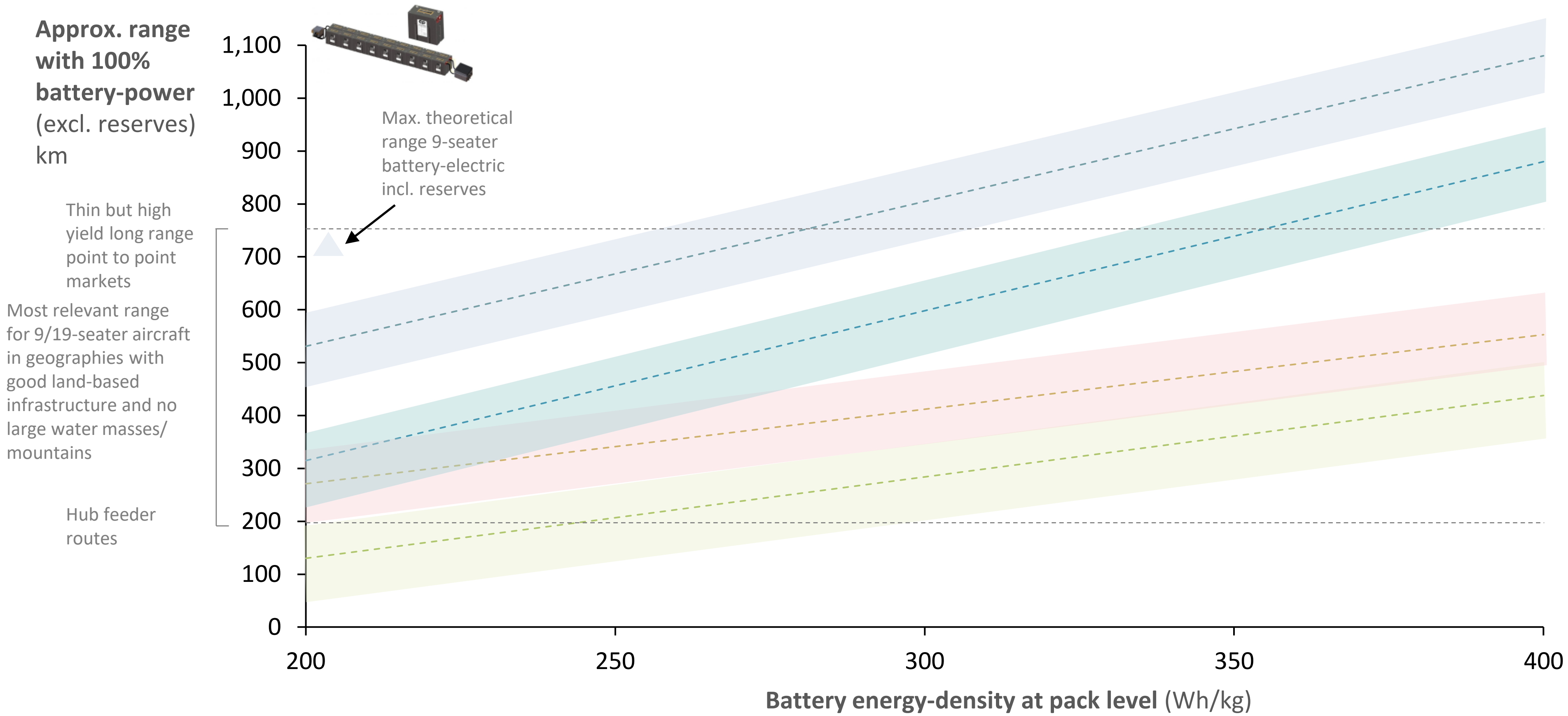
How realistic are these assumptions?

1) Targets set by the European Technology and Innovation Platform
2) The 3,000 cycle life is based on 80% depth-of-discharge at 3C charging and 1C discharging at 23 degrees C temp. The cost model used for economic analyses assumes 2,000 cycles at 80% DoD
3) Specific forecast for the use of batteries in aircraft requiring additional safety/cooling measures etc. Excluding the resale value of batteries
4) Source(s): Strategic Research Agenda for batteries 2020 by the European Technology and Innovation Platform December 2020, Batteries Europe; expert interview with DLR, M3 analysis

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

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+



Discussion:

What could be the approximate timeline?

9-seater hybrid-electric

9-seater battery-electric

19-seater hybrid-electric

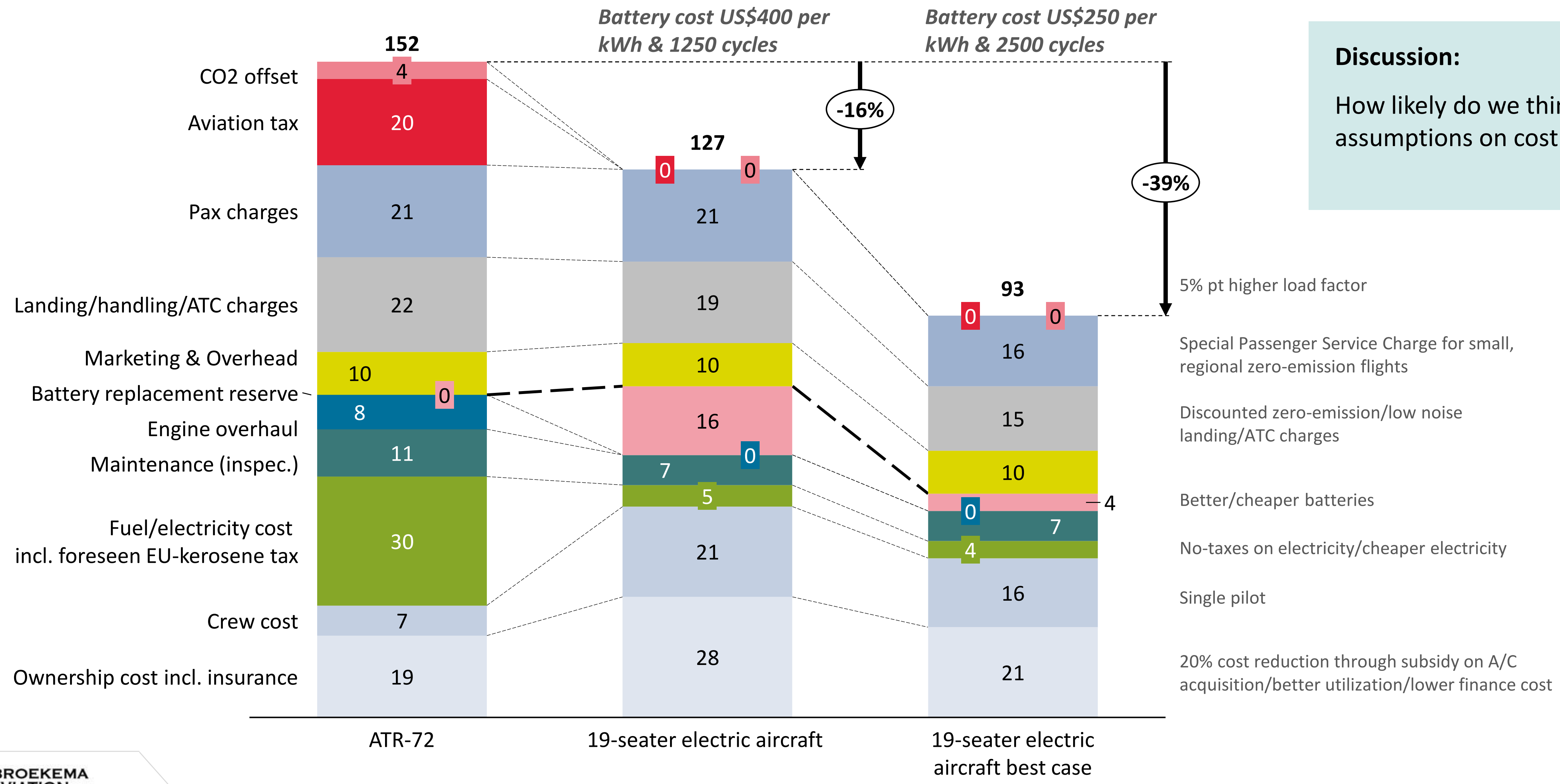
19-seater battery-electric

[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

There are many assumption underlying the cost level of eRAM service

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



Discussion:

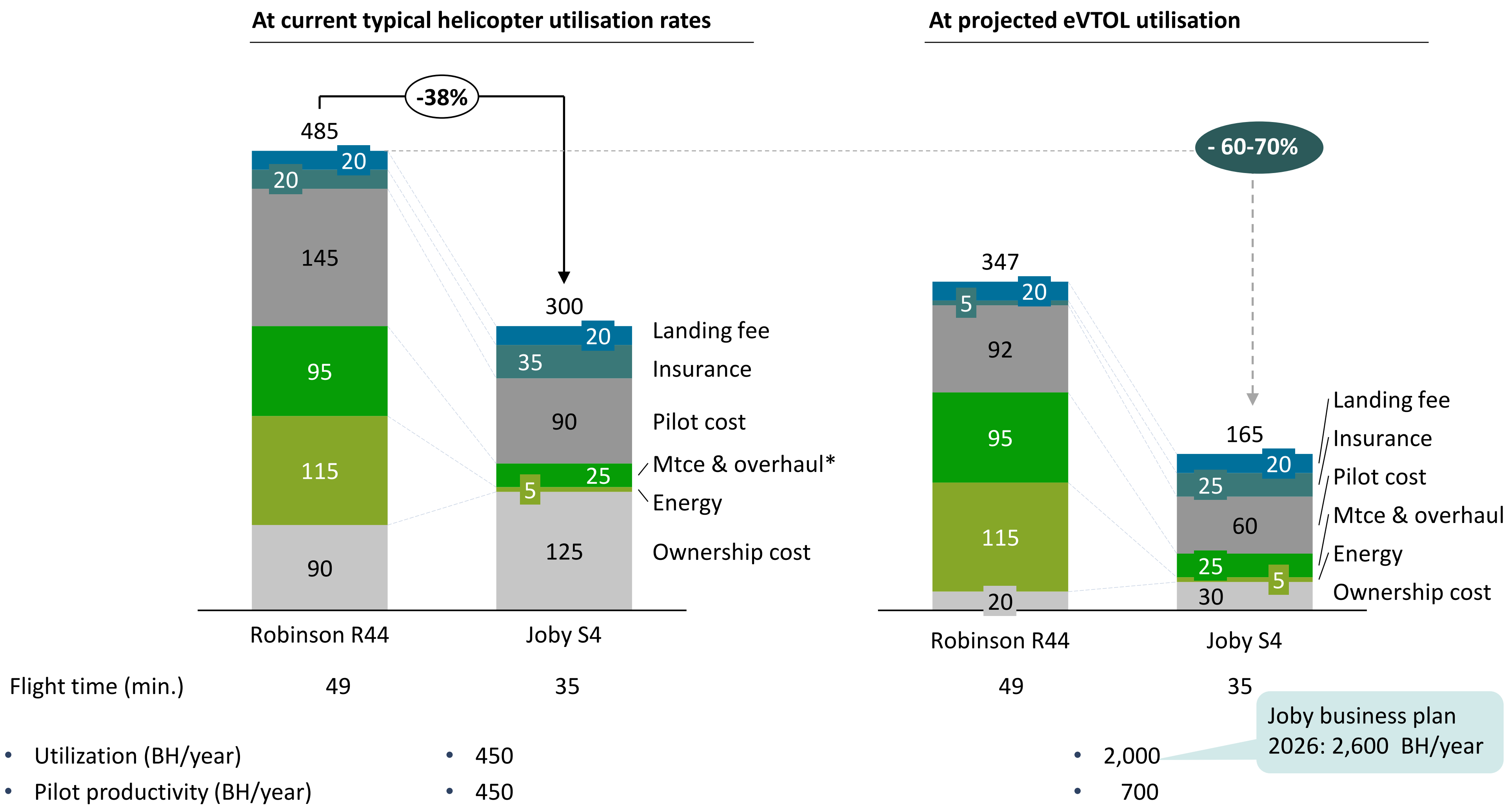
How likely do we think this assumptions on cost are?

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

eVTOL operating cost mainly driven by utilization and pilot productivity

Estimated trip operating cost for a 150 km trip excluding variable passenger charges and overhead cost in EUR



* Includes battery reserve cost

Sources: M3/PEN EM analysis

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

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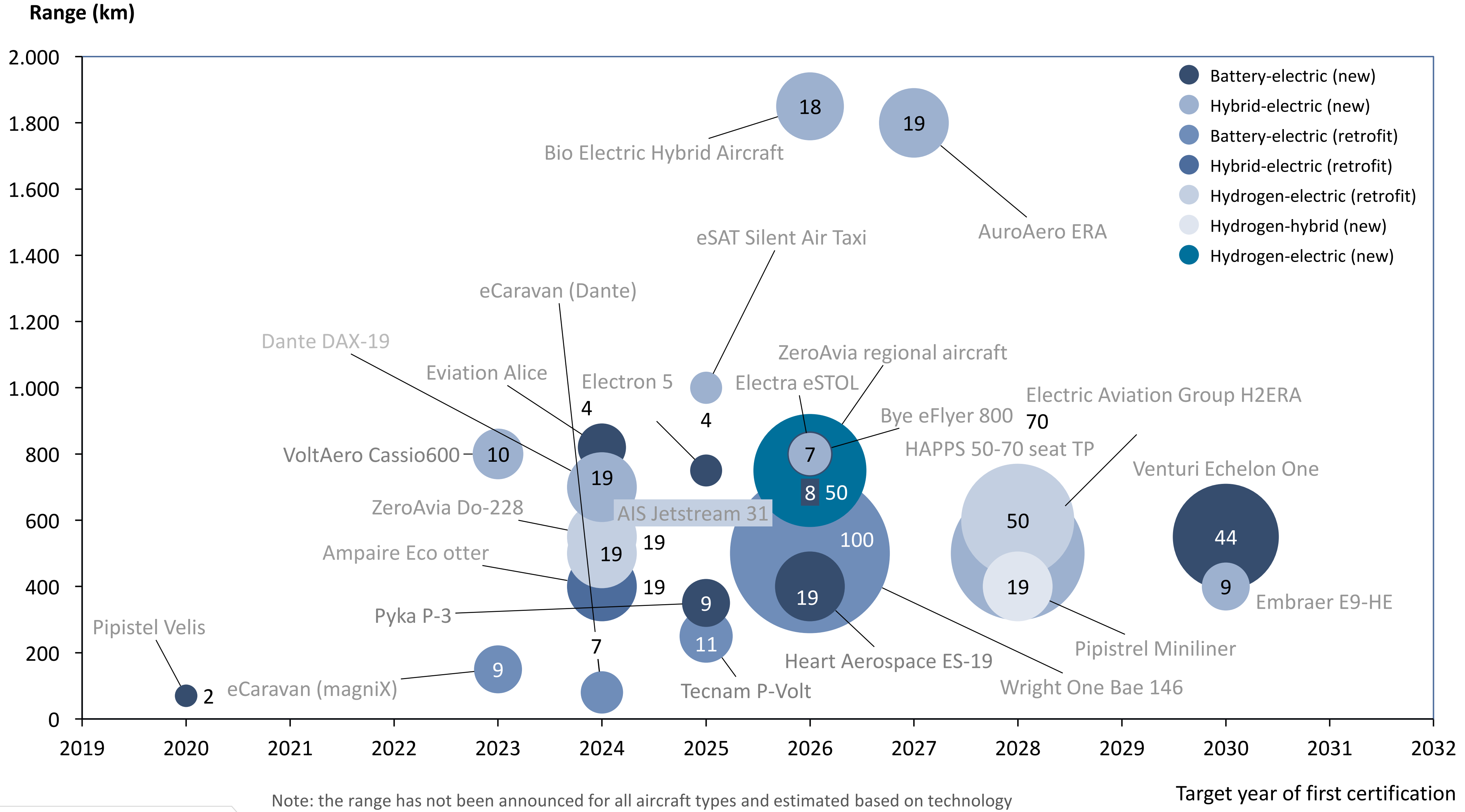
There are currently nearly 25 eCTOL aircraft in development with the majority being targeted for certification in the 2023 – 2028-time window — timing and expected performance are (very) ambitious

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



Discussion:

How realistic are these target years for certification?

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

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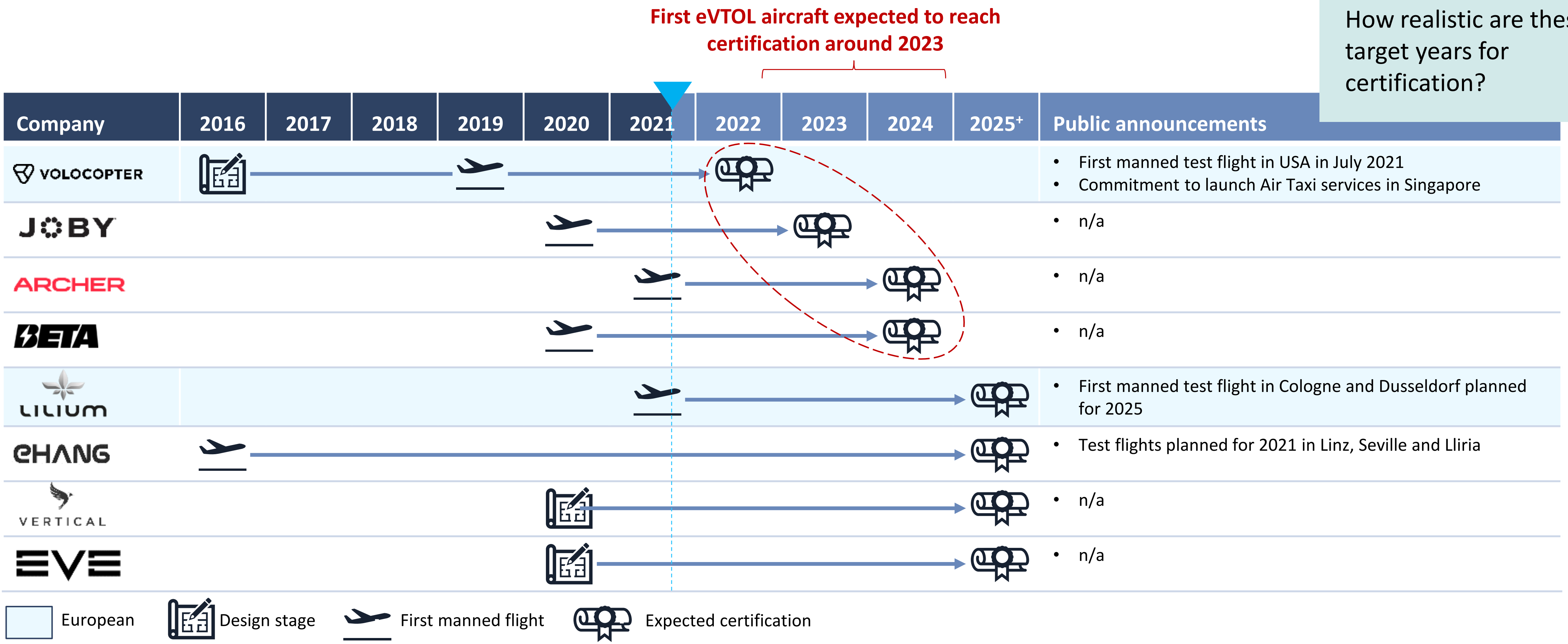
Certification of eVTOL aircraft is in the process of being launched, resulting in the first certified aircraft for UAM near the end of 2022 at earliest

Targeted certification timeline as announced by eVTOL OEMs

Discussion:

How realistic are these target years for 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

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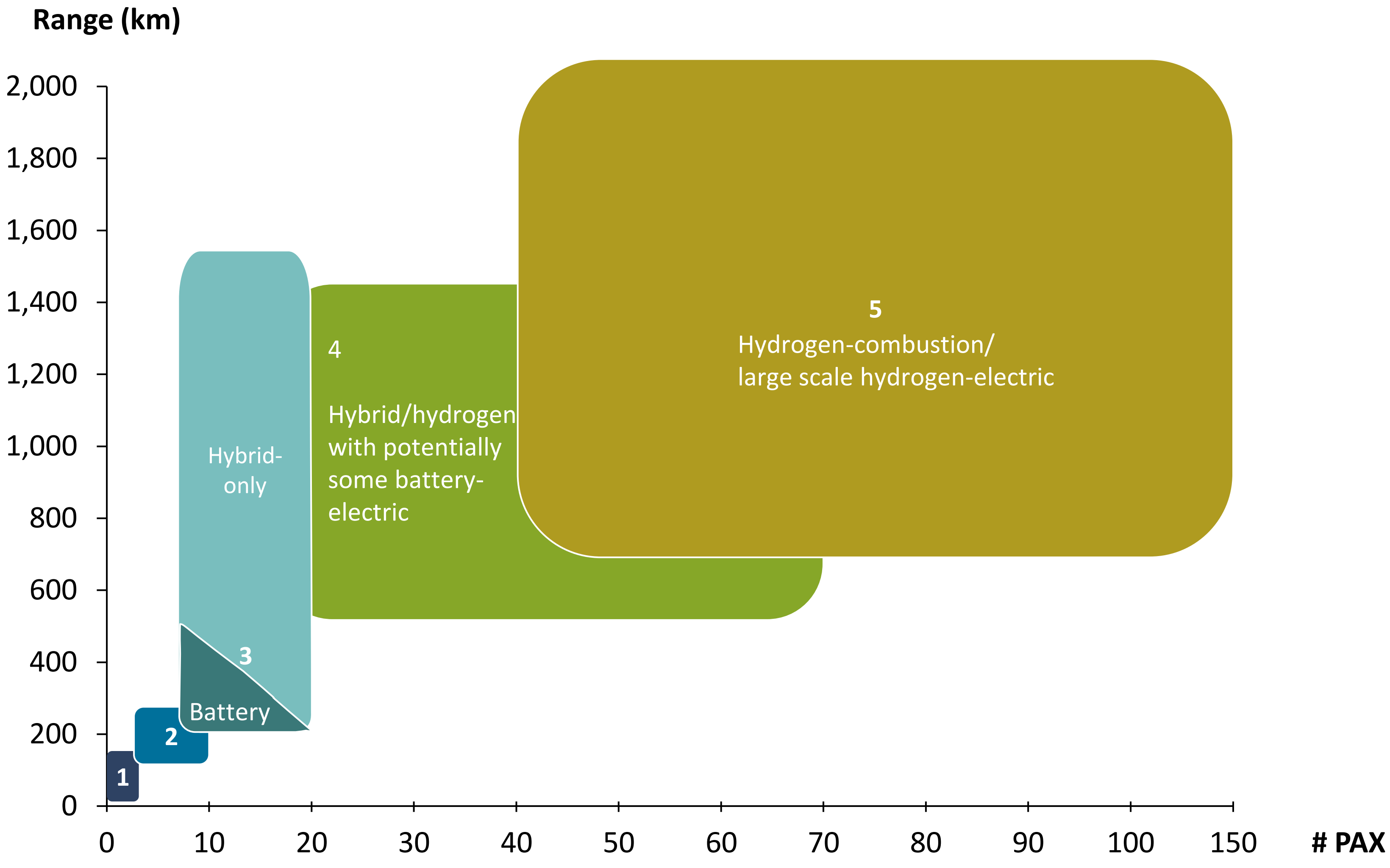
Zero-emission aircraft are expected to reach maturity in 5 distinct stages towards 2040

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

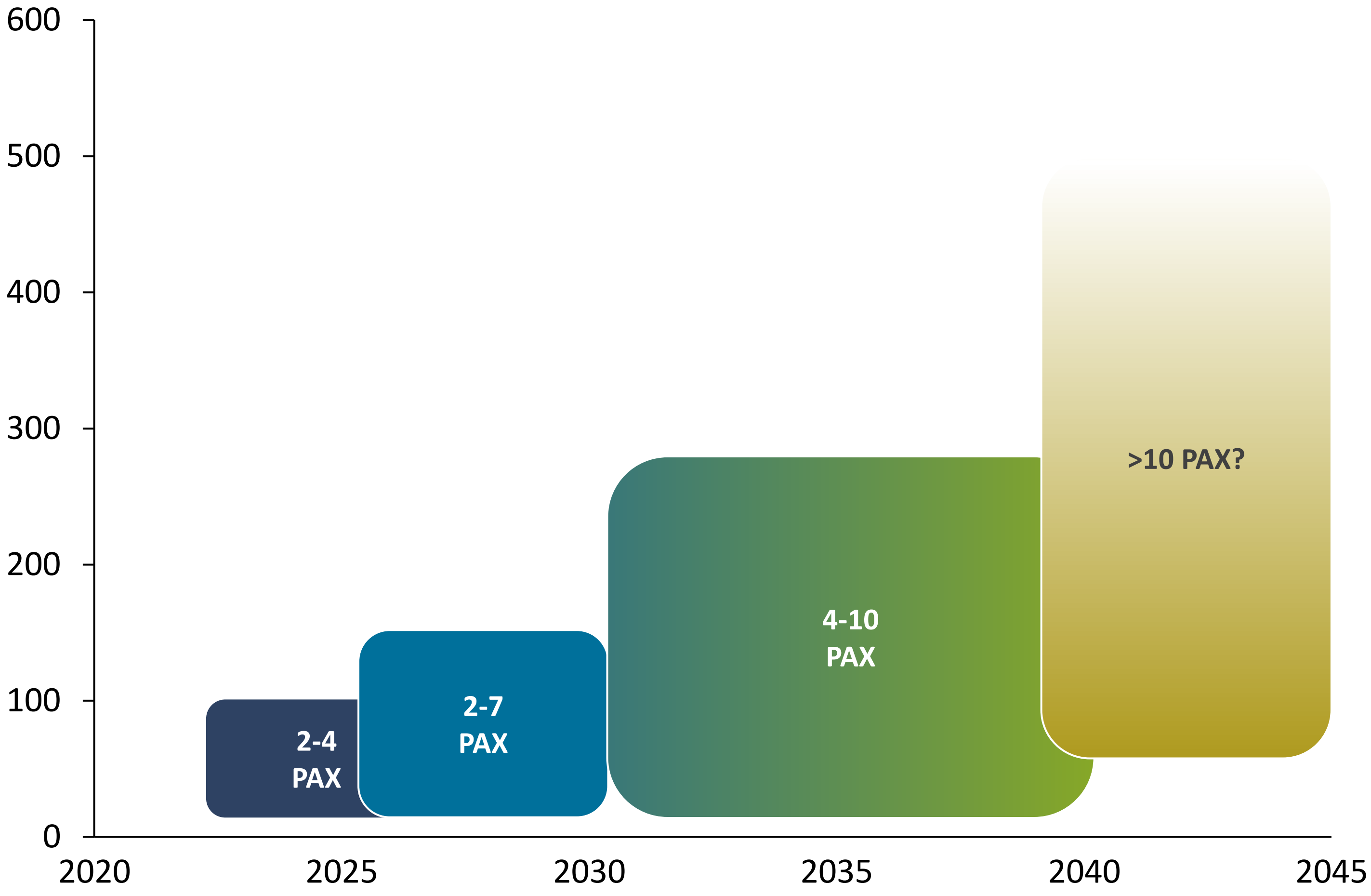
4 **2030-2035**: 2e generation new battery-electric (up to max 30-40 seats; hybrid-/hydrogen electric up to 50-70 seats

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

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

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Proper business planning requires assumptions on when is what possible

Type of business	Key external factors driving business planning
• Aircraft OEM	• Battery-density availability
• Operator	• Pre-certification tests completed • Certification date • Production upscaling/delivery times • Airport readiness
• Airport	• As operator above • Which airlines will order eRAM aircraft
• Suppliers to aircraft OEM	• Certification timing • Production upscaling

Discussion:

Where do we see the biggest bottlenecks? What does that mean for business planning?