



▶ The Future of Vertical Mobility

Sizing the market for passenger, inspection, and goods services until 2035

A Porsche Consulting study

Note to the reader

Flying promises a very special and seemingly boundless form of freedom. People have always dreamt of taking off and moving through the air. Leonardo da Vinci (1452-1519), the Italian artist, engineer, and natural philosopher, studied birds for ideas on how to design flying machines. His results used muscle power for propulsion.

Vertical mobility, which includes vertical take-off and landing (VTOL) abilities, played a role even in da Vinci's time. Around 1490 he sketched an aircraft with an aerial screw, which is a precursor to today's helicopters. He called his invention the helix pteron, or "spiraling wing". The Chinese had already applied this principle of upward motion some 2,500 years before to a toy in the form of a vertically ascending top.

Da Vinci was not able to put his invention into practice. He lacked lightweight and stable materials. Nor was a sufficiently powerful drive system available at the time. Many designers subsequently attempted to produce rotary-wing aircraft. It was not until much later, in 1901, that the first helicopter rose into the air above Berlin. Today, more than a century later, rotorcraft machines are acquiring new significance. As small-scale, versatile drones, they could play an important role as links between different modes of connected, future-oriented transportation—whether as four-seat aerial taxis, delivery vehicles, or for inspection purposes.

Why are small aircraft of this type attracting serious attention? The aviation industry has undergone enormous development. Wide-body planes can carry as many as 850 passengers. Flying throughout the world is a routine practice. But only now are future-oriented technologies making it possible for short-distance connections to utilize the airspace, above large cities in particular.

Environmentally friendly electric propulsion systems, high-performance batteries with extremely short charging times, minimal spatial requirements for taking off and landing, high-speed computers, and big data have laid the foundation for revolutionary new applications. We are entering an era in which everyone will be able to operate aircraft. Even without a pilot's license. Because drones can be remote-controlled. In their role as pilots, passengers need do little more than select a destination.

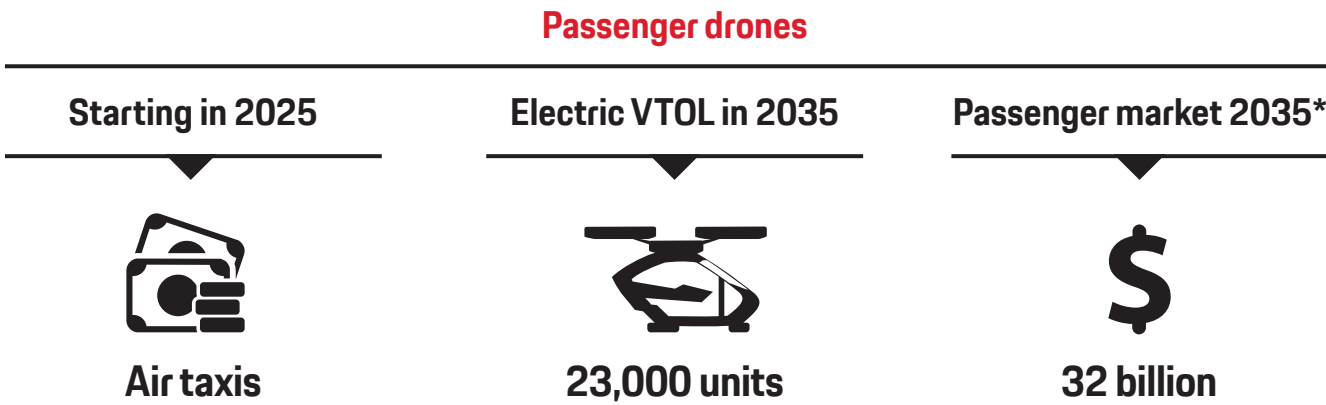
All new developments first need to be accepted, of course. Reservations and concerns are natural human reactions to major changes. Aware of these responses, the authors of the study "The Future of Vertical Mobility" have addressed them. Yet they are also certain that superior technology will encompass the necessary safety and security features to convincingly eliminate reservations and concerns. The study therefore takes a thorough and comprehensive approach in its analysis of the feasibility of vertical mobility.

At a Glance

Vertical mobility offers mankind a serious shot at turning the dream of flying into a reality for everyone, and inspection, goods, and passenger services have the potential to become a global market worth \$74 billion by 2035.

After first field tests, we expect electric passenger drones or eVTOL aircraft (short for electric vertical take-off and landing) to start providing commercial mobility services in 2025. In just seven years from now, the first drone air taxis will lift off, primarily in big cities around the world. They will mostly connect

airports and city centers, offering short transfer flights for business travelers. Within one decade after that, by 2035, drones could already be servicing their own elaborate passenger network with about 23,000 aircraft plying major routes and creating a market worth \$32 billion (fig. 1).



* Intracity and city-to-city
Figure 1. Air taxis for everyone: the timeframe for commercial passenger drones.

Graphic: Porsche Consulting

If this vision is to become reality, the four key elements of the eVTOL ecosystem have to be debated, designed, and developed in the coming years: the underlying technology, the regulatory framework, social acceptance, and the necessary infrastructure. Even though much points to a future in which vertical mobility will elevate personal transportation to the third dimension, in its current state it is a venture fraught with significant risks.

Vertical mobility will only be one piece in the larger puzzle of urban transport because it has a limited range of applications and can typically beat other modes of transportation, such as taxis, at distances of 20 kilometers or more.¹ This minimum range is almost twice as long as the average urban journey of 11 kilometers (1). Still, vertical mobility holds promise in relieving some pressure from particularly congested urban hot spots – but only some. If one tried to solve all traffic problems on the ground by moving into the air, the myriad take-off and landing spots would become the new choke points.

There is no need to worry that the skies will be clogged with drones, however, since passenger drones and flying cars that

can take off and land anywhere are not a realistic scenario for the mid-term future. Even a megacity with five to ten million inhabitants will have no more than 1,000 passenger drones in operation by 2035. Passenger drones will for some time remain a hub-to-hub travel option that depends on other modes of transportation, rather than an end-to-end solution.

Looking at unmanned eVTOL aircraft, the market for inspection drones will grow to \$34 billion and 21.5 million active units by 2035, complemented by the market for goods-and-delivery drones at \$4 billion and 125,000 units. Inspection drones are in use today, and goods drones are already being tested around the world. The market for supporting services around inspection, goods, and passenger drones will reach another \$4 billion by 2035.

To be sure, the time for vertical mobility has come. The only questions are how big the market will be and how fast it will evolve. This is the focus of the following report.

¹ This report differentiates between intracity and city-to-city applications since various travel distances require different technical concepts.

Preface

Air taxi

Airport to the city

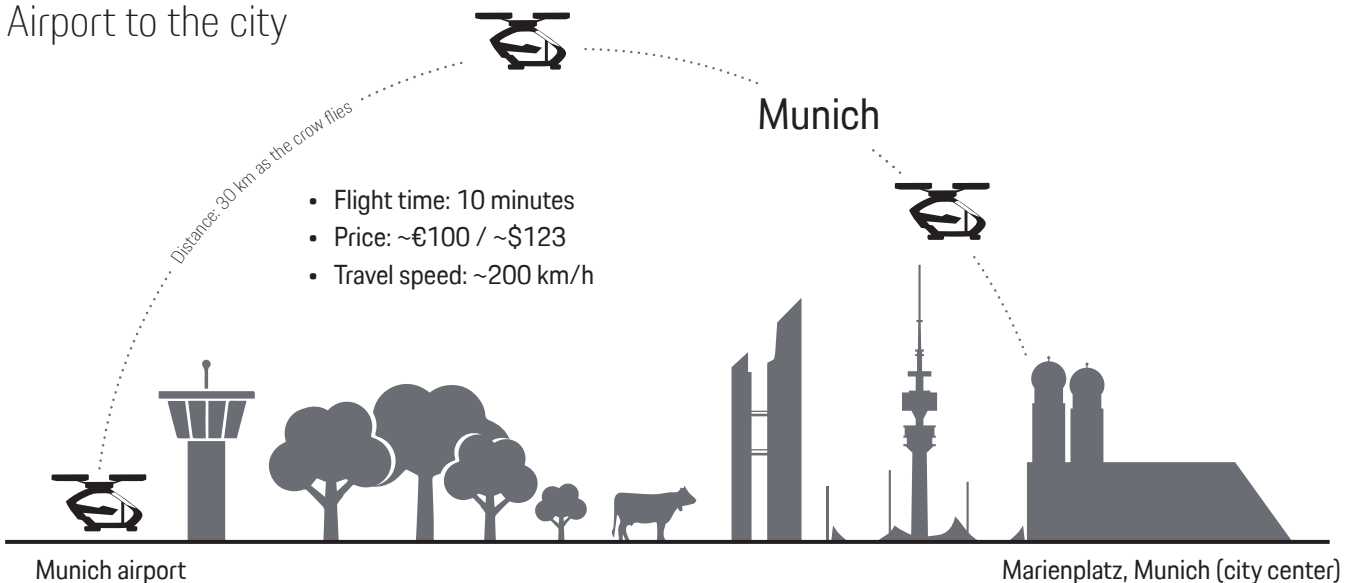


Figure 2. Air taxis are available for fast connections between airports and cities: in Munich, for example, the fastest connection would take only ten minutes.

Graphic: Porsche Consulting

This report provides a strategic overview of a more detailed analysis and aims to accomplish three goals:

01 Add a fact-based foundation to the hype around vertical mobility, which inspires the public's imagination as the first passenger drones are tested and details of the Uber Elevate air taxi service emerge (2).

02 Offer pragmatic and neutral analysis following our mission to "think strategically and act pragmatically."

03 Share our findings with the ecosystem of companies and startups, city governments, and the public, as well as aerospace and other regulatory entities.

The following pages will identify and assess the drivers and barriers defining the vertical mobility ecosystem and describe the most likely development paths and scenarios. It represents a market-based model grounded in today's mobility patterns and current market predictions. We focused on electrically propelled aircraft and excluded military applications.

This report brings together the expertise and input of Porsche Consulting and 62 internationally renowned experts from the domains of aerospace, technology, and automotive.

We want to answer three key questions raised by the new mobility landscape:

- **What is the market potential in 2035?**
- **What are basic, conservative, and progressive market scenarios to get there?**
- **What are the opportunities for customers, cities, manufacturers, operators, and investors?**

Porsche Consulting will do its part to continuously observe the vertical mobility space.

The authors want to thank the team, external partners, and project sponsors who made this report possible. Special thanks go to our key partner, the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR).

We look forward to hearing your thoughts, comments, and questions to keep the debate around vertical mobility going.

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1 The Ecosystem

Taking flight has always fueled human imagination and fascinated artists as well as tinkerers, but only recently have technological innovations—from electric propulsion systems to artificial intelligence and communications networks—opened a window into what will be possible in the near future.

Vertical mobility for everyone is no longer a fantasy or wishful thinking but is making steady progress in research labs and companies around the world. It is becoming a piece in the ever-changing puzzle called mobility. Novel ride-hailing and ride-sharing services on the ground have demonstrated that there are new ways to transport goods and people more efficiently and more economically. We need to take a more detailed look at vertical mobility and its proper role in an integrated and seamless mobility ecosystem to better understand three things: the utility for consumers, the challenges ahead for regulatory authorities, and the market opportunities for investors and enterprises.

Vertical mobility will become an integral part of overall urban mobility if it is connected with first- and last-mile modes of transport, as illustrated in figure 3. Passenger drones can play an important role here because they are fast and available on demand. They are an attractive and competitive way to cover distances of 20 kilometers or more since they require relatively few infrastructure investments and can service secondary and tertiary routes. Vertical mobility is also a fast escape from clogged routes.

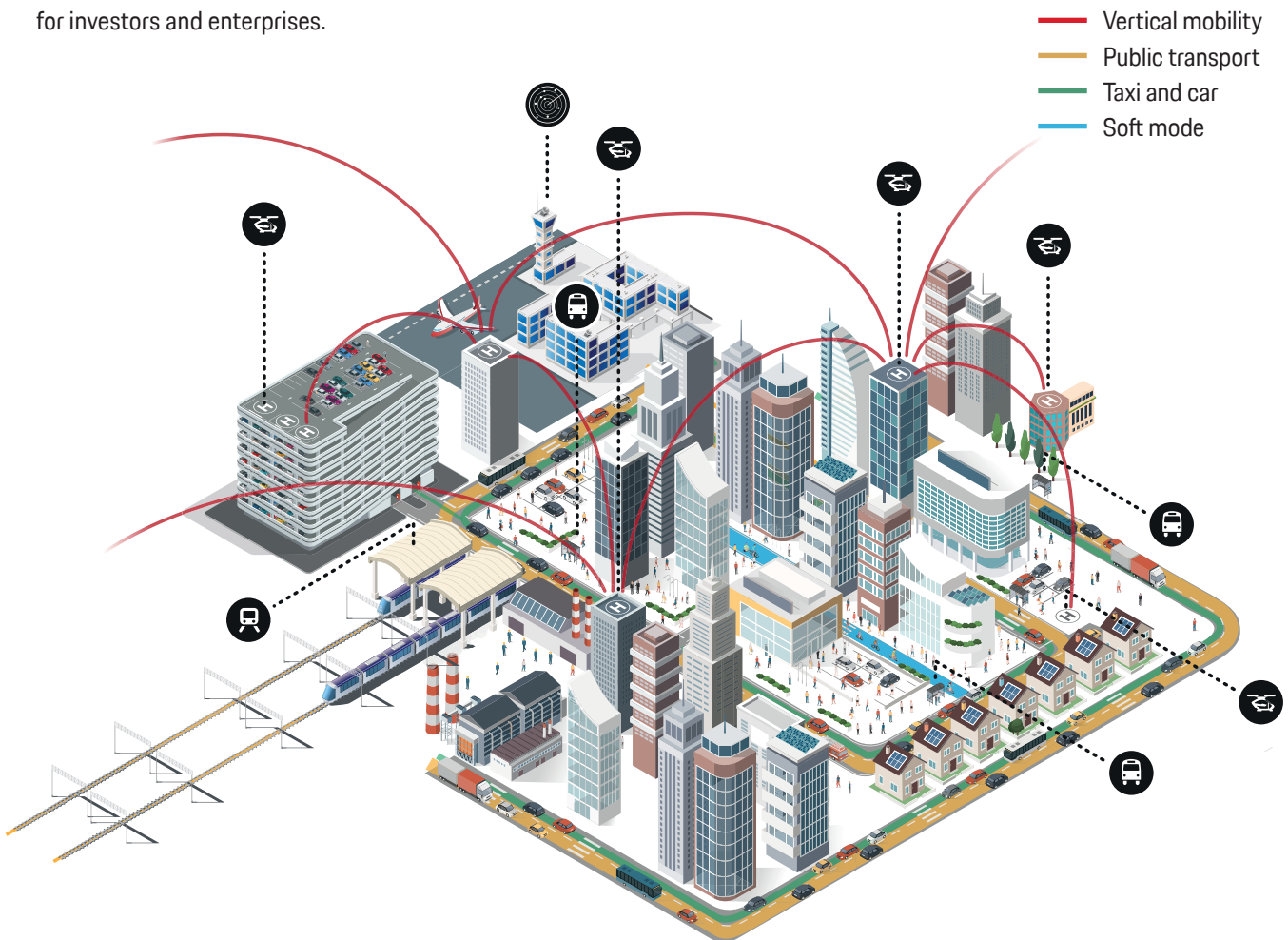


Figure 3. Pieces of an integrated puzzle: air taxis can make a significant contribution to urban transport networks.

Graphic: Porsche Consulting

We analyzed four segments of vertical mobility: inspection, goods, and passenger drones as well as drone-related services. Unmanned inspection drones help with monitoring and surveying infrastructure or covering events, while goods drones deliver time-critical wares. Passenger drones satisfy intracity and longer city-to-city transportation needs. The fourth segment across these three markets is comprised of various supporting services for drones. Air traffic management (ATM) for manned and unmanned drones alike is a key foundation for making the mobility ecosystem of the future reliable, safe, and economically viable.

We have identified 26 relevant vertical mobility services (fig. 4) and more than 70 detailed sub-services. The main purpose of inspection drones is to gather data, while goods drones transport goods and deliver parcels. As the name implies, passenger drones are designed to transport private passengers and offer mobility services to the broader public. Finally, supporting services assist and enable all three major segments, from operations and maintenance to charging, insurance, and financing.

Vertical mobility services

Inspection



- Hobby drones
- Media and entertainment
- Precision agriculture, farming, and forestry
- Inspection and monitoring
- Ad-hoc communication network
- Surveying and mapping
- Learning, training, and gathering scientific data
- Security, law enforcement, and people search

Goods



- Cultivation and fertilization
- Maintenance and air handling
- Last-mile express delivery
- Cargo transportation
- Delivery network extension (to remote areas)
- Emergency transport (medicine and organs)

Passenger



- Personal eVTOL aircraft ownership
- eVTOL aircraft rental
- On-demand eVTOL air taxi incl. sightseeing
- eVTOL air bus
- eVTOL rescue operations

Supporting services



- Development and production of eVTOLs
- Certification service
- Air traffic management services
- Drone defense
- Maintenance, repair, and overhaul (MRO)
- Vertiports-/stops operation, charging, and parking
- Insurance and financing

Figure 4. Four clusters with 26 services: the vertical mobility services at a glance.

Graphic: Porsche Consulting

While we analyzed all four service clusters in detail and while each service cluster presents its own opportunities and challenges, this report will mainly focus on the passenger segment. Nevertheless, aspects such as market data that are relevant for the overall eVTOL ecosystem will be addressed in a comprehensive fashion.

For vertical mobility to become a reality, the ecosystem needs to satisfy requirements across four areas that will otherwise pose barriers to adoption (fig. 5). First, there are the techni-

cal requirements for the aircraft system itself, including propulsion. Equally important are requirements in the realm of certification and law in order to approve, operate, and properly maintain these novel aircraft. Third, there is the crucial question of social acceptance when it comes to noise, safety, and the security of users and city residents alike. Both constituencies will determine mass suitability. Infrastructure is the final important component, as this mode of transportation requires a network of take-off and landing sites as well as resources for air traffic control, charging, and parking aircraft.

Vertical mobility ecosystem

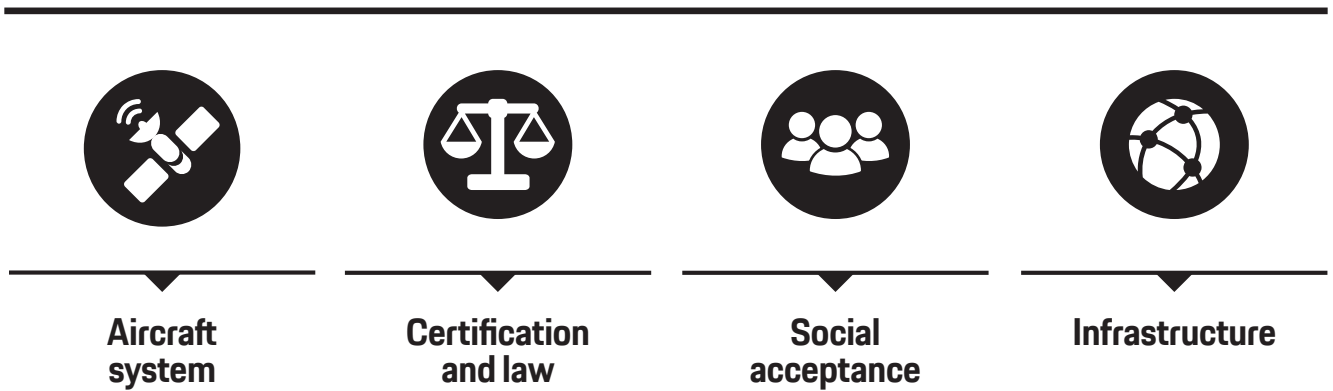


Figure 5. From drones to laws and landing pads: the four key realms of the vertical mobility ecosystem.

Graphic: Porsche Consulting

Aircraft system

The design of the aircraft system is critical, and companies in this field are experimenting with several aerodynamic concepts. We can distinguish between three major systems (fig. 6). "Multirotor" systems, such as camera drones or aircraft by the German startup Volocopter, distribute multiple motors around the periphery of the drone to provide lift. "Lift-and-cruise" concepts, such as the Aurora eVTOL, combine rotors for lift and fixed wings for forward flight. Other market entrants, such as Lilium's eVTOL concept, rely on "tilt-x" designs in which wings, rotors, and ducts can be

tilted. Developing and refining the right aerodynamic concept is a key determining factor for making vertical mobility a reality. Each system has its own pros and cons when it comes to time to market, travel speed, ideal routes, efficiency, and potential market size.

Simplified aerodynamic vertical mobility concepts

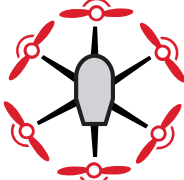
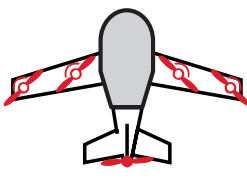
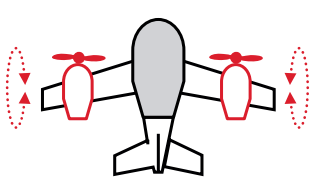
	Single phase	Dual phase	Transition phase
			
	MULTIROTOR lift	LIFT AND CRUISE combination	TILT-X tilt-wing, tilt-rotor, tilt-duct
Time to market	Fastest certification	Slower certification	Slowest certification
Travel speed (indicative)	~70–120 km/h	~150–200 km/h	~150–300 km/h
Routes	Selected	All	All
Potential	~70% of intracity 0% of city-to-city	100% of intracity 100% of city-to-city	100% of intracity 100% of city-to-city

Figure 6. Faster and further: the three basic aerodynamic concepts for drones, each with pros and cons.

Graphic: Porsche Consulting

Multirotor, as the name implies, is a rotorcraft with two or more motors, often arranged in a ring around or atop the cabin. Flight control is accomplished by varying the speed of the individual rotors. Multirotor systems have the twin advantage of being fairly simple and offering safety through

redundancy. On the downside, they are hampered by lower travel speed as well as limitations in weight and range due to significantly lower efficiency. Initial multirotor systems, however, have a low risk profile and will help define future standards in a step-by-step process.

The second type of aircraft system is comprised of various hybrid models, all with separate drive trains for the lift-and-cruise flight phases. The hybrid model allows them to take advantage of the respective properties of fixed-wing and rotor aircraft. Wings give them longer range, while rotors enable them to vertically take off and land more efficiently and maintain a higher air-speed. The basic technologies of both elements are already available, and the overall complexity of hybrid models is in the middle range, depending on a particular system's design. Next-generation hybrid drones can be considered the second phase in eVTOL aircraft development as they offer increased speed and efficiency. They provide more time savings and lower operational costs, two key drivers for commercial success in comparison to other modes of transportation.

And finally, there are tilt-x concepts with wings and rotors or ducts, all of which can be tilted. Since they have rotating components that need to reliably and safely handle the transition from the lift to the cruise phase, the complexity of tilt-x systems is significantly higher. By design, tilting wings, tilting rotors, or tilting ducts carry a higher risk of a single point of failure. As such, the

underlying technology cannot currently be considered mature enough to handle passenger transport under critical weather conditions and requires further development to satisfy safety requirements. At the same time, Tilt-x aircraft can cover long distances at high speed and therefore have clear potential for mobility services.

Regardless of the particular system, eVTOL aircraft will be an improvement. Even in this technological day and age, vertical mobility has remained the exclusive domain of the wealthy. Helicopters are not only expensive but also noisy and unsafe compared to other modes of transportation. It is also not available to the average consumer as an on-demand option. Compared to a traditional helicopter, an electric passenger drone is by orders of magnitude quieter, more reliable, safer, and less expensive (fig. 7).

Batteries are the key component of any passenger drone system, with energy density acting as both the biggest constraint and most important driver for their future development.



eVTOL compared to a helicopter



Figure 7. Quiet, reliable, safe, and inexpensive: the main advantages of eVTOL over conventional helicopters.

Graphic: Porsche Consulting

Certification and law

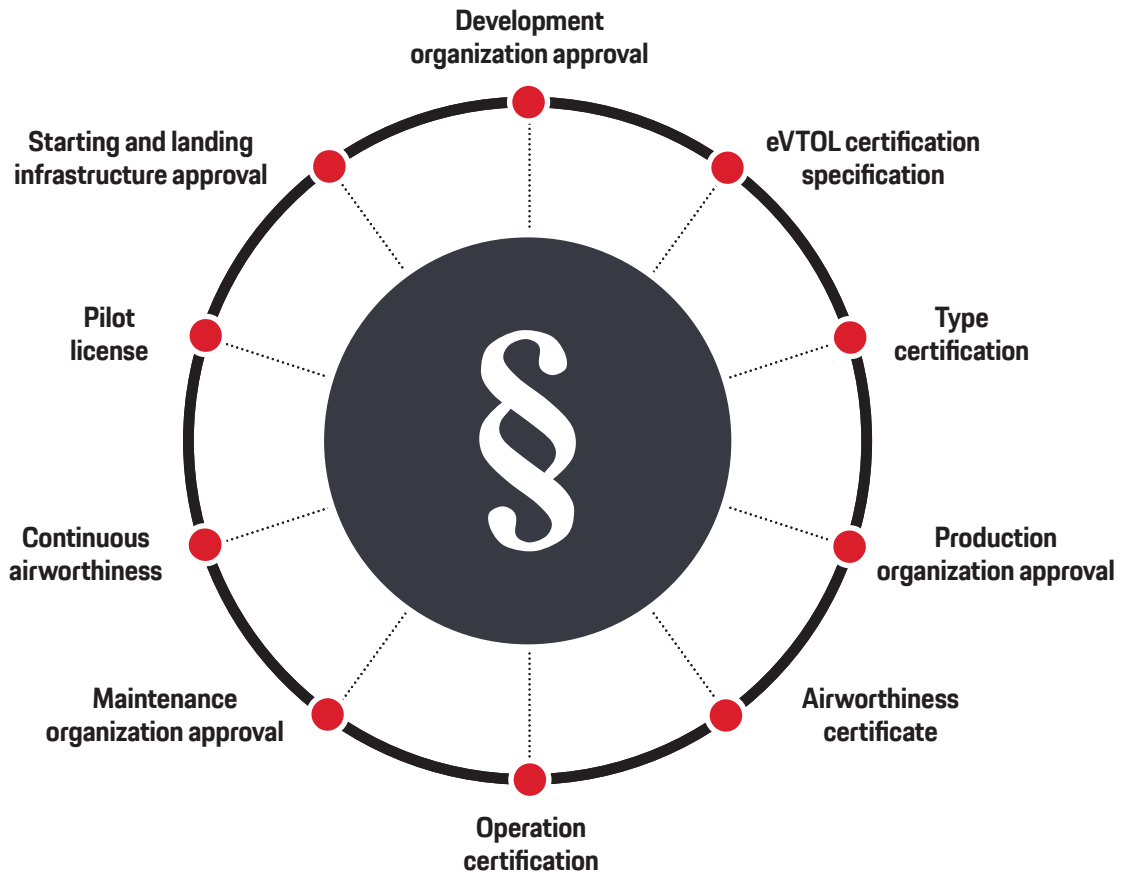


Figure 8. Safety first: overview of certification requirements for drones.

Graphic: Porsche Consulting

We expect commercial passenger transport to remain a highly regulated market that will remain under the guidance of the two globally preeminent regulatory agencies: the FAA in the US and EASA in Europe. Looking at the regulatory and legal requirements, one can differentiate between certification of the aircraft development organization, the aircraft itself, the aircraft production, the operations, the service, and the pilot license (fig. 8). The system—whether for a helicopter or another type of aircraft—determines which regulations currently apply. For instance, the European standards for small rotorcraft or light sport airplanes (e.g., CS-23, CS-27, or CS-LSA) will be used to certify drones for testing; the equivalent organizational standards are Part 21J&G, 145, M, and Part OPS (see appendix). However they will not be directly applicable for commercial eVTOL certifications.

Existent certification standards for inspection and goods drones as well as active aviation standards can serve as the basis for certifying passenger drones. We expect these different certification standards to be a starting point for developing and certifying the various aerodynamic concepts shown. Authorities are ready for talks to develop new certification

standards and provide areas in which to test them. There are also enough local opportunities around the world to test and certify new drones. It is worth keeping in mind that certification in the aviation world is usually an incremental, step-by-step process—and for good reason. Starting with existent and stable systems, incremental certification will address distributed electric propulsion (DEP) and, later, “sense-and-avoid” technologies and device autonomy.

Further legal issues revolve around airspace and traffic management. How will eVTOL aircraft deal with various weather conditions and how will they sense and avoid other aircraft? Will they use centralized or decentralized communication channels? How will the airspace of tomorrow be structured to accommodate regular aviation and drones? One of the drivers in this regard will be the safety of traditional aircraft, as the number of inspection and goods drones will rise into the millions. Today, aircraft safety is already an important topic, as witnessed by almost daily reports of drone encounters. This process will also fuel an ongoing debate over the safety risks and potential misuse of such systems for criminal or terrorist purposes.

Social acceptance

Getting the public on board to accept and use eVTOL aircraft will depend on solving several key issues around safety and security concerns, the potential for visual and noise pollution as well as proving that everyone will benefit from these systems being integrated into city mobility—not just the wealthy, as with today's private helicopters.

Experts expect the targeted noise profile of a drone to be about 65 dBA at 300 feet flight altitude, which registers at one-fourth the noise emitted by a helicopter. The actual value will, of course, depend on ambient noise, distance from a drone, its noise characteristics, and maximum noise level.

The overarching goal here is to weigh the personal benefits against mass suitability and decide how to best reconcile the increased comfort of travel and transport with the larger cultural change wrought by passenger drones. The public's perceptions and opinions about vertical mobility vary from continent to continent, from country to country, and from city to city, covering everything from fear and skepticism to outright enthusiasm.

We will see the first implementations in locations that are more open to testing new technology and have quick decision-making processes in place, such as Singapore, Dubai, and China. Their first implementations and resulting lessons will shape the perception of safety and security concerns and offer ideas for dealing with visual and noise pollution.

Infrastructure

The crucial component in the success of vertical mobility is the infrastructure to take off, land, charge, and service a drone as well as park it in wait for passengers. While there is no shortage of airspace, interfacing with existent transportation is key. Electric VTOL aircraft will only become a useful component of tomorrow's mobility if they are well and thoughtfully integrated into the overall transport network of a city. From their location and number to their size, eVTOL landing sites, or vertiports, are a determining factor for the ecosystem. A city needs to have sufficient sites for take-off and landing as well as charging, in addition to the necessary resources to operationalize air traffic control. Finally, urban eVTOL infrastructure has to strike an acceptable balance between benefits and disturbances, such as defining and zoning the proper use of rooftops.

Many cities already have heliports and therefore possess the necessary infrastructure for landing sites. In the first phase, just five heliports will suffice to create attractive routes. In the next phase, selected geographies will have up to 40 vertiports as relatively small take-off and landing sites specifically designed for passenger drones. In the final phase, megacities with a population of five to ten million or more will have up to 100 such sites to provide good service coverage.

Infrastructure growth will be driven by the initial build-out phase and the ensuing stages of expansion and elaboration, when an increasing number of vertiports service a growing base of passenger drones. Other components that need to be built are standardized and efficient, such as fast-charging stations and systems for air traffic control (ATC) communications.

2 The Benefits of Vertical Mobility

Vertical mobility has the potential to create wide-ranging social benefits by addressing all-too-familiar transportation bottlenecks.

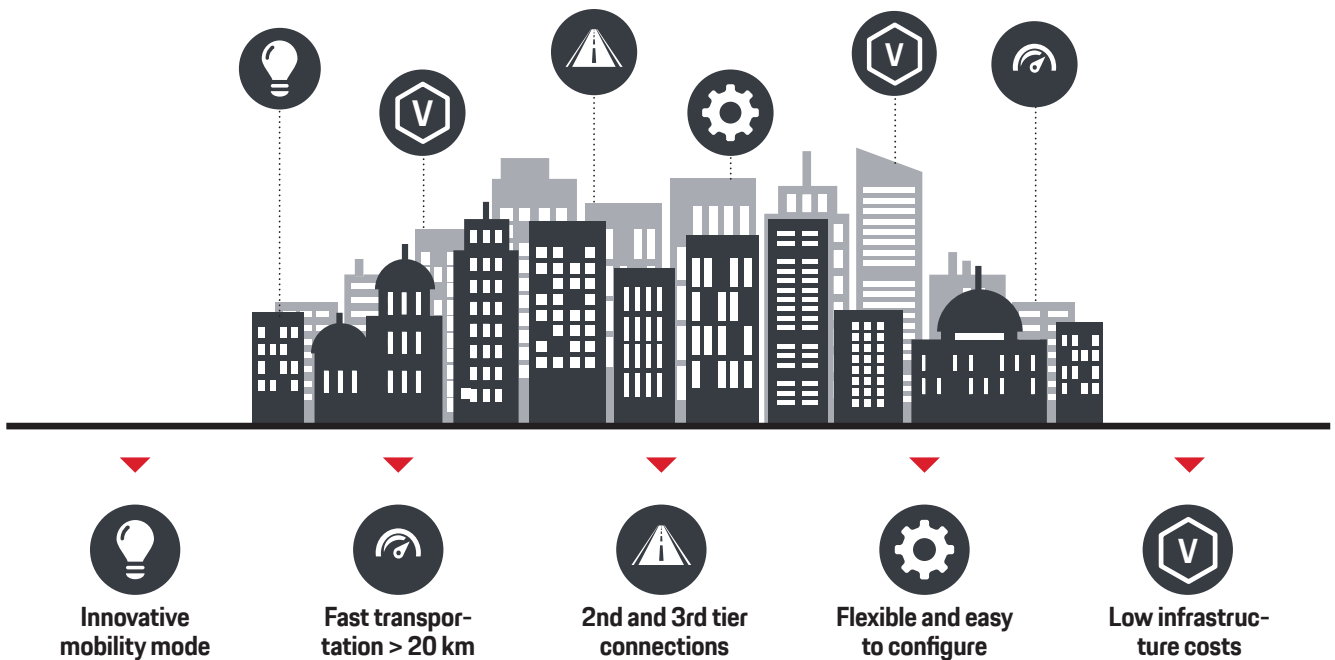


Figure 9. Winning on time, space, and cost: passenger drones will be an integral part of future urban mobility.

Graphic: Porsche Consulting

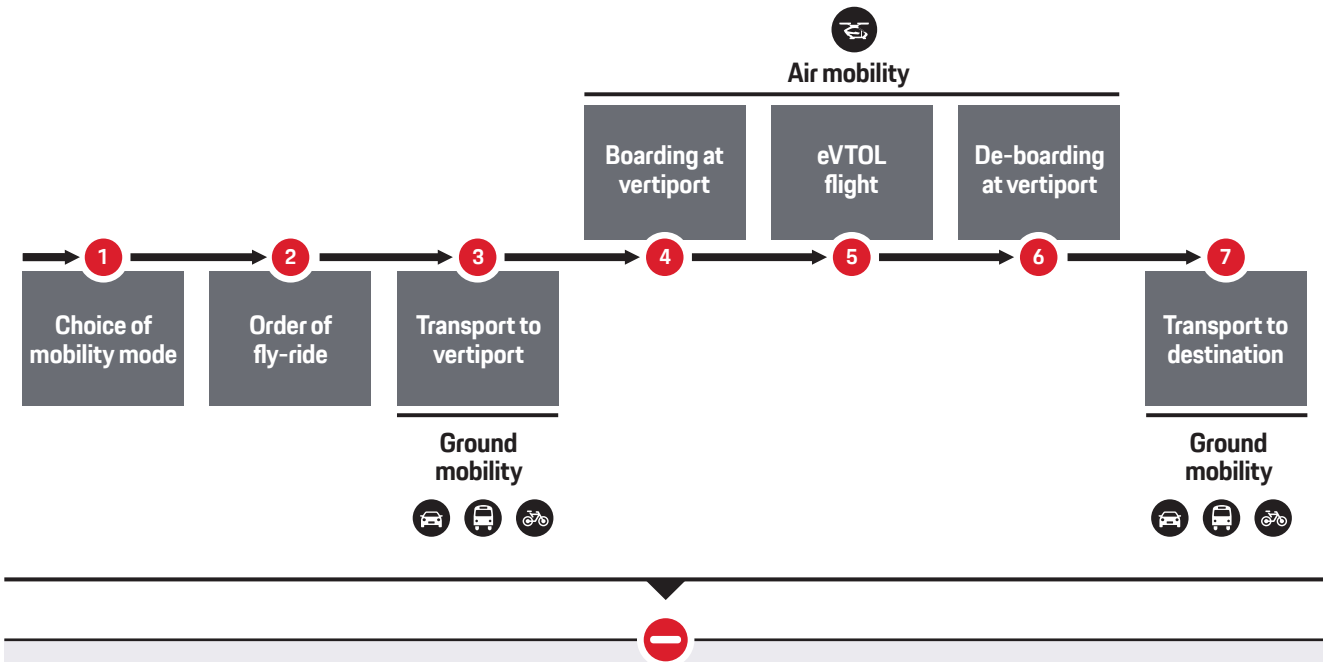
Sitting in traffic is a global phenomenon that comes with serious negative consequences in terms of time wasted, increased fuel consumption, higher emissions, and loss of property and human life. The infrastructure provided by the world's cities to channel the ever-growing traffic flows has in many cases reached its limit or is about to, often due to a lack of funding, available space, or both. It has simply become too costly and complicated to add new roads and highways, and more roadways also have a negative impact on residents' quality of life.

Increasing urban populations therefore face the prospect of spending more and more time en route. By most recent estimates, the average inhabitant of Los Angeles loses approximately 102 hours a year sitting in traffic jams, followed by Moscow and New York with 91 hours, and São Paulo with 86 hours. Munich is the German city where drivers spend the most time in stop-and-go traffic, coming in at 51 hours

annually. Overall, German drivers incurred per capita traffic-related losses of \$1,770 in 2017 alone (3). Despite this worsening congestion on the ground, cities have lost nothing of their attraction. The U.N. estimates that by 2050, 70 to 80 percent of the world's population will be urbanized, bringing with it new challenges and opportunities for more efficient and sustainable mobility solutions (4). Some of them include leaving the traffic jams behind and literally lifting off with vertical mobility.

As an integrated part of future urban mobility, passenger drones offer significant advantages (fig. 9). They are an innovative, quick transportation mode that requires low infrastructure investments because "air roads" are almost cost-free and lack traditional limiting factors such as intersections. Drone rides provide extra flexibility because they are easy to configure and adopt second- and third-tier connections in a city.

Customer journey on-demand eVTOL air taxi



Constraints

- No end-to-end mobility – transfer between other mobility modes necessary
- Infrastructure limitations (starting and landing)
- Complementary mobility service only

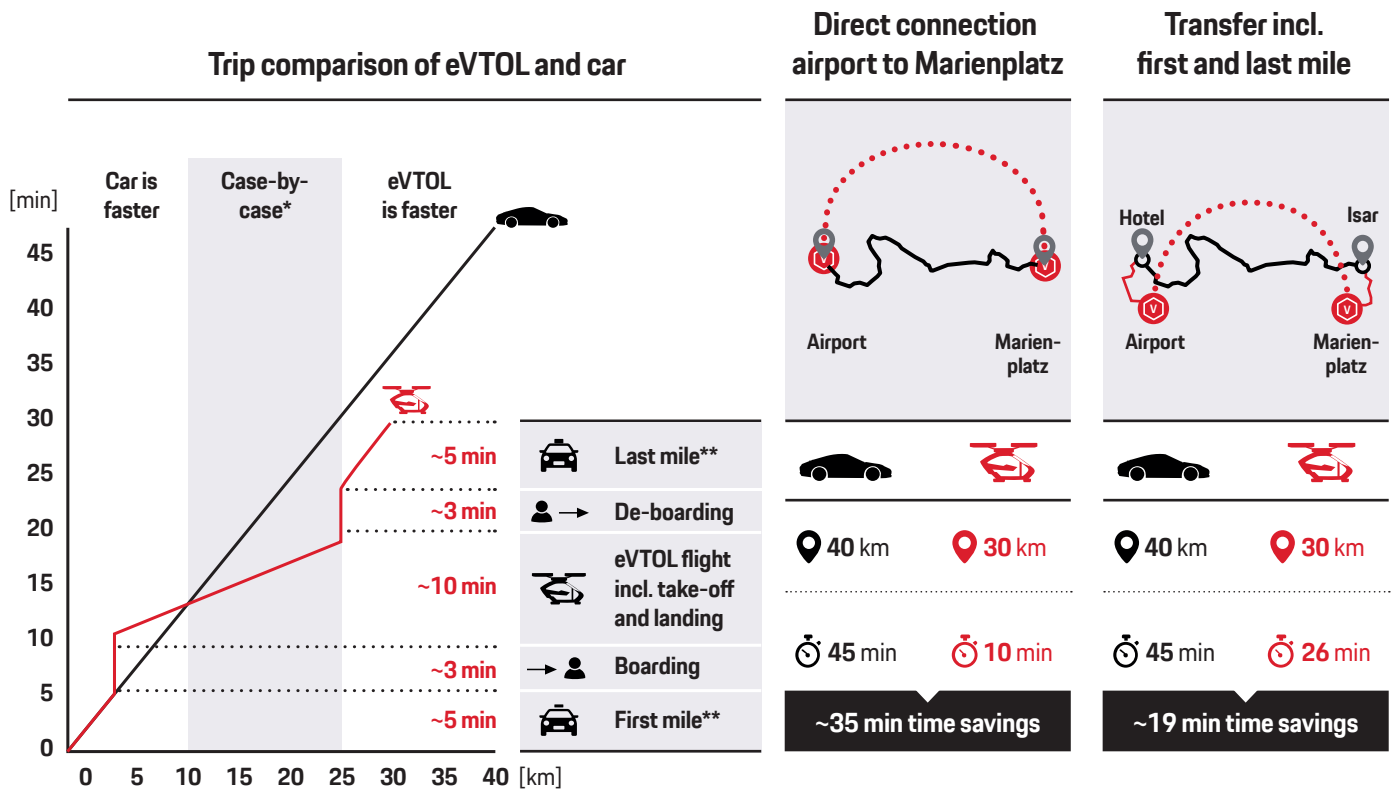
Figure 10. From click to lift-off: eVTOL mobility services offer an end-to-end journey that combines ground with air transport. Graphic: Porsche Consulting

Saving time on transportation—or avoiding traffic jams on the ground—is the basic precondition for this market to develop. At the same time, the hub-to-hub architecture requires passengers to transfer, which can be time consuming. In most cases, vertical mobility will only win against other modes of transportation when passengers can save at least 20 percent in total travel time, notwithstanding transfers.

A seamless experience will be another key to the success of passenger mobility service offerings (fig. 10). Customers already have a wide choice of transportation modes in which passenger drones must find their appropriate place. On the one end of the spectrum are fixed line modes like the subway, train, or commercial airlines that predictably go from point A to B. On the other end are individual modes, from riding a bike to driving a personal vehicle. A seamless experience of mobility-on-demand via personal flight will

take customers from quickly putting together their itinerary, ordering their fly-ride, catching ground transport to a vertiport, boarding the eVTOL flight, and, once landed, having a ride-hailing service waiting to cover the last mile. Navigating this multipart journey also allows for the more efficient use of existing bottlenecks on the ground by unburdening congested infrastructure.

Travel time comparison road vs. air – direct connection and transfer



* Depending on congestion and minimum time savings to accept transfer connection with ride-and-fly

** Depending on location of vertiport

Graphic: Porsche Consulting

Figure 11. Getting in and getting on: drones beat cars when it comes to travel time, as with this example in Munich.

For distances of 20 kilometers and more, a passenger drone offers an attractive alternative to a conventional taxi, as shown in figure 11. The more congested a roadway on the ground, the more compelling a ride in a passenger drone becomes.

become a crucial part of an integrated solution to mitigate our growing transportation woes. The limited number of take-off and landing sites constrains eVTOL aircraft, for instance, so there is a risk of traffic jams in the sky.

In short, there will always be main arteries for mass transit and the fast conveyance of people and goods, complemented by secondary arteries and even smaller routes, similar to the finely tiered circulatory systems of a biological organism. Vertical mobility is an innovative option to provide fast service for second- and third-tier connections with lower transportation capacity. It is important to note, however, that while vertical mobility will not be a panacea to solve congestion, it can

3 The Timeline: A Journey to Zero-Emission Flying Taxis

Time window for market launch

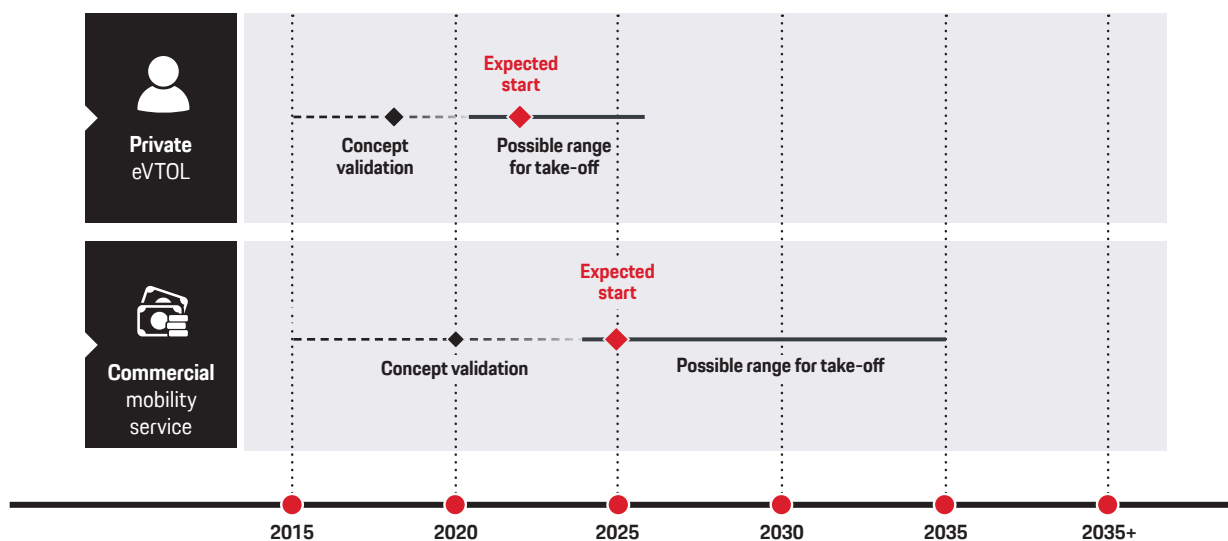


Figure 12. Designing for the coming volume market: development timeline for private and commercial markets until 2035. Graphic: Porsche Consulting

The introduction of electric passenger drones will go through several phases until they become flying taxis—a full-fledged, integrated, commercial mobility offering. As pictured in figure 12, initial designs for both private and commercial passenger drones have yielded various proofs of concept. They will take flight in a niche market, starting in 2022. A volume market will begin to emerge during the decade from 2025 to 2035.

We have identified three major drivers that lead down different paths to the passenger drone's success. The variance in these three drivers results in diverse growth scenarios. The first factor is the starting time for initial tests and services and a particular technology's pace of development. The second is the speed in modifying multiple generations of eVTOL aircraft that achieve a higher overall equipment efficiency. The third and final factor impacting each development corridor is the adoption rate, or how many cities build vertiports and other basic components of the necessary infrastructure.

Privately owned passenger eVTOL for individual use and ownership could become a reality within the next five years. We expect passenger drones to be a niche market initially, with private eVTOL becoming available between 2022 and 2025. This will be due to lower certification barriers compared with commercial passenger service and to social acceptance, which will in turn influence the legal framework.

The private eVTOL aircraft segment will be a luxury or premium offering that substitutes for and complements heli-

copters. Since they make up a very small, even shrinking, transportation niche, these drones will not be a volume market. Commercial air mobility services like air taxis will not be launched before 2025 with eVTOL.

Big investments in technology and infrastructure will accelerate the creation of the overall ecosystem, generating growth in cities all over the world.

An earlier starting point requires positive breakthrough developments worldwide, which would lead to faster and more frequent iterations. This would compress the process of certification and development of passenger drones into a period of just five years. More frequent update cycles would result in more mature drone generations between 2025 and 2035. A later starting point, on the other hand, would lead to a sequential and slower development flow, during which certification and development would take eight years and produce only one generation of drones between 2025 and 2035.

The journey to lift-off can be divided into three phases beginning today and lasting until 2020, then from 2020 to 2025, and finally from 2025 to 2035. Each interval serves as an important milestone for technological development, certification, and commercial build-out. While the current phase is mostly focused on testing, the five years from 2020 onward will revolve around being first to market, and the decade after 2025 will be characterized by defining and refining the winning concept.

From today to 2020: plenty of testing

The first wave of personal air taxi designs was released in 2015, with companies such as Ehang, Volocopter, Airbus Vahana, and SureFly conducting the first successful flights of their prototype models in 2017 and 2018.

Commercial mobility services are already being tested and will be launched a decade from now as electric air taxi and aircraft rental services. Innovative cities such as Singapore, Dubai, São Paulo, or Dallas/Fort Worth will be the main early adopters of eVTOL aircraft, conducting limited tests in preparation for a global roll-out. We can expect to see tests of commercial air taxi service concepts involving traditional helicopters. Since current energy density is limited to 250 W h/kg a passenger drone can only be airborne for a maximum of 30 minutes, not accounting for a payload and additional safety time, as a buffer (alternate time) for emergency landing.

Whether commercial mobility services can be realized as described hinges on successful tests in the first few cities. Companies in this field will initially focus on becoming the first mover who can bring a working concept to market. Later, attention will shift to the speed at which new technologies can be developed and implemented.

From 2020 to 2025: being first to market

The five years from 2020 to 2025 will be characterized by a wide range of tests and experiments to evaluate the various technical and business aspects. New concepts such as Lilium, Volocopter, or Uber Elevate will have to substantiate their claims and ambitions for private mobility in competition with existing mobility concepts. The lowered safety standard for novel and unproven eVTOL aircraft carries the risk that players in the field act in a too risk-prone or careless manner. Any resulting setback would endanger social acceptance.

Major improvements in battery technology and noise emissions will occur during this phase. Until 2025 we expect that batteries using today's conventional lithium-ion (Li-NMC) will be able to achieve a density of up to 300 W h/kg. Assuming an available charging rate of 2C to 4C (see glossary) batteries can be charged to 80 percent capacity in 15 to 30 minutes, thereby only achieving a short lifespan of 500 to 700 cycles.

Noise is another barrier to adoption. Helicopters are too loud, and there is a clear need to conduct additional research into the noise emissions of eVTOL aircraft, since their overall noise profile also depends on the number of drones operating in a city and their take-off and landing frequency. In many areas today, noise pollution is the limiting factor for helicopters, meaning that often only half of all planned sightseeing flights receive the permission to take off.

Certification standards will be augmented and newly defined to become the basis for certifying DEP (distributed electric propulsion) technologies. Those certification standards will be developed step by step. Technical factors and regulatory requirements combined will help define the design envelope for drone aircraft systems. We believe that the high safety standards of commercial aviation are the non-negotiable basis for certifying drones, even though some new and disruptive market entrants argue that safety standards for existing hobby drones suffice. In this case, the generally accepted risk models for hobby drones (10^{-5}) imply that 23,000 passenger drones clocking close to 50 million flight hours per year would translate into one critical (not necessarily fatal) incident every second day, which is clearly not acceptable.

A lot will hinge on whether people perceive drones as bringing benefits to all parts of society. Deploying them for search and rescue operations and government security can have a positive impact on demonstrating the mass suitability of eVTOL aircraft. Over time, these systems should prove that their benefits outweigh the costs, ushering in broader passenger mobility services.

The public should also rightfully expect laws to define appropriate clearance above private property to prevent privacy violations. Additionally, there is a clear need to develop suitable safeguards for network security that allow remote pilots to override the on-board pilot in an emergency and prevent remote misuse, such as a terrorist taking over a eVTOL aircraft.

The sensitive topic of visual and noise pollution must also be addressed. This can be achieved by creating airspace constraints for particularly susceptible areas or by consolidating traffic into existing commuter corridors. More measurements and additional research are necessary to determine what noise levels are acceptable with regard to a location, for example, in the vicinity of a vertiport.

In the first phase of the roll-out, existing infrastructure such as airports and helipads will be used to support private mobility for intracity and city-to-city trips. Passenger eVTOL services will initially use defined air corridors to allow experts to devise and augment the existing air traffic management system (ATM). In the future, we expect unmanned aircraft system traffic management (UTM) including automated flight towers.

From 2025 to 2035: eyes on the winning concept

Once first movers have begun to introduce their concepts to the market, the focus will shift more toward technology development and increased speed to roll out innovations faster. It will be a dynamic ecosystem marked by an expanding group of players, a growing number of varying concepts, and updates to already existent systems. In short, competition around vertical mobility will heat up in the decade from 2025 to 2035.

One of the key areas in which we will see improvements is battery technology to accommodate longer distances and higher payloads. The goal until 2035 is to achieve an energy density of 400 to 500 W h/kg or more, roughly double from today. From 2025 to 2035, more advanced battery technologies such as lithium-silicon, lithium-sulfur, or all-solid-state can be expected to increase energy density to between 350 and 400 W h/kg, or even more. New technologies will extend a battery's lifespan to between 700 and 1,000 cycles and increase the charging rate, meaning it will take only 15 minutes to reach 80 percent capacity.

Car batteries would only last a few months if they had to endure the charging cycles of a drone. Passenger drones also need significant reserves for emergency situations, which today are budgeted at an additional 45 minutes of flight. Even if this safety buffer were lowered to just 15 minutes, due to a dense network of alternate landing spots, it would still require half of today's battery capacity.

The regulatory and legal framework for eVTOL aircraft will be further fleshed out during this decade. New certifications for passenger drones could be based on yet-to-be developed standards for unmanned aerial systems (UAS) on which the international standards body JARUS is currently working. At the same time, a range of certification options (for very small aircraft or ASTM, CS-LURS, CS-LUAS, CS-23, CS-25, CS-27, CS-29) exist to determine airworthiness and certify specific aircraft.

As previously mentioned, the organization and service of passenger drones also need to be certified, and we can expect that existing regulations for pilot licensing will be amended and adjusted to cover passenger drones. In addition, the increasing number of cities developing their vertical mobility infrastructure will trigger the wider adoption of vertiports as standard hubs. Furthermore, we expect assisted or autonomous systems to be certified during this decade. Vertical mobility has to operate within its own set of traffic conditions and challenges. Instead of navigating many other drivers and intersections, passenger drones will have to operate at great heights above a city and travel at much higher speeds.

As eVTOL aircraft become more widespread, a new vertiport infrastructure is required for intracity mobility services. Development of such vertiports is critical for the commercial success of passenger drones and will be shaped by social acceptance and authorities' actions. This phase calls for more urban integration to accommodate those take-off and landing sites as well as a new charging infrastructure that offers both standardized hardware and software for high-efficiency charging.

Finally, ATM needs to be augmented to encompass both ATM and UTM, to in turn enable higher traffic density for passenger drones. It is likely that this will evolve from the best practices developed in operating inspection and goods drones.

4 Sizing Up the Market until 2035

Overview: inspection, goods, passenger

The combined market for inspection, goods, and passenger drones and supporting services is projected to be roughly \$74 billion in 2035. Inspection drones will be a \$34 billion market, followed by passenger drones with \$32 billion (\$21 billion for intracity and \$11 billion for city-to-city service), goods drones with \$4 billion, and finally supporting services at \$4 billion (fig. 13).

Vertical mobility market size 2035

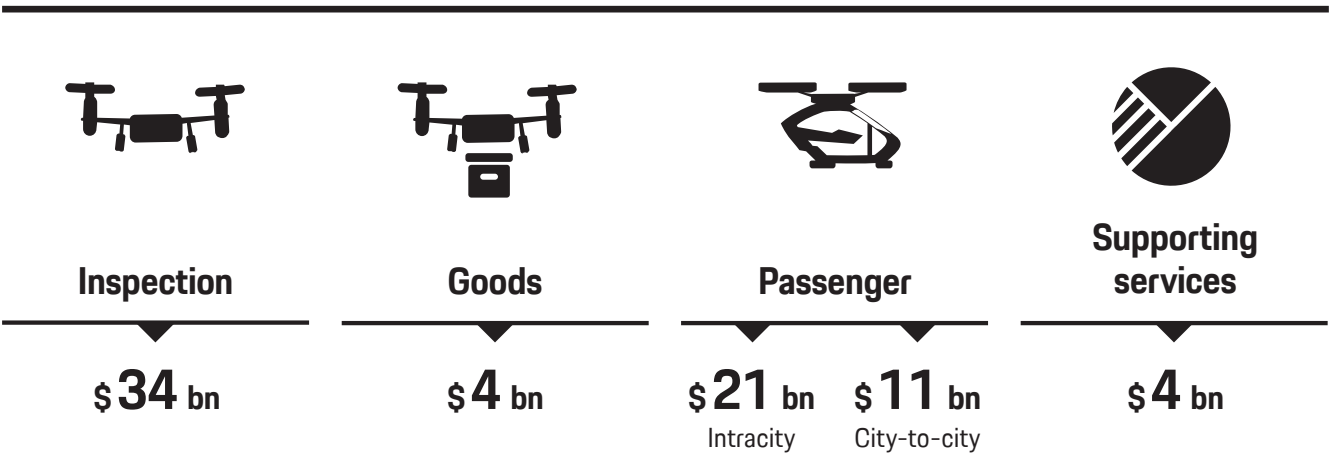


Figure 13. Billions in play: market size for inspection, passenger, and goods drones plus supporting services.

Graphic: Porsche Consulting

Flying taxis in urban areas: passenger market in 2035

Starting from a small base in 2025, the market for urban passenger drones is estimated to grow quickly at about 35 percent CAGR (Compound Annual Growth Rate) to reach \$21 billion by 2035 for intracity mobility, leaving aside city-to-city connections (\$11 billion) for the moment.²

Looking at the evolution of mobility over time, the year 2025 will see a \$1 billion market for passenger eVTOL aircraft and an installed base of 500 units. By 2030 those numbers will rise to \$4 billion and 2,000 units, until they reach \$21 billion and an installed base of 15,000 passenger drones in 2035 (fig. 14).

² Based on market model by Porsche Consulting.

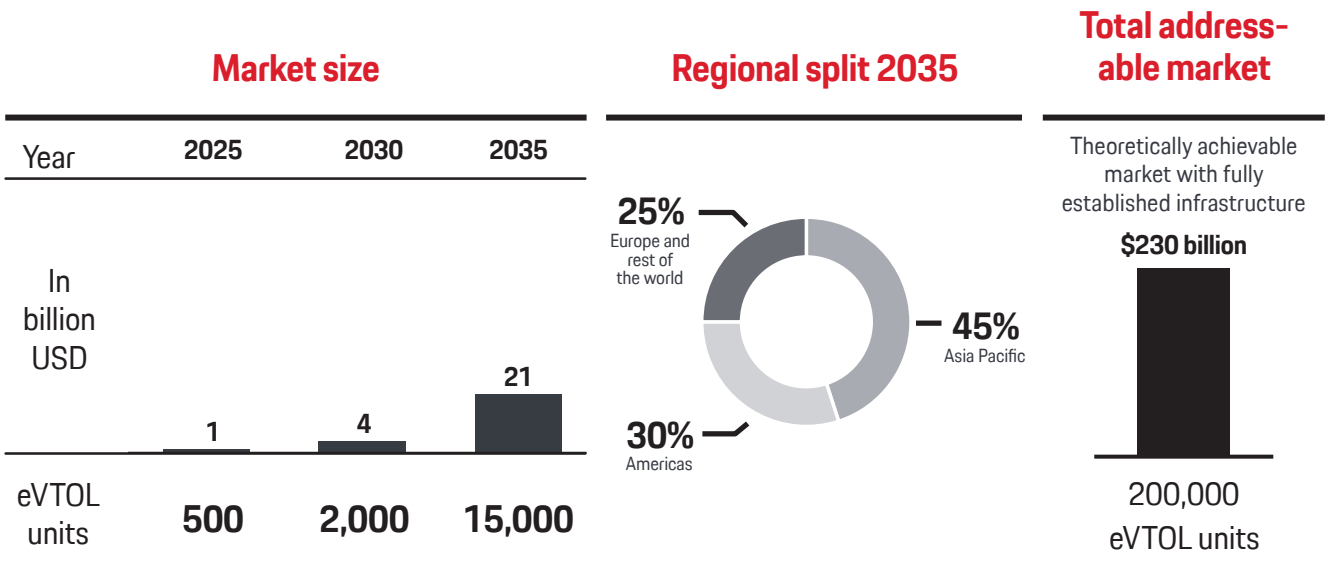


Figure 14. Ramping up: how and where in the world the passenger drone market will grow until 2035.

Graphic: Porsche Consulting

To put this market into a global context, by 2035 the installed base is projected to reach 1.7 billion cars (5) and 42,000 aircraft with a passenger capacity of more than 100 seats or more than 10 tons of cargo (6).

This estimate is based on up to 100 vertiports per city, assuming that mobility services are introduced and the necessary infrastructure is built out in early adopter cities, followed by deployments in additional cities around the world. Market saturation is not expected by 2035, although this depends on regulatory framework and social acceptance in urban areas.

In theory, the total addressable market for eVTOL aircraft is much larger, comprising up to \$230 billion and 200,000 units, depending on the price of the service, the available infrastructure, and social acceptance. Yet it is unlikely that this volume could be attained. In order to achieve 200,000

units operating at a price point similar to today's taxis, passenger drones would have to be deployed in all types of cities around the world—not just in a few dozen large and megacities, but in medium and small population centers as well. These cities would have to offer a fully built-out network of vertiports. In megacities and large cities the total addressable market will not exceed 75,000 active units, and without major infrastructure build-out the number will be limited to 40,000 active units.

The Asia-Pacific region is expected to capture around 45 percent of this market by 2035, translating to \$9.5 billion and an installed base of 6,750 units, followed by the Americas with approximately 30 percent of the market, equal to \$6.3 billion and an installed base of 4,500 units. Europe and the rest of the world will garner the remaining 25 percent, or \$5.3 billion and 3,750 units.

Value chain for intracity mobility: hardware, services, and others

The value chain for the passenger drone market in 2035 can be broken down into three main categories (fig. 15). Hardware will be a \$5 billion market or only about 25 percent of the total, including product, certification, and charging infrastructure. Services will comprise roughly 50 percent of the value chain. Looking at the details of various services, we

expect the majority of the market to be on-demand transportation and the rest to be split into eVTOL aircraft rental, private ownership, and other mobility services. Over time, we foresee a shift toward on-demand transportation. The remaining quarter of the market, or \$5 billion, will be made up of insurance, maintenance, certification, and other services.

eVTOL market size distribution 2035 in billion USD – intracity mobility scenario

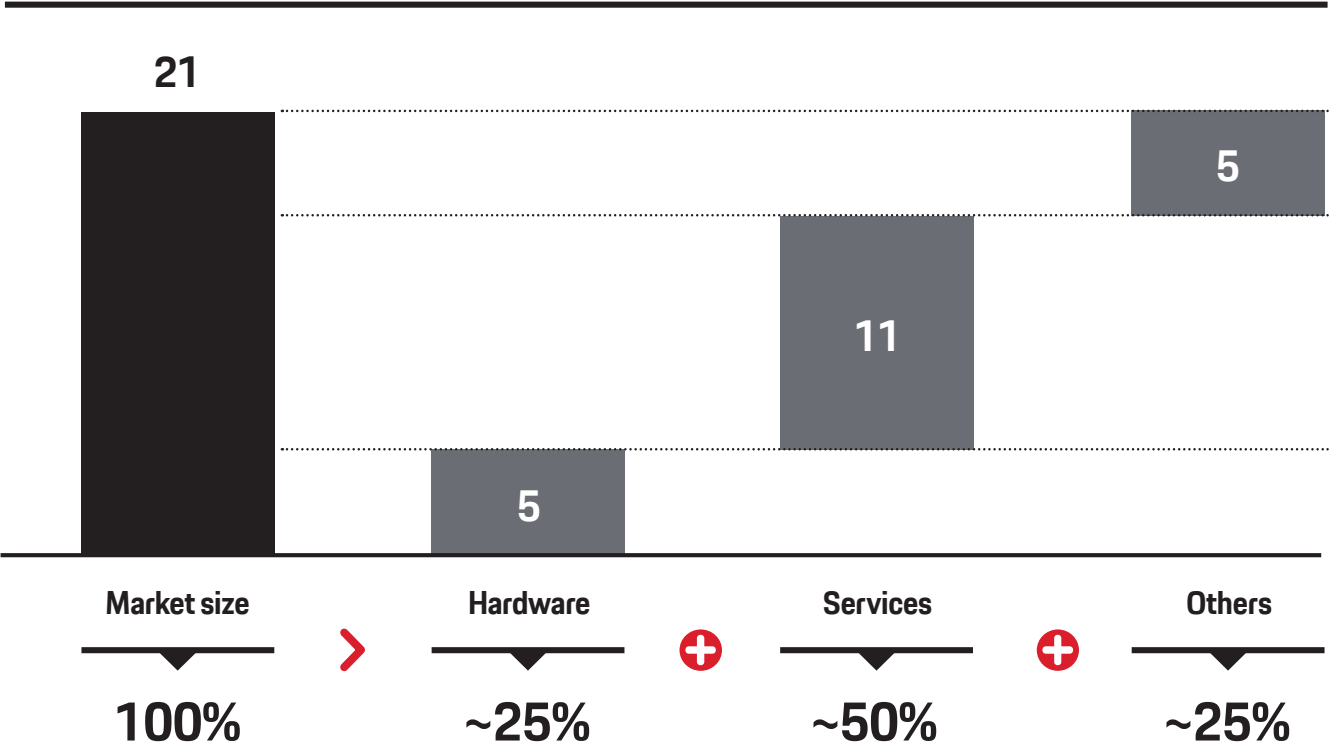


Figure 15. Services will rule: breaking down the overall passenger drone market by major categories.

Graphic: Porsche Consulting

Example for intracity mobility

Attractive cities for vertical mobility

To analyze what eVTOL aircraft and services can add to a city's mobility mix, it is useful to take a closer look at cities of different size and population density. Cities around the world can be grouped into 50 to 60 megacities with a population of five million or more, followed by around 100 large cities with three million or more people, approximately 400 medium cities with more than one million people, and finally a cluster of 3,500 smaller cities. For the purposes of this study, we have classified cities according to their density, settlement, and income structure, ranging from urban to suburban and rural, and segmented into income levels. We then performed a detailed analysis on each of the five resulting city clusters, selecting at least one sample city for each category. Future scenarios for each sample city incorporate criteria such as their topography, mobility modes, mobility needs, and traffic flows, as well as the distribution of live-and-work patterns across their geographic area.

Example São Paulo

São Paulo in Brazil is a megacity with an estimated population of roughly 21 million within the metropolitan region. At full build-out, São Paulo can accommodate roughly 1,050 passenger drones because of their high potential to replace several modes of transport, chief among them private cars, public transit, and taxis for activities such as commuting, business trips, shopping, and leisure. Another 130 eVTOL aircraft stand to replace a third of today's more than 400 helicopters operating in the city (fig. 16).

No matter what city we examine, every one of them has different modes of transportation at various levels of availability and suffers from its own specific bottlenecks. Dallas, for instance, has little to no public transport, while London lies at the other end of the spectrum. In the final analysis, each city has its own mobility characteristics, resulting in individual strengths and pain points that can be addressed when vertical mobility is introduced.

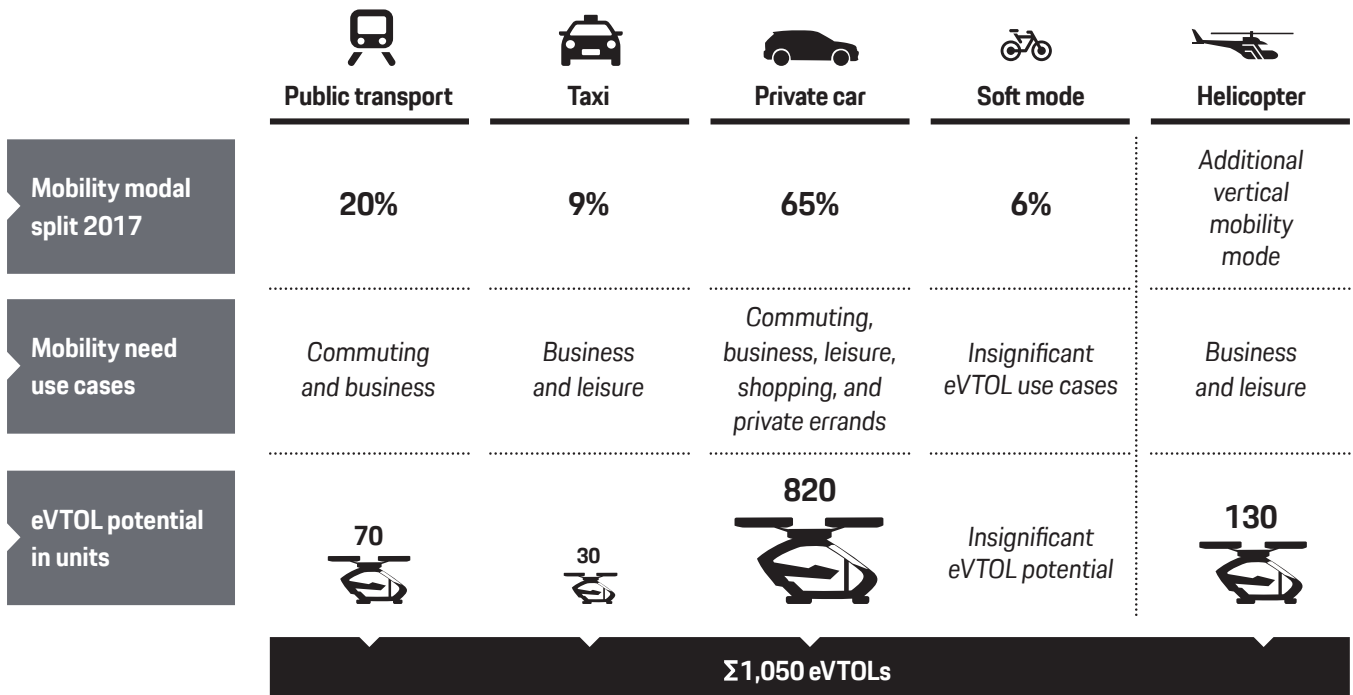


Figure 16. Replacing cars and public transport: the potential of passenger drones for a megacity like São Paulo.

Graphic: Porsche Consulting

Vertiport infrastructure build-up in example city São Paulo

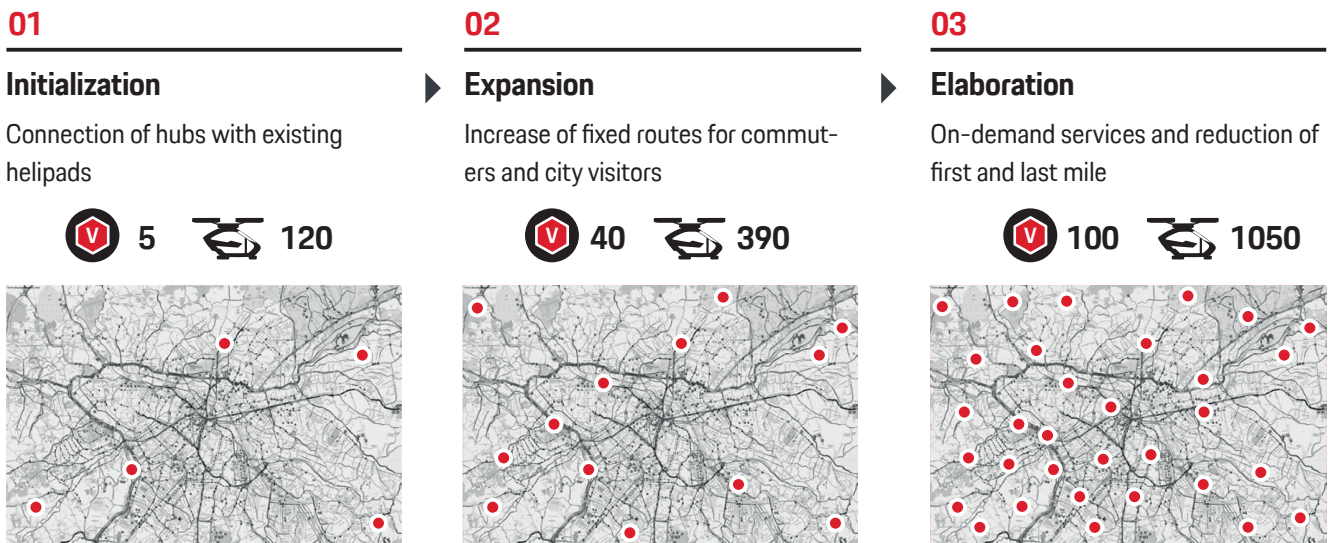


Figure 17. Expansion in three steps: intracity development of vertiports in relation to the number of passenger drones. Graphic: Porsche Consulting

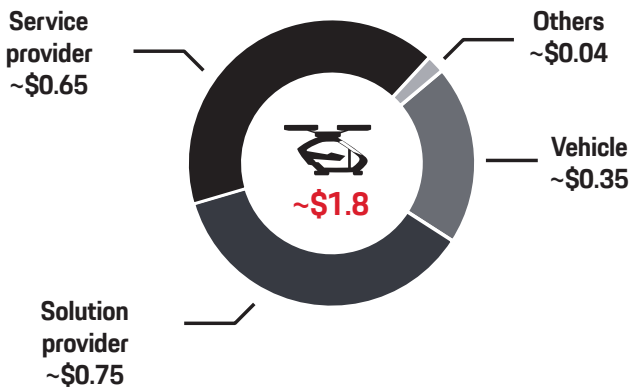
In the future, the way we transport people and goods will change, and this transition is already under way. Individual cars with a driver or owner behind the wheel have begun to make way for car-sharing options and the first autonomous vehicles. Taxis are being supplemented and replaced by ride-hailing and ride-sharing services such as Uber and Lyft or Uber Pool and MOIA. Innovation is even beginning to change soft modes of transportation, where walking and biking are complemented by e-bikes and urban bike-sharing programs. Likewise, helicopters, currently the only option for vertical mobility, will share the skies with passenger drones. To efficiently use various mobility choices, a city needs an intermodal system that can tie all modes together.

We foresee the starting and landing infrastructure for drones in the city developing in three phases, largely due to the sizable infrastructure costs involved (fig. 17). Vertical mobility services will initially start at existing transport hubs, like airports and railway stations, partially replacing helicopters and utilizing existing heliports that provide fast connections between heavily congested roads. We envision around five such vertiports in major hubs, such as airports and hotel rooftops, accommodating an active, installed base of around 120 eVTOL aircraft.

During the expansion phase, a growing number of fixed routes along major arterials will serve commuters and visitors. Depending on the particular city, the number of vertiports in frequently visited hubs can scale up to 40, with an installed base of around 160 to 390 passenger drones. The full-service phase or elaboration of a city network will draw in more and more customers because of the attractiveness of on-demand passenger drones. An expansion to up to 100 vertiports and 400 to 1,050 passenger drones is likely because it provides sufficient coverage for the city and also guarantees that the vertiports are widely accessible on foot and by bike, the standard soft-mode transportation options for the first and last mile in many cities.

We expect that intracity passenger drones will operate mainly during daylight hours (on average 12.5 hours per day) at an estimated cost of \$1.80 per kilometer (fig. 18). Of that total, 20 percent will be product-associated costs, including depreciation, battery, and eVTOL certification, and 42 percent will fall on the solution-provider side for landing fees, charging, and the like. Service provider costs for the pilot, operations, air traffic management, and maintenance will constitute 36 percent of total costs, with other costs like insurance claiming the remaining two percent. This cost scenario is based on initially operating drones with pilots. Once autonomous systems come online, passenger drone flights will become less expensive.

Mobility service costs per eVTOL km



Product hardware costs*

\$0.25 million – \$1 million

Infrastructure costs (exemplary)

Vertiport > \$4 million

Charging infrastructure > \$0.1 million

* Costs depending on concept, seats, volume, and the like

Figure 18. Where the money goes: passenger drone costs per km broken down by service, hardware, and infrastructure.

Graphic: Porsche Consulting

Vertical mobility comes with other costs, among them about \$4 million to build one small vertiport and around \$100,000 to install one high-speed charging column, depending on the existing infrastructure, especially the electric grid. Each drone costs between \$250,000 and \$1 million or even more subject to production volume and air performance. We expect drones to have a relatively brief lifespan for two reasons: First, they undergo rapid technological progress and short innovation cycles. Second, series production will become increasingly efficient compared to maintaining an aging fleet over time. While planes in the commercial aviation sector undergo regular rounds of repair and overhaul to last an average of 30 years, a passenger drone will only exist five to six years while their volume continually increases over their product life cycle.

As with any projection, actual numbers are sensitive to significant assumptions. There are four major levers that will determine the eVTOL market's upside and downside potentials, albeit with varying impacts (fig. 19). A higher or lower flight price per minute, fewer vertiports in a city, slower eVTOL cruising speeds, and additional transfer time while boarding due to more stringent security checks can all have a large impact on the market. A considerably higher congestion index—or more traffic jams in cities—will only have a minor impact, however. In general, we assume a price range for on-demand air taxis of 8 to 18 dollars per minute, which is comparable to a premium taxi fare, considering the greater speed, shorter distance, and potentially higher load factor of more than one passenger.

Sensitivities for size of intracity market

Sensitivities	Congestion index	Number of vertiports	Cruising speed eVTOL	Transfer time
Baseline	18%–39%	100–200	200 km/h	5
Change	38%–59%	15–40	70 km/h	15
Market impact	+2%	-40%	-30%	-20%

Figure 19. Price matters, traffic jams not so much: sensitivity analysis of the eVTOL mobility market by major factors.

Graphic: Porsche Consulting

Scenario for intracity market: conservative and progressive

As to how vertical mobility may play out, there are more scenarios on the horizon than the aforementioned one. It is therefore useful to complement this basis scenario with both a conservative and a progressive outlook (fig. 20).

Under conservative assumptions, the market will start out at \$0 and no relevant installed base in 2025 and slowly grow to \$1 billion and 1,000 units in 2030 within four major cities, reaching only \$4 billion and 3,000 eVTOL aircraft in 2035

within 16 cities. A more progressive scenario foresees a \$2 billion market with 1,000 aircraft operating in 16 cities by 2025, growing to \$18 billion and 12,000 units in 2030 in 25 cities, and eventually reaching \$58 billion and 43,000 units in 64 cities by 2035—the most aggressive scenario we could imagine. This aggressive outlook is predicated on the assumption of semiautonomous and autonomous drones. Otherwise, a shortage of tens of thousands of human pilots would become the bottleneck to vertical mobility.

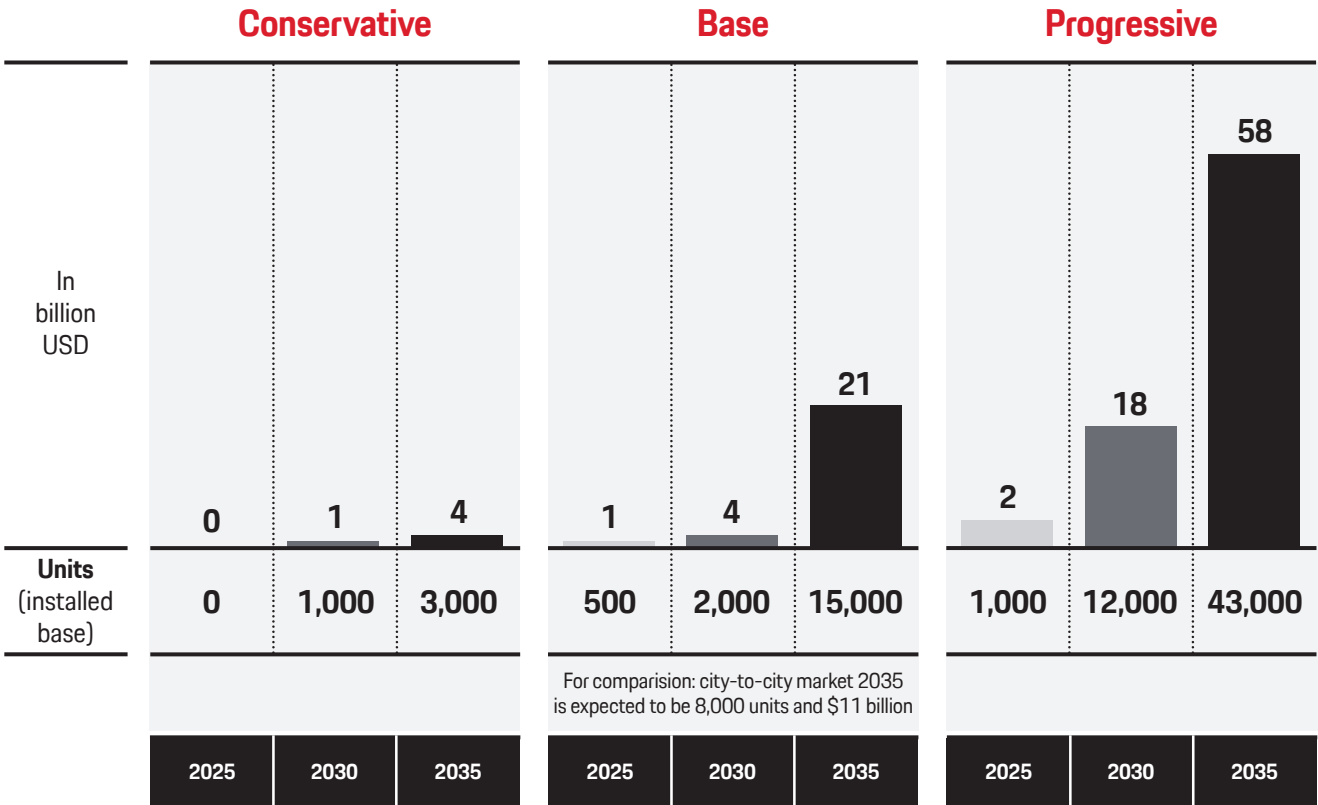


Figure 20. Modest to max: conservative and progressive scenarios of how the passenger drone market will evolve.

Graphic: Porsche Consulting

**Additional market:
city-to-city and additional trips**

Beyond the intracity passenger drone market, there are two more markets worth paying attention to. City-to-city transportation could be worth an additional \$11 billion in 2035 on top of the \$21 billion for intracity rides (fig. 21). Further segments created by city-to-city flights and increased demand for new mobility services are hard to estimate at

this point, but the evolution of passenger drones will certainly generate additional revenue and business opportunities. We envision these new transportation offerings as a wide range of spontaneous, on-demand trips to quickly get from A to B, escape to the countryside, or visit a neighboring city to shop or attend an event.

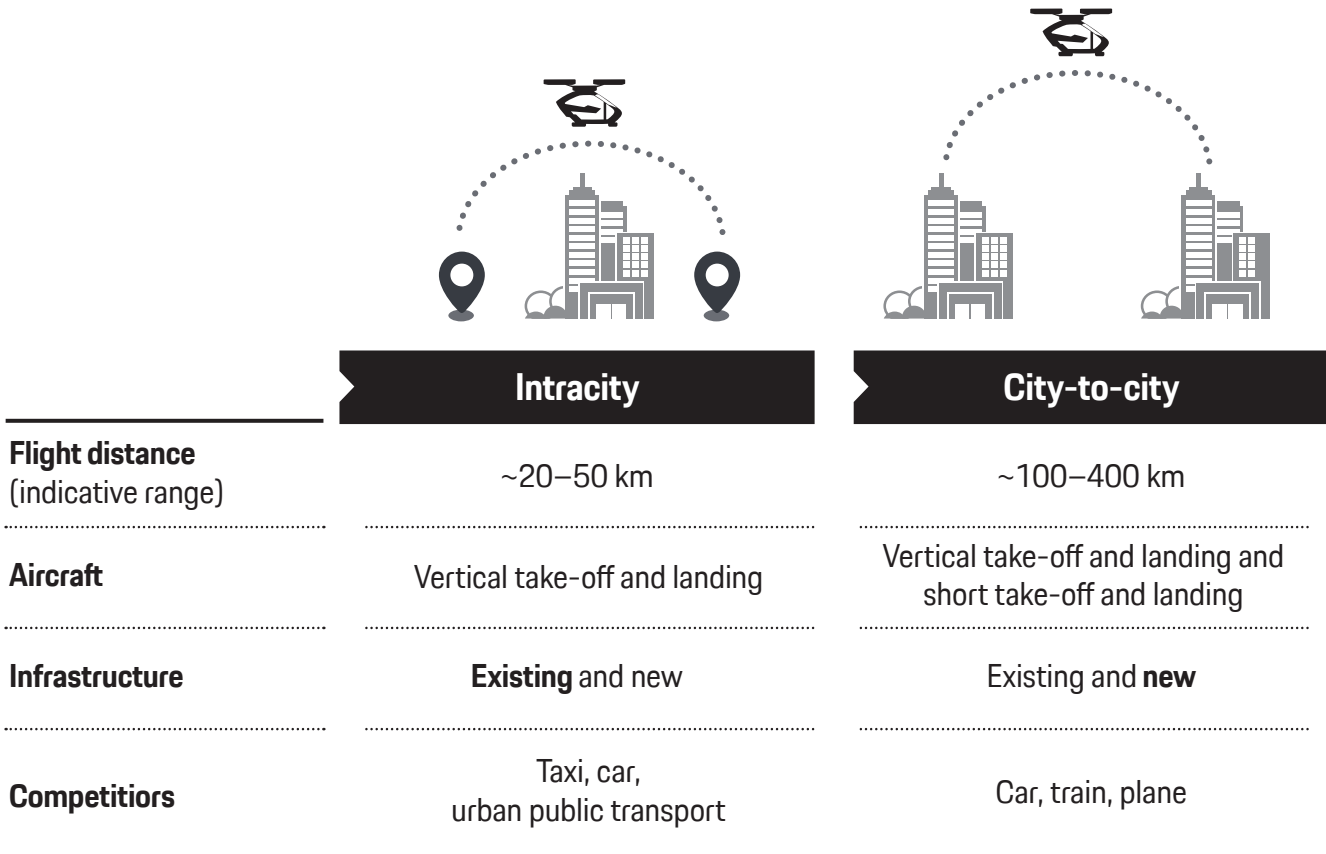


Figure 21. Going further: city-to-city trips represent an additional market segment worth billions.

Graphic: Porsche Consulting

Inspection and goods market: a very brief overview

Whether surveying fields and forests for crop maturity or pest infestation, checking up on real estate and infrastructure such as bridges and wind turbines in remote locations, making movies and gathering television footage, or creating compelling live entertainment, as at the recent Olympic Games in South Korea, today small eVTOL aircraft are routinely used in significant numbers for inspection applications all over the world.

Drones are also deployed for real-world field testing to deliver goods. In fact, the first niche applications for such transport drones began in 2016. Among the major companies testing these aircraft are Amazon, the global courier service DHL, and the Chinese company JD.com, in areas ranging from the United States and several European countries to Asia and Australia.

The major driver of market development⁹ for non-passenger drones is the autonomy level of remote operations. While the current wave of aircraft, whether consumer or commercial applications, depends on visual line of sight (VLOS) operations, within three to five years they will be operated beyond VLOS (BVLOS). The limitation so far has been the missing approval for such BVLOS operations in most countries. Going to BVLOS operation will enable an additional range of applications and allow one human to control many drones. Autonomous drones will become a reality in the next 10 to 25 years. Aerospace companies and aviation agencies around the world have just begun discussions, and one can expect cargo planes to be tested in rural areas.

As a last-mile delivery option, goods drones will have to compete with other existing and new offerings such as bike couri-

ers and urban delivery robots navigating roads and sidewalks. Goods drones have a solid business case with BVLOS operations, for instance in delivering medication and emergency supplies to remote locations, but they will not become widely deployed until the third phase—semi-autonomy—becomes reality. Operating autonomously will give these drones the necessary efficiency advantage over other modes of delivery.

Certification of future unmanned aircraft systems (UAS) is the responsibility of JARUS, a group of experts from the National Aviation Authorities (NAAs) and regional aviation safety organizations in 54 countries as well as the EASA. Its stated purpose is to recommend a single set of technical, safety, and operational requirements for the certification and safe integration of UAS into airspace. The organization aims to provide guidance material to make it easier for authorities to draw up their own requirements. Once the framework has been created, it will influence the certification and usage of inspection, goods, and passenger drones. In both cases, very similar safety and security concerns will have to be addressed.

The market for inspection drones will grow at a CAGR of 20 percent to reach nearly 22 million active units and \$34 billion by 2035, with the commercial market being its biggest driver (fig. 22). Starting in 2020, this market will initially be comprised of \$8 billion in commercial and \$1 billion in hobby drones. It is expected to take off between 2019 and 2025, depending on local regulations and operational areas of service and will hit \$24 billion in 2025 with 21.3 million active drones. By 2030 the market size will reach \$32 billion and top out at \$34 billion in 2035. The number of active drones will remain roughly stable at 21.5 million in 2035.

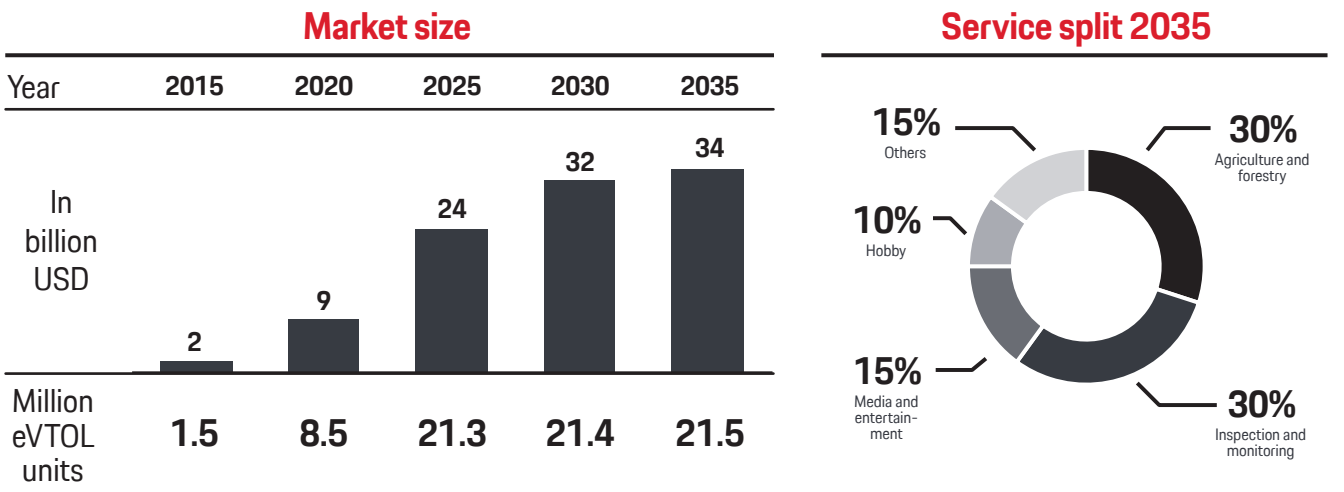


Figure 22. Keeping tabs on crops and infrastructure: a breakdown of the market for inspection drones until 2035.

Graphic: Porsche Consulting

⁹ In order to model market development, this report drew on a large number of basic data sets. Essential sources are listed in the reference section (7-12).

Significant revenue in 2035 will come from the agriculture, farming, and forestry sectors (30 percent) as well as inspection and monitoring of assets such as real estate and infrastructure (30 percent). The third largest segment will be media and entertainment at 15 percent. Services around hobby applications will only capture 10 percent of the market in 2035.

The comparatively small market for goods drones will grow from \$300 million in 2020 to \$1.1 billion in 2025, and from \$3.1 billion in 2030 to \$4 billion in 2035 at a CAGR

of approximately 20 percent (fig. 23). Regulatory framework and new delivery robots are expected to limit this market and will influence the cost structure. The number of active drones will go from 7,000 units in 2020 to 25,000 in 2025, reaching 95,000 in 2030 and 125,000 in 2035. The market for goods drones will be orders of magnitude smaller than the market for inspection and passenger drones for several reasons. Goods delivery is already a hotly contested market occupied by established modes such as bikes and new solutions like AGVs (Automated Guided Vehicles).

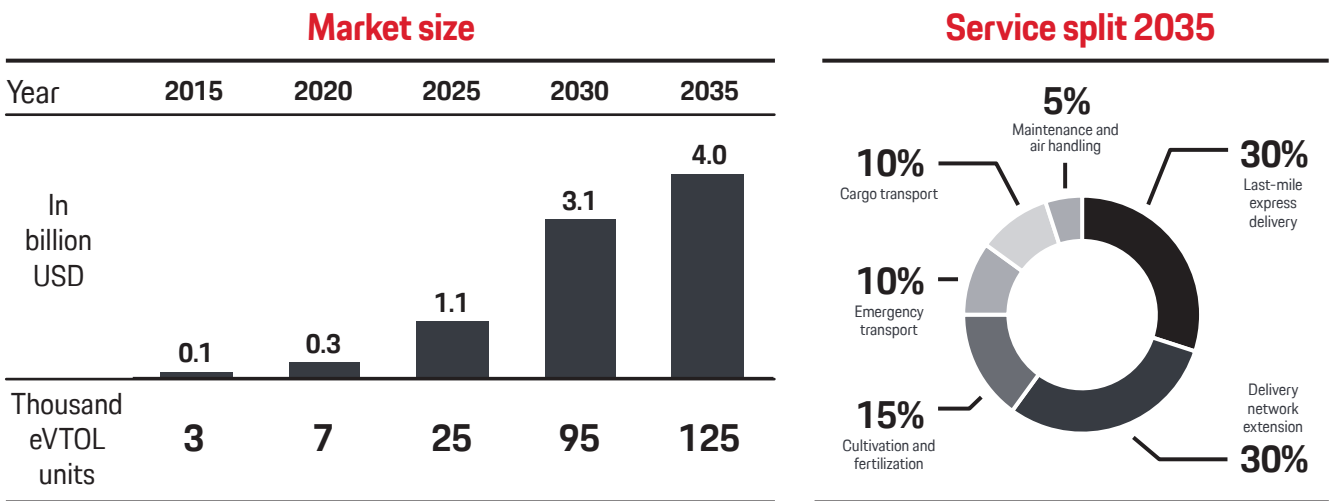


Figure 23. When time is of the essence: the market for goods drones and their applications by sector until 2035.

Graphic: Porsche Consulting

Goods drones are only advantageous when time is of the essence or remote locations need to be reached. They are also limited in terms of how much weight they can carry over certain distances. While the global market for CEP (courier, express, and parcel services) is worth \$145 billion, time-critical shipments requiring instant, same-day, and highly reliable delivery only comprise one-fifth (13,14). Drones also face additional limitations when it comes to landing spot availability and noise restrictions in urban areas. At the same time, goods drones have few benefits for rural areas compared to autonomous vehicles, because traffic density outside a congested urban area is not critical. In other words, there is no need to make a large number of urban deliveries by air.

Most of the goods drones revenue in 2035 will come from last-mile express delivery, with a 30 percent share, while drones deployed to extend an established delivery network will also capture a 30 percent share. Drones for cultivation and fertilization in agriculture will capture around 15 percent. The fourth and fifth largest applications for goods drones will be emergency transport and cargo transport, with 10 percent each. Maintenance and air handling will account for the remaining 5 percent of the market in 2035.

5 Seizing the Opportunity of Vertical Mobility

To view a city from above is to observe a world in perpetual motion. Mobility is the lifeblood of our cities and essential to sustaining urban life by moving people and goods around. The strongest layer is a network of public transport options consisting of subways, trains, and buses that carry thousands of people to and from work every day along fixed routes. Another layer of urban mobility offerings is private transport, a dynamic puzzle of private cars and taxis circulating in abstract and ever-changing patterns. Add to that hustle and bustle fleets of trucks that deliver goods, pick up orders, and cart away garbage or recyclables. Finally, there are soft-mode transportation options such as pedestrians and people weaving through traffic on their own or shared

bikes and scooters. In the sky, helicopters serve narrowly defined emergency and transportation needs.

Passenger drones also allow cities to use their existing resources more efficiently by sharing and pooling trips and by integrating mobility as a service into larger mobility platforms. This transition will bring about change for everyone involved. Cars will make way for autonomous vehicles and car-sharing services. Taxis will be replaced by ride-hailing and ride-sharing. The private bike will see competition from e-bikes and bike-sharing programs. Helicopters finally will share the airspace with eVTOL aircraft.

Players in the vertical mobility ecosystem need strong partners

Vertical mobility ecosystem players will need to establish strong partnerships between public and private entities to succeed. They have to demonstrate the social benefits for

the broader population and ensure the concerted and coordinated efforts of all parties: you and me, cities and lawmakers, hardware and service players as well as investors.

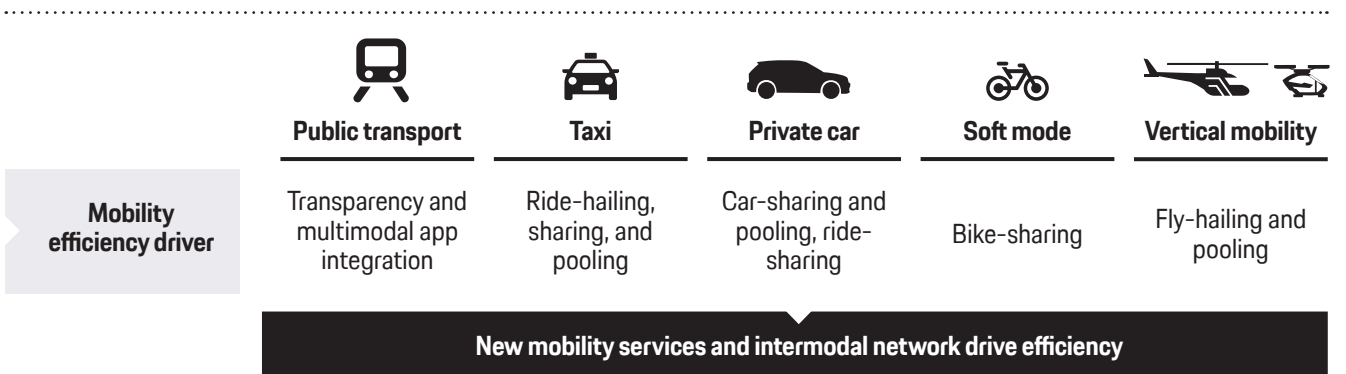


Figure 24. The best way to get around: intermodal mobility services allow the efficient use of a city's resources.

Graphic: Porsche Consulting

You and me

Vertical mobility will take off in several phases until it becomes a means of transport for you and me. In the beginning, it will offer point-to-point transportation for business travelers and wealthy people, just like today's well-to-do can afford to use helicopters. But before long, passenger drones will hold the promise to democratize vertical mobility.

Electric VTOL aircraft will be able to cover fairly long—and as time goes by even longer—distances of up to several hundred kilometers, including city-to-city transport. They will go from initially being a premium product to becoming affordable and accessible to most of us. Drones will make mankind's dream of flying a reality, for instance, by providing the freedom to spontaneously escape into a green suburban environment to spend time with the family.

Electric VTOL aircraft can also have a positive impact on emergency, safety, and rescue operations. Passenger drones will make it easier to transport patients, while goods drones can ensure the timely delivery of medication, blood, or donor organs. Inspection drones can perform important safety and surveillance missions in a crisis or during a natural catastrophe.

As with all modes of transportation, safety comes first. Whether vertical mobility becomes commercially successful and socially accepted will depend on establishing public approval before commercial development can occur. The individual's anticipation and eventual excitement to take to the sky has to be reconciled with a framework of rules and regulations that ensure eVTOL aircraft are accessible to all, at an acceptable price and noise level.

City and lawmakers

Pioneer cities will set standards early on, but they have to maintain control of the infrastructure and make good use of the possibilities vertical mobility offers them. As soon as vertiports are built, they should be open to all providers, similar to the concept of net neutrality that aims to prevent the preferential traffic flow for bits on the Internet. Such neutrality for vertiports is particularly crucial during the initial infra-

structure build-out and should apply to all key traffic hubs to ensure the vertical mobility ecosystem does not become dominated by quasi monopolies. Therefore, urban planners, politicians, and regulators should focus on each city's traffic-specific pain points to make sure they can provide test beds in a timely fashion and guarantee network neutrality for eVTOL infrastructure (fig. 25).

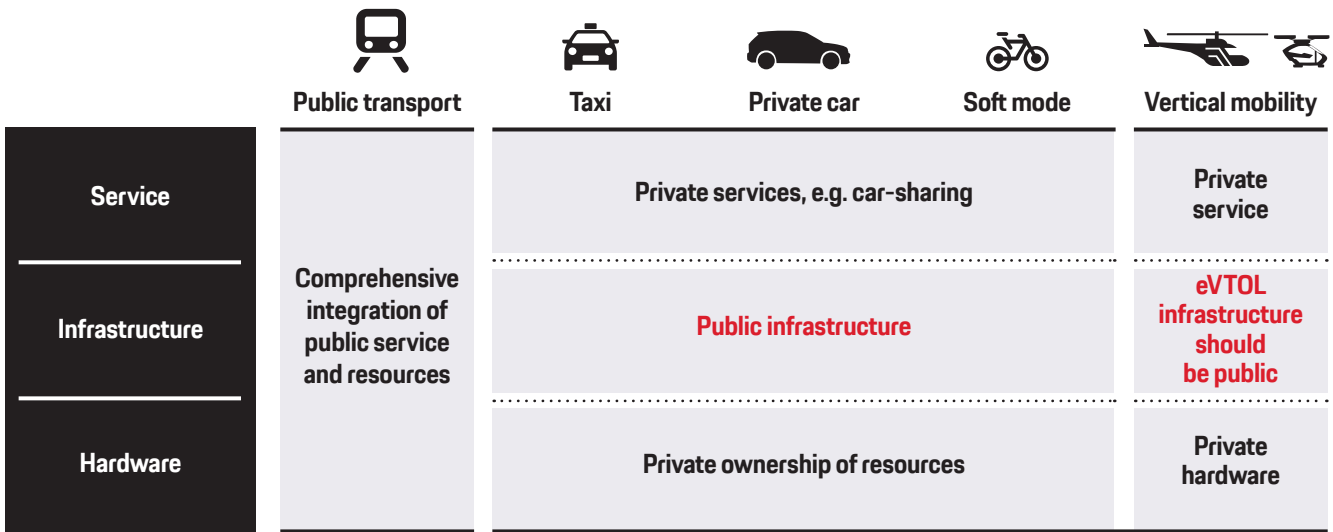


Figure 25. Keeping options open for all: why public infrastructure needs network neutrality to flourish.

Graphic: Porsche Consulting

A city can attain high transportation flexibility with a low number of vertiports because these take-off and landing sites allow many possible connections. A network of just 10 vertiports, for instance, already equals 45 possible connections.

Cities can also reap the benefits of low infrastructure costs. Vertical mobility has the advantage of lower capital expenditures for passenger drones per distance unit than for other modes of transportation. Construction costs for a 35 kilometer section of intracity highway or a new light-rail or subway

line can range anywhere from hundreds of millions to billions of dollars, depending on whether the track is at ground level, elevated, or located in a tunnel. By comparison, passenger drones require only a few resources, such as vertiports and charging stations.

Action is also required to safely and securely manage the comings and goings of inspection and goods drones in cities. An integrated ATM/UTM scheme has to include cybersecurity to prevent the misuse of inspection and goods drones.

Hardware and service players

The hardware and service players in this emerging space will consist of established aircraft manufacturers (e.g., Boeing, Airbus), automotive OEMs, startups (e.g., Ehang, Jobi Aviation, Lilium, Volocopter), technology companies such as Intel, and mobility service providers like Uber.

Hardware is a key component of this future ecosystem and has an important impact on what the infrastructure, laws, and regulations as well as social acceptance will look like. By hardware we mean the eVTOL aircraft itself, the charging equipment, other equipment, batteries, and DEP. The latter will, to a large degree, be defined by its acoustic profile.

As previously mentioned, multirotor concepts have the advantage of being first to market. Other concepts that are faster and significantly more efficient will follow. At this point, it is unclear which aircraft system will win. Different players are exploring and evaluating several aerodynamic concepts, but it is safe to say that drone systems with airfoils have clear advantages when it comes to travel speed and efficiency. Companies in this area have to strike a balance between their desire to be the first to market and the inherent advantages of certain concepts, all the while inter-

acting with regulators to define the future standard. In the beginning, all concepts will be operated by a human pilot, followed by assisted and autonomous systems.

Hardware must always be part of a larger, coherently integrated service, since mobility services will capture the majority of this new market. The future belongs to those providers who can offer their customers ride-hailing via passenger drones that seamlessly ties into the larger mobility network.

Investors

Vertical mobility is a venture that has been funded to the tune of more than \$3 billion. Approximately \$500 million in investments flowed into this market in 2016 alone. We expect costs ranging from \$500 million to \$1 billion to bring one type of passenger drone up to volume production (fig. 26). Partnerships will be necessary to make the required investments in all market segments. The biggest bets to date have been placed in the areas of passenger drone hardware and new air traffic management systems.

Investing in vertical mobility requires a long-term horizon. The ecosystem has just begun to take shape and will undergo major inflection points between the years 2025 and 2035 until it can become an important part of tomorrow's electrified mobility mix. Investors who want to be active in this space need to be aware of the various risks associated with the eVTOL market, ranging from technical development, certification, and regulation to commercial viability and public acceptance.

eVTOL development costs in million USD

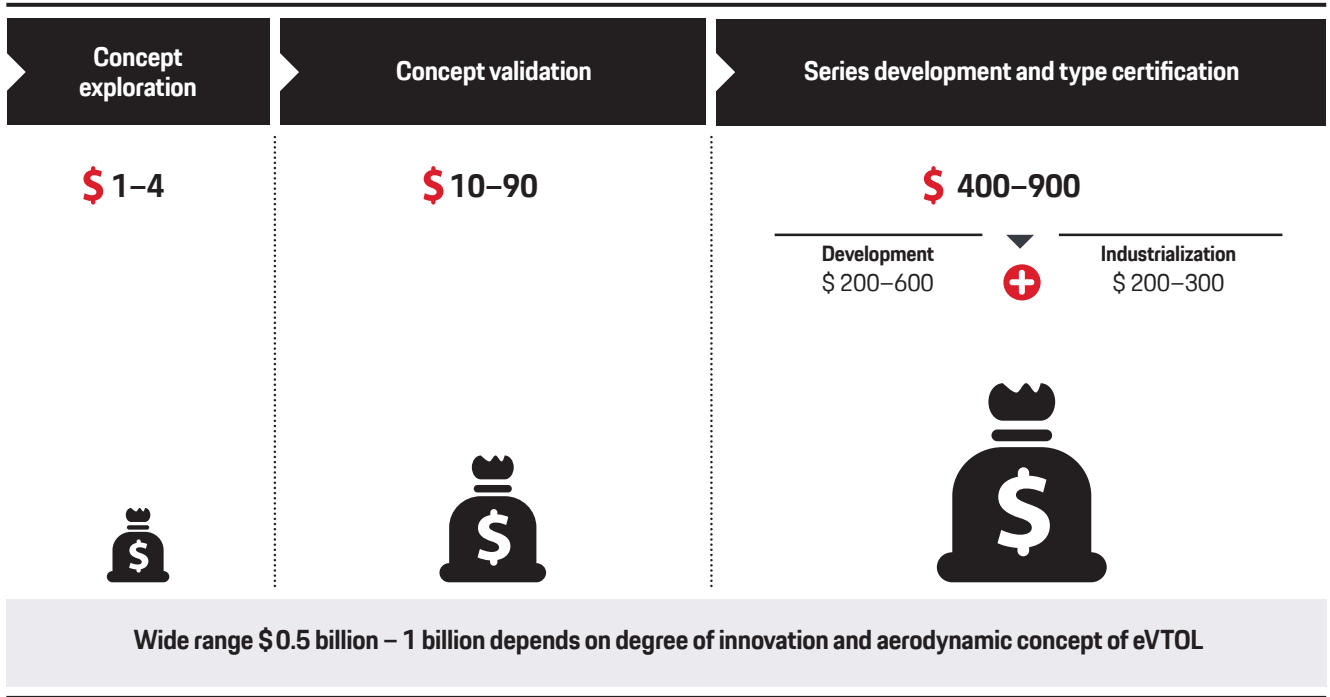


Figure 26. The \$1 billion play: range of eVTOL costs from concept to series development.

Graphic: Porsche Consulting

Appendix

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Glossary

2C/4C	charge and discharge rates. Compared to 2C, the 4C charge and discharge rate indicates an electric current use twice as high during the same time interval.
AGV	automated guided vehicle
APAC	Asia Pacific
ATC	air traffic control
ATM	air traffic management
BVLOS	beyond visual line of sight (sometimes also called BLOS)
CEP	courier, express and parcel services
DEP	distributed electric propulsion
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EASA	European Aviation Safety Agency
eVTOL	electric VTOL
FAA	Federal Aviation Administration
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
Li-NMC	lithium-nickel-mangan-cobalt-oxide battery
NAA	national aviation authority
service provider	piloting, flight operations, air traffic management services, MRO services, etc.
solution provider	landing fee, charging, etc.
STOL	short take-off and landing
TAM	total addressable market, theoretically achievable market with fully established infrastructure
UAS	unmanned aerial systems
UTM	unmanned aerial systems traffic management
vertiports	VTOL hubs with multiple take-off and landing pads, as well as charging infrastructure
vertistops	a single VTOL pad with minimal infrastructure
VLOS	visual line of sight
VTOL	vertical take-off and landing

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Design: Daniel Vogel

Publication: Luisa Boger, Dunia Fernández, Heiner von der Laden, and Darius Selke

A future awaits when flying will be a natural part of our daily lives. We look forward to hearing your thoughts, comments, and questions to keep the debate around vertical mobility going.

We welcome all feedback at verticalmobility@porsche.de

“Explore. Dream. Discover.”

Mark Twain

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