December 4, 2024

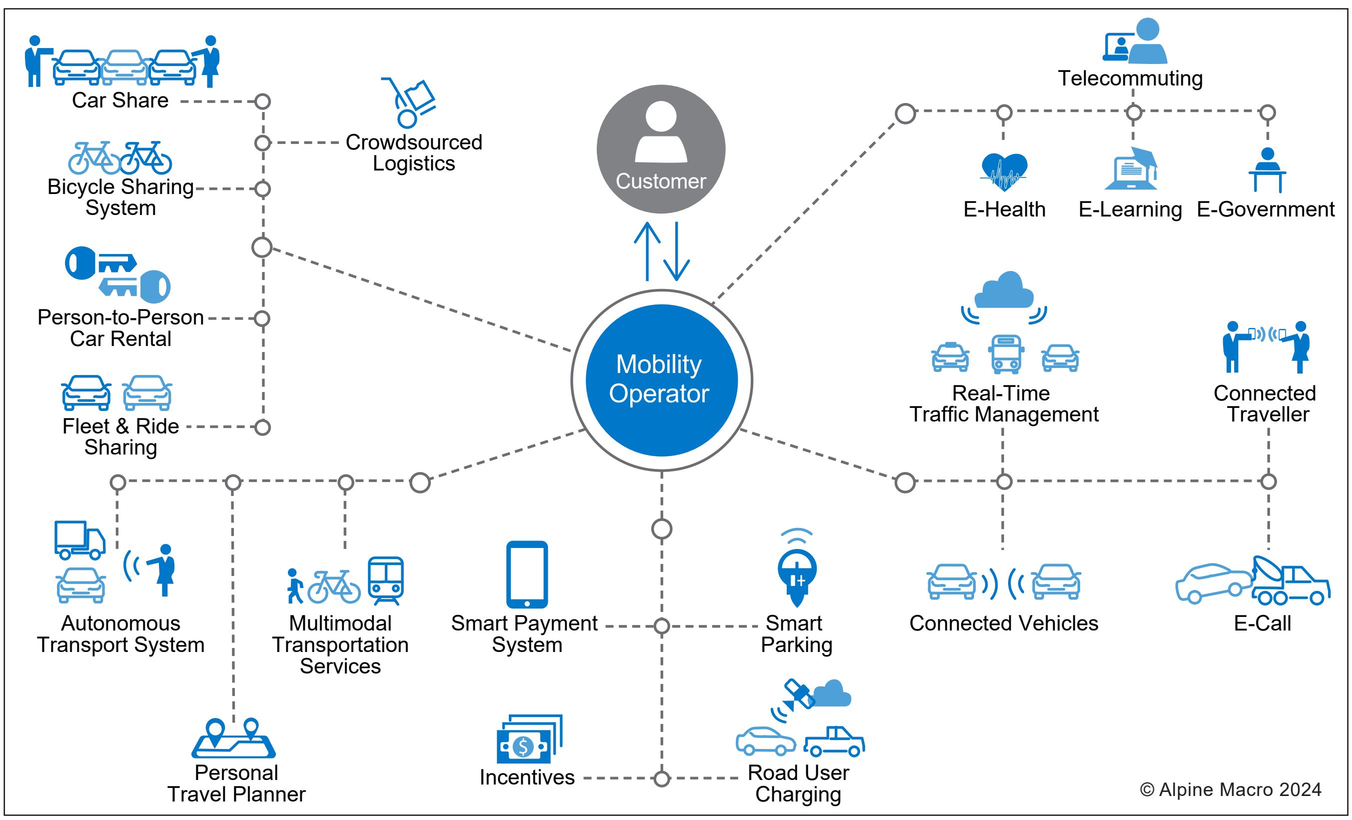
The Autonomous Mobility Revolution: Shaping The Future Of Transportation

Autonomous mobility represents a transformative megatrend poised to not only revolutionize the way we move but also fundamentally reshape the future of transportation. We view autonomous vehicles (AVs) as one of the largest AI-driven initiatives globally, with unparalleled potential to disrupt traditional industries through technological convergence. However, despite the renewed optimism surrounding the sector, we caution that the path to widespread use of fully autonomous vehicles remains a long-term endeavor.

This report offers a comprehensive analysis of the autonomous mobility ecosystem, highlighting its opportunities, challenges, and potential impact on industries

In This Report

Chart 1 Mobility As A Service Web



Source: Cubic Transportation Systems

globally. Notably, Mobility as a Service (MaaS) — a model that integrates various transportation services into a single, on-demand service — is poised to significantly influence not just the future of transport but also infrastructure, logistics, and urban planning (Chart 1). Notably, both Uber and Lyft, once having abandoned MaaS development during the pandemic, have refocused on expanding capabilities in this area.

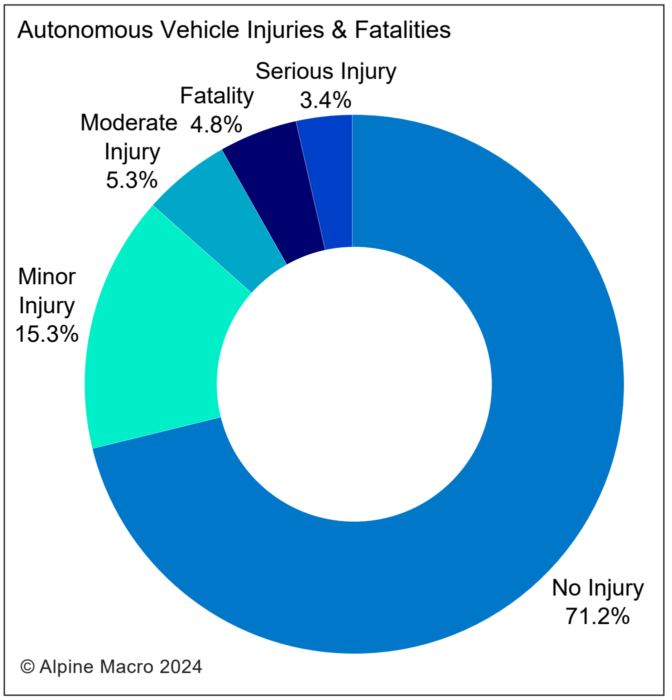
We stress that autonomous mobility's dependence on evolving technology combined with regulatory hurdles makes it challenging to predict precise timelines for widespread adoption. In our view, it is a fool's errand to predict when autonomous adoption will be truly disruptive. The more critical reality is that the conversation has shifted from "if" to "when". Although this autonomous transformation will not happen overnight, its inevitability underscores the importance of understanding the dynamics of autonomous mobility and proactively preparing for its far-reaching implications.

The Convergence Of AI And Autonomous Mobility

AI has become the cornerstone of autonomous mobility. Advanced machine learning algorithms enable autonomous vehicles to interpret complex sensory data, make split-second decisions, and navigate unpredictable scenarios with increasing proficiency. As a result, the industry has reached an inflection point where autonomous vehicles make fewer errors than human drivers.

Examples of AVs demonstrating capabilities that exceed human limitations and enhance safety

Chart 2 AV Safety Profile

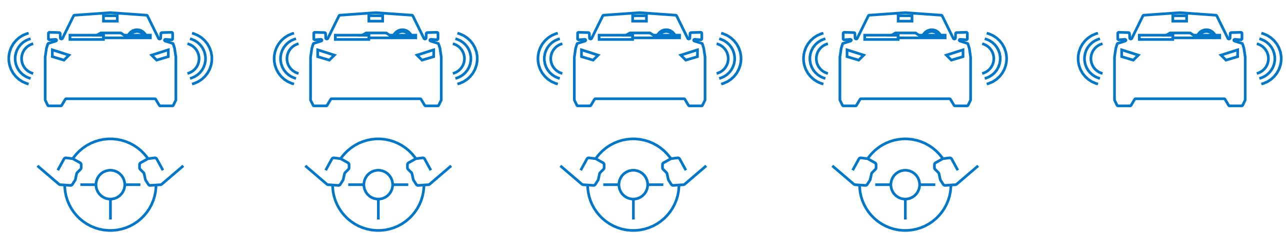


Source: National Highway Traffic Safety Administration (NHTSA)

are growing more frequent. For instance, over 22 million miles, Waymo's autonomous vehicles have achieved an 84% reduction in crashes involving airbag deployments, 73% fewer crashes resulting in injuries, and 48% fewer police-reported crashes compared to human-driven vehicles. Similarly for Tesla, self-driving is ~5x safer than manual mode and ~16x safer than the national average (Chart 2).

Improved safety, unlocked by AI, has been the driving force behind the significant growth in rider-only (RO) miles, a key progress tracker of level 4 autonomy (Chart 3). In the first half of 2024, Waymo's driverless vehicles alone logged over 22.2 million RO miles — almost a quarter of the distance between Earth and the Sun. This milestone is crucial, as RO miles greatly expand the data pool necessary for refining autonomous capabilities.

Chart 3 Five Levels Of Vehicle Autonomy



LEVEL 1
Driver Assistance: The vehicle can assist the driver or take control of either the vehicle's speed, through cruise control, or its lane position, through lane guidance.

LEVEL 2
Occasional Self-Driving: The vehicle can take control of both the vehicle's speed and lane position in some situations, for example on limited access freeways.

LEVEL 3
Limited Self-Driving: The vehicle is in full control in some situations, monitors the road and traffic, and will inform the driver when he or she must take control.

LEVEL 4
Full Self-Driving Under Certain Conditions: The vehicle is in full control for the entire trip in these conditions, such as urban ride-sharing.

LEVEL 5
Full Self-Driving Under All Conditions: The vehicle can operate without a human driver or occupants.

Source: SAE & NHTSA

Embodied AI, where autonomous systems interact with and learn from their physical environment, is turbocharging AV development. Similar to humanoid robots, embodied AI eliminates the need for human oversight in the learning loop. "Self-supervised" learning now processes raw sensor data to generate driving commands with unmatched precision. This is particularly important as it could reduce the testing miles needed to validate AV safety by over 99%.[1]

Access to unconstrained AI computing power is enabling the development of AV-specialized neural networks — learning algorithms that mimic the human brain's structure to process data. These neural networks, which leverage diverse real-world data, help AVs understand their environment semantically, rather than just geometrically, improving their ability to handle unpredictability. Improved AI capabilities reduce reliance on onboard hardware.

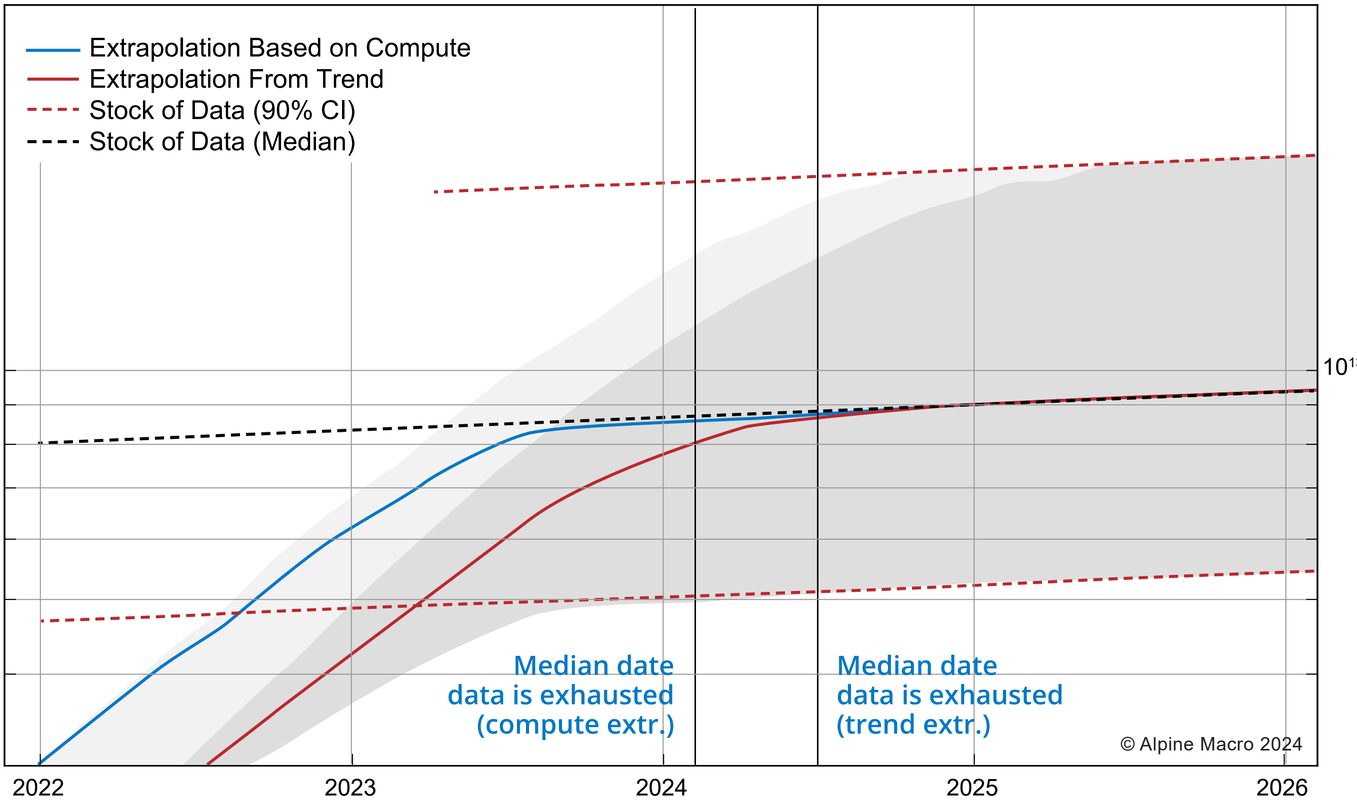
1 Dense reinforcement learning for safety validation of autonomous vehicles

An Evolving Hardware Landscape

Hardware inputs, especially sensors, are essential for autonomous vehicles, however, the industry is shifting away from the traditional belief that more sensors lead to better performance. Instead, the focus is now on a layered approach that leverages AI. Developers are using fewer, but more advanced sensors and LiDAR systems (laser-based radar), with AI enhancing their functionality.

For example, Waymo's sixth-generation robotaxi reduced its onboard cameras from 29 to 13 and its LiDAR sensors from five to four. Tesla is aiming

Chart 4 Training Data Bottleneck



Source: Pablo Villalobos, Jaime Sevilla, Lennart Heim, Tamay Besiroglu, Marius Hobbhahn, and Anson Ho, "Will We Run out of Data? An Analysis of the Limits of Scaling Datasets in Machine Learning".

to move away from LiDAR entirely, relying solely on cameras and AI-powered neural networks. Tesla's Full Self-Driving system relies on vision-based sensors instead of LiDAR. Access to visual data is becoming critical to improving autonomous neural networks, as AI could run out of high-quality text training data by 2026 (Chart 4). While the ideal combination of LiDAR, radar, and other sensors is still uncertain, minimizing hardware is crucial for reducing AV costs and spurring adoption.

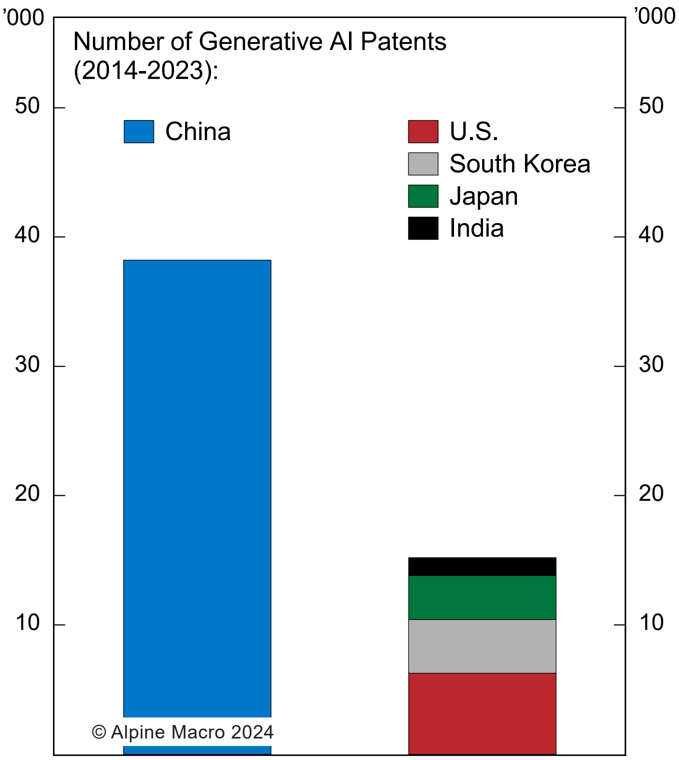
Reducing onboard hardware is also supported by the development of infrastructure, such as "smart roads" — roads embedded with an array of technology and designed to maintain constant communication with autonomous vehicles. Smart road infrastructure is a key enabler of MaaS and plays a central role in the U.S.-China tech race.

U.S. Lags China In Autonomous Mobility Race

It is evident that the Chinese government is willing to pour its support into the autonomous mobility sector to achieve global leadership, while the West continues to employ a more cautious approach. As we have outlined in previous reports, China is the global leader in 57 out of 64 critical technologies[3] and has filed 38,000 of 54,000 GenAI patents over the past decade (Chart 5). Autonomous mobility is

2 Australian Strategic Policy Institute's Critical Technology Tracker

Chart 5 China's GenAI Dominance



Source: WIPO Patent Landscape Report on Generative AI

a clear pathway for the Middle Kingdom to combine leading capabilities in both vehicle manufacturing and AI to dominate this cutting-edge field.

Comparing infrastructure investments between the U.S and China, particularly in transportation, reveals stark differences. In 2023, China's annual investment in transportation infrastructure reached 3.9 trillion yuan ($553.5 billion), a record high. This was the seventh year in a row that China's annual investment in transportation infrastructure exceeded 3 trillion yuan. In contrast, the U.S. government spent $44.8 billion on infrastructure in 2023 and transferred an additional $81.5 billion to states.

Aside from investment leadership, China's regulatory framework, autonomous vehicle permitting process, and public demand for autonomy are accelerating autonomous capabilities. This year, the Ministry of Industry and Information Technology granted nine permits for testing advanced autonomous driving technologies on public roads. These permits covered various MaaS areas such as ride-hailing, freight, and public transport. China has issued 16,000 test licenses for driverless cars and opened around 20,000 miles of roads nationwide for testing, with 20 cities already fielding robotaxis. From a consumer perspective, autonomous features, such as automatic parking, are highly valued, with Chinese consumers demonstrating a stronger desire and greater willingness to pay a premium for these capabilities compared to their counterparts in the U.S. and Germany.[3]

Furthermore, China has launched a pilot program to develop "smart roads" in 20 cities, including Beijing and Shanghai. Beijing has already expanded its autonomous driving zone from 160 to 600 square kilometers, with over 400 road intersections and 10 kilometers of expressways now equipped with smart infrastructure. Access to 5G stations is crucial for linking autonomous vehicles to this infrastructure. By mid-2024, China had built over 3.83 million 5G stations, accounting for more than 60% of the global total.

The United States has adopted a more cautious approach to autonomous transportation compared to China's aggressive strategy. This difference is evident in several key areas. For instance, the U.S. recently completed the first three-mile stretch of its "smart highway" infrastructure in July. Still under development, this highway will cover 39 miles, connecting Detroit and Ann Arbor, with cameras, sensors, and wireless systems along the route.

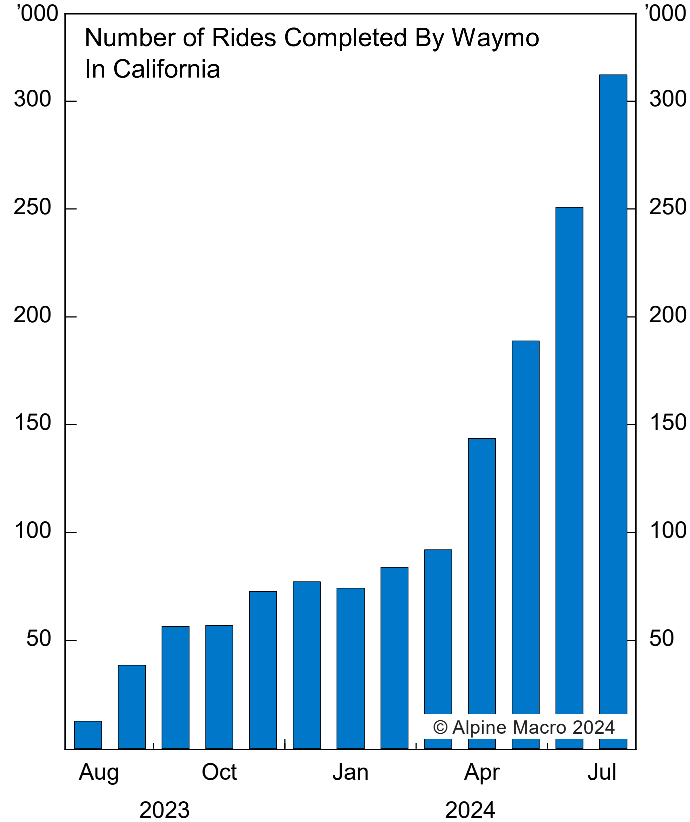
3 S&P Global Mobility

On the autonomous vehicle front, the National Highway Traffic Safety Administration (NHTSA) currently allows manufacturers to deploy up to 2,500 self-driving vehicles annually. Yet, the regulatory landscape remains complex, as overlapping jurisdictions create confusion and inhibit innovation. While the NHTSA oversees vehicle safety, individual states regulate vehicle operations. This has led to regulatory gray areas when software acts as the "driver", prompting states to take matters in their own hands and develop their own laws. In the event of streamlined federal legislation, state laws could remain potential roadblocks.

President Trump's administration previously prioritized creating a federal framework for self-driving vehicles and has pledged to go further this time. During his first term, a related bill passed the House but stalled in the Senate. With Republican control of Congress and input from innovation advocates like Elon Musk, the likelihood of passing streamlined, pro-autonomous legislation appears higher but not guaranteed.

Despite unclear regulations and limited "smart road" infrastructure, U.S. autonomous vehicle miles are increasing rapidly. Waymo, for example, now provides over 150,000 rides weekly, covering more than one million fully autonomous miles. The company's rides surged from 12,000 in August 2023 to over 312,000 in August 2024 (Chart 6). In another noteworthy development, Tesla has recently unveiled "cybercab" with hopes of deployment in 2026. In 2025, the company aims to have Full Self-Driving technology (level 4) available on its popular Model 3 and Model Y vehicles in Texas and California. This is a significant tailwind for algorithmic refinement.

Chart 6 Surge In Waymo's Rides In California



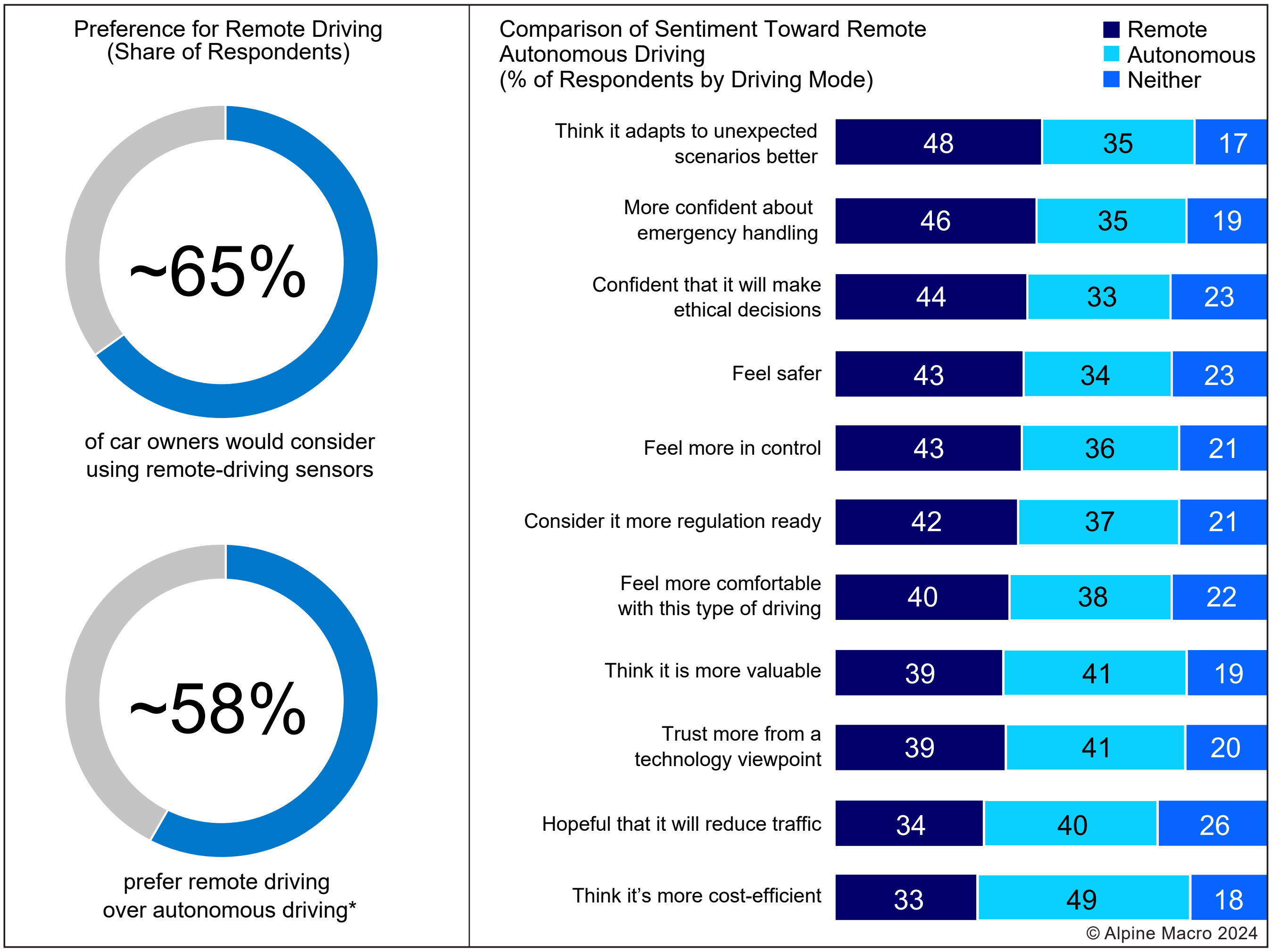
Source: California Public Utilities Commission

Remote Driving Is Essential To Autonomous Evolution Of Smart Mobility

Remote driving is emerging as a vital bridge toward fully autonomous vehicles, addressing current technological and regulatory limitations. By enabling human operators to remotely control vehicles in real-time, it provides a "safety net" for navigating high-variability environments where autonomous systems struggle.

This technology accelerates autonomous development by collecting valuable real-world data to refine AI algorithms and decision-making. It is also positioned to expand the operational range of level 4

Chart 7 Remote Driving Appeal



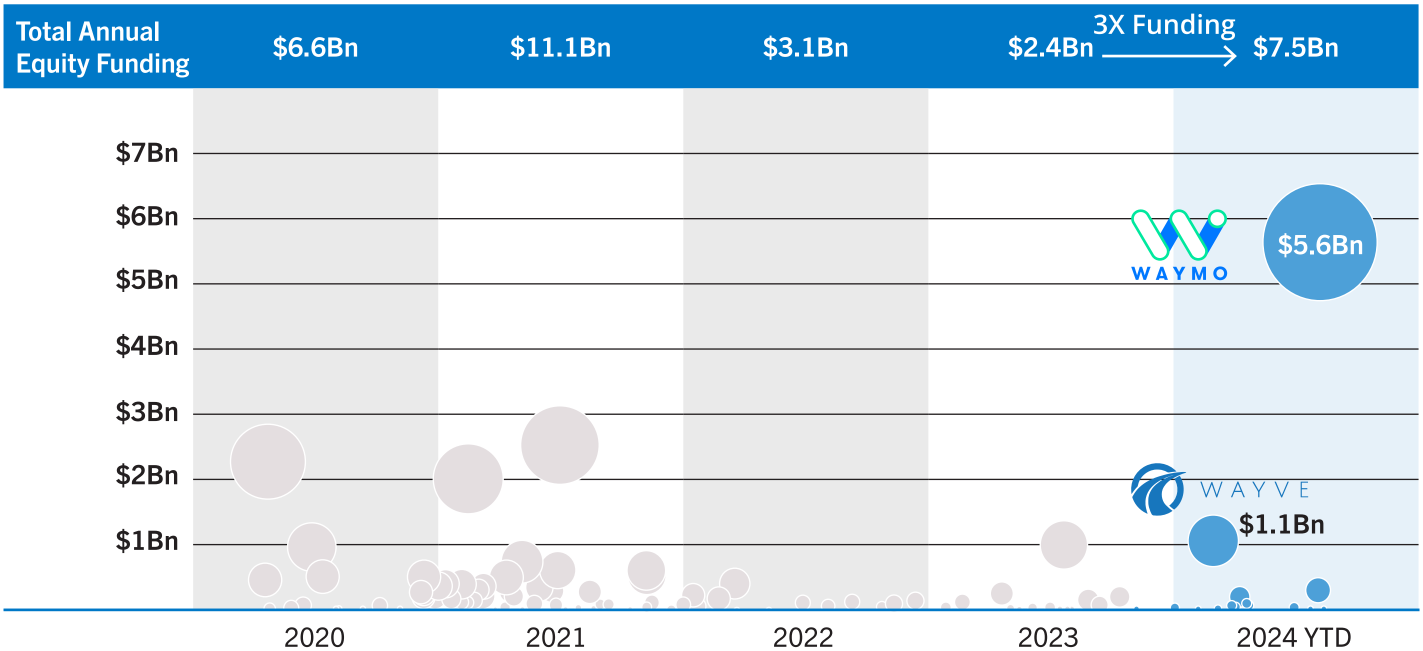
*For this analysis, we included only those respondents who said they had a preference for one mode of transport over the other; those who were neutral were not included in the analysis
Note: Figures may not sum to 100% because of rounding; source: McKinsey Remote Driving Survey 2024; n = ~1,500

autonomous vehicles by allowing human intervention when needed. Remote driving is a direct accelerator of MaaS, with impacts across logistics, ride-hailing, and public transportation. Crucially, remote driving is mitigating public concerns about full autonomy. A McKinsey survey revealed 65% of respondents were "likely" or "very likely" to use remote driving services, demonstrating greater acceptance compared to fully autonomous systems (**Chart 7**).

Investment Considerations

Autonomous mobility is emerging as a disruptive megatrend at the convergence of AI and mobility technology. The rise of MaaS is set to revolutionize not only transportation but a wide range of interconnected industries. The growth of ridesharing, exemplified by Uber's facilitation of over 200 million weekly trips, underscores the vast market opportunity and scaling potential. Investment in autonomous mobility has surged this year, with

Chart 8 Record AV Funding



Note: Size of bubbles represents funding round size, data as of 11/13/2024
Source: CB Insights advanced search for autonomous driving company funding

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equity investment levels tripling compared to 2023, fueled by growing confidence in robotaxi fleets and their supporting platforms (**Chart 8**). However, the impact of autonomous mobility extends far beyond human transportation, with profound implications for logistics, urban planning, and infrastructure development.

The development of next-generation technologies (most specifically AI and advanced sensing), shifting regulatory landscapes, and the evolution of global transportation infrastructure embody a triad of themes investors must closely monitor in this space.

We recommend investors seeking exposure to autonomous mobility do so through a diversified approach that prioritizes key areas of technological convergence across the various underlying technologies critical to supporting this mobility revolution. The **appendix** on the following page includes key technological buckets.

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Global Strategist

Key Technological Buckets

Improvements	Key Technologies
Batteries and Battery Supporting Infrastructure	Solid-state batteries, novel inroad charging, battery swapping, next-generation battery cathodes
Vehicle-to-Everything (V2X) Communication	Awareness-enhancing technology that enables AVs to communicate not only with other vehicles but also with surrounding infrastructure, such as traffic lights and road sensors.
Ultrasonic Sensors	Facilitate close-range object detection, especially during parking or in low-speed maneuvers. Assist vehicles in detecting objects like curbs or pedestrians that might be in the immediate vicinity.
5G and Advanced Connectivity	Provide ultra-low latency, high bandwidth, and massive device connectivity. Unlocks real-time communication capabilities needed to function safely in dynamic environments.
Autonomous Fleet Management Software	Software provides the tools needed to monitor, control, and optimize the performance of multiple autonomous vehicles in real-time, enabling efficient operations across a variety of use cases, from ride-hailing to logistics and public transportation.
Smart Road Infrastructure	Equipment includes sensors, cameras, radar, and LiDAR, to monitor traffic, detect road conditions, and identify potential hazards in real-time. Critical to reducing “onboard” tech requirements.
AI and Next-Generation Chips	Next-generation AI chips enable real-time edge processing, allowing autonomous vehicles (AVs) to analyze data locally for immediate decision-making, reducing latency and enhancing safety. These chips also integrate seamlessly with sensors like LiDAR, radar, and cameras while providing the computational power needed to process vast amounts of sensory data and operate advanced AI models.

A Unique Mind On The Markets