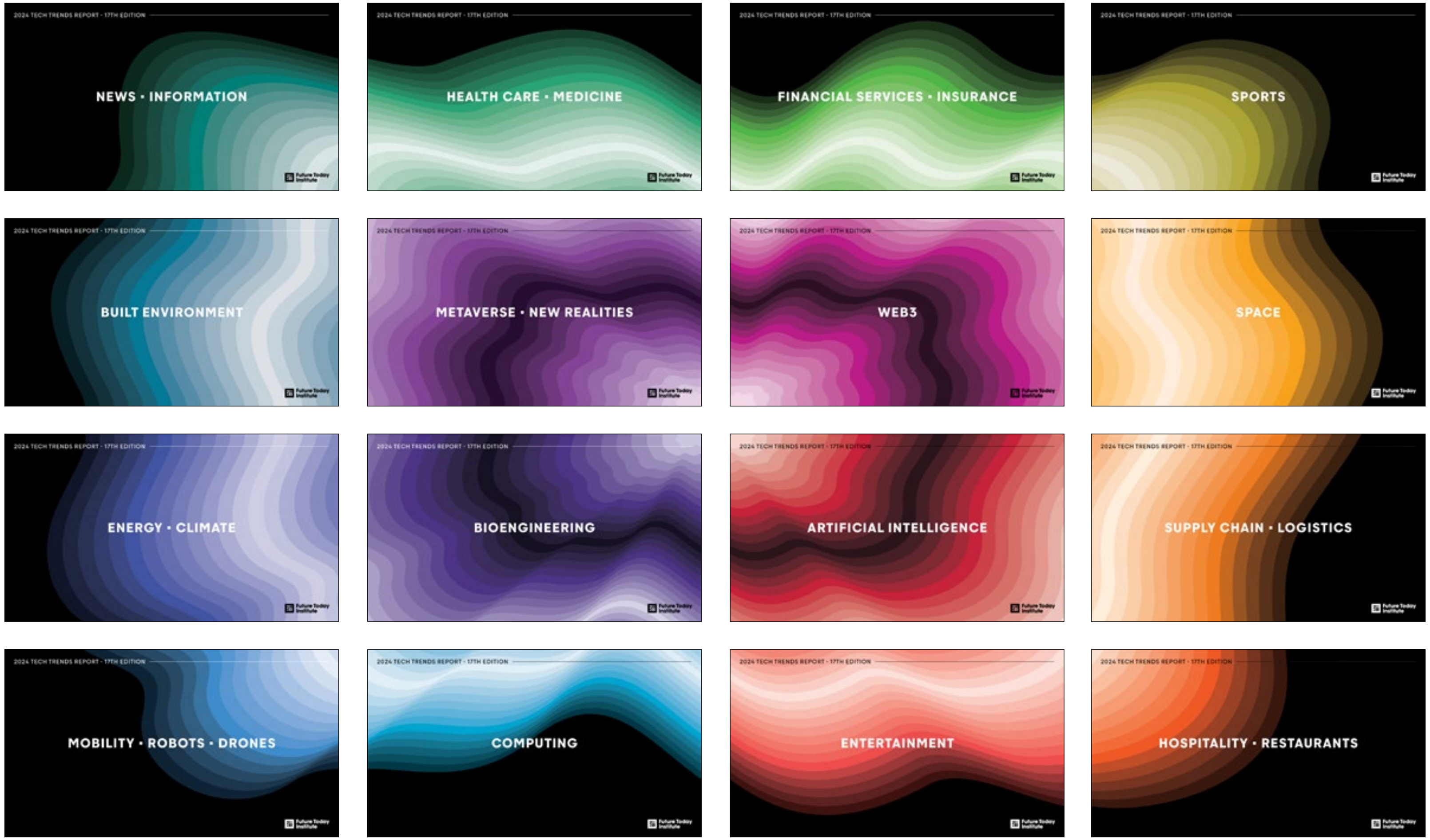
MOBILITY · ROBOTICS · DRONES

Future Today Institute

FUTURE TODAY INSTITUTE'S 2024 TECH TREND REPORT

Our 2024 edition includes nearly 700 trends, which are published individually in 16 volumes and as one comprehensive report with all trends included.

Download all sections of Future Today Institute's 2024 Tech Trends report at **http://www.futuretodayinstitute.com/trends.**



THE YEAR AHEAD: TECH SUPERCYCLE

The theme for our 2024 report is Supercycle. In economics, a "supercycle" refers to an extended period of booming demand, elevating the prices of commodities and assets to unprecedented heights. It stretches across years, even decades, and is driven by substantial and sustained structural changes in the economy.

We believe we have entered a technology supercycle. This wave of innovation is so potent and pervasive that it promises to reshape the very fabric of our existence, from the intricacies of global supply chains to the minutiae of daily habits, from the corridors of power in global politics to the unspoken norms that govern our social interactions.

Driving this seismic shift are the titans of technology and three of their inventions: artificial intelligence, biotechnology, and a burgeoning ecosystem of interconnected wearable devices for people, pets, and objects. As they converge, these three macro tech segments will redefine our relationship with everything, from our pharmacists to our animals, from banks to our own bodies. Future Today Institute's analysis shows that every technology—AR/ VR/ XR, autonomous vehicles, low Earth orbit satellites, to name a few—connects to the supercycle in some way.

The ramifications are stark and undeniable. As this tech supercycle unfurls, there will be victors and vanquished, those who seize the reins of this epochal change, and those who are swallowed whole. For business leaders, investors, and policymakers, understanding this tech supercycle is paramount.

In this 17th edition of FTI's annual Tech Trends report, we've connected the supercycle to the nearly 700 trends we've developed. Our research is presented across 16 technology and industry-specific reports that reveal the current state of play and lists of influencers to watch, along with detailed examples and recommendations designed to help executives and their teams develop their strategic positioning. The trends span evolutionary advancements in well-established technologies to groundbreaking developments at the forefront of technological and scientific exploration. You'll see emerging epicenters of innovation and risk, along with a preview into their transformative effects across various industries.

We've visually represented the tech supercycle on the report's cover, which is an undulating image reminiscent of a storm radar. Vertical and horizontal lines mark the edges of each section's cover. When all 16 section covers converge, the trends reveal a compounding effect as reverberating aftershocks influence every other area of technology and science, as well as all industries.

It's the convergence that matters. In isolation, trends offer limited foresight into the future. Instead, the interplay of these trends is what reveals long-term change. For that reason, organizations must not only remain vigilant in monitoring these evolving trends but also in cultivating strategic foresight—the ability to anticipate future changes and plan for various scenarios.

Our world is changing at an unprecedented rate, and this supercycle has only just begun.

Amy Webb
Chief Executive Officer
Future Today Institute

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TOP HEADLINES

The mobility, robotics, and drones industries are building on their substantial gains of the past year to increase capabilities and capacity.

01 Demand for Customization Outweighs Supply Chain Delays

Even as supply chains bounce back from extreme conditions, customers have indicated they are willing to wait for what they want, impacting traditional business models.

02 Vehicles Are No Longer a Private Refuge

While vehicles have traditionally functioned as a utility to get us from point A to point B, they are now following and integrating into our digital lives, eliminating one of the last spaces that was not immersed in tech.

03 Battery Capacity Drives Capability

The expanded capacity and shifting form factors of emerging battery technology are enabling units to go further, faster and take on a higher compute load to enhance their capabilities and communication.

04 General Purpose, Yet Impressive, Results

General-purpose robots are moving closer to reality. As bots become more capable, they will be more versatile, able to execute on a variety of different tasks.

05 Cobots Merely Supplement Staff, for Now

Assistive robots promise to help humans be more efficient at their jobs and supplement a shrinking labor force, but as bots improve, inevitably, they will eliminate the need for humans to conduct certain tasks.

STATE OF PLAY

Overcoming challenges to electrify and bring about the age of smarter, autonomous systems.

While the diverse industries of mobility, robotics, and drones have prominent differences impacting each domain, they also have common drivers. Electrification remains a major driver of change for all of them thanks to the support of consumer and ESG (environmental, social, corporate governance) demands, coupled with global, legislative shifts bringing an electric future to the forefront.

Fully autonomous systems are still on the horizon, especially for automobiles, but systems are becoming smarter and more alive. A wealth of data is proving to be foundational for molding these systems, and virtual and simulated testing environments are increasingly being used to teach them before they are placed in real-world environments.

Although these systems are getting smarter, they are still fraught with challenges. There is a vast dichotomy between those that have been successfully testing and expanding in select US markets, while others have been forced to halt real-world operations after too many public failures.

Similarly, in the world of robotics, a general purpose, fully autonomous humanoid robot has long been a dream of many and presented as a holy grail of innovation. However, while there are early signals of such robots, they are unlikely to fully supersede the human workforce any time soon, with most job replacement coming from functional robots with a limited task set. Contrastingly, drones have already been successfully impacted by autonomous systems and are seeing annual capability enhancements across commercial and consumer sectors.

The bifurcation of these industries will likely continue as the world pushes to bring about electrified replacements for billions of vehicles and impart autonomy to make vehicles, robots, and drones smart enough to drive real efficiency gains across the marketplace.

KEY EVENTS

MAY 25, 2023

Ford Teams Up with Tesla
The automakers align to use the NACS plug, promoting industry standardization for charging.

AUGUST 04, 2023

Ukrainian Drone Attack
A Ukrainian drone with 450kg TNT hits a Russian Navy base in the Black Sea, damaging a docked warship.

AUGUST 14, 2023

Self-driving Cars Block Ambulance
Two autonomous cars prevent an ambulance from getting to a crash site, delaying an injured pedestrian's transport.

SEPTEMBER 19, 2023

AI Masters Complex Tasks in Hours
Toyota Research Institute engineers use generative AI to teach robots new skills quickly and with dexterity.

OCTOBER 30, 2023

Cruise Suspends Robotaxis
The GM business puts a stop to operations in Arizona and Texas, after having to halt operations in San Francisco.

LIKELY NEAR TERM DEVELOPMENTS

MORE CERTAINTY IN COMPLEX SYSTEMS

In the immediate future, a wave of transformative development is poised to reshape our world across various domains. From the continued integration of connectivity in automobiles—fueling advanced driver assistance systems and enriched in-car experiences—to the pressing challenges facing our electrical grids as we pivot toward an all-electric future and the changing regulatory landscapes impacting drones and autonomous systems, these developments underscore the dynamic nature of technological progress. They collectively signify an era of both challenge and opportunity, where adaptability and forward-thinking will be key to navigating the disruptive forces of technology.

Continued Connectedness

Automobiles are only becoming more connected. This will impact advanced driver assistance systems as well as infotainment within the cabin. Automobiles will be less isolating as drivers and passengers seamlessly expand how they connect to their lives outside the car.

Supply Chain Disruptions Persist

Even as the supply of vehicles and chips for robotics stabilizes, manufacturers and sellers should still brace for continued supply chain disruptions. Additionally, chip nationalism and other geopolitical factors will also threaten supplies of goods.

Viability of Drone Traffic Management

The escalating use of drones and eVTOLs has necessitated advanced traffic management solutions. As various regions have put measures in place, the viability of ubiquitous drone use will be determined in the short term.

Challenges to the Grid

As we idealistically transition to an all-electric future, many have speculated our electrical grids will not be able to handle this adjustment. Others are more optimistic. In time, we will have more certainty.

New Modalities for Robotics

Researchers have developed many innovative modalities for robotics and drones, seeking inspiration from various sources. This innovation will continue, with unexpected inspiration from nature or animals, and some systems will incorporate several different modalities in their designs.

Clarity on Robotaxis

Robotaxis have been the source of much controversy, as different companies have tested their systems with varying success. The near future will shed light on long-term feasibility, especially as regulations shift to account for recent events and developments.

11 MACRO SOURCES OF DISRUPTION

Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution

WHY BUILT MOBILITY, ROBOTICS & DRONES TRENDS MATTER TO YOUR ORGANIZATION

A Deluge of Data

Increased connectivity and semiautonomous systems have led to a rise in data collection. This, combined with information gathered from fleets, vehicles, or bots, can provide valuable insights for improved decision-making and product development.

The “Threat” of Decarbonization

Transportation is one of the leading contributors to carbon emissions. The regulations are already affecting the industry, and this trend is expected to continue. Although many manufacturers have adopted electric strategies, they still need to take steps to proactively offset more of their emissions.

New Applications for Robotics-as-a-Service

As businesses explore ways to enhance their workforce or even automate their operations, it may not always be beneficial for them to personally own their own fleet of robots. A comprehensive understanding of robots’ full capabilities can help businesses determine whether it is better to own the robots themselves or outsource for the service.

Optimizing Your Workforce

As collaborative robots continue to advance and become more sophisticated, businesses have a chance to improve the efficiency of their workforce and complete tasks quicker. By incorporating collaborative robots, companies can also safeguard their employees from harsh working conditions. Keeping up with these trends is vital for optimizing workforces.

Leveraging Last-Mile Delivery

The regulatory and technological landscapes for last-mile delivery are evolving. Companies that can both master the technology and stay ahead of regulatory changes will be well-poised to serve their customers effectively, providing goods and services quickly and efficiently.

Dramatic Changes to Insurance

As systems become semiautonomous and fully autonomous, insurance strategies will need to adjust. This will impact automobiles, robotic systems on warehouse floors, and even employees whose roles change in light of collaborative and assistive robots.

WHEN WILL MOBILITY, ROBOTICS & DRONES DISRUPT YOUR ORGANIZATION?

Forecasted Time of Impact

0-4 YEARS	5-9 YEARS	10-14 YEARS	15+ YEARS
Transportation	Grid management	Space exploration	All trends will be relevant
Infrastructure development	Energy storage		
Supply chain management	Manufacturing		
Energy generation	Construction		
Warehouse management	Health care		
Delivery	Eldercare		
Last-mile delivery			
Prosthetics			

OPPORTUNITIES & THREATS

Threats

OEMs, and other automotive service and parts players, are facing uphill pressures if they fail to adapt to the growing electric market. The longer-term threat will persist as more customers seek green options and governments phase out fossil fuel-powered vehicles.

As vehicles gain more ability to observe and control the passengers within them, the industry is creating entirely new venues for privacy and data security concerns. With increased levels of data collection, automobiles are becoming a more attractive cyber-infiltration point, posing risks for OEMs, third parties, and customers.

The rapid adoption of EVs could potentially lead to an increase in brownouts, electrical surges, or fires resulting from overloading home or even commercial electrical systems. As EV adoption scales, real estate is at a greater risk of damage and increasing insurance premiums, until the infrastructure modernizes and stabilizes.

As bots become more dynamic and function across multiple modalities, organizations that fail to adopt general-purpose robotics could be at risk of falling behind competitors that masterfully incorporate these systems into workflows.

While the applications for robots and drones become seemingly endless, organizations that are slow to conceive and execute new ways of using these systems risk underserving their customers and their employees.

Opportunities

To get more electric vehicles on the road, manufacturers can look for new and novel partnerships to drive adoption. Partnerships such as ones that assist gig workers in leasing EVs can serve as the template for new programs.

Technology companies and startups have a significant opportunity to create seamless experiences across all mobility modalities, providing consumers with multiple options for arriving at their desired destinations with minimal friction.

As bidirectional charging becomes more pervasive, the traditional role of cars is transformed. Vehicles can now be the powerplant that runs a home or business in an emergency and could potentially run full time as capabilities and capacities increase.

When cobots create efficiencies and robotics begin to automate repetitive and even dangerous tasks, organizations can upskill their workforce to engage in more creative and meaningful undertakings, bringing new value to the organization.

Training robots and drones in virtual and simulated environments allows these systems to learn complex tasks virtually before transitioning to the real world. Championing this process will place organizations in enviable positions.

INVESTMENTS AND ACTIONS TO CONSIDER

1

As autonomous systems become more prevalent, data will continue to be widely available. Businesses can utilize advanced machine learning and AI to unlock new insights that can feed into new products and services. This leads to opportunities to surprise and delight customers along their journeys.

2

For transportation industry leaders, focusing on sustainability is now a basic requirement. However, leaders should not become complacent in their efforts and must continue to push for new technologies that can provide competitive advantages, such as better and smaller batteries.

3

Consider calculated investments in collaborative and assistive robots, which can supplement strained workforces and create efficiencies. However, there is not a blanket call for organizations to pursue such solutions. They will have to balance the threat of not acting with the capital expenditures required for adoption.

4

Pilot and passenger observation technologies might seem invasive to drivers and passengers, but investment in this tech can reduce accidents and save lives. In a future where autonomous driving becomes viable, these systems can be transformed to assess and anticipate the wants and needs of passengers, providing new ways to reach them.

5

Electrification is radically changing the transportation industry, and there will increasingly be new ways to engage with consumers who experience this new paradigm. Consider new products and services as passengers wait for their charging vehicles, providing opportunities for companies outside the traditional transportation industry.

6

Investing in robot compiling and training technologies has the potential to radically accelerate robots' abilities to learn and to adapt to their environments in real time. While hardware is very important to robotics, software is equally, if not more, important, potentially resulting in efficiencies that compound in time.

CENTRAL THEMES

Electrification Upends the Industry

As electrification becomes more pervasive in the world of mobility, the entire industry is being drastically redefined. While electric vehicles' range increases, spurring more adoption of EVs, the roadside experience is radically changing to include opportunities to engage drivers and passengers in novel ways. The advent of electrification is having impacts on the traditional business models associated with dealerships, forcing significant restructuring of how business is done. Repair servicing is at significant risk, as electric vehicles require less maintenance and different skill sets for making repairs. This shift is affecting supply chains and changing the types of materials needed, forcing manufacturers to make substantial investments in areas such as lithium processing. Electrification is also having an impact on safety standards, as EVs are less likely to be heard by bystanders. Amid electrification's scaling, stakeholders must fully consider its implications on the future.

Better Batteries Boost Improvements

Electrification of the broader industry will continue to face a "chicken or the egg" dilemma—battery capabilities must grow to drive electrification demand, and electrification demand must grow to drive battery technology. However, battery development continues to press forward, with capacity improvements, efficiency gains, and shrinking or altering of form factors to make them more relevant and useful. Improvements are helping increase the range of vehicles or the operational time of drones and robots, reducing the "range anxiety" of consumers and commercial buyers alike. These updates also enable these vehicles and units to focus more power on their compute abilities either in a trade-off for range or in addition to that extended range. This is leading to a new class of devices and vehicles that are more powerful and capable than ever before over longer time spans and distances.

Expanded Capacity and Capability

In both automobiles and mobility at large, robotics and autonomous systems are growing in their capacity to do tasks and support payloads, while their overall capabilities are increasing, too. These achievements are due to advances in both hardware and software. A constellation of vision, audio, and touch sensor systems, including lidar, radar, 2D and 3D cameras, accelerometers, gyroscopes, bump sensors, force sensors, and temperature sensors are enabling these devices to better sense the environments around them. Advanced methods for training and modeling, including using virtual elements to simulate training scenarios, are increasing these systems' capabilities and helping them achieve new thresholds of what is possible on even shorter timelines. As these systems become more adept and dexterous, they also benefit from increased strength and increased payload capacity. And as they become more dynamic, they will be better equipped to tackle new challenges.

CENTRAL THEMES

Maximizing Connectivity and Communication

The increased capabilities of vehicles, robots, and drones mean they can use their additional sensors and software to know more about their environments. This also requires these form factors to collect substantially more data than ever before and, in most instances, communicate back to their OEM, a third party, the end user or owner, and even each other. This is forcing product and vehicle designers to more closely consider the connectivity needs of these devices and the potential partnerships required to enable these higher levels of communication. As levels of autonomy increase over time, the compute load will as well, in addition to the vast amounts of data that will need to be collected in real time, and then streamed back and forth to the cloud's future iteration.

Mimicking Your Surroundings

When it comes to designing complex systems, nature is a meaningful muse for development and execution. To achieve fluid movement for robots, engineers often find inspiration from the movements of creatures and plants like jellyfish, caterpillars, and even vines—these allow the bots to be dynamic and even reactive based on external stimuli. Organic material also lends itself to the material design of robots, where tissues of specific organisms become instrumental in optimizing the functionality of a bot. Organisms, both living and dead, are increasingly finding themselves as key components of a robotic system, functioning as hands or grippers to lift and move objects. Organisms even factor into the training of robotics, as engineers have used ants as inspiration for enhancing the navigation capabilities of robots in challenging terrains. As robotics design remains challenging, nature will continue to provide valuable design solutions.

Tempered Autonomy

The development of autonomous systems is a major driving force for scientific advancement across the domains of mobility, robotics, and drones. Although the promise of fully autonomous vehicles has not yet been fully realized, autonomous driver assistance systems have significantly impacted the automotive industry and provide a strong signal for increased autonomy in the future. In the field of robotics and drones, varying degrees of autonomy are required for efficient and effective operation. The methods for programming these systems are becoming more sophisticated but are still in the early stages of refinement. As the technology advances, the level of autonomy in these systems is expected to continue increasing, leading to more efficient and advanced robotics and drones. The future of these domains heavily relies on the development of autonomous systems, and the progress made in recent years reflects a positive step toward achieving fully automated systems in the future.

ONES TO WATCH

Sertac Karaman, associate professor of aeronautics and astronautics at MIT, for his contributions in driverless cars, unmanned aerial vehicles, distributed aerial surveillance systems, air traffic control, and certification and verification of control systems software.

Aaron Becker, associate professor of electrical and computer engineering at the University of Houston, for his contributions to swarm robotics, distributed robotics, medical robotics, and motion planning.

Jonathan How, professor of aeronautics and astronautics at MIT, for his role in developing algorithms that keep drones from colliding in midair.

Bilin Aksun Güvenç, research professor in the Department of Mechanical and Aerospace Engineering at The Ohio State University, for her role in the development of Vehicle-in-Virtual-Environment testing, which allows testing of driverless cars in a safe virtual environment.

Steven Hartley Collins, associate professor of mechanical engineering at Stanford University, for his contributions to versatile prostheses and exoskeleton design.

Martin Nisser, a Ph.D. candidate in the HCI Engineering Group at MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL), for his efforts to democratize robotics and hardware by creating self-configurable and self-assemblable systems that address a diverse functionality of needs.

Chris Anthony and **Steve Fambro,** co-CEOs of startup Aptera Motors, for working to leverage a lightweight chassis, low-drag aerodynamics, solar cells, and materials science to provide high efficiency solar electric transportation.

Wei Wang, researcher at the US Energy Department's Pacific Northwest National Laboratory, for his contributions to using sugar to design better flow batteries.

Gill Pratt, CEO of Toyota Research Institute, for his role in using generative AI technology to quickly teach robots new, dexterous skills.

JB Straubel and **Andrew Stevenson,** co-founders of Redwood Materials, for pioneering circular supply chains and recycling pathways for end-of-life EV batteries.

Dr. Pisak Chermprayong and **Dr. Ketao Zhang,** who as researchers at the Imperial College London produced innovative work on 3D printing with drone swarms.

Daniel Preston, assistant professor of mechanical engineering at Rice University, for pioneering necrobotics.

Jensen Huang, founder of Nvidia, for his vision in enabling key components for robotics, autonomous systems, and AI.

Dr. Robert Playter, CEO of Boston Dynamics, for pushing the robotics industry forward while pledging to never weaponize technology, and other efforts to instill public trust.

Dr. Marc Raibert, founder of Boston Dynamics, for his dedication to the study of dynamic moving systems, including robots with legs, simulated mechanisms, and animated figures.

Henry Liu, professor of civil engineering at the University of Michigan, for his contributions to the first realistic simulated driving environment based on a "crash-prone" Michigan intersection.

Manoj Raghavan, CEO of Tata Elxsi, for his vision in leading a company whose advanced sensors and AI algorithms aim to keep individuals safe from the hazards of driving.

Michael Smith, postdoctoral researcher in soft robotics at EPFL, for his work in developing flexible, stretchable pumps for soft robotic systems.

Jocelyne Bloch, neuroscientist and neurosurgeon at Lausanne University, for her work in functional neurosurgery.

Giuk Lee, associate professor at Chung-Ang University, for his work on assistive exoskeletons and wearable robots.

Hyung Ju Suh, Ph.D. candidate in electrical engineering and computer science at MIT's CSAIL, for his work in enabling robots with human-like dexterity and intelligence in manipulation.

Russ Tedrake, Toyota Professor of Electrical Engineering and Computer Science, Aeronautics and Astronautics, and Mechanical Engineering at MIT, for his work in combining systems theory and robot manipulation.

Zachary Manchester, assistant professor of robotics at Carnegie Mellon University, for his efforts to enable robotic systems to match or exceed the level of agility, efficiency, and robustness demonstrated by humans and animals.

Josephine Galipon, associate professor at the Graduate School of Science and Engineering at Yamagata University, for exploring the potential benefits of collaborations between robots and living creatures.

IMPORTANT TERMS

MOBILITY

ADAS (advanced driver assistance systems)
Technologies that assist drivers by performing certain functions in a vehicle, such as blind-spot monitoring, lane departure warning, pedestrian detection, emergency braking, and traffic sign recognition.

AMD (assistive mobility device)
A mobility aid such as a wheelchair, scooter, walker, or orthotic.

Bidirectional charging
A system that enables an electric vehicle to transfer electricity back to the grid, as well as to charge using electricity from the grid.

EV charging port
The connector that supplies power to an electric vehicle when it is plugged in. Of the different connector types the most common in the US is the North American Charging Station, or NACS. Tesla uses it, and more manufacturers are adopting this connector.

ICE (internal combustion engine)
An engine powered by fuel combustion, most commonly gasoline or diesel fuel.

V2G (vehicle-to-grid)
Allows bidirectional charging so electric vehicles can receive electricity from a charging station, or share their stored electricity with the grid.

V2I (vehicle-to-infrastructure communication)
Enables vehicles to communicate with traffic lights, RFID readers, cameras, lane markers, and other parts of the physical world.

V2V (vehicle-to-vehicle communication)
Allows vehicles to exchange information with other vehicles, sharing data such as speed and location.

Levels of Automation
The Society of Automotive Engineers (SAE) clearly defines six levels of driving automation:

- **Level 0**
  No Automation
  A human driver manually performs all tasks.
- **Level 1**
  Driver Assistance
  A driver controls the vehicle, but the vehicle design may include some driving assistance features.
- **Level 2**
  Partial Automation
  The vehicle has combined automated functions, like steering and acceleration. However, the driver must always remain engaged and monitor the environment constantly.
- **Level 3**
  Conditional Automation
  A driver is essential. Driver does not need to monitor the environment, but must be ready to assume control at any time.
- **Level 4**
  High Automation
  The vehicle is capable of performing all driving functions under specified conditions. The driver has the option to take control.
- **Level 5**
  Full Automation
  The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to take control.

LEVELS OF EV CHARGING

There are three levels of charging. The higher the level, the less time it takes to reach a full battery.

- **Level 1**
  These charging stations use a standard 120v outlet. The time to charge a vehicle's battery can take 60 hours or more.
- **Level 2**
  These are the most commonly available charging stations and are used most often for home charging. The time to reach a full battery is around 11 hours.
- **Level 3**
  There are two types of rapid charging stations: DC Fast Charging and Supercharging. Level 3 stations can fully charge a battery in under 30 minutes and most closely resemble the customer experience of gasoline-powered cars. Tesla's standard is Supercharging, and the company has the largest network of Level 3 charging stations in North America.

IMPORTANT TERMS

ROBOTICS

Cobot
A collaborative robot built for interaction with human workers, assisting with certain tasks, often those that are repetitive or harmful to humans.

Exoskeleton
A rigid, mechanical robotic structure that encases the human limb, or envelops the body, and assists the wearer in motion-based activities, such as walking or lifting.

Microrobotics
A field of robotics that develops miniature robots, typically smaller than 1 mm (or .001 meters) in size.

Nanobot
A field of robotics that develops robots at the scale of a nanometer (or 10-9 meters).

Necrobotics
A field of robotics that utilizes biological material, such as insect cadavers, as robotic components.

Quadrupedal robot
A four-legged robot.

Robotics
The use of a physical, mechanical device capable of performing tasks at various levels of complexity, either on command or via preprogrammed instructions.

DRONES

AGV (automated guided vehicle)
A robot that follows specific lines, lanes, or other markings, often used in industrial settings.

AUV
Autonomous (or uncrewed) underwater vehicle.

BVLOS (beyond visual line of sight)
Operating an UAV outside of the visual line of sight of the operator.

Drone
An unmanned vehicle that can operate in the air, on land, or in the sea:

- **Fixed-wing drone**
  A drone with one rigid wing, resembling an airplane. It is typically capable of remaining in the air longer and flying longer distances than other drone types.
- **Fixed-wing hybrid VTOL**
  A drone with a rigid wing, and rotors that are attached to either side, enabling vertical takeoffs and landings.
- **Single-rotor drone**
  A drone with a single rotor on top, much like a helicopter.
- **Multi-rotor drone**
  A drone with multiple rotors. The most common multi-rotor drone is a quadcopter, which has four rotors.
- **Drone swarm**
  Fleets of networked drones capable of coordinated operations and communication.
- **eVTOL (electric vertical take-off and landing)**
  An electric-powered drone that has the ability to take off and land vertically, as well as hover.
- **Federal Aviation Administration (FAA)**
  Drone operators are required to comply with FAA rules. There are a multitude of airspace restrictions as well as FAA-Recognized Identification Areas (FRIAs). In a FRIA, a drone operator may fly their device without Remote ID.
- **UAV**
  Unmanned aerial vehicle.

MOBILITY TRENDS

ELECTRIFICATION TRANSFORMS MOBILITY ECOSYSTEMS

Decarbonizing Mobility

In the US, the transportation sector generates the largest amount of greenhouse gas emissions—primarily from burning fossil fuel for cars, trucks, ships, trains, and planes. In efforts to mitigate climate change, this industry is a prime candidate for impact. Some states offer proactive examples. California allocated more than $50 billion in funds to address climate change and move away from the use of fossil fuels. In the area of transportation, the state is implementing regulations to reduce toxic freight pollution and accelerate the deployment of zero-emission trucks; officials are also allocating emergency funding to ensure the safety of public transit riders and workers, in hopes of persuading more people to choose that form of transportation. California also enacted a Low Carbon Fuels Standard to ensure that it aligns with climate and environmental justice priorities. In Europe, the transportation sector is also a major contributor of greenhouse gasses, and officials are aiming for a 90% reduction to meet the EU's target of carbon neutrality by 2050. This transition poses significant challenges for European cities, which significantly contribute to these emissions; to support them in this effort, the EU is offering help creating Sustainable Urban Mobility Plans. However, various obstacles, including governance issues, need to be addressed. Additionally, the Council of the European Union has recently passed a new regulation aimed at facilitating EV travel across the continent while mitigating the impact of greenhouse gas emissions. The regulation mandates the installation of fast charging stations that offer a minimum of 150 kW of power at a maximum distance of 60 km (37 miles) from each other along the Trans-European Transport Network (TEN-T) highway system by the year 2025. As more electric mobility technology is adopted, cost structures and operations will continue to change. The mobility industry, including vehicle manufacturers, is already feeling the impact and rethinking business models.

Automaker Restructuring

Major car companies and transportation platforms are making significant investments in an electric future, with plans and announcements from the late 2010s now becoming reality. Western automakers are even investing in lithium mining companies to ensure a stable supply of this key component of EV batteries, committing billions of dollars to secure the resource. General Motors has invested $650 million in Lithium Americas to develop the Thacker Pass Mine in Nevada and has entered into supply agreements with lithium companies like Livent. Ford has arranged lithium supply deals with Chilean supplier SQM, Charlotte-based Albemarle, Nemaska Lithium in Quebec, and the Argentina mining company Rio Tinto.

Ford and Uber are collaborating through the Ford Drive program to provide flexible leases of EVs to Uber drivers. The goal is to support Uber's efforts to convert more drivers to EVs and reduce emissions, while Ford will benefit from expanding the presence of its Mustang Mach-E EVs. The initial pilot program offers one- to four-month leases in San Diego, Los Angeles, and San Francisco.

School districts are replacing traditional buses with electric models to reduce emissions and save on fuel costs, with potential orders up to $1 billion over the next five years. Blue Bird has opened a new Electric Vehicle Build-Up Center in Georgia to meet the increased demand for electric school buses, and aims to increase production from 100 to 5,000 electric buses annually. Blue Bird will assemble its "Vision" and "All American" buses, each with a 155 kWh battery providing 120 miles of range.

Mass Market Goes Custom

During the COVID-19 pandemic, the shortage of semiconductor chips caused significant supply chain constraints. The lack of chips, used in automotive parts such as operating systems, cameras, sensors, and entertainment systems, led to a decline in production, resulting in a shortage of vehicles. Dealers had little to no stock on their lots and were forced to operate as showrooms, where some customers placed orders for a custom vehicle with a longer lead time. While supplies are slowly and tortuously improving, CEOs of major car brands anticipate that inventory

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levels will never go back to where they were pre-pandemic. But this window has revealed that customers will wait and pay for their dream car, with the ability to pick their desired color, features, and accessories. Consequently, build-to-order purchases will likely continue to increase and render big vehicle inventories less necessary. Ford is extending this schematic to its Mustang Mach-E, offering a $1,000 discount in some instances for customers who pre order. This trend is likely to continue as more production lines shift to increased EV manufacturing. Such a shift does have tremendous implications for the industry, changing the nature of dealerships and impacting current commission and profit-sharing structures. Both the industry and consumers will have to adjust to such restructuring, and adequately prepare for impending shockwaves.

Incentive-Driven Investments

Many vehicle manufacturers and battery makers are investing heavily in the development of electric vehicles and their future success. A recent analysis by Atlas Public Policy reveals that a total of $860 billion will be invested globally by 2030 toward the transition to EVs. In the US, investments are expected to total $210 billion—almost a quarter of the entire investment. Amid this spending increase, some of the benefits are trickling down to consumers. Increased plant capacity, production scaling efforts, and improved battery material costs are enabling Ford to reduce the prices of its F-150 Lightning electric truck models by up to $10,000 to incentivize sales. The base F-150 Lightning Pro will be priced at $49,995. Elsewhere, Geely announced the Galaxy E8 sedan (about the size of a Honda Accord) will be on sale in the Chinese market for under $25,000. Automakers are also taking advantage of tax incentives associated with EV production. The state of Georgia has offered Rivian $1.5 billion in tax incentives for the company to build a $5 billion factory east of Atlanta. There, Rivian plans to produce 400,000 electric vehicles annually and provide 7,500 new jobs after officially getting the green light to move forward with production. While tax credits have been effective at enticing consumers to purchase EVs, the Inflation Reduction Act has unexpectedly complicated the practice. In August 2023, the law restricted the $7,500 tax credit to only EVs assembled in North America. As a result, automakers that can no longer incentivize new car buyers this way are encouraging consumers to lease EVs.

Global Battery Belts

Major players in the automotive and battery chemistry industries are investing in US battery production. States that attract electric vehicle manufacturing and battery plants highlight the job opportunities these investments create, not only within the plants themselves but also in the surrounding supplier and logistics sectors. The growth in EV manufacturing is especially prominent in the Battery Belt: The area, which runs from Detroit to Georgia, offers lower electricity costs and strong manufacturing employment growth, driving industry expansion. As an example, Hyundai Motor Group and LG Energy Solution announced a joint investment of $4.3 billion in a new electric battery plant in southeast Georgia. By late 2025, the plant expects to be producing batteries for electric vehicles and aims to accelerate the production of electrified Hyundai and Kia vehicles in North America. But despite this push by US companies to produce more batteries, most production is still dominated by China. Last year, China refined approximately 95% of the world's manganese, around 70% of cobalt and graphite, two-thirds of lithium, and over 60% of nickel, all of which are vital components in the production of lithium-ion batteries. In time, that could change, especially with the 2023 discovery of lithium in a US volcano along the Nevada-Oregon border, which could result in a stable and sustainable source of the metal for the US for decades to come.

Battery Recycling

The debate surrounding the sustainability of EVs versus internal combustion engine vehicles (ICEs) revolves around the environmental impact caused by the mining of lithium and cobalt, which are crucial materials for batteries. However, by using recycled battery components, the need for new mineral mining can be reduced, leading to a more environmentally

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friendly EV market. Currently over 80 companies worldwide are engaged in the recycling of electric vehicles, with over 50 startups receiving at least $2.7 billion in funding from corporate investors such as automakers, battery manufacturers, and mining companies. Industry insiders predict that by 2040, up to 40% of the battery materials used in new electric vehicles could come from recycled sources. A prominent player in this space, Redwood Materials, has partnered with Ford and Volvo to establish responsible disposal and recycling pathways for end-of-life EV batteries. They are also going beyond EVs and collaborating with Rad Power Bikes to conduct the same process for retired e-bike batteries. Ascend Elements has secured $542 million in Series D funding along with $480 million in earlier Department of Energy grants for recycling lithium batteries into black mass to be reused in other materials. Additionally, Nth Cycle has secured a focused Series B funding round of $50 million, and Green Li-ion has received $20.5 million in funding to support its recycling initiatives.

Better Batteries

Electric vehicle manufacturers and their partners are working hard to improve batteries by exploring new battery types, designs, and materials. The development of solid-state batteries and other innovative battery solutions will make batteries smaller, safer, and capable of providing longer ranges, much like the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) research that developed a new way to make solid-state batteries with a lithium metal anode. Beyond the obvious safety and range benefits, enhanced batteries will provide greater versatility in terms of battery shape, which will allow for more options in different mobility platforms and provide more cabin space in vehicles. QuantumScape is striving to make solid-state batteries available to the public as early as this year. This technology will allow EVs to travel up to 400 miles on one charge and recharge in only 15 minutes. Toyota plans to be using solid state batteries by 2028, reducing the size, cost, and weight of its EV batteries by 50%. General Motors is investing $60 million in Mitra Chem to use iron-based cathodes to make battery technology more accessible and cost-effective. Researchers at Pacific Northwest National Laboratory have developed a breakthrough in flow battery technology by using a solution based on sugar to lead in the development of low-cost, long-duration energy storage systems, which could impact the source of energy for charging EVs. Startup Ample is taking a different approach, focusing on battery swapping as a means to keep EVs on the road.

Solar Vehicles

Solar-powered EVs require less frequent charging and can increase efficiency. A recent study found that solar-powered cars can travel between 11 and 29 kilometers per day using solar energy, reducing the need for frequent charging. These solar cars have the potential to make electric transportation cleaner and more affordable by minimizing pollution from electricity production. Dutch startup Lightyear saw the advantage of solar, but despite its efforts, was declared insolvent in 2023 shortly after releasing its $250,000 Lightyear 0 solar car. After raising more capital, the company will try again with a more affordable Lightyear 2, which has a starting price of $40,000. First revealed as a concept, Kia’s EV9 SUV features solar panels to supplement its 100-kilowatt-hour battery; the company started taking reservations for the EV9 in late 2023. In contrast to a large SUV, California-based Aptera Motors focuses on producing ultra-efficient EVs through aerodynamics and weight savings. Its three-wheeled EV, the Aptera, boasts a highly aerodynamic design with a drag coefficient of 0.13, offering up to 400 miles on a single charge, which can be supplemented through included solar panels. While solar vehicles will not eliminate the need for charging any time soon, their integration will help the industry move toward more sustainable transportation.

Shifts in the Servicing Model

While the mobile service model is not new, it’s increasingly impacting the mobility and automobile industry. Now, mechanics can travel to meet customers in their physical locations, and over-the-air updates can, in some

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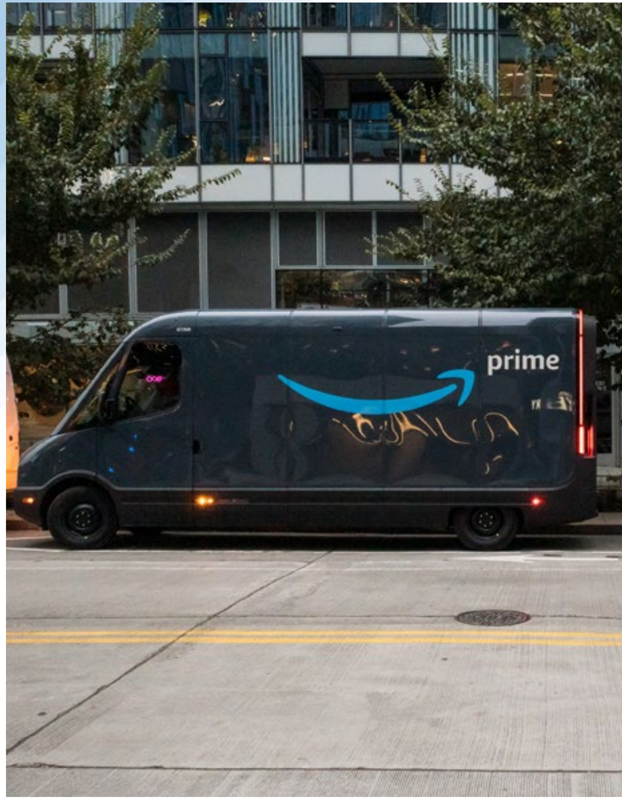
instances, resolve digital-based issues. As the model takes hold, this presents a significant threat to traditional dealership/servicing models, and companies are racing to adapt. Rivian plans to repurpose large commercial Amazon vans to function as mobile service vehicles for its consumer and commercial vehicle fleet. These electric Rivian Service Vans will offer maintenance, repair, and vehicle-to-vehicle charging. Ford is recognizing the need to enhance the vehicle service experience and is moving to expand its remote service offerings. The company will be providing complimentary pickups and deliveries of its vehicles and mobile repair options to more of its customers. Startups are also taking advantage of this shift. On-demand car care startup Spiffy has acquired $30 million in funding to aid car dealerships in expanding its mobile service offerings. Through sales of its software and van upfits, Spiffy plans to help dealerships and repair shops provide mobile brake maintenance and oil changes. Repair servicing is really beginning to go the extra mile to win customers and foster and enhance relationships.

Electrification Expands to Other Vehicles

The rise in electrification of vehicles is extending beyond consumer cars. Delivery carriers like Amazon and the US Postal Service are investing in the technology: Amazon aims to deploy 100,000 electric delivery vehicles by 2030, and the USPS says it will buy over 66,000 electric vehicles by the end of 2028. When it comes to aviation, ZeroAvia has successfully flown the world's largest hydrogen-electric aircraft as part of the HyFlyer II project, a government-funded initiative aimed at making small passenger planes more environmentally friendly. Magpie Aviation, a California company, has proposed using electric aircraft as towing planes to connect with passenger or cargo planes that have sufficient battery power for takeoff, landing, and flight to alternative airports. Electric boating is impacting both small and large-scale initiatives. BMW and Tyde have launched the ICON electric boat, a 43-foot eco-friendly vessel powered by hydrofoils, six BMW i3 batteries, and two electric motors. It has a range of more than 50 nautical miles and a max speed of 30 knots. On the other end of the spectrum, China has unveiled its first battery-electric container ship, the 700 TEU, which has a capacity of carrying 700 20-foot containers. Even micro mobility is becoming electrified, as the e-bike company Cowboy introduces a more affordable Core line of its e-bikes and startup AtmosGear has unveiled electric inline skates featuring a 20-mile range on a full charge.



Amazon Prime electric delivery vans built by Rivian on the street in Seattle.

Image credit: 400tmax/istock.com

VEHICLE CHARGING SCALES

Charging Gets A Roadmap

The electric vehicle revolution is well underway, but a key bottleneck remains a concern: charging infrastructure. Rural and suburban consumers alike have had their desire to adopt EVs hampered as a result of "range anxiety"—the fear of running out of charge mid-journey. Recognizing this anxiety, regulators in the US have approved $5 billion for EV charging projects over the next five years and recently allocated an additional $2.5 billion for community chargers. Europe has gone even further, mandating fast charging stations within every 60 km length of major highways by 2026.

The private sector is stepping up its efforts, too. Automakers have gotten closer to convergence on charging standards with several top manufacturers adopting the Tesla connector for their vehicles. Major brands like Walmart, Sam's Club, Comcast, Ikea, Marriott, and Hilton have committed to build tens of thousands of new chargers across all of their properties, in addition to tens of thousands in combined charging station commitments made by BMW, GM, Honda, Hyundai, and Mercedes. Improvements to existing infrastructure are also underway with Tesla promising 40% faster charging through its V4 technology, companies like EVgo launching initiative's to "renew" existing stations, and navigation services like Waze integrating charging locations into its navigation tech to improve peace of mind in trip planning for EV adopters.

Charging Standardization

One of the lingering issues in the development of the EV market has been fragmentation of charging standards. Globally, the Combined Charging System (CCS) has been the prevailing standard, but the North American Charging Standard (NACS)—commonly known as the Tesla connector—has become the standard in North America with Tesla's overwhelming EV market share. This divergence has become more complicated since Tesla began open-sourcing its NACS connector design at the end of 2022, but progress has been made toward cross-compatibility.

Major automakers including Ford, Rivian, Fisker, GM, Honda, Volvo, Jaguar, Nissan, and Mercedes-Benz have pledged to adopt Tesla's NACS connector or offer NACS adapters, making standardization one step closer in the US. Tesla has also begun to expand its "Magic Dock " superchargers in several US states, adding CCS compatibility in much the same way it has had to in Europe. These two developments have not only moved global charging capacity closer to universal compatibility but have instigated a renewed incentive for further charger development.

As EV adoption and universal compatibility increases, the need for charging station capacity intensifies. This opens up a new vector of competition throughout the industry where vendors, partnerships, and entertainment offerings at charging stations may dictate station utilization rates, and innovations like real-time pricing could allow for solar-powered stations to out-compete traditional stations during fluctuations in solar availability.

Redefining the Roadside

The rise of EVs is transforming our roadside experience. Extended charge times have led retailers like Walmart, Ikea, and Macy's to integrate charging tech, turning wait times into retail opportunities. Tesla's drive-in-diner concept provides culinary and film experiences while EVs charge, while Juxta offers autonomous stores at traditional charging hubs.

With the surging EV demand, innovative solutions are addressing infrastructure gaps. Ample swaps batteries in just five minutes. EV Safe Charge is piloting robots to charge vehicles in non-equipped garages. SparkCharge delivers on-demand charging where fixed infrastructure is lacking.

Even in emergencies, adaptations are evident. Apple's new satellite function broadens the coverage for roadside assistance in low-signal areas. Meanwhile, AAA assists stranded EVs with mobile charges and is exploring electric tow trucks for green, on-the-go recharging.

VEHICLE CHARGING SCALES

Electrifying Cities

Accelerating frequency and severity of climate events, along with rising electric vehicle adoption, has seen cities push their electrification strategies to the top of their agenda. On the grid, decentralized energy systems have been a consistent theme. Public utilities like Vermont's Green Mountain Power are installing batteries in customers' homes to ensure power resilience during outages and to optimize costs by utilizing stored resources during periods of low supply or peak demand. In North Carolina, a residential community called Heron's Nest is being developed to include a microgrid independent of the larger grid. Each home includes a solar energy system contributing to a collective network that not only powers the community but ensures its resilience and sustainability.

In transportation, cities like New York City and Los Angeles have considered requiring rideshares to run completely on EVs by 2030. To cope with rising demand for charging in cities, governments are racing to expand capacity. France, for example, is working with Electreon to install wireless charging on its roadways, and the US recently earmarked $25 billion to expand community charging capacity. These actions underscore what is becoming a global shift toward a sustainable and resilient urban future, ensuring cities remain powered, efficient, and ready for the next era of electrification.

EVs At Home

As the EV market has matured, a significant shift has been taking place in the home. On the heels of California's 2020 mandate for solar installations in new homes, Illinois has passed laws requiring new and renovated properties to have at least one EV-capable parking space for each residential unit that has dedicated parking by 2024. A proposal under consideration by New Mexico legislators would go even further, mandating all new homes be constructed with a solar-powered system and EV charger. In Germany, a grant to help fund home-charging installations was tapped out in one day, with over 33,000 people applying just hours after it went live. These regulatory efforts coincide with initiatives from automakers to try to bring chargers to the home. Hyundai, for example, has pushed promotions that would provide a free EV charger and a reduction in installation costs to every new customer.

These efforts to transform have paved the way for more widespread adoption, but the swift transition has also uncovered potential challenges for EVs at home. Surveys by the Electrical Safety Foundation indicate that the electrical systems of over half of US homes may be unable to safely carry the continuous load that EV charging demands. If the rapid adoption of EVs leads to an increase in brownouts, electrical surges, or fires resulting from overloading home electrical systems, more stringent regulations may become more popular for concerned local governments and homeowners associations. Still, forward-thinking communities may use the opportunity to collaborate on more communal solar arrays or shared charging stations, presenting an efficient and cost-effective solution.

Electric vehicles taking advantage of chargers on city streets.

VEHICLE CHARGING SCALES

Bidirectional Charging

Electric vehicles with bidirectional charging capabilities present an exciting frontier. These vehicles can not only consume energy but also supply it for other applications, transforming the traditional role of cars. No longer merely used for transportation, bidirectional EVs now have the potential to energize homes, businesses, and entire communities. With bidirectional charging, owners can strategically charge their cars overnight using affordable grid energy and then utilize the EV's stored energy during high-demand daytime periods, ensuring efficient use of resources. Growing challenges such as the energy crises linked to geopolitical events in Ukraine, escalating climate disruptions across the globe, and widespread concerns around outdated infrastructure and cybersecurity only underscore the timely importance of this technology.

The automotive industry has been quick to embrace this innovation. Ford, Genesis, Hyundai, Kia, Mitsubishi, Nissan, and Volkswagen have all rolled out vehicles with bidirectional charging. GM has gone a step further, declaring that by 2024, vehicle-to-home (V2H) charging will be a standard feature in its vehicles. Other industry leaders like BMW, Volvo, and Porsche are actively testing this technology. Even Tesla, which initially seemed skeptical, has announced plans to incorporate bidirectionality in all its vehicles by 2025.

Municipalities are recognizing the value of this transformative technology in energy management. Utrecht, a prominent city in the Netherlands, stands out in its adoption, actively installing bidirectional charging stations that allow shared vehicles to contribute energy back to the grid. In the US, California is at the forefront, contemplating legislation to make bidirectional charging mandatory for new EVs. The possibilities are vast, and the trajectory suggests a future where our vehicles play an integral role in a sustainable energy ecosystem.

Rendering of the Nissan Vehicle to Home (V2H) System concept

Source: Nissan

IMMERSIVE VEHICLES CONNECT TO OTHER ECOSYSTEMS

Livable Cabins

Auto manufacturers are revolutionizing the way we experience our vehicles. Rather than a car solely serving as an uninspired vessel to get us from one location to another, manufacturers are emphasizing enhancing cabin environments. Now, they're not just for driving but also for riding, relaxing, working, and playing. In many instances, automakers attempt to transform these landscapes through the increased use of screens. In a Peugeot concept called Inception, a screen-supported human-machine interface replaces the traditional steering wheel and displays control information. Continental is also capsulizing on the screen-infused future with its ultrawide In2visible: a touchscreen that spans the full length of the dash resulting in a high-intensity driving experience. Ultimately, such interfaces are intended for fully integrated digital experiences. Chrysler has given its view of a fully electric future where the cockpits of its vehicles integrate Stellantis-branded software, including the STLA Brain operating system, STLA AutoDrive Level 3 driver assist, and STLA Smart Cockpit infotainment system. This connected experience will sync with calendars and smart home data, handle driving tasks within designated areas, and even offer wellness and fun features, like meditation and in-car games. But the proliferation of large and clunky screens is being sharply criticized, as they have impacts on ergonomic, safety, and aesthetic factors. If they continue to grow unchecked, they could ultimately be challenged by regulators. Despite these concerns, as personal mobility is enhanced with longer ranges and increased implementation of autonomous driving features, auto manufacturers will continue to improve comfort within vehicles and engage customers through new onboard touchpoints, impacting how we've traditionally engaged with roadside attractions and amenities.

Simulated Driving Experience

Electric vehicles are known for being incredibly quiet, and some view this as problematic. Specifically, EVs don't make the typical shifting noise that drivers are used to hearing, and this can cause issues by depriving drivers of auditory and even touch-based feedback they are accustomed to. This also affects bystanders. The lack of noise from electric cars contributes to their high rate of accidents: EVs are 40% more likely to hit a pedestrian than a normal car, and for the visually impaired population, this number jumps to 93%.

Toyota is adding audible features to its electric cars—including a simulated gear stick and artificial "noise" simulating a combustion engine—aimed at drivers who prefer a more traditional driving experience. This simulated manual transmission experience might even come with the possibility of stalling in order to retain the charm and enjoyment of driving a manual transmission car. Hyundai and Dodge are also exploring sound design in the execution of their EVs, not just for preference reasons but because the addition of artificial engine noise is also a safety standard, alerting pedestrians to the presence of electric vehicles. Ultimately, some manufacturers are hoping that drivers are more likely to adopt electric cars if they sound and feel just like their gas-powered counterparts, while the inclusion of these simulations is primarily about keeping people safe.

In-Vehicle Connectivity

The role of high-speed, low-latency connectivity is becoming a prominent factor impacting the performance of the vehicle along with the in-cabin experience. While internet access in cars is not new—Starlink currently provides connectivity for Subaru—carriers such as AT&T and Verizon have ambitions for executing on this modality. AT&T, in particular, sees 5G connectivity in conjunction with edge computing as a way to enable new functions and services through this network and cloud convergence. This framework will not only support the safety and mission-critical functions of the car but also intelligent transportation systems, teleoperations,and autonomous driving, along with onboard infotainment systems. More tactically, Verizon launched the Connected Car by Verizon, which offers select BMW models features such as voice, data, and unlimited Wi-Fi hotspot connectivity through subscription. With regards to more tech

IMMERSIVE VEHICLES CONNECT TO OTHER ECOSYSTEMS

demonstrations or spectacles, General Motors collaborated with Etisalat to host a gaming tournament that took place entirely within connected Chevrolet and GM cars equipped with in-vehicle Wi-Fi. The tournament featured 10 gamers who participated in a 12-hour event covering 450 km of roads in the United Arab Emirates, organized by OnStar. Cradlepoint partnered with The University of New South Wales for the Bridgestone World Solar Challenge race, by providing 5G/LTE wireless network edge solutions for the Sunswift 7 solar race car and support vehicles. This technology allowed the team to remotely monitor the car's performance and telemetry data. As connectivity becomes more reliable, more subscription services like Verizon's Connected Car are inevitable, much to the disappointment of most consumers.

Mobile Entertainment Hubs

Vehicles are becoming increasingly equipped with multiple entertainment options for passengers and drivers, including technologies such as immersive audio, large screens, and the ability to stream movies, TV shows, and video games. While Apple and Mercedes-Benz have enabled spatial audio in vehicles, Jaguar Land Rover is turning to haptics to enhance the music experience. Its "Body and Soul Seat" technology, dubbed BASS, features headrest-mounted membranes and transducers that provide haptic feedback in response to lower frequencies in music—and even offer health benefits through integrated wellness programs. Automakers are continuing to add features to be enjoyed by passengers while they're commuting or charging their EVs. Xperi and BMW have collaborated to use TiVo's video media platform in cars to offer customers access to various video content providers, including linear and on-demand streaming services, covering country-specific content such as news, movies, and media libraries. Polestar's most recent software update, P2.9, includes the addition of YouTube for streaming videos during vehicle charging and a revamped version of Apple CarPlay that allows Maps to be projected onto the instrument cluster. Polestar is also the first automaker to offer Nvidia's cloud gaming service, GeForce NOW, in its vehicles. The service connects to the cloud to access an extensive gaming library. While the use of these technologies is limited for safety, inevitably, these technologies are intended for broader adoption as we inch closer to an autonomous driving future. Ultimately, these new platforms intend to simplify content discovery and enhance in-car entertainment.

CarOS

As cars become even smarter and offer more immersive experiences, navigational and entertainment systems will continue to evolve, necessitating a holistic and centralized operating system. In the current market, many options are available, developed by both OEMs and technology companies. While tech companies have taken a lead in years past, some OEMs are attempting to regain control. Google is making progress in the automotive industry through Android Auto—an app that operates on the user's smartphone and wirelessly sends navigation, parking, media, and messaging to the infotainment system of the vehicle—and Google Built-in, which directly integrates Google services within the vehicle. Brands like Chevrolet, Renault, Volvo, Polestar, and Honda are set to showcase features like YouTube available in cars with Google Built-in, gaming with GameSnacks, conferencing with Cisco, Microsoft Teams, and Zoom, and further integration with Google Assistant. General Motors is indexing significantly on Google, and in the process is ditching Apple CarPlay for Android Auto in its upcoming electric vehicles. Relating to OEMs, Swedish EV manufacturer Polestar has teamed up with Xingji Meizu to develop an operating system for its cars in China, as part of Geely Group's strategy to tailor vehicles for the Chinese market. The new system, based on Flyme Auto, will connect with in-car apps and mobile phones, and use the latest smart technologies. Jaguar Land Rover is set to release its new electrical/electronic (E/E) architecture, EVA Continuum, with the help of Continental subsidiary Elektrobit for running its software platform and operating system. This move enables faster development and over-the-air software updates, a strategy that other automakers are also beginning to adopt.

SCENARIOS

SCENARIO YEAR 2038

What if expanded vehicle capabilities redefine the nature of home ownership?

As younger generations grapple with lower real income, higher housing prices, and an expanded tolerance for remote work, connected vehicles became the new starter home of yesteryear. Risks associated with pandemics, crime, and higher rates of depression drove people out of cities and closer to nature, and their vehicles stepped in as an invaluable resource. Mesh networks of 5G and satellite-enabled internet allow people to work, consume entertainment, and connect with others virtually in the comfort of their vehicle—no matter where it's located. Vehicle cabins are redesigned around sleeping, working, and relaxing, while new features that enable cooking, food storage, and waste management become popular add-ons. AI allows vehicles to assist passengers with daily tasks like cooking food or supporting work, while providing security, health monitoring, and the ability to contact emergency services or autonomously drive the vehicle to receive help during situations of duress.

DATA COLLECTION ENABLES SAFETY AND AUTONOMY

Mobility Simulation

Simulation has become an increasingly ubiquitous component across several areas of mobility and will be a defining characteristic in the development of its future. Tesla, for example, has been relying on its Dojo supercomputer to simulate billions of miles of driving for its autonomous driving software since choosing to rely purely on cameras and neural nets to provide its vehicles with self-driving capabilities. Mercedes has also made simulation more central to its strategy, forming a partnership with Nvidia that only underscores this trend. Leveraging Nvidia's Omniverse Generative AI platform, Mercedes hopes to improve its vehicle designs and craft enhanced driving algorithms by simulating countless potential real-world scenarios, to create vehicles that respond optimally across various conditions.

Universities like Ohio State and the University of Michigan have brought mobility simulation to academia as well. Ohio State, for example, uses simulated environments to test the safety and aptitude of real driverless cars, while the University of Michigan has begun running simulations on historically crash-prone intersections to try and reduce incidents. Globally, the Indian city of Chennai is now using traffic simulation to study and improve congestion within its borders; while academics in Egypt and Brazil are relying on simulation to test and demonstrate new innovations in traffic signal technology. As data abundance exponentially expands, simulation will increasingly be at the heart of mobility design.

Self-Aware Vehicles

Vehicle connectivity is changing the landscape of mobility. The abundance of sensors, monitors, computing power, and network availability has enabled vehicles to provide information and, in some cases, act on it in ways that would have once been considered unprecedented. For example, this year, Goodyear tested its SightLine tires, which can measure tire-road friction, wear, load, inflation pressure, and temperature. Software-enabled vehicles can integrate with and monitor multiple powertrains or propulsion sources, allowing vehicles to reach as much as 1,000 horsepower while maintaining equilibrium to prevent risks like disintegration. Indian technology company Tata Elxsi is developing technologies that would alert automobiles to approaching emergency vehicles, and indicate slippery roads, dangerous curves, and potholes or roads under repair so that they can appropriately adapt to the approaching conditions. Honda and Sony's Afeela cars are being designed to "feel" their driver's moods and allow them to express themselves and interact with others on the road via external screens on the front of their cars. Ford has even patented self-reporting technology that allows cars to lock out drivers, disable features like air-conditioning, restrict driving to only certain hours or locations, and to even utilize self-driving to return cars to an impound lot. As vehicles continue to get more connected and aware, mobility will look strikingly different from the modern day mobility environment as we know it.

Pilot and Passenger Observation

Technological advancements have enabled detailed monitoring of both driver and passenger behaviors, significantly enhancing safety and operational efficiency within vehicles. Safety sensors and equipment are now being built to detect distraction, drowsiness, and substance influence. Smart Eye's Driver Monitoring System, for example, gauges driver attentiveness, providing real-time feedback to prevent mishaps. Similarly, Magna's advanced driver assistance systems use cameras and interior mirrors to identify distracted behavior and try to reduce accidents. In the US, the government is pushing to require in-vehicle breathalyzers by 2026 so that drivers under the influence cannot take the wheel until the vehicle confirms their capacity to wield it responsibly. As vehicles gain more ability to observe and control those within them, entirely new privacy and data security concerns are emerging. With monitoring systems becoming more common in standard vehicle requirements and designs, a balanced framework that addresses both safety enhancements and privacy concerns will become crucial for

DATA COLLECTION ENABLES SAFETY AND AUTONOMY

getting the best out of these technologies.

Mobile Weather Stations

The Mobile Weather Station (MWS) has become a crucial instrument for the real-time monitoring of weather and environmental conditions, offering granular insights crucial for sectors like transportation, agriculture, and emergency response. While universities across the United States, along with companies like Verizon, are creating some of the technologies that enable the stations, several states and municipalities are using them to bring about improvements across their domains. For example, in New York City, the FloodNet Initiative utilizes MWS to monitor water levels, predict flooding events, and optimize drainage systems to minimize potential damage to the metropolitan area. In California, MWS is being used to detect early indicators of potential wildfires and changes in algae levels that can ultimately save lives and preserve ecological health. In Connecticut, MWS was introduced to gather air pollution data to ensure public health and enforce breaches in regulatory compliance. As drones, cameras, sensors, meteorological instruments, particle detectors, mobile networking, and high precision GPS technology continue to improve, expect to see the MWS become more ubiquitous across the US.

Mobility Superapps

Superapps are emerging as a powerful force, amalgamating various transportation services into a singular mobile platform, and subtly changing the mobility landscape for governments, businesses, and consumers alike. They embody a convergence where ride-hailing, public transit, and even non-transportation services harmonize, offering a seamless user experience. Leading this transition are companies like Uber and Grab. For example, Uber's ambition extends beyond ride-hailing; in the UK, its app integrates bikes, scooters, trains, buses, and even planes, aspiring to set a precedent in global mobility solutions. They're not just about consolidating services for consumer convenience but also about orchestrating a smarter, sustainable urban mobility framework. And with every transaction, Uber gathers invaluable data that enhances the user experience in addition to providing insights that can inspire better urban planning, public transit, and infrastructure decisions by local governments. Companies across Asia and the Middle East have already proven the viability of superapps, but now US mobility and technology companies are striving to be the first to make superapps the norm domestically.

Utilizing Mobility Data

Mobility data has become a pivotal asset in modern transport dynamics. Real-time monitoring and analytics, combined with geospatial data, enables companies to harness spatial information to create and enhance products and services across the mobility spectrum. New open map data sets like what are provided by the collective efforts of Amazon, Microsoft, and Meta add to the map data already offered by Apple and Google; this additional competitive pressure will likely lead to further innovation across the space. More widespread availability of data and analytics has also allowed companies like Uber and Lyft to leverage mobility data to pinpoint underserved areas and identify burgeoning potential for new markets or services. This data can also help automakers and municipalities identify optimal locations for charging stations or micromobility docks, to effectively spread charging capacity and achieve optimal utilization. Richer mobility data can also lead to improved regulatory efforts. For instance, data insights can help inform regulations for autonomous vehicles and ride-sharing frameworks, and potentially become the catalyst for standardizing data-sharing protocols among mobility providers. As the investment in and availability of mobility data continue to grow and the sources for collecting the data expand, a future where mobility solutions are seamless, efficient, and tailored to individual needs will start looking like the norm.

Relying on ADAS

As the auto industry continues to push toward fully autonomous self-driving, advanced driver assistance systems (ADAS) are giving drivers a glimpse of what that future might look like.

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New vehicles are increasingly coming with automated technology to monitor blind spots, stay within lanes, parallel park, and trigger automatic emergency braking (AEB). The driver's experience is evolving, with ADAS reducing the manual load, creating a more relaxed yet controlled driving environment. Estimates suggest that ADAS implementation has the potential to prevent up to 250,000 deaths between 2021 and 2050, not only saving lives but likely also reducing insurance and health care costs . On the regulatory front, regulators are already proposing stricter requirements for AEB to mitigate high-speed collisions and better protect pedestrians and drivers. Looking ahead, ADAS applications will continue to expand. Advancements like adaptive cruise control and intersection assist can further mitigate risks and improve traffic flow. Several collaborations are taking place across the industry to make these systems a reality. Porsche and Mobileye, for example, are pushing the boundaries, developing systems capable of full collision avoidance and other sophisticated functionalities. Such advancements portend a future where features of these kinds are the standard and hopefully driving is safer, more accessible, and economically beneficial as a result.

Pedestrian Concerns

The advent of autonomous vehicles (AVs) and micromobility solutions like e-scooters and e-bikes in urban landscapes has triggered a cascade of pedestrian concerns. In Austin, Texas, complaints are rife about dangerous encounters with AVs, one notable incident being a Cruise vehicle veering off-road into a small building. Similarly, in San Francisco, robotaxis have been reported blocking traffic, obstructing emergency vehicles, and causing nuisances. The micromobility sphere isn't devoid of issues either; e-scooters and e-bikes have been associated with injuries, like in incidents reported where riders navigate recklessly amid pedestrian traffic or lose control, leading to accidents. Research from the US Consumer Product Safety Commission shows that micromobility incidents increased by 21% year over year in 2022, as e-bikes, e-scooters, and hoverboards grew more popular.

These real-world incidents have spurred a mix of public, regulatory, and commercial responses. In California, legislation requiring safety operators on autonomous trucks was a notable step toward ensuring safer road interactions, but in San Francisco, the expansion of driverless taxi services has prompted protests by city officials and civic groups. Commercial entities are also pitching in; Cruise officials in Austin have been training first responders to foster safer interactions with their AVs. As AVs and micromobility solutions continue to meld with urban mobility, addressing pedestrian safety concerns through a combination of legislation, community engagement, and technological advancements will be paramount.

AV Viability

Autonomous vehicles are making major strides in capability and level of adoption, but full self-driving still remains far out of reach. Most come standard with autonomous features that keep them in lanes and cause them to brake automatically, and features that allow automobiles to autonomously change speeds, change lanes, and take advanced actions like parallel park are becoming increasingly common. Mercedes has begun to test Level 3 autonomous driving, and more major auto manufacturers are slated to begin testing their Level 3 vehicles in the coming years. Some AV software developers have been testing robotaxi services in select municipalities, with some going as high as Level 4 autonomy. Meanwhile, several auto manufacturers have started adding features and services to their vehicles to facilitate productivity and entertainment for passengers in anticipation of autonomous driving freeing up drivers' attention. Yet several major hurdles remain for Level 5 autonomy. Some friendly legislators have resisted pressure from stakeholders like truckers and pedestrians, giving AV manufacturers some breathing room to begin testing and rolling out their vehicles. But federal legislation to address the topic has been stuck in Congress for six years with no signs of life. With challenges that include safety concerns, cybersecurity threats, insurance liability risks, and questions regarding infrastructure readiness, privacy protection,

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and ethical frameworks to dictate how AVs make decisions in trade-off situations, full implementation faces many major hurdles. That's why Ford, for example, stopped developing full self-driving in favor of nearer-term goals like Level 3 and Level 4 autonomy. What's clear is that whether it's full self-driving or not, autonomy is here to stay.

Local AV Regulations

As vehicles become more sophisticated, adding semi- or full-autonomous features, local governments must determine when and how to authorize their use within city limits. Many local governments and business communities eye autonomous vehicles as an engine for economic growth. Cities and states are exploring new ways to integrate autonomous vehicles into their longer-term planning. Phoenix and Los Angeles, among other cities, are developing innovative approaches to designing, building and testing autonomous vehicle systems. Several states and cities are considering legislation to help bring the technology to market. But regulations intended to spur development could hit a roadblock—city and state governments control their local streets, but the federal government regulates surrounding highways; for autonomous vehicles to become ubiquitous and practical, America's roads would need to be interoperable.

Robotaxi Growth

Robotaxis are undergoing significant testing and deployment across numerous US cities, with 23 states having enacted laws permitting companies to do so. Moreover, at least eight other countries in Europe, Asia, and the Middle East have embraced the robotaxi revolution through testing and operations. Operating up to Level 4 autonomy, robotaxis primarily function within geofenced urban areas that are well-mapped, characterized by slower speed limits, and highly trafficked, which provides ample data for system refinement. Robotaxis have now amassed several million miles, and over 100,000 users wanting to experience a robotaxi service are still on Waymo's waitlist alone. Although assertions that robotaxis are safer than human-driven vehicles may be premature pending more extensive service miles, the initial results are encouraging. Yet, challenges persist. Cruise, projected to incur over $2 billion in losses in 2023, has been striving to extend service hours and geographic coverage to bolster revenue and meet the high demand. The rollout of robotaxis in Texas and California has also spurred public protests, especially following a series of incidents relating to traffic congestion and safety. And despite a string of approvals to expand service in California, the state's DMV recently moved to suspend Cruise's permits following a number of new incidents. Concurrently, a lawsuit challenging the regulatory body overseeing robotaxi deployments in the state has started to gain traction, and federal authorities initiated a probe into Cruise's safety practices during its operational rollout. To achieve broader public acceptance, autonomous vehicles will need to demonstrate markedly better safety outcomes when compared to human drivers. The enthusiasm from manufacturers and municipalities to expedite robotaxi adoption globally is palpable, yet public apprehensions and the accident incidence rate during the testing phase will influence whether the pioneering companies can achieve substantial testing benchmarks to draw meaningful comparisons with human drivers, and the time frame required to reach this goal.

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Personal Everything Mobility Platforms

While superapps were ubiquitous in Asian countries as early as the 2010s, they didn't gain momentum in North America until the mid-2020s. The movement began when Elon Musk pushed for X to become the everything platform, but his vision did not come to fruition after the company failed due to advertising conflicts and users abandoning the platform. Instead, where everything platforms began to gain traction was in the travel and mobility industries. While there's still competition among these platforms to avoid antitrust laws, one particular platform has risen to prominence: OmniMoble, which successfully aggregated many major touchpoints and access points for an individual's comprehensive mobility needs. By fully integrating into users' schedules, the platform removes most frictions, frustrations, and hurdles that present themselves in the tediousness of everyday life. Now, when a user is told to go on a business trip, OmniMoble will recommend, unprompted, available livery, flight, and hotel options, accounting for both her personal preferences and company allowances. Once she's presented with options meeting those criteria, the user can make her selections with minimal effort. On the day of travel, she boards her flight with ease. However, while on her flight, she realizes she didn't pack a belt for her business attire. From the plane, she consults OmniMoble, and it provides available options closest to her hotel from her favorite designers. Before landing, the belt is delivered to the hotel.

ROBOTICS & DRONES TRENDS

COBOTS BECOME COWORKERS

Accelerated Adoption

Cobots serve to supplement or even replace workforces, especially those constrained by labor shortages. This evolution is already happening in Japan, which is in the midst of a significant demographic shift, as the working-age population begins to decline. The resulting extreme labor shortages are causing industries in Japan to turn to increased cobot usage, but the country is also able to undertake this endeavor because of a highly computer-literate workforce. With a strong knowledge base for mechanical and control systems and IT skills to manage the cobots, companies are supplementing more workplaces with these bots—and also improving productivity in the process. In one example, Fujita Works has successfully incorporated cobots in welding processes, reducing the time required to master welding techniques. In a broader geographic lens, cobots are expected to have a tremendous impact on the future of work. According to Grand View Research, the collaborative robot market is expected to grow by more than 30% by 2030, reaching a value of $11.04 billion. Cobot adoption is also being driven by major players, as Amazon seeks to expand its robotics operations at fulfillment centers with updated sorting machines, robotic arms, and mobile robots. This new system, Sequoia, is intended to work in collaboration with humans and is expected to increase delivery fulfillment speed by 25%. Amazon contends that this increase in speed will not be at the cost of eliminating humans from the workforce. Whether or not that turns out to be true, the inclusion of new bots in the workforce will likely have at least one positive outcome for human workers: They increase safety and reduce human injuries.

General Purpose Robots

Versatile, general purpose robots are the holy grail of robotics, promising bots that do not have to be limited or pigeonholed into single categories but can be used for vast and diverse purposes without requiring extensive calibration between disparate tasks. Several robots are in the works that may bring this kind of general purpose robot closer to reality. One, from startup Figure, is a versa-

A “Digit” robot working in an Amazon fulfillment center.

Source: Amazon

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tile, bipedal humanoid robot that can perform a range of tasks, from manual labor to eldercare. Figure has raised $100 million and hired top talent from leading tech companies, including Boston Dynamics, Apple, Google, and Tesla. Its plan includes an unveiling of the robot this year, with a starting focus on warehouse and retail applications and potentially a robotics-as-a-service (RaaS) leasing model. Tech startup Sanctuary AI is pursuing a similar model, and has created a humanoid robot named Phoenix that can perform a variety of workplace tasks. Standing at 5'7" and weighing 155 pounds, Phoenix is equipped with advanced sensors and human-like hands with haptic sensors that enable it to carry out precise tasks. The robot is powered by Sanctuary's AI control system, Carbon, which can be trained to learn new tasks either by simulation or human demonstration. But in order for general purpose robots to succeed, real-world and simulated training data is necessary to teach bots to adapt to various tasks. RoboCat, a self-improving AI agent for robotics, attempts to do just that. In as few as 100 demonstrations, it can operate various robotic arms and learn to perform different tasks. RoboCat's approach accelerates robotics research by reducing the need for human supervision, bringing us closer to versatile, general purpose robots.

Robots in the Home

The landscape of domestic robotics is transforming homes into hubs of automation, easing daily chores and offering companionship. For instance, robotic vacuum cleaners have become household staples, tirelessly navigating living spaces to keep them dirt-free. Similarly, robotic lawn mowers now keep lawns well-trimmed without the sweat, while robotic pool cleaners keep swimming areas sparkling day or night. As artificial intelligence has permeated these robotic devices, their ability to recognize voice commands, integrate with smart home ecosystems, and operate with minimal human intervention has made a significant stride for at-home robotics and automation. More recently, however, robots at home are becoming hubs for companionship. For instance, ElliQ, an AI-powered companion robot, is bridging the emotional gap for seniors, offering friendly interaction and ensuring their safety. The robot proactively engages in conversation, offers medication reminders and issues emergency alerts; these aren't just features but a leap toward combating loneliness among the elderly. Robosen's Grimlock transformer toy similarly provides companionship, but for kids and young adults. Their toy not only transforms but is capable of understanding a variety of commands and can communicate with those who play with it. In what is maybe the most extreme example of robotic companionship, individuals known as iDollators are even using AI-augmented synthetic dolls to form sexual relationships at home. And with new ideas like Bopeep's robotic furniture—carefully designed to overcome robots' typically overbearing presence—or old ideas brought to life like Prosper Robotics' robot butler, efforts are underway to blend household capabilities and companionship together. The fusion of AI with robotics is blurring the lines between the mechanical and the emotional, pushing the boundaries of what robots can offer in the home. As technology continues to evolve, the role of robots is set to expand, heralding a future where our domestic companions are not just helpers but friends who share in our daily lives.

Robots Coexisting with Creative Applications

The field of robotics continues to demonstrate how possibilities are endless for application. In Switzerland, AI-powered robots are now acting as security guards where their surveillance capabilities and real-time response mechanisms are improving safety without the need for human intervention. South Korea witnessed a remarkable blend of art and robotics with EveR 6, a robot conductor that fuses music and technology, broadening the horizon of what robots can achieve in what are typically viewed as human-centric creative domains. In the US, robots designed to handle hazardous materials were able to execute a mission to safely dispose of chemical weapons, reflecting a crucial application in high risk environments. In education, hundreds of kindergarten classes are now using a small robot named KeeKo, which tells stories, poses

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logic problems, and reacts with facial expressions when students master content. Scientists at MIT are using a teddy bear robot named Tega to improve the language and literacy skills of 5 and 6-year-olds, and have so far seen positive results. While these are just a few disparate examples among many, the versatility of robotic applications already appears endless, and the plethora of possible uses for the technology will likely only grow from here until robots become ubiquitous across our everyday experience.

Space Robots and Drones

Space exploration has long been an area that has embraced robots and drones. This technology is central to space exploration's mission; without them, exploration of harsh and distant environments would be impossible. Currently, NASA's Astrobee smart robots, operating aboard the International Space Station (ISS), underscore the role of robotics in aiding scientific research and routine maintenance in space. These cube-shaped robots, capable of free flight within the ISS, allow astronauts to offload mundane tasks, freeing them to focus on more critical, human-centric activities. While most people know about NASA's Mars Rover, NASA's Ingenuity drone has been testing off-earth flight, recently registering one of its longest flights. There are also several recent examples of new applications for space robotics and drones being developed for space. On the orbital front, ClearSpace, a Swiss space company, is pioneering efforts to mitigate space debris. With its ambitious ClearSpace-1 project, the company is building a claw-like spacecraft capable of capturing and deorbiting space junk, marking a significant step forward in cleaning up Earth's orbital environment. At MIT, researchers are testing modular lunar robots, equipped with flexible robotic arms resembling worms, showcasing how innovative approaches are being adopted to navigate and interact with extraterrestrial terrain. Another project by ETH Zurich has been exploring how quadruped ANYmal robots have the potential to exhibit robotic teamwork in executing lunar missions, such as material harvesting for base construction. Similarly, GITAI is building robotic rovers and arms with the goal of creating an autonomous labor force for the moon and Mars to reduce space labor costs. Further extending the capabilities of space robots, NASA's Goddard Space Flight Center is developing OSAM-1, a satellite repair robot aimed at prolonging the operational lifespan of satellites. This initiative heralds the onset of in-orbit servicing and manufacturing, which could revolutionize space infrastructure management. The various projects and technologies in the realm of space robots and drones exhibit a confluence of robotics, aerospace engineering, and collaborative endeavors, driving forward the frontier of space exploration and habitation enabled by advances across drones and robotics.

ETH Zurich's modified quadruped ANYmal robots.

Source: ETH ZURICH / TAKAHIRO MIKI

ROBOT AND DRONE INFRASTRUCTURE

Robot Compiling and Training

Virtual training harnesses the power of AI, simulation, and digital twins to propel the capabilities of robots and drones to new heights. Nvidia, in particular, has been a leader in this space. The company's Isaac Sim and Isaac Gym platforms simulate 3D physics in video game–like environments, allowing for parallel training sessions across numerous virtual realms, thus significantly reducing robot and drone training time. A collaboration from Nvidia, UPenn, Caltech, and the University of Texas at Austin known as Eureka showcases this by making use of OpenAI's GPT-4 to design and refine training goals. It then runs through parallel simulations in virtual environments to help robots learn complex tasks virtually before transitioning to the real world. Toyota's AI robot recently showcased the ability to master complex tasks in a matter of hours, again highlighting the accelerated learning curve that comes from virtual training. Digital twins are also being used to help autonomous robots and drones improve their path-planning by navigating through various environmental conditions safely and efficiently in virtual space. They can even help train robots to pack objects into tight spaces, as was shown by MIT, which developed a technique to use virtual environments to improve robots' ability to optimize space utilization. In anticipation of robots and drones working together in reality, Nvidia's robot simulator recently gained the ability to simulate human co-workers as well, mimicking real-world scenarios to improve robot-human interactions. This evolution in digitally enabled training not only promises a future of highly skilled robots and drones but also hints at a paradigm shift in how training and development in the field of robotics and drones are approached and the potential for much more rapid development across the space in the future.

Robot and Drone Swarms

Drone swarms, made up of groups of drones functioning as a collective unit, unlock capabilities far beyond the reach of individual drones. Despite their first commercial use-case coming in the field of entertainment as a fireworks alternative for complex light displays, their breadth of applications have significantly expanded. The US and Chinese governments have shown a keen interest in using drone swarms across their militaries, leveraging them for surveillance, tactical engagements, and logistical support. The agricultural sector stands to gain too, with promising applications in pest control, monitoring, and harvesting, which are ripe for disruption by drone swarms. The technology is also expected to highly impact emergency response: sensor-equipped swarms can offer invaluable real-time information and assistance during natural disasters or search-and-rescue missions. However, the path to wider adoption faces challenges. Real-time data processing, communication, and decentralized control algorithms limit current drone swarms to applications with limited need for adaptability due to the current requirement for extensive preprogramming to effectively use them. The research community is actively tackling these issues. The University of Houston is exploring algorithms for better swarm control, while MIT is developing WiSwarm, a novel algorithm facilitating the management of high loads of time-sensitive data. As the technology overcomes these technical hurdles and continues to capitalize on emerging applications for the technology, drone swarms are poised to have a transformative impact across various domains.

Drone Fleets

Drone fleets are steadily gaining traction as companies seek to enhance operational efficiency, reduce delivery times, and minimize human intervention. Amazon, for instance, has been testing prescription deliveries via drones in College Station, Texas, with turnaround times guaranteed to fall within an hour. This venture not only expedites delivery times but also caters to immediate medical needs, marking a leap toward on-demand health care services. Similarly, Uber unveiled plans to deliver Uber Eats orders via drone, though not direct to customers' homes but to designated locations for final delivery by drivers. This hybrid model could significantly reduce meal delivery times. Wing, a subsidiary of Alphabet, is on a trajectory to handle tens of millions of

ROBOT AND DRONE INFRASTRUCTURE

deliveries for millions of consumers, showcasing the potential scale possible with drone delivery services. The collaboration between Wing and Walmart to offer 6-mile drone deliveries over Dallas is a testament to drones' potential to revolutionize retail logistics. FedEx, too, is exploring autonomous drone cargo transports, hinting at a future where intercity cargo transport could be drone-driven. On a larger spectrum, Saildrone and the National Oceanic and Atmospheric Administration have collaborated to deploy sailboat drones to monitor climate change's effects on oceans; this kind of use unveils a broader scope of drone applications beyond aerial vehicles. The infusion of drones in these diverse domains underscores a promising potential for automated, efficient, and perhaps, more environmentally friendly operational frameworks that could come from the use of drone fleets. As regulatory landscapes evolve to accommodate drone operations, the horizon seems expansive for drone fleets, potentially altering the traditional contours of service delivery and environmental monitoring.

Drone Traffic Management

The escalating use of drones necessitates advanced traffic management solutions to ensure safe and efficient operations. In the US, the Federal Aviation Administration, partnering with NASA and other bodies, is pioneering Unmanned Aircraft System Traffic Management (UTM) initiatives to oversee low-altitude drone operations. In 2023, they unveiled a UTM implementation plan that includes, in the short term, devising essential protocols and infrastructure, alongside long-term goals like enabling real-time airspace status updates and achieving full operational capability for routine beyond visual line of sight (BVLOS) drone operations. In India, the rise in drone activities has fueled the need for sophisticated UTM systems, leading to a goal of managing a daily drone fleet of 10 million by 2030. Conventional aviation traffic management, dependent on communication between pilots and air traffic controllers, is inadequately equipped to handle the burgeoning drone traffic. In contrast, UTM systems, with their digital interfaces and real-time communication capabilities, are poised to diminish communication lags and effectively oversee drone operations. Initiatives are also underway in New York, Oklahoma, and the UK to designate specific airspace corridors exclusively for drone operations. Notably, the UK's Project Skyway aims to establish a 265 km UAV corridor by 2024, marking a significant stride towards BVLOS drone operations. Concurrently, MIT has developed an algorithm centered on real-time path planning, which could be assimilated into UTM systems to help drones dynamically adjust their paths, avoiding midair collisions. Collectively, these advancements highlight the evolving realm of drone traffic management, each contributing uniquely to fostering safe and proficient drone operations.

Rendering of Altitude Angel's ARROW technology enabling the UK's Project Skyway.

Source: Altitude Angel

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Drone Harvests

Over the years, drones aided precision agriculture by planting seeds, assessing crop health, and using targeted pesticides. These integrated units have worked remarkably well to boost crop yields. But now, drones are even able to manipulate the weather. During the early 2020s, researchers discovered that drones could target specific clouds and use lasers to trigger rainfall by forcing water droplets to pool in the air. By the turn of the decade, this practice gained awareness, and precision ag startups began experimenting with it. Through such systems, farmers gain even more control of the crop harvesting process by manipulating the weather with drones after conducting health analyses on crops. They also benefit by being able to supplement irrigation systems and reduce associated costs. But, not surprisingly, much controversy has surrounded this new practice, as regulators are concerned with the possible larger implications this process has on the environment. While these concerns persist, there's currently no effective way to limit the activity, and regulators are working diligently with precision ag startups and farmers to better monitor its use.

MOVING PEOPLE, PETS AND OBJECTS

Last-Mile Delivery

Delivery robots and drones are significantly altering the logistics paradigm for last-mile delivery. Companies like Uber Eats have forged partnerships with Serve Robotics to begin bringing autonomous food delivery into the mainstream, though not without hurdles. Recent incidents of vandalism against delivery robots highlight the operational challenges and financial implications faced by ventures diving into this arena. However, the convictions of several people for incidents caused to delivery robots in LA, along with Serve's claimed 99.9% delivery success rate, give reason for hope. On the aerial frontier, drone delivery enterprises Zipline and Wing have built sophisticated delivery systems indicating an operational readiness to tackle the US market. The trajectory of commercial drone deliveries is notable. As of the first half of 2023, approximately 500,000 commercial deliveries have already been made, and progress doesn't appear to be slowing down. Walmart, for example, has established drone-delivery hubs across seven US states, partnering with companies like DroneUp, Flytrex, Zipline, and Wing to make drone delivery a key component of its last-mile delivery strategy. The regulatory landscape is also evolving to make drone delivery a more tangible reality. The FAA's BVLOS initiative allows for drone delivery operations under specific conditions at seven test sites. As these regulatory frameworks coalesce, the ensuing cost advantages and sustainability benefits are making drone delivery an attractive proposition for a variety of industries. Food delivery companies like Uber Eats, DoorDash, Domino's, Starbucks, Taco Bell, Papa Johns, Wendy's, and KFC have all begun exploring the technology; retailers like CVS, Amazon, Walgreens, GNC, Walmart, T-Mobile, and Tesco have begun testing or forming partnerships in the space. Even parcel delivery companies like UPS have started drone delivery trials. The ongoing exploration by mainstream retailers, combined with emerging regulatory standards, is not only pushing the envelope for what's possible in last-mile delivery but setting the stage for an exciting era where drones and robots could become a regular facet of the logistics and delivery industry.

Expanded Payload Capacity

Increasing payload capacities and extending flight distances are pivotal in accelerating the adoption of drones across sectors. In last-mile delivery, Alphabet's Wing has increased its drone's capacity to carry up to 7 pounds, a significant upgrade from its flagship drone's original 2.5-pound capacity. In the heavy-lift area of drone development, Elroy Air has showcased plane-like drones capable of transporting up to 700 pounds of cargo across 300 miles. This development could redefine how goods are transported, especially in remote or disaster-stricken areas where conventional delivery systems are unviable. In China, Northwestern Polytechnical University has built bionic drones that can fly continuously for over three hours. And while their exact range of expansion capabilities is still an open question, hydrogen fuel storage systems being developed for drones through a collaboration between Honeywell and the US Department of Energy hold the potential to dramatically increase capacity. Regulatory frameworks are also evolving to accommodate these advancements. The FAA recently granted licenses for unmanned commercial drones to operate beyond a pilot's sight, opening the door for more commercial attempts to push the limits of drones. Attempts include Valmont's joint trial with T-Mobile, where Valmont's drone set a record for a BVLOS operation, covering 237 miles in a single flight. In the military domain, Iran recently unveiled a long-range drone, with the ability to cover distances of 1,240 miles and up to 24 hours of operation—double the distance of the Mohajer-6 drone, which the US has accused Iran of supplying to Russia in its war with Ukraine. While Iran claims its new drone is the longest range drone in the world, that's unlikely to be the case: Drones publicly known to be in operation by the US, including Ultra LEAP and and Global Hawk, have shown an ability to fly for over two days straight, and experiments conducted by the US Army using Airbus' Zephyr 8 drone have been able to stay in flight for up to 62 days straight using solar energy to sustain operation. These developments collectively showcase the vast potential for drone technology, where increased payload capacity and longer flight durations

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can push the boundaries of what's possible in both existing as well as unexplored domains.

Flying Taxis (eVTOLs)

The realm of urban air mobility is buzzing with the promise of electric vertical takeoff and landing (eVTOL) aircrafts, often referred to as "flying taxis" or "air taxis." Like helicopters, these vehicles are capable of taking off and landing vertically, but unlike their predecessors, they leverage electric power, significantly reducing their environmental footprint. Companies and governments are undertaking several initiatives throughout the US and the globe to make this new form of transportation a reality. New York, California, and Utah have all begun projects in this space. In partnership with Delta Air Lines, Joby Aviation is building vertiports to support a future where passengers transfer from flying taxis to their flights at New York's JFK airport and Los Angeles' LAX airport. Utah released a report outlining plans for the rollout of vertiports across the state, leveraging underutilized parking lots as potential vertiport sites. Meanwhile, globally, Archer Aviation recently announced plans to introduce eVTOLs to the UAE by 2025, and Paris is gearing up to introduce the world's first electric air taxi network for the 2024 Olympics in partnership with Groupe ADP. Meanwhile, China's Ehang gained approval to start operating its EH216-S autonomous air taxi, capable of carrying two passengers or 600 pounds of cargo over a flight range of 18 miles at speeds up to 80 mph. As the regulatory frameworks evolve and public acceptance for the technology grows, the skies of urban landscapes may soon be dotted with eVTOLs, heralding a new era of urban air mobility. The collaborative efforts among aviation companies, regulatory bodies, and city administrations are fueling the momentum toward making air taxis a reality, promising a blend of innovation, convenience, and sustainability in urban transportation.

Ocean-Faring Drones

Ocean-faring drones, comprised of both unmanned surface vessels (USVs) or autonomous underwater vehicles (AUVs) are changing the nature of exploits across the seas. Commercially, Yara Birkeland is a pioneering project developed in Norway by Yara International and Kongsberg Gruppen, pushing the boundaries in autonomous shipping. Their vessel is designed to operate initially with a reduced crew, gradually transitioning to fully autonomous operations using sensors, radar, and cameras, paired with artificial intelligence. On the scientific front, innovative projects like the University of Bremen's TRIPLE (Technologies for Rapid Ice Penetration and subglacial Lake Exploration) are using AUVs to probe beneath Antarctica's ice shelves and potentially explore even alien marine ecosystems on icy moons like Jupiter's Europa and Saturn's Enceladus. Militaries are also exploring these technologies. The US Marine Corps, for instance, is testing a drone boat designed to transport loitering munitions for precision strikes and act as a reconnaissance platform for surveillance and intelligence. Recently, ocean-faring drones have even been utilized by Ukraine to target military ships and Russian naval bases throughout their military conflict. While the upfront costs associated with the development and procurement of ocean-faring drones can be substantial, their long-term benefits are compelling. Reduced human risk, operational cost savings, and the ability to conduct missions in challenging or previously inaccessible environments underscore the transformative potential of these autonomous maritime assets. As the technology matures and regulatory frameworks adapt, the horizons of what's achievable on and beneath the world's oceans are set to expand significantly, heralding a new era of maritime exploration, commerce, and security.

BLURRING THE HUMAN-MACHINE LINE

Natural Exoskeleton Movement

For individuals hampered by limited mobility or injuries, exoskeletons can help. This past year, the FDA cleared Wandercraft's Atalante exoskeleton for stroke rehabilitation in the US. The self-balancing and battery-powered device assists in gait training and helps individuals regain their walking abilities. Ekso Bionics, which has been optimizing exoskeleton bionic devices since 2005, used its technology to assist a paralyzed community college graduate from Virginia to walk across the stage at his graduation ceremony. While exoskeletons have traditionally been large and bulky, researchers at the Swiss Federal Institute of Technology are turning to fiber-like pumps that employ high-pressure fluidic circuits that can be woven into fibers and maybe even into future clothing. This form factor would allow for less cumbersome textile-based exoskeletons that can enable muscular support, thermoregulation, and haptic feedback. In an alternative fashion, researchers at Lausanne University used brain implants to assist a paralyzed patient with walking. The implants wirelessly transmitted the patient's thoughts to his legs and feet through a second implant on his spine, and movements were assisted with an exoskeleton. This, in conjunction with smaller exoskeletal form factors, provides innovative solutions for improving conditions for those with limited mobility.

Superhuman Abilities

Exoskeletons can not only enhance worker performance in industrial settings but also impact athletic performance. Researchers at Virginia Tech's Department of Industrial and Systems Engineering are looking into the effectiveness of exoskeletons in real-world construction applications, postulating that they have the potential to significantly reduce the risk of back injuries and shoulder problems. The robotic exoskeleton startup German Bionic has showcased two products: the Apogee and the Smart SafetyVest. The Apogee assists workers by offsetting up to 66 pounds of load on the user's lower back while the Smart SafetyVest can monitor the wearer's movements and body positioning, providing ergonomic insights, assessments, and recommended actions. While these technologies can be used to ease the burden of repetitive tasks associated with the logistics, construction, and health care industries, some worry that corporations might use the devices to exploit workers with increased output and working hours. Besides job-related tasks, researchers from Chung-Ang University in Seoul, South Korea, have developed a wearable exoskeleton that enables runners to run 0.97 seconds faster by assisting with acceleration and hip extension through electrical motors.

Personal Mobility

Robotics has the opportunity to be an incredible democratizer, capable of supporting, supplementing, and enabling mobility for individuals with mobility impairments. Control Bionics is an Australian company that specializes in advanced assistive technology. It recently developed a wheelchair module called DROVE, which uses AI to enhance mobility for individuals who cannot use traditional steering systems, such as joysticks, due to conditions that affect hand function. DROVE is equipped with a wheelchair-mounted digital camera system, the NeuroNode interface, and home sensors for precise navigation, enabling users to move independently within their homes. Labrador Systems, a California-based technology company, recently launched a new product named Labrador Retriever. It's an autonomous personal robot that can assist individuals with mobility impairments in carrying items around their homes. Users can place items on the robot, and instruct it to move to specific locations through a touchscreen or voice commands. They can also program it to navigate between predefined "bus stops" located within the house. Researchers from Stanford's Biomechatronics Laboratory are taking more of an assistive approach, having developed an exoskeleton that provides personalized assistance to improve limited mobility. The exoskeleton is not designed to walk for the user. Instead, it helps to decrease resistance and friction, thereby enhancing walking speed and energy efficiency. In testing, users reported a 9% increase in walking speed with a 17% decrease in energy used. Ultimately, these

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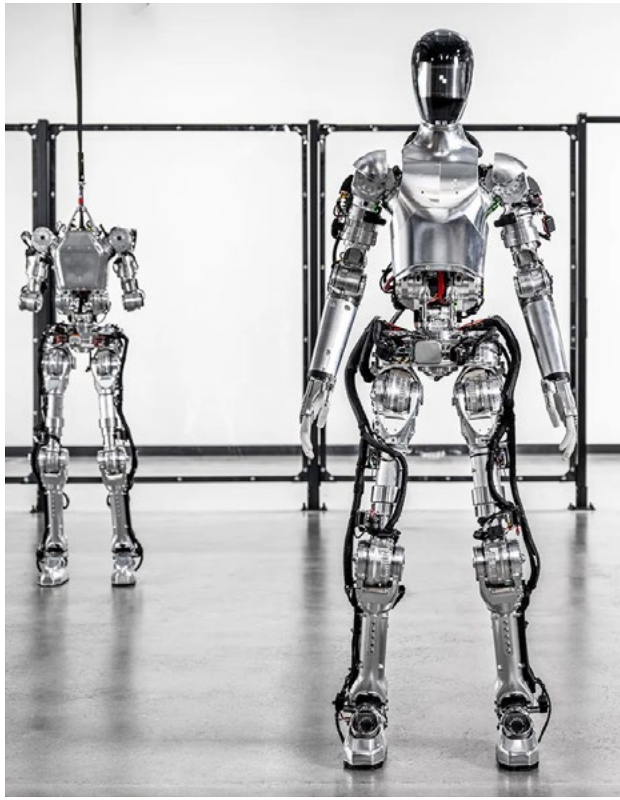
types of applications empower users by giving them back their independence, comfort, and control.

Humanoid Robots

Various companies and startups have made significant advancements in developing robots that mimic the abilities and activities of humans. While initially rudimentary in execution, these humanoid robots are becoming more capable and graceful by virtue of advancements in computer vision, machine learning, and more power-dense batteries. In most instances, these robots are intended to address the challenges of labor shortages and high turnover in many different industries. Tesla is recognized for its early renderings of humanoid robots and recently updated its associated program, Optimus, showing improved abilities in walking, picking up, and identifying objects. Intel has invested significantly in Figure, an AI robotics company whose general purpose Figure 01 robot is being developed to accomplish tasks including walking up and down stairs, opening doors, and picking up small objects. Amazon has also entered this domain, having tested Agility Robitic's Digit robot to work in its warehouses; it is capable of high reach, carrying heavier loads, and interacting with humans. Besides these more obvious applications, Shanghai-based Fourier Intelligence is developing its GR-1 humanoid robot to address the increase in demand for health care services precipitated by an aging population. The robot is envisioned as a caregiver, therapy assistant, and companion for the elderly. More contrastingly, scientists at Arizona State University have developed the Advanced Newton Dynamic Instrument robot to study the impact of extreme heat on humans, much like a crash-test dummy is used to measure the impact of car crashes. Whether using humanoid robots in labor situations or for testing extreme conditions, there are both the clear benefits for protecting humans and the perceived risk of reducing available menial jobs.

Soft Robotics/Getting a Grip

Traditionally, robots have not been nimble enough to handle delicate objects: They apply too much force, making them unsuitable for human replacement. But increasingly, soft robotics have been used for their ability to gently grab and pick up objects, making them ideal for use in warehousing and distribution. Advances in both materials and computer vision are enhancing the efficacy of soft robotics. Researchers at MIT's Computer Science and Artificial Intelligence Laboratory have developed a robotic system called Series Elastic End Effectors, which uses soft bubble grippers and embedded mapping cameras to grasp tools and apply the appropriate amount of force for various tasks. The system is adept enough to write with a pen or wipe up liquid spills. Researchers from the University of California, San Diego developed a 3D printing method that produces soft robotic grippers that only require a bottle of high-pressure gas as their power source, rather than actual robotics, and is a prime candidate for handling delicate materials such as fruits and vegetables. Soft robotics are now also able to account for weight, in addition to delicate touch. Researchers at the Korea Advanced Institute of Science and



Figure's humanoid robots.

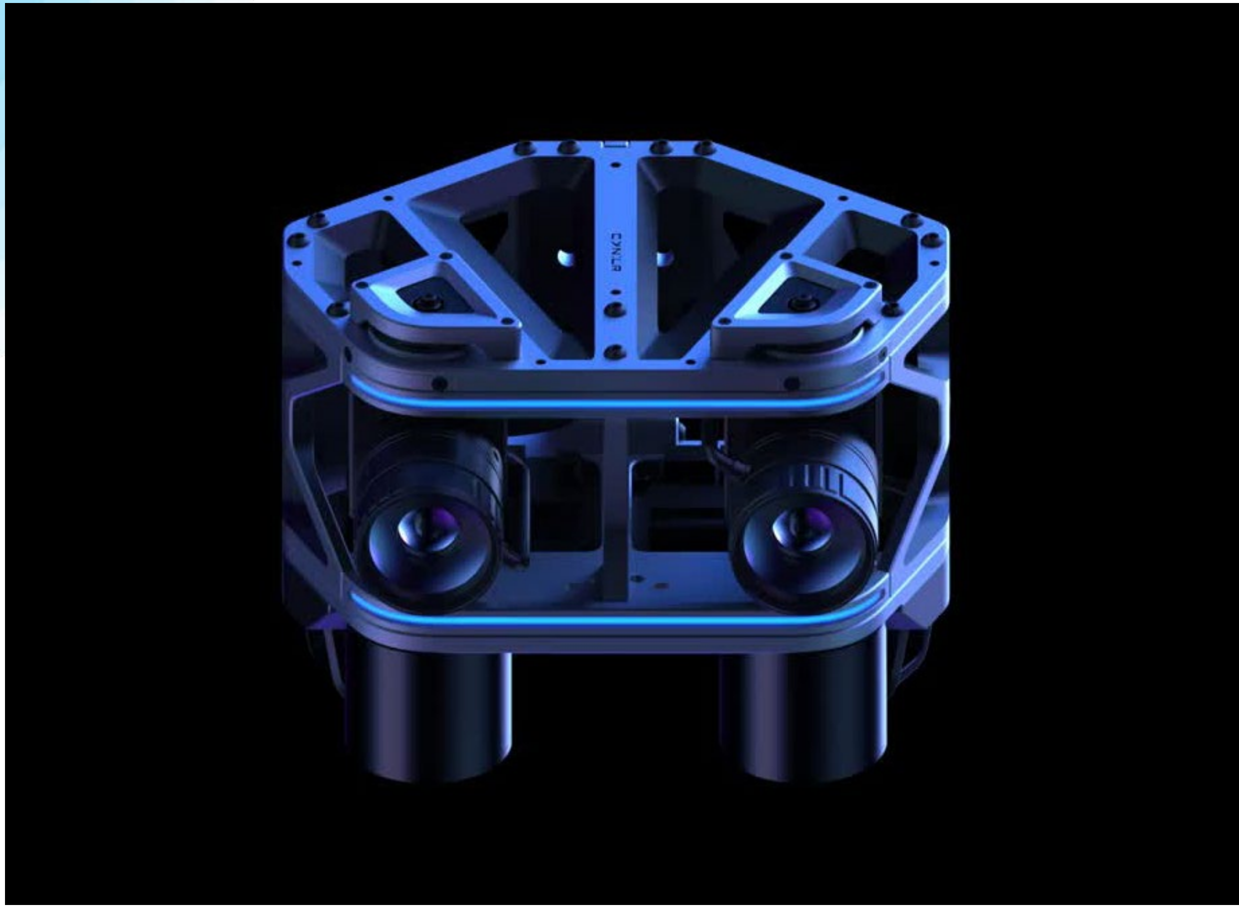
Source: Figure

BLURRING THE HUMAN-MACHINE LINE

Technology developed a soft robotic gripper consisting of a woven structure capable of lifting objects weighing more than 100 kilograms. As soft robotics become more dexterous, they will also become stronger.

Robot "Eyes"

As with many advanced technological systems, a constellation of disparate technologies is required to enable the effective and efficient use of the technology. When it comes to robotics, an advanced constellation of tech is required to help the robots "see." While robots are not literally able to see their surroundings, vision, audio, and touch sensor systems, including lidar, radar, 2D and 3D cameras, accelerometers, gyroscopes, bump sensors, force sensors, and temperature sensors, are needed to help robots successfully navigate their surroundings. This phenomenon is also known as sensor fusion. In addition to sensor fusion, other approaches are impacting the way robots sense the world around them. Researchers from the University of Edinburgh have developed a robot navigation system that takes inspiration from ants and helps robots navigate challenging terrains. They created an algorithm that mimics the brain processes ants use during navigation; when it's implemented on hardware that simulates brain computations, the algorithm has outperformed state-of-the-art computer vision systems in navigation tasks. The robotics company CynLr (Cybernetics Laboratory) uses visual cognition and tactile feedback and action to empower bots to "see." CynLr created a visual object intelligence platform that functions with robotic arms to achieve universal object manipulation, which enables the bot to pick up unrecognized objects without needing to recalibrate hardware. Ultimately, these technologies have numerous potential applications for systems requiring navigation, including autonomous cars.



CynLr's CLX1.

Source: CynLr

SCENARIOS

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The Evolution of Disaster Response Robotics

When imagining how robotics would impact the world of disaster response, one might have envisioned giant, bulky, transformer-like robots that could be sent to a disaster site and push around debris in their path with brute force. However, this approach could actually make rescue efforts more complicated. Robotics company TechNex Robotics has been fine-tuning its MorphGuard robotics line, which consists of a swarm of tiny, shape-shifting soft-robots measuring 3” x 3” and each weighing around 2 pounds, which employ fluid movements to help those in distress. Taking cues from nature, researchers determined that a swarm or collection of smaller bots could actually be greater than the sum of its parts. While not as comparably strong as their natural counterpart of the ant, these small units can still lift six times their weight, and researchers are diligently working to increase this individual capacity over time. While individually, this may not seem like much, true power comes from the collective unit. When 50 or 100 bots are used in concert, they can deliver meaningful results. But before they are able to lift or transport an individual to safety, they must first locate the victim. By employing fluid and shape-shifting movements, the bots can navigate various terrains and burst through pockets of debris. Smaller, modular bots have proven immeasurably more effective for disaster response than single-unit, bulky robots. From these learnings, researchers are discovering additional applications for this divergent approach.

TAKING CUES FROM NATURE

Quadrupedal Robots

Companies such as Boston Dynamics and Unitree have popularized quadrupedal robots that can be used for a variety of purposes, including security, monitoring, inspection, and data collection. As this type of robot gets more popular, it becomes more agile and used for new applications. Researchers at Carnegie Mellon University's Robotics Institute have used a reaction wheel actuator system to enable quadruped robots to walk on a narrow balance beam, making the bot more versatile and nimble. DEEP Robotics aims to democratize ownership of quadrupedal robots through its Lite3 series, with its most affordable model targeted toward technology enthusiasts and more advanced versions catering to research purposes and opportunities. The Lite3 bot also boasts improvements with the ability to perform horizontal jumps, high jumps, and front flips. Researchers at ETH Zurich have their sights on sending these bots to the moon, having tested their ANYmal robots in simulated lunar activities. Boston Dynamics and Unitree have incorporated GPT-based technologies in their quadrupedal robots, boasting more realistic movements and the perception to understand and interact with users. While Boston Dynamics uses this function to transform its bots into talking tour guides, such signals can begin to fuel our terminator-driven AI doomsday scenarios.

Necrobotics

In 2022, Rice University researchers transformed a deceased spider into a robot, giving rise to a new field called necrobotics. In this process, they manipulated the legs of the spider carcass with a puff of air from a syringe, exploiting the spider's natural hydraulic system for opening and closing its legs. Over the course of the experiment, the spider carcass lifted over 130% of its body weight in more than 1,000 open-close cycles before the joints degraded beyond usability. The results inspired other research teams to further explore the use of insects in robotics. Since the experiment, the Rice University researchers have been recognized for ushering in the era of "necrobotic" design, having been awarded a 2023 Ig Nobel Prize. But reception of this activity has not all been auspicious. Stian Rice and James Tyner at Kent State University published a scathing critique of the practice in the journal Human Geography called "Along came a spider ... and capitalism killed it." In it, they bemoan the act of converting death into "useful, productive labor," going so far as to say that the acts "portend a deepening of necrocapitalism and the violence of science." While necrobiotics may lead to the creation of low-cost, eco-friendly substitutes for existing robotic systems, Rice and Tyner raise important ethical concerns as we continue to navigate technological innovation.

Using Live Organisms (Ethically)

Researchers have built applications that use organic and biological compounds and now even specimens themselves for robotic applications. Robotic engineers are increasingly incorporating living tissues into traditional robotics in order to achieve complex behaviors that would be limited by artificial materials. Kit Parker of Harvard's Wyss Institute for Biologically Inspired Engineering, John Dabiri of Caltech, and Janna Nawroth of the Helmholtz Pioneer Campus have collaborated to create a "medusoid," a creature that uses rat muscle tissue attached to a silicone polymer to produce an undulating jellyfish-like robot. Besides using animal tissue in the construction of robots, some researchers are using living organisms in their robot applications. Dr. Josephine Galipon and her team at Japan's Tohoku University have developed a robotic system that uses wood lice and chitons to serve as the effectors or hands of robotic arms. While both examples differ at their foundation in their use of organic matter, they both call into question ethical concerns that arise from this type of technological experimentation. Regardless, they are valuable explorations of how organic material has the potential to improve robotics in ways unachievable through artificial materials.

Insect-Like and Animal-Like Designs

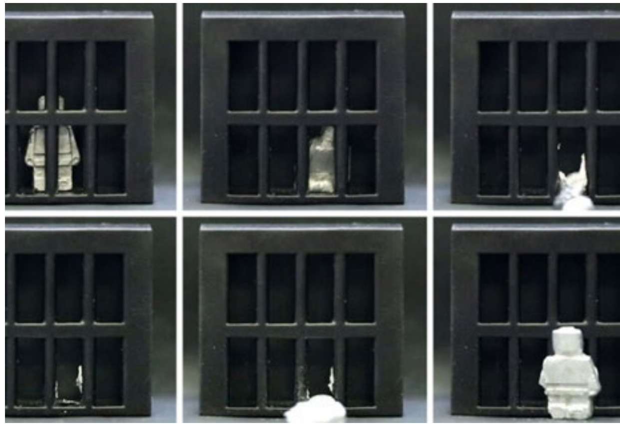
As robots become more capable and sophisticated, engineers are turning to living organisms for inspiration for overcoming even more complex challenges. The US Navy is using

TAKING CUES FROM NATURE

Gecko Robotics' wall climbing and AI-powered bots for building digital models of its vessels to reduce maintenance time and keep vessels out of drydock. ETH Zurich has taken inspiration from geckos but also spiders for its Magnecko, which employs electro-permanent magnet modules on its feet to walk on walls and ceilings, supporting 2.5 times its weight. Caterpillars are the muse for researchers at North Carolina State University, whose robots mimic the movement of the specimen through a system of silver nanowires that use heat to control their movement. Jellyfish have inspired researchers at the Indian Institute of Technology, while researchers at the University of Notre Dame have studied the forms of sea turtles, mimicking the organism's propulsion with front flippers for forward movement and smaller hind flippers for changing direction. And it's not just real animals: Researchers from Tampere University in Finland have taken inspiration from mythical folklore with its fairy-like robots made of stimuli-responsive polymers capable of flight, which could be used to pollinate crops. MIT researchers have developed a platform called SoftZoo that is intended for studying soft robots, making use of 3D models of various animals, such as panda bears, fish, sharks, and caterpillars, to ultimately determine the best configuration for a soft robot's shape. By using nature as a muse, engineers are creating more capable and adaptable artificial creatures.

Fluid Movement

Fluid movement enables robots to work in diverse environments, which holds promise in fields like medicine and machinery repair. Researchers at the Soft Machines Lab at Carnegie Mellon University along with scientists from Sun Yat-sen University and Zhejiang University in China are making breakthroughs in shapeshifting robots that are capable of moving from solid and liquid states through the control of magnetic fields. This phase change allows the robots to accomplish feats such as jumping, climbing, and even escaping from a cage. Researchers envision these robots could be used for tasks including targeted drug delivery, circuit assembly, or the creation of universal screws. To capitalize on this modality in another unique way, researchers at Northwestern University have created a soft quadruped robot that could be used in hazardous situations: it can sense damage and autonomously repair itself before resuming movement. The robot, which is shaped like the letter X and powered by compressed air, has a layer of self-healing sensors on its top surface. The sensors are made of transparent rubbery material, and if one is cut, it can chemically react to fuse back together. Researchers at the University of California, Santa Barbara have developed a vine-like robot that can detect and move toward heat sources. The robot is also capable of moving around simple obstacles and bending backward to ward off heat and could be used for search-and-rescue and firefighting missions.



Miniature metal shapeshifting robot liquefies itself and reforms to escape a cage.

Source: Carnegie Mellon University

TAKING CUES FROM NATURE

Moving Across Modalities

Robotics are no longer limited to a single modality or simple movements. They are becoming more complex in their operation and maneuverability, capable of driving, jumping, crawling, and even mimicking origami. Caltech is working on a versatile robot called the Multi-Modal Mobility Morphobot that can switch between various modes, including four-wheeled movement, crouching, climbing steep slopes, standing upright with propellers, and turning into a flying quadcopter. Such characteristics make it a prime candidate to assist in search-and-rescue missions, as it is able to cover very diverse terrains. Researchers at MIT have created tiny soft-bodied robots that can be controlled by a simple magnetic field, enabling them to walk, crawl, and swim and making them ideal for tasks in confined spaces and suitable for transporting delicate cargo. Researchers at the University of Washington have created small robotic devices known as microfliers. These devices can change how they descend by folding themselves, using an origami technique called Miura-ori. OrigaMechs, developed by researchers at the University of California, Los Angeles add data processing capacity to the concept of origami robots. The researchers have embedded flexible and electrically conductive materials into a precut, thin polyester film sheet, resulting in fully flexible robots that can perform various complex tasks without reliance on semiconductors. As robots begin to function in multiple modalities, they become better suited for extreme environments and are imbued with new abilities for sensing, deciding, and responding.

University of Washington’s microflier.

Source: Mark Stone/University of Washington

SCENARIOS

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Self-Regulating and Repairable Robots

QuantumSync Robotics has emerged as a trailblazer in the field, redefining the traditional boundaries in both business and manufacturing landscapes. It's enabled a world where robots not only perform tasks efficiently but also possess the capability to diagnose and fix issues autonomously, leading to a new era of self-healing machines. By applying the Robotics-as-a-Service (RaaS) business model, QuantumSync can offer customers a full suite of robotics applications from the ground up, or supplemental robotics that just perform the diagnostic and repair functions for a preexisting robotics system.

Robots equipped with QuantumSync's central nervous system, known as AdaptiveMind, become highly self-aware of themselves and the robots integrated into their ecosystem. As a robot carries out its designated tasks, such as a manufacturing component or warehousing task, sensors and advanced diagnostics constantly evaluate its condition. When a robot detects a deviation from optimal functioning or predicts an impending failure, it notifies the network of a self-repair protocol. The system calculates the severity of the maintenance or repair and assigns a nearby robot with the task of resolving the issue, whether this be a simple calibration or something more involved such as printing and extruding replacement parts. While this will affect overall performance in the moment, such an approach reaps meaningful returns in the long run. Capable operations will be able to continue in real time while addressing pressing issues with urgency and prioritization. By applying new business models with novel robotics, QuantumSync Robotics continues to revolutionize a more fully automated manufacturing future.

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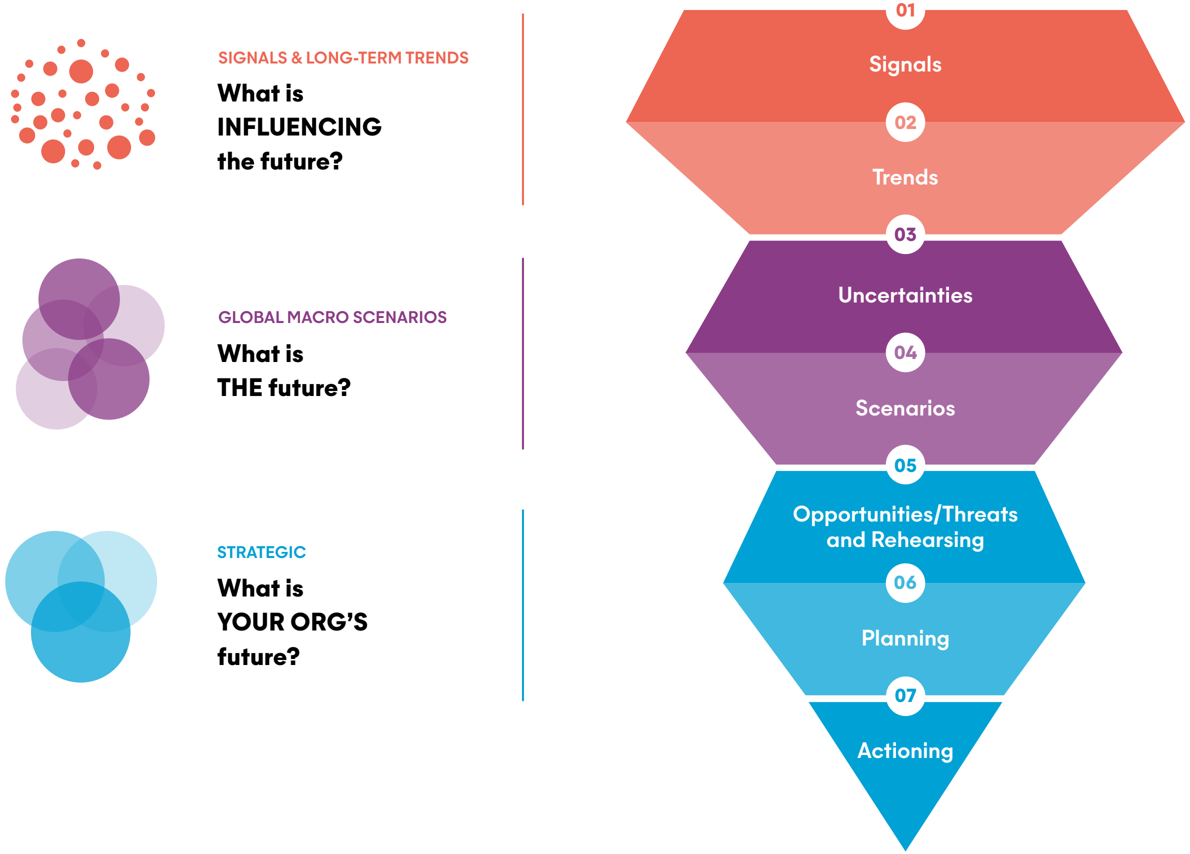

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