Transformation

Next Gen Tech: Mobility

13 August 2024

Key takeaways

- Inefficiencies in the current network make the transportation industry likely to be transformed by disruptive technologies. After all, mobility is expensive: US households spend an average of 15% of their disposable income on transportation, according to the US Bureau of Transportation Statistics.
- Several converging technologies can unlock the future of mobility. Better batteries and rapid advancements in AI and computational capabilities are enabling vehicle electrification and autonomy. Is electric aviation, next?
- Bank of America Institute's 'Next Gen Tech' series explores 30 breakthroughs across artificial intelligence (AI), computing, robots, communication, healthcare, energy and mobility, that are about to alter our lives.

This publication is part of Bank of America Institute's 'Next Gen Tech' series – focused on sharing 30 breakthrough technologies that will transform the world. Each publication will highlight one of seven categories (artificial intelligence, computing, robots, communication, healthcare, energy and transport), and share advancements within each.

Future mobility: Are we there yet?

Transportation remains the poster child for an industry that will be transformed with disruptive technologies, owing to the relative inefficiencies of the current transport network and vast addressable market. Transportation is expensive: congestion cost the US economy $95 billion in 2022, and US households spend an average of 15% of their disposable income on transportation, according to the US Bureau of Transportation Statistics.

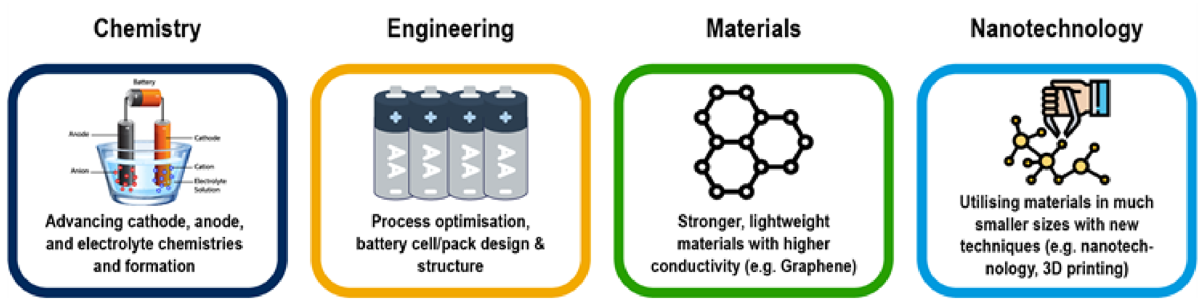
However, several converging technologies can unlock the future of mobility. Transportation is going electric and autonomous enabled by better batteries and rapid advancements in AI and computational capabilities, which will also aid in electric aviation, initially in drones, and soon for passengers, too. Here, we explore three breakthroughs driving the transportation transformation.

1) Next-gen batteries

The transition to electric vehicles (EVs) is reliant on improving battery technology. Battery energy density continues to increase, and costs continue to fall, driving demand growth in several applications. As such, EV adoption has spread to all areas of road transport, from two-wheelers to cars to more recently, commercial vehicles. However, limitations remain in the viability of EVs due to a number of trade-offs (e.g., range, safety, durability and charging rates), and fierce competition as the global auto industry races to electrify.

Exhibit 1: Advancing chemistry mix of battery components, engineering of cells/packs, and utilizing materials in smaller sizes and greater consistency are key enablers of next generation batteries

Battery breakthroughs enabled by chemistry, engineering, materials and nanotechnology



Source: BofA Global Research

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However, several converging trends could enable improvements in the functionality and form factor of the next generation of batteries, with a convergence of improved chemistry, engineering and material science research and techniques (Exhibit 1). These are underpinned by increased funding and urgency, with batteries key to mitigating climate change as a cleaner power source than fossil fuels. Furthermore, advances in AI and machine learning technologies could accelerate this by identifying new materials or chemistry iterations at a faster pace and simulating their performance to speed up the development time.

Leading the charge with chemistry diversification

The initial battery technology roadmap was categorized by nickel-based chemistries (particularly NCM: nickel, cobalt and manganese based), which is preferred in the west vs. lithium iron phosphate (LFP)-based chemistries launched in China. However, there are now multiple derivatives of each battery chemistry, each having unique benefits and drawbacks to their commercialization. Rather than a single chemistry emerging as the future "winner," it is likely that each can serve different uses and customers as the addressable market increases.

What are the next-gen EV battery chemistries?

- **LFP batteries:** A lithium ferrophosphate (LFP) battery is a type of lithium-ion battery that uses lithium iron phosphate as the cathode material. LFP batteries operate in a similar way to other lithium-ion batteries, moving between positive and negative electrodes to charge and discharge. As the name suggests, LFP requires three elements: lithium, iron, and phosphorus, and doesn't contain nickel or cobalt, which leads to reduced raw materials costs and fewer environmental concerns. Moreover, it has lower energy density compared with ternary (NCM) batteries.

- **LMFP:** A lithium manganese iron phosphate (LMFP) battery uses a mixture of lithium iron phosphate and lithium manganese phosphate in the same structure as in lithium iron phosphate. Adding manganese into LFP will lift energy density by increasing the voltage within the same specific capacity, and will improve the low-temperature performance, the two biggest pain points of traditional LFP. Meanwhile, the incremental cost is minimal given the inexpensive metal used, making LMFP a pioneer technology and considered to be an upgraded version of LFP.

- **High-nickel batteries:** High-nickel NCM (nickel, cobalt, manganese) batteries use a high content of nickel – usually over 80%, but more recently, many battery and cathode makers have commercialized nickel content over 90%, with cobalt and manganese below 10%, to maximise the energy density of a cell and thus driving range.

- **High voltage single-crystal mid-nickel cathodes:** Mid-nickel cathodes have 40-60% nickel content making them cheaper and more stable than high-nickel cathodes. Battery manufacturers are increasingly attempting to apply high voltage to mid-nickel cathodes to raise the energy density close to that of high-nickel cathodes. Furthermore, using single-crystal cathode materials can extend battery life.

- **Manganese rich:** Manganese is the fifth most abundant metal in the earth's crust, which makes it relatively cheap and easily accessible, and it is often blended with other metals to improve stability and performance in batteries. Lithium-ion batteries with high content of manganese but lower contents of high-price metals, including nickel and cobalt, are not only cheaper and safer, but also have a higher energy density than LFP.

- **Sodium-ion batteries:** Sodium-ion batteries are gaining prominence as a potential substitute for existing lithium-ion battery technology, mainly because they are cost-effective, using raw materials that are more abundant, and have lesser environmental impact given the ease of obtaining sodium relative to lithium. As the cost of manufacturing the cathode is relatively similar for both sodium-ion and lithium-ion battery technologies, the primary savings with sodium-ion batteries stems from the affordability of its raw materials: sodium and aluminium.

- **Solid-state batteries:** Solid-state batteries have long been considered a crucial innovative technology for the future of electric vehicles, thanks to advantages including: 1) higher energy density: a solid-state battery uses an anode made of pure lithium metal and can as much as double energy density compared with a traditional lithium-ion battery, resulting in a lighter and smaller battery; 2) improved safety: replacing the liquid electrolyte found in current lithium-ion batteries with solid components helps prevent safety issues related to electrolyte leaks or fires; 3) longevity: a thicker separator allows the batteries to be more resistant to high temperatures, which makes the separation between the anode and cathode more reliable, with consistent performance over time and a longer service life; and 4) fast-charging: the improved resistance to high temperatures also provides fast-charging features – a solid-state battery can be charged up to 6x faster compared with a traditional lithium-ion battery.

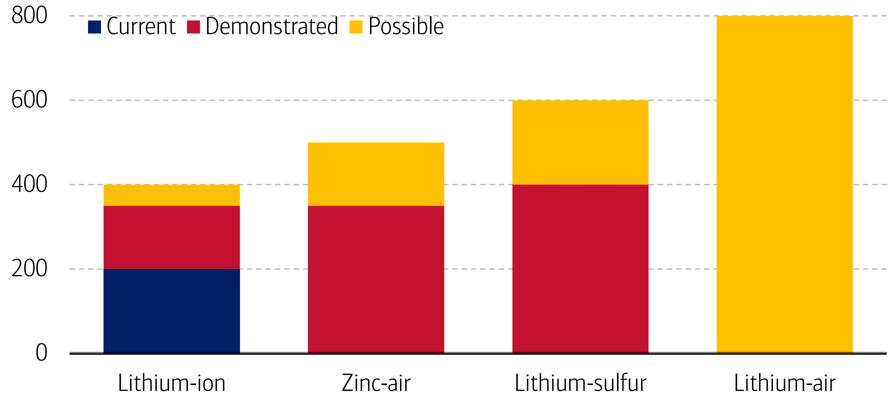
- **Lithium sulphur batteries:** Lithium sulphur (Li-S) batteries could offer an alternative to Li-ion batteries because of their high energy density and reduced cost due to the use of sulphur (instead of cobalt). Applications so far are mainly outside of transportation – for example, NASA has invested in solid-state Li-S batteries to power space exploration. On the downside, Li-S batteries have low electrical conductivity, thereby requiring extra conductive agents, which could increase the weight and stress on the battery pack.

- **Metal air batteries:** Metal air batteries are a type of fuel cell battery that utilizes oxidation of a metal at the anode and reduction of oxygen at the cathode to produce electricity. Pairing metal and oxygen (from the air) can theoretically lead to electrochemical cells with the highest specific energy. Research projects, such as Argonne National Laboratory, suggest 5x more energy can be achieved than for a Li-ion battery, making it one of the most sought-after battery breakthroughs.

  However, metal air batteries come with challenges including capturing enough volume and purity of oxygen from air, battery recyclability and cycle life. Being able to create the complex packaging and air breathing interfaces in the cell to enable them to recharge is also a key challenge. Improvements in zinc-air and lithium plating could mitigate this, but commercialization will also depend on significant cathode improvements.

Exhibit 2: Alternative battery chemistries to lithium-ion could double achievable gravimetric energy density with further breakthroughs

Next generation battery energy density outlook



Source: Tyson, Madeline, Charlie Bloch. Breakthrough Batteries: Powering the Era of Clean Electrification. Rocky Mountain Institute, 2019. NOTE: Denotes Wh/KG (watt-hour per kilogram) energy density

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Nanotechnology for extreme fast charging (XFC)

Varying anode chemistry can also enable extreme fast charging (XFC). Current (graphite) anodes are stable at normal charging rates but face high electrical resistance – fast charging can cause dendrites on the anode surface, damaging the cells. Replacement with materials such as silicon/tin can alleviate that, allowing faster conductivity. However, nanotechnology and new materials are required to enable the use of smaller-sized particles. These can give more area to penetrate the active material and lower resistance and heat.

AI could accelerate battery development

The current approach to battery design is slow, complicated and expensive for a number of reasons: 1) the infinite number of battery materials that could be combined; 2) long testing times that require high compute resources; and 3) difficulty in predicting how change in battery design will impact performance. Combined, these challenges slow the path to next-generation batteries. However, recent breakthroughs AI technologies could accelerate battery development significantly by combining data with machine learning and forecasting models to speed up development from years to months, or potentially less. Our Next Gen Tech: AI publication further explores this topic.

When AI meets quantum tech: Battery abundance

Furthermore, as computational capabilities continue to advance with high-powered compute getting cheaper, and eventually quantum computing able to be commercialized, the development of battery chemistries could accelerate. The ability to parallelize multiple experiments is already being tested in order to analyze the structure of molecules and combination of materials and how they interact, with the aim to identify new battery materials and chemistries faster and simulate potential outcomes and cycle life testing. This work can begin to be tested prior to quantum computing becoming commercially available by combining AI with cloud computing. See Next Gen Tech: Computing for more on this topic.

Structural & Material breakthroughs could bring next-gen batteries faster

Alongside battery cell chemistry improvements are methods to integrate the cells directly into battery packs to increase energy efficiency and lower costs, which can eliminate or simplify battery module structures. The key rationale is to improve energy density in the short term, but the trajectory of the technology is evolving towards eliminating the need for dedicated battery packs, and instead integrating cells within the structure of objects such as a vehicle chassis. If achieved, this could enable higher energy density as well as performance feedback loops in EVs by reducing weight, thereby the volume of energy required to travel the same distance, and therefore cost.

Further development of the technology to integrate batteries into the structure of objects is paving the way for "massless" energy storage in vehicles and other technologies. Current batteries account for a large proportion of vehicle weight without fulfilling any load-bearing function. Integrating batteries into the structure of objects could remove that incremental weight of batteries (hence the term "massless" energy storage), having the effect of reducing both the volume of stored energy required to power the vehicle, and the raw material resource intensity of the vehicles. To do so requires using materials that can offer both rigidity *and* conductivity such as carbon fibre, or graphene (see: Next Gen Tech: Energy for more on graphene).

2) Autonomous vehicles

Autonomy (via autonomous vehicles, or AVs) remains the key technological goal for the mobility industry. Increased processing capability at a lower cost and power consumption can enable this, accelerated by advances in machine learning and AI capabilities, albeit with longer timelines than initially hoped. The key near-term trends in AVs include:

1. **ADAS first, full AV later**: Advanced driver assistance systems (ADAS) including self-parking and highway driving with urban self-driving at a later stage, have the driver either partially in control or as a backup. However, increasing levels of autonomous features in private cars to achieve further levels of conditional automation remains dependent on regulation, technological approaches (which sensors to use and proven safety) and cost.

2. **Sensor wars, lidar and/or radar:** An ongoing debate within the industry relates to whether light detection and ranging (lidar) sensors are needed to achieve autonomous driving and, if so, whether the cost could come down far enough to accommodate them profitably in privately owned vehicles. Lidar unit costs are expected to halve in the next few years as volumes ramp up, but improving radar capabilities aided by software could suffice and be far cheaper.

3. **AV1.0 is here**: Fully autonomous driving, while taking longer to be commercialized than initially hoped, is beginning to be deployed for set routes/use cases (e.g., in select ride-hail cities) with a consolidating handful of providers piloting AV services. Proprietary data and computation are the key required competencies.

4. **AV2.0 = embodied AI**: Generative AI advances can enable vehicles to be equipped with onboard intelligence to drive independently (vs. the rules-based mapping approaches of most of the current AV programs), specifically using the emergent AI technologies of 1) reinforcement learning onboard cars, 2) synthetic training data to speed up the testing and safety validation work, and 3) multimodality to control and understand more vehicle functions.

5. **"Driver as a service" or "AI defined vehicles"**: Software subscription business models are emerging as several AV technology companies near commercialization, either via a monthly subscription fee for private drivers, pay-per-mile for truck fleet operators, or the licensing of software/sensor pods to vehicle manufacturers to enable them to create new experiences or "AI defined vehicles." This advancement extends beyond cars to industrial machinery, e.g., agriculture.

Reducing the cost and hardware needed for autonomy

Two converging trends could accelerate the development of autonomous vehicle software: 1) utilizing next-gen AI and computational tools could make AVs cheaper to launch and scale as well as faster as it would negate the need to remap or recalibrate systems in every new location or environment, and 2) the dropping cost of sensors required to enable autonomous driving due to rising volumes and using software to improve existing sensor capabilities (e.g., radar). Many connected high-end cars already in production now have the hardware/software integration potential to adopt self-driving technology with an over-the-air software update.

Embodied AI: The ChatGPT moment is coming to driving

While generative AI models are at an early stage of commercialization, their rapid progress is revealing the emergent capabilities that could accelerate autonomous driving. They could provide vehicles with embodied intelligence to understand what's ahead and act on it in real time, as opposed to the rules and mapping-based approaches adopted in the majority of self-driving vehicle programs currently in operation. The premise is to switch from an engineered system interconnected by lines of code to a purely data-driven approach with a single neural network (ChatGPT style).

Hallucinations and a "data diet"

Whilst generative AI could accelerate the development of self-driving systems, there are risks. For one, the potential lack of transparency and controllability of such systems means that regulators may lack confidence that they won't 'hallucinate' (make misjudgements or catastrophic errors). Secondly, autonomous cars and control systems would also create vast amounts of data, which is costly. To mitigate this, several companies are working to create the hardware and storage levels that would be required, with solves including 'purpose-built chips' aimed at achieving not only the processing power required but reduced power consumption and increased efficiency in AVs.

Software defined vehicles

Several auto/tech suppliers have demonstrated visions of "software defined vehicles" that are set to be a key enabler of self-driving systems, as well as improve the range of features cars can adopt, such as payments or better entertainment. To enable this requires a shift from the largely independent electronic control units (ECUs) that control each tech component in most vehicles today, towards a few high-powered computers controlling multiple functions within cars. This would allow companies to launch new features and content more quickly (requiring software changes rather than hardware), using less wiring thus saving on weight/cost, and enable upgrades to cars over time.

Software defined vehicles are particularly important in enabling autonomous driving, too. Firstly, the shift to centralized high powered compute can power all automated driving components centrally from one chip, which makes them easier to integrate and program. More importantly, they can be upgraded over the air remotely as self-driving software improves, or bugs can be fixed without down-time impacting safety or commercial potential.

Challenges remain

Several challenges remain prior to full-scale commercialization of autonomous driving, centred around regulation, reducing cost, power and cybersecurity threats.

- **Regulation**: Crossing to Level 3 automation (i.e., a mode in which all aspects of driving are handled for you, but the driver must be present at all times in case an intervention request is made) is challenging owing to legislative and liability questions over such technologies. Finding a solution is complex and encompasses a wide range of factors including AI decision-making parameters, cybersecurity, insurance cover, and consent for monitoring – the ideologies around which vary by region and government.
- **Cost**: Far greater sensing perception is required for higher levels of autonomy. Level 1 ADAS requires approximately $300 of sensing equipment and a Level 2-enabled vehicle $1,000, but Level 3 jumps to over $4,000. This equates to 30% of the average bill of materials of an entire vehicle (largely reflecting the addition of lidar), which severely impacts the affordability of higher levels of autonomy in the short term.
- **Power consumption**: Limiting the battery drain from autonomous driving computation is becoming an increasing challenge for AV developers. As autonomous driving tasks and computation become more complex, the energy required to power them increases.
- **Cybersecurity**: As mentioned in our Safety first! publication, today's cars already run on 100 million lines of software code, expected to rise to 300-500 million to enable increased safety and "software defined vehicle" features. To put this into perspective, a passenger aircraft has an estimated 15 million lines of code, a modern fighter jet about 25 million, and a mass-market PC operating system close to 40 million. This dramatically raises the potential for cyberattacks – not only on the car itself but on all components of its ecosystem.

3) Future air mobility

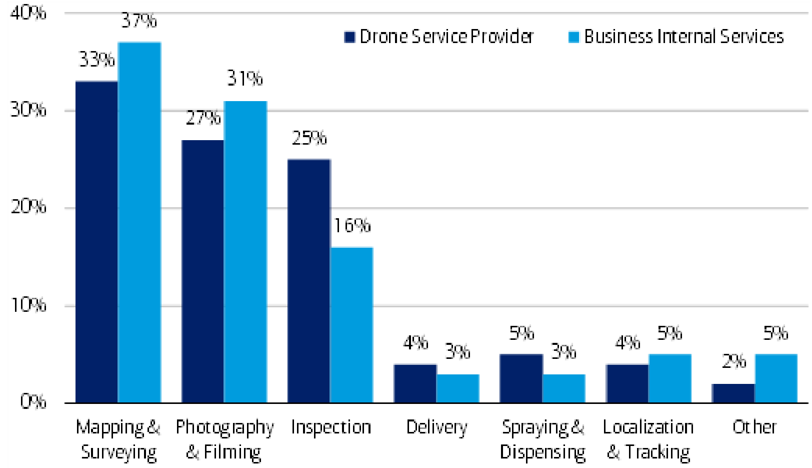
A combination of improving technologies (including batteries, avionics, and autonomous systems/sensors), regulatory frameworks and decarbonization targets are accelerating the growth potential and commercialization of "future air mobility" industries. Here, we focus on drones and eVTOL (electric vertical take-off and landing aircraft) given their near-term commercial trajectories.

Commercial drones:

The largest use case for commercial drones thus far is mapping and surveying (e.g., in the energy industry), followed by filming and inspection drones. However, the use cases are expanding to areas such as agriculture, precision tracking in warehouse logistics, and food/goods delivery.

In fact, drone delivery is rapidly growing following regulatory approval and certification of several company drone designs, and a range of new operating platforms enabling the delivery of goods from medicine to food to packages. The number of deliveries has swelled, and growth is expected to accelerate as improving tech and favorable regulation improve economies of scale.

Exhibit 3: Mapping and surveying, photography and filming, and inspection were the key use cases for drones in 2023
What are drones used for?



Source: Drone Industry Insights

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So why now? A combination of improving technology and confidence in the capabilities of commercial drone platforms from regulators is leading to operational restrictions being removed. In turn, this is increasing the scale of operations permitted with the key enablers including:

- **Technology**: Improvements and the falling cost of batteries, materials, and sensing for autonomous flight capabilities are enabling them to be commercialized, increasing the payloads that can be carried and extending flight time and range.
- **Emissions**: The per-package emissions for drone delivery are 85-90% lower than for a single package delivery via vehicles with combustion engines, per McKinsey, and as much as 97% lower per delivery, according to Zipline.
- **Regulation**: Regulators have placed several restrictions on commercial drone operation, but they are beginning to be loosened as more services are tested and proven. As well as limiting the number of drones they can fly simultaneously, operators are also required to deploy visual observers to oversee drone operations within the line of sight, a restriction that is beginning to be loosened, however.
- **Cost**: Drones are already cost-competitive with other forms of transport in areas with poor road infrastructure or where pooling deliveries doesn't make sense, but they could become more widely cost-competitive as volumes increase and the operational restrictions from regulators reduce. Removing observers completely with more automation would reduce delivery costs even further.

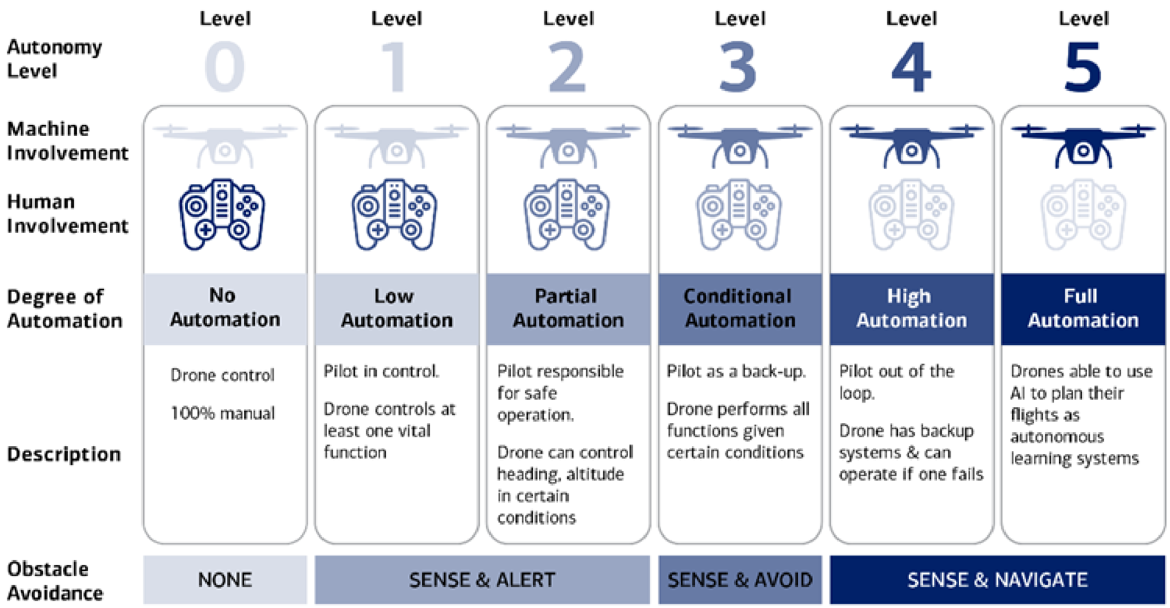
Autonomous drones: Coming soon

In order to fly, drones combine robotic and aeronautic technologies and use a mix of propellers and flight controllers to maintain stability. The improving capabilities of the onboard computing and sensing equipment enables them to perform certain functions or entire routes autonomously using a combination of onboard global positioning system (GPS), cameras, and sensing equipment such as radar/lidar – similar to autonomous vehicles on the ground.

Drones are also categorized by the level of automation they can achieve without remote pilot control, from low to high. Most of the commercial drone operations have progressed to Level 3, equipped with "sense & avoid" technologies that enable them to navigate safely beyond an operator's line of sight, but still be piloted or controlled remotely if required. No full automation operations exist yet, but some highly automated (Level 4) systems are being commercialized for mapping/surveillance of challenging environments such as industrial inspections.

Exhibit 4: Drones are categorized by the level of automation they can achieve without remote pilot control, from low/none (0) to high (5). No full automation operations exist yet.

Autonomous drones: Increasing levels of drone autonomy driven by tech & regulation



Source: Drone Industry Insights

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Is it a car? Is it a drone? Is it a plane? No, it's eVTOL

Electric vertical take-off and landing aircraft (eVTOL) is a new classification of light commercial aircraft for passengers and/or cargo. As the name suggests, they can take off and land vertically like helicopters, but use electric propulsion. Some are un-winged for short distances, like drones, while some are winged and fly forward like planes. The lighter weight, distributed propulsion and lower complexity are intended to make them more maneuverable, efficient, and at a lower cost compared to traditional helicopters. They're designed to fly at lower altitudes than commercial aircraft, and to be piloted initially and eventually flown fully autonomously as regulation permits.

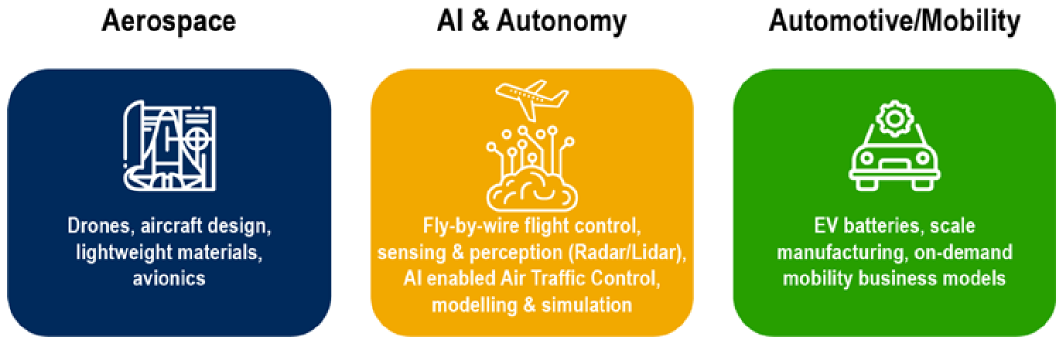
However, challenges to commercialization remain, largely relating to technical and regulatory issues along with public acceptance. Their key use cases are likely to be drone cargo (with increasing payloads) and passenger transit for short inner city and regional trips; hence the industry is often referred to as urban air mobility (UAM).

Converging technologies

Several technologies are converging that eVTOL companies are looking to capitalize on, particularly from the aerospace, automotive and technology industries.

Exhibit 5: Advancing capabilities in lightweight materials, compact flight control, AI-enabled systems, improving electric propulsion, and on-demand mobility networks are key technologies enabling eVTOL UAM from the aerospace, tech and automotive industries

EVTOL enabling technologies: combining Aerospace, AI, and Automotive



Source: BofA Global Research

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- **Aerospace**: Improving drone technology capable of increasing payloads, aircraft design (to accommodate multiple rotors and distributed propulsion), and materials (advanced lightweight composites) are all enablers of eVTOL aircraft from the aerospace industry. Improving software and digital capabilities that air-based vehicles can deploy already – such as avionics, navigation and flight control systems – are being advanced and redesigned for eVTOL.

- **Autonomy**: Combining fly-by-wire compute, navigation, and collision avoidance sensors such as radar could allow eVTOL vehicles eventually to fly autonomously. Advancing AI technologies, modelling and simulation can enable new air traffic control systems specifically for autonomous UAM that monitor and communicate with vehicles without human intervention.

- **Automotive**: As EVs scale, the improving energy density and falling battery costs are key enablers of the first eVTOL concepts to use lithium-ion batteries for zero-emission travel. While current cell energy density/weight may limit the range of initial vehicles, improving and next-gen cell chemistries could allow longer UAM trips and eVTOL companies are already partnering with battery cell developers to design bespoke chemistries for UAM vehicles.

- **Manufacturing**: eVTOL companies envision higher scale (and lower cost) of manufacturing compared to today's aircraft. The simpler design and fewer moving parts will be the key drivers of increased manufacturing. To enable this, many eVTOL companies have sought investments and partnerships with auto companies in order to leverage strategic synergies including manufacturing. However, all manufacturing will need to be certified to aerospace standards

eVTOL concepts are taking off

The number of eVTOL vehicle design concepts proliferated from six known designs in 2016 to over 900 in 2023, according to the Vertical Flight Society. Spanning 413 companies, eVTOL aircraft are categorized by the type of design and propulsion they intend to deploy. For personal travel, there are hover bikes: single-person eVTOL aircraft piloted in a saddle or standing (all wingless configurations), and roadable aircraft ("flying cars") – mostly winged vehicles requiring a traditional airstrip, or similar, in order to take off. Thus, the latter are not categorized as eVTOLs, but rather eSTOLs (electric short take-off and landing).

For passenger transit based UAM, in addition to electric rotorcraft (e.g., electrifying conventional helicopters), three new categories make up the majority of the active eVTOL developments with the key difference relating to the propulsion they use, impacting the range/speeds they can achieve, and the certification/technical requirements to operate. These aircraft include: 1) wingless multicopter (more akin to larger commercial drones); 2) lift and cruise (have separate propulsion units for take-off and cruise; and 3) vectored thrust (have tilting rotors or a ducted fan-base, which use the same propulsion to take-off and cruise).

Challenges to commercialization

Three key challenges remain to the near-term commercialization of future air mobility services: 1) type certification: the official stamp that vehicles are safe, hence a heavy required testing period and length of time to obtain the necessary certification path, but also 2) infrastructure: ensuring cities are ready with landing infrastructure and routes approved by the civil aviation authorities, and 3) public perception – testing in several locations globally, to raise awareness.

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