The New World of Electric Vehicles

Investment and M&A Trends

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About This Report

The purpose of this report is to share market knowledge, insights, and perspective about the titanic shift from Internal Combustion Engines to Electric Vehicles. The industry value chain in the evolving ecosystem of Autonomous, Connected, Electric, and Shared (ACES) vehicles is different from what it was for one hundred years since Ford Model T. Many of the changes have software and connectivity at the center, requiring automakers and suppliers to build or acquire expertise in software development and digital/cloud services.

The report is intended for CEOs, other leaders, and investors of emerging growth companies who are working on making Electric Vehicles a mass market reality and strategy and corporate development executives at established companies in the auto and related industries.

Report Authors and Acknowledgments

This report was prepared by Mukesh Ahuja and George Jones of **Woodside Capital Partners** in partnership with Vasudha Madhavan of **Ostara Advisors** and Sri Purisai of **RiSo Capital**. The authors would like to acknowledge Alex Casey of Woodside Capital Partners and Priyamvad Ranade of Ostara Advisors for their contributions to the research and analysis in this report. We also thank Nihar Patel of RiSo Capital for his insights based on thirty years at top global automakers, and Vamshi Kandalla, Automotive Networking, Semiconductor, and Systems ecosystem executive, for his contributions.

About Woodside Capital

Woodside Capital Partners is a leading global independent investment bank delivering strategic and financial advice to emerging growth companies in the technology sector. We know how to close the deal through mergers and acquisitions (M&A), capital raising, private placement, or strategic partnering to get results for our clients.

About Ostara Advisors

Ostara Advisors is India’s first and only Electric Mobility-focused boutique investment banking firm. Founded by Ms. Vasudha Madhavan in 2015, the firm is credited with several firsts, including advising on India’s first Electric two-wheeler M&A deal in 2018 and raising one of India's largest funding rounds from Global and Indian private equity and corporate venture funds for a leading electric three-wheeler maker in 2022. The firm brings decades of experience executing capital-raising strategies and crafting business combinations to drive win-win M&A outcomes for its clients.

About RiSo Capital

As an early-stage/ seed investor that invests in India-based startups solving global problems, RiSo Capital believes in partnering with entrepreneurs to actively work towards realizing their dreams and achieving their goals.

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The Big Disruption – From Combustion Engines to Electric Vehicles

The global automotive world is going through the biggest changes in nearly one hundred years as it moves from Internal Combustion Engine (ICE) to Electric Vehicles (EVs).

Several factors including Tesla's stunning success since its introduction of Model S in 2012, public pressure for a response to climate change, and regulatory and financial support from national and regional governments have changed the landscape in which automakers operate. Virtually all the major automakers have announced timelines and targets for producing EVs in large quantities. Participants in the global automotive supply chain in countries from China, India, and Korea in Asia to Germany, the UK, France, and Italy in Europe are preparing for this transition.

Most of the auto industry's R&D spending has shifted to EVs. Investments by venture capital and private equity funds, M&A activity, IPOs, and public automakers' valuations reflect that the change from ICE to EVs has reached the tipping point. In the US, 2022-2023 is a very consequential year for the switch to EVs with two major federal spending bills and an announcement by the State of California that it will ban the sale of new combustion engine cars starting in 2035.

According to the Union of Concerned Scientists, the top 5 annual global carbon emitters (2019 data in Metric Gigatons and % of worldwide total) are:

1. China 9.9 GT or 29%
2. United States 4.7 GT or 14%
3. India 2.3 GT or 7%
4. Russian Federation 1.6 GT or 5%
5. Japan 1.1 GT or 3%.

All five countries are part of the Paris Climate Accord. In both China and India (including 2 & 3-Wheelers), the adoption rate of EVs is above the worldwide average with wide-ranging government policy support for EV producers and consumers.

This report is the first report in a series on the new world of Autonomous, Connected, Electric, and Shared (ACES) vehicles. It covers electric 4-Wheelers, 3-Wheelers, and 2-Wheelers. We analyze the market trends, investments, and M&A activity in the sector from 2021 and look ahead until 2025.

Executive Summary

The report is broken into six sections:

Section 1

Status of Automotive Software and Electronics

Traces the evolution of software and electronics in vehicles, starting with the Electronic Control Unit (ECU). Then we discuss Domain Control Unit (DCU), Vehicle Control Unit (VCU), and the possibility of seeing the adoption of operating systems in vehicles.

Section 2

The Move to Electric Vehicles and 2022 - 2025 Roadmap

Presents the technology roadmap, investments, M&A activity driving toward the development of **Autonomous, Connected, Electrified, and Shared (ACES) vehicles.**

Section 3

Electrification and Charging Infrastructure

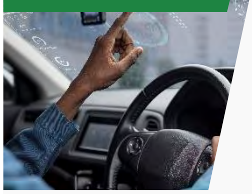
The rates of EV adoption and the number of charging stations are uneven worldwide. 85% of global EV sales in 2021 occurred in China or the EU. The US and Japan are far behind China, EU, and the rest of the world in EV adoption. In 2021, 4% of passenger cars sold in the US were electric, vs. 19% in the EU, 15% in China, and 9% worldwide.

Section 4

Connected Vehicles

Discusses Connected Vehicles with the ramifications for internal networking and external connectivity. Internal networking in vehicles is going through a major revolution but external connectivity will require major infrastructure upgrades to accommodate the bandwidth requirements of Autonomous vehicles, infotainment and content services.

Section 5



Autonomous and Shared Vehicles

Covers Autonomous and Shared Vehicles. We are still in the very early stages of autonomous driving, at level 2 out of 5 levels (full autonomy). The shared vehicles segment has attracted very large amounts of private as well as SPAC and IPO investments. We also discuss interesting ways in which autonomous vehicles benefit shared mobility and shared vehicles help justify the cost of autonomous features with their high usage rates.

Section 6

Response from Incumbent OEMs and the Path Forward

Covers the response of the incumbent automakers to the changes and the path forward. With the varying government responses to national regulation, financial incentives needed for consumers to be early adopters, and the large infrastructure investments needed, many new entrants, especially in China have entered the top tier of EV and battery makers.

1. Status of Automotive Software and Electronics

The auto industry was a hardware-oriented business for over one hundred years. The share of software and electronics costs in the average vehicle grew as automakers introduced electronic safety and assist systems, GPS, infotainment systems, lighting, and a hybrid powertrain. It increased from under 5% in the 1970s to 40% by 2020.

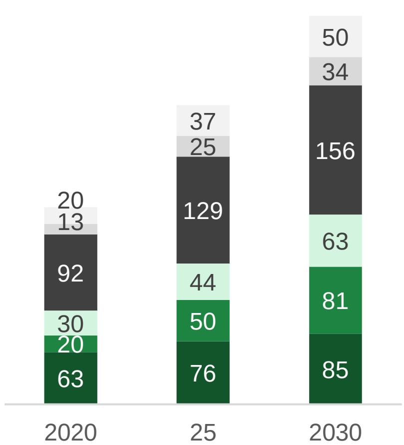
With the addition of new electronic subsystems, the number of Electronic Control Units (ECUs) has been steadily increasing since the 1980s.

With the introduction of electrified vehicles around 2010 and the ubiquitous presence of connectivity in consumers' lives, the innovation path of automotive design, supply chain and manufacturing has been disrupted. We are on our way to software and electronics accounting for ***50% of the cost of a new vehicle***.

In Internal Combustion Engine vehicles, control systems are dedicated to a single function such as anti-lock brakes or power windows.

Automotive SW and E/E Market - CAGR of 7% Until 2030[1]

Automotive SW and E/E market
$ billions



Components	CAGR 2020-30
Total	**+7%**
SW (functions, OS, middleware)	+9%
Integration, verification and validation services	+10%
ECUs/DCUs	+5%
Sensors	+8%
Power electronics (excel, battery cells)	+15%
Other	+3%

Total electronics and SW by geography in 2030	
EU	112
China	161
US Canada Mexico	68
Korea Japan	50
RoW	78
Total	**469**

Automotive Sales
USD billions

2020	**2025**	**2030**
2,755	3,027	3,800

CAGR 2020-30 +3%

1 Source: McKinsey (Automotive software and electronics 2030)

As the new electric powertrain and networking features are being added, the architecture of a modern automobile becomes several domains such as autonomous driving connected by an internal network and connected to the outside networks for services. With the interconnected domains for power management, charging, infotainment, and content services, the need develops for a vehicle operating system.

Most of the auto industry's R&D spending, investments from venture capital and private equity investors, and governments have moved to Autonomous Connected Electric and Shared (ACES). While EVs accounted for only 9% of worldwide auto sales in 2021 and are a much smaller percentage of all vehicles on the road, most of the technology investments and R&D spending have switched over to ACES. Spending on the design of new fossil fuel vehicle models has decreased dramatically. Many automotive companies (such as Daimler Benz) have discontinued R&D on internal combustion engines.

The changes coming to the auto industry are similar to what the PC industry went through in the 1980s and what the mobile smartphone industry went through in the early 2000s. Apple introduced the Macintosh computer in 1984, using a closed design and a vertically integrated ecosystem. Apple priced its products high and sold them to professional users at high profit margins. In under two years after Macintosh, Microsoft launched Windows, licensed it to any company that wanted to build PCs for the mass market bringing competition and lower prices. Microsoft allows hardware and software to be separated. In a few years, Microsoft reached 90% market share and Apple was left with 10% market share, although with a much higher share of the industry's profits.

In 2007, Apple introduce the first iPhone and within 15 months, Google introduced Android, licensed it to any company that wanted to make smartphones and compete on features and price. Again, Android and its open ecosystem took nearly 90% market share, leaving Apple with around 10% share.

In the EV world, Tesla followed the Apple playbook launching a closed ecosystem product with a vertically integrated model. Now the race is on for companies to offer mass-market EV products using off-the-shelf and interoperable software and hardware components, as well as batteries. Many companies such as Red Hat, Blackberry, NVIDIA, Apex.ai, Google, and WindRiver/Aptiv are working on vehicle operating systems that automakers can use as the brain of their vehicles.

Large automakers such as Tesla, Mercedes, and Toyota will build their own versions of the operating system and all other automakers will have to design their vehicles using off-the-shelf operating systems and buy components in the open ecosystem.

The race for market share in the new EV world is global as the demand for EVs is still dependent on government regulations, subsidies, and investment in charging infrastructure. China and the EU have taken a lead and the US and Japan are playing catchup in the global EV race. 85% of EVs sold worldwide in the year 2021 were sold in China or the EU.

2. The Move to Electric Vehicles – 2022-2025 Roadmap

With the re-introduction of EV subsidies in the US and new investments in building batteries and charging infrastructure, it remains to be seen how US automakers other than Tesla can compete with new EV models.

Most people would be surprised to learn that **one-third of cars in the US were electric in 1900**. But with the lower cost of the Ford Model T and cheap gasoline prices, electric cars disappeared from the US by 1935. A Facebook video published by the World Economic Forum shows a fascinating history of the popularity of electric cars before Ford Model T was introduced and cheap oil was discovered in the US (you can watch it **here**). The US Department of Energy has an enlightening history of the Electric Car on its website (you can read about it **here**).

The initial cost of EVs compared to the older gasoline models is the single biggest barrier to the adoption of EVs in the US and in other countries. The second biggest barrier is the availability and speed of charging stations.

EVs are fundamentally different from combustion engine cars in their design. They have fewer parts, and different component costs with the battery accounting for half of the vehicle cost. In connected vehicles, automakers can deliver new features and fix problems with over-the-air software updates.

EVs will go from being a high-end luxury product to a mass-market product in the US and other countries only if consumers do not have a pay a premium to buy an EV. The operating and maintenance costs of an EV are already lower than an ICE vehicle. However, for mass-market adoption, the initial costs must come down sufficiently with no government subsidies, as they are only a temporary phenomenon.

There are a few key drivers of the EV initial costs. First is the battery prices which have been coming down steadily for years and will likely continue to do so for the next few years. Second is an open ecosystem of suppliers of software and components and industry standards, so automakers can integrate off-the-shelf software and components to meet consumer and government requirements. Additional big drivers of the EV costs are larger volume and increased competition.

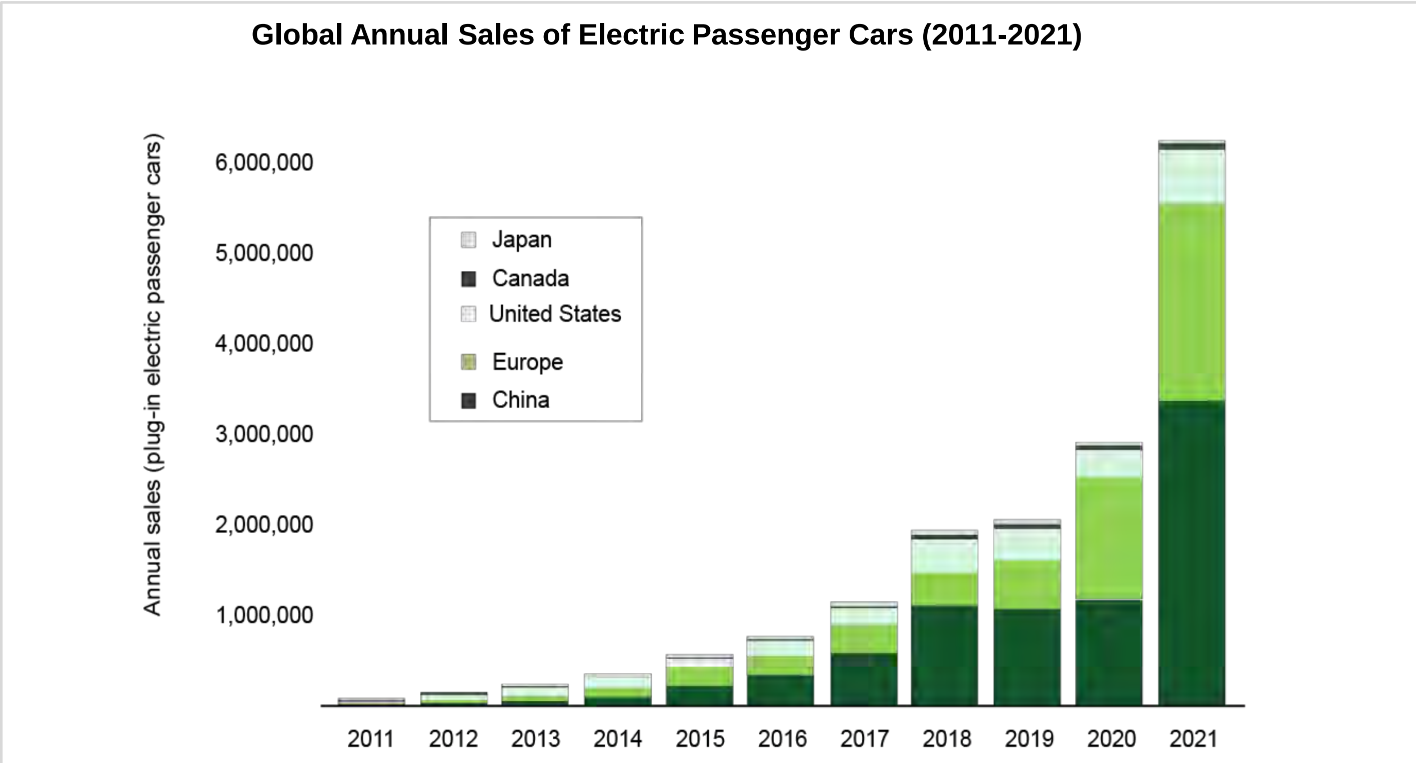
3. Electric Vehicles and the Charging Infrastructure

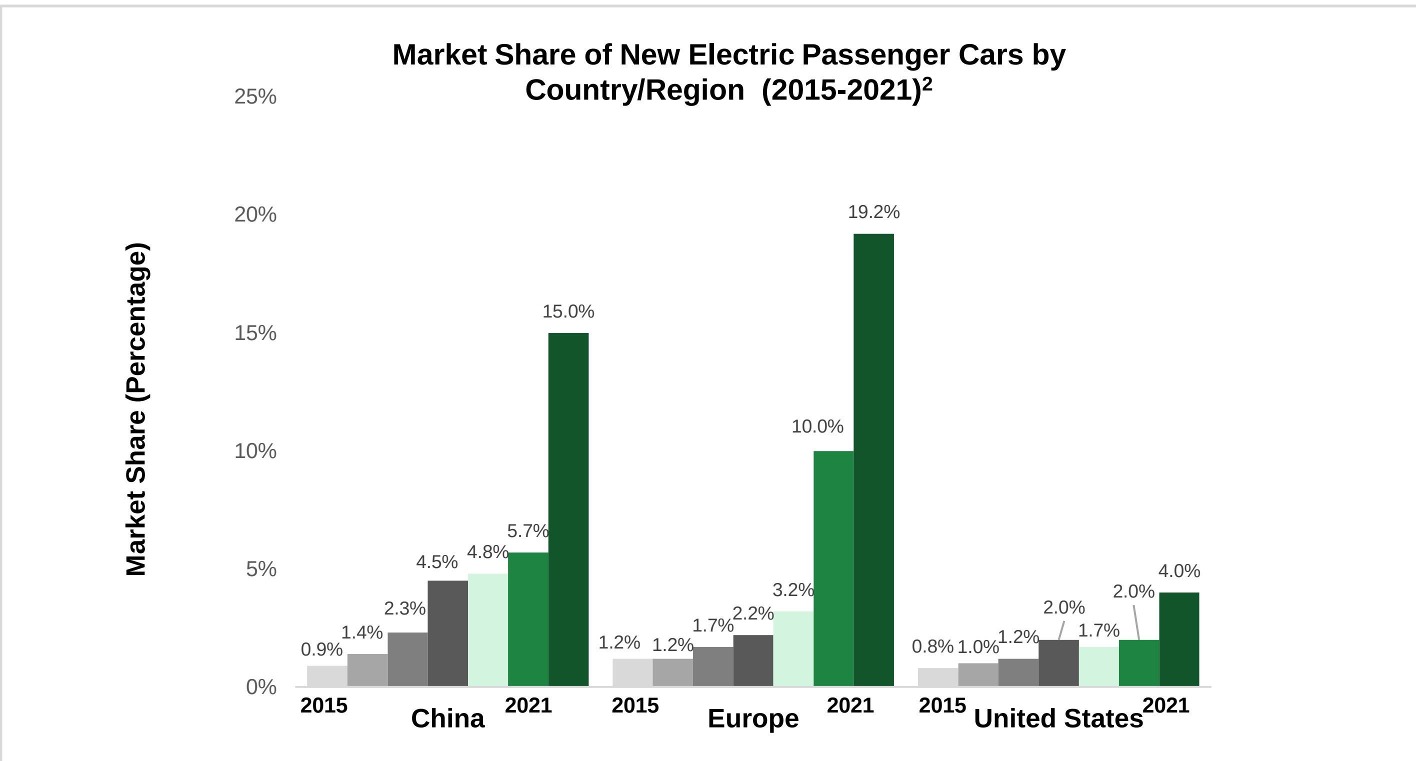
The rates of EV adoption and electrification are uneven worldwide. 85% of global EV sales in 2021 occurred in China or the EU. The US is far behind China, the EU, and the rest of the world in EV adoption. Japan also has a much lower EV adoption rate than China and the EU. In 2021, 4% of passenger cars sold in the US were electric, compared to 19% in the EU, 15% in China, and 9% worldwide.

With the passing of the federal Infrastructure Bill in the US, the re-introduction of $7,500 subsidies and California's ban of combustion engine cars from 2035, the US market will change in the next 2-3 years.

The operating costs of an EV in the US is far below equivalent gas prices. The total cost per mile of operating a Tesla Model 3 is $0.03 per mile compared to $0.13 for a Honda Civic and $0.14 for a Toyota RAV4. In spite of this advantage of owning an EV, mass adoption is still dependent on a reduction in the initial purchase price, especially after governments phase out the subsidies.

Executive Summary





2 Source: IEA

Ford Motor CEO Jim Farley is predicting a price war between automakers leading to lower prices, but this view is not shared by many experts and there are significant obstacles along the way.

Motorcycles and 3-Wheelers Fleets

While 4-Wheelers are, by far, the largest segment of the automotive market in developed markets, eBikes, 3-Wheelers, and 2-Wheelers dominate in large emerging markets, including India and China. **For comparison, there are roughly 1.4 billion cars in the world in 2022 and about 600 million motorcycles (including scooters, and mopeds).**

Electrifying 2-Wheelers and 3-Wheelers is a big part of China and India working to meet their carbon emissions goals. 70% of 200 million registered vehicles in India are 2-Wheelers.

Both China and India are far ahead in electrifying the 2-Wheeler and 3-Wheeler segments than the 4-Wheeler segment. 45% of 3-Wheelers and 54% of 2-Wheelers sold in India are electric in 2022.

Charging Infrastructure

There were more than 450,000 fast publicly available chargers in Chia in 2021, compared to around 20,000 in the US. Similarly, there were 700,000 slow publicly available chargers installed in China in 2021, compared to less than 100,000 in the US, and 300,000 in the EU.

Due to the local nature of charging stations and their dependence on regulations and securing the real estate for chargers, charging stations and services companies are one of the most active areas of M&A deals of any emerging sector. (Source: Pitchbook)

It is important to point out that if consumers moved to EVs as rapidly as governments would like them to, the electric grid in most regions of the world would not be able to support the charging needs and there would be frequent blackout periods. In addition to charging stations, charging infrastructure includes electric grids, not to mention whether the grids are powered by renewable, fossil fuel, or nuclear sources.

4. Connected Vehicles

With the advent of the electric drivetrain, ADAS/Autonomous features, increasing importance of user experience (and the emergence of the digital cockpit), internal vehicle networking is undergoing a complete overhaul. Electronic Control Units that controlled specific functions such as keyless entry are being replaced by Domain Control Units that communicate using a high-speed Control Area Network bus. ADAS and Autonomous features require guaranteed delivery of data and need security features.

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From the previous Control Area Networks (CAN bus), internal networks are moving to Flexible Data-rate CAN and Automotive Ethernet to accommodate the real-time needs of autonomous driving. CAN FD (CAN with Flexible Data-rate) is 5 to 8 times faster than the first-generation CAN bus used in cars, but that is still not enough for the high bandwidth requirements.

The value chain in the automotive industry – how automakers (OEMs) work with their suppliers is changing as vehicles become endpoints in a network consisting of connected devices, a power grid, charging stations, and payment infrastructure. Many companies from semiconductor, software, and telecom industries such as Marvell, Synopsys, Qualcomm, Red Hat, BlackBerry, NVIDIA, and Hitachi along with new startups are working on the networking needs of the new ACES cars.

Outside the vehicle itself, software, cloud, and apps have become key to how people buy, rent, share, charge, drive and experience their vehicles. The vehicle of the future will include a subscription to a high-speed data service to communicate with external devices, other vehicles, cell towers for new infotainment and content services. However, the amount of data generated by autonomous vehicles is in terabytes per day per vehicle and even fully built-out cellular 5G networks will not be able to support the bandwidth requirements. New rules of engagement between consumers, automakers, and service providers (vehicle ISP) will eventually emerge so that vehicles can have appropriate external connectivity. The initial use cases will be in industrial fleets, trucks, warehouses, and campus driving before reaching urban consumers.

5. Autonomous and Shared Vehicles

The Society of Automotive Engineers defines 5 levels of automation of the driving function. In 2022, we are at the early stages (Level 2 out of 5) of automation of the driving function. Currently, a handful of Autonomous Level 2 systems are being sold with luxury vehicles. At the end of 2021, Mercedes Benz became the first automaker to secure internationally valid system approval for conditionally automated driving (Level 3).

While autonomous vehicles require a long period of heavy investments and depend on infrastructure to come into place, shared vehicles offer an immediate mass market with ready cash flows. As a result, shared vehicles attracted large amounts of capital from private investors as early as 2016 when Uber and Lyft raised big rounds of private investments and had their IPOs. Autonomous technologies and shared mobility reinforce each other and are related to each other in ways that impact the patterns of use.

Shared vehicles have higher usage and therefore can justify higher costs which helps to mitigate the additional expense of autonomous use cases.

6. Response from Incumbent OEMs and the Path Forward

To understand the path forward for the new automotive world, it is very useful to look at the response from the incumbent automakers in the US, the EU, and Japan to three major changes – the success of Tesla, China's lead in EV adoption, and the entry of Google, Apple, Amazon, and Uber into parts of the auto industry. Tesla had a 70% market share in the EV segment in the US in 2021, and likely an even higher percentage of the profits in the segment.

The year 2022 can be called the year of "Incumbent Automakers Meet Silicon Valley, China, and Big Tech" or "The Old Auto World Meet the New Auto World." It is the year when GM and Ford finally became serious about EVs, partially because the US government brought back subsidies and California announced a ban on fossil fuel vehicle sales from 2035. Even Toyota and Honda had to change direction in 2022, announcing massive new investments in batteries and accelerating EV plans.

The possibility of Biden removing or negotiating the 25% tariffs on goods from China when he came into office was real, but so far that has not happened. This is a key issue in bringing the cost of EV components down for US automakers. In 2022 when the Inflation Reduction Act brought back subsidies, it included the provision that consumers cannot get the $7,500 incentive if the batteries come from China. In 2022, automakers other than Tesla would find it hard to sell large volumes of EVs without the $7,500 incentive. Without the supply of components from China and the easing of the supply chains, EV prices will remain high in the US and will slow the adoption of EVs by several years. Within one month of the Inflation Reduction Act law, Toyota and Honda (with LG Energy) announced massive investments in battery manufacturing in the US.

The threat of Google (Waymo), Apple, Uber going big into autonomous vehicles is real and automakers should be concerned about the software and cloud capabilities that they can bring to consumers. Section 6 of the report includes an interview with Francis Chow, VP and GM of In-Vehicle OS and Edge at Red Hat (IBM). It will be interesting to see how incumbent automakers can increase their software capabilities. We discuss three kinds of responses from auto OEMs:

1. Build Software Engineering Capabilities and Teams
2. Partner with Software, Semiconductor Companies and Service Providers
3. Make strategic acquisitions of companies with domain expertise.

Porsche ex-CEO had announced plans to hire 10,000 software engineers before leaving the company. Automakers will have difficulty in fighting for and attracting software talent. We discuss some of the recruiting challenges and strategies in Section 6.

Final Thoughts - Investment and M&A Environment for 2022-25

Pitchbook tracks investments and M&A activity data for 139 emerging spaces. As of late 2022, the top two emerging spaces by the amount of money invested were Autonomous Trucking with $118 Billion and Next Generation Battery Technology with $109 Billion. The Autonomous Trucking amount was skewed by the Rivian IPO as the company became worth more than GM, Ford, and VW before shipping many vehicles. The top 10 emerging spaces by the amount of money invested included two more auto-related segments – EV Platforms and Autonomous Vehicles. The top emerging space by the number of deals in late 2022 was EV Charging Infrastructure with more than 1,100 deals including 28 IPOs, 714 venture capital deals, 171 M&A deals, and 180 private equity, debt, or other deals.

2022-2023 has been a watershed year in the global move from fossil-fuel vehicles to electric vehicles. The re-introduction of EV subsidies in the US and California's ban on fossil fuel car sales from 2035 materially shifted the momentum toward EVs. In most of the past innovations after high oil-price shocks, California blazed the trail for the other US states, and we can expect the same thing to happen again.

The EV subsidies announced in the US exclude vehicles with battery or battery materials sourced from China. This is in opposition to the important goal of lower-cost EVs. EV adoption will be limited to high-end consumers and luxury cars if the initial costs of EVs don't come down. Tesla has been famously unsuccessful in building a lower-cost model.

The prospects of mass-market EVs at prices comparable to fossil fuel cars appearing in 2023 and 2024 are not clear. The very large battery investments in the US announced by Toyota, Honda (with LG Energy), Ford and others will not go into full production until 2025.

Other than the price of batteries, the separation of hardware and software and the use of off-the-shelf standards-based components and software is the other major source of reducing the initial price of EVs. Strong investment and M&A environment in electric, shared, connected, and autonomous vehicles (in that order) will certainly continue due to push from governments and public demand for progress in meeting the Paris Climate Accord goals.

We expect that as auto OEMs strengthen their software capabilities, they will partner with and acquire companies with software-based IP and software development teams with auto industry expertise.

1. Status of Automotive Software and Electronics

Starting in the 1980s, automakers around the world have offered more and more features powered by microcontrollers and electronic subsystems. The number of Electronic Control Units (ECUs) has increased steadily since then. Vehicle customers have been willing to pay for these new features by purchasing higher-priced models or add-on options.

By 2010, cars sold in the US contained an average of 15 ECUs to perform functions such as anti-lock brakes, power-assisted features, digital displays, etc. A luxury auto contained nearly 30 ECUs to perform additional advanced functions such as digital entertainment, navigation, wireless connectivity, and driver assistance.

As the amount of electronics in automobiles grew, the architecture of a modern automobile grew into several domains connected by an internal network. As we will discuss in Section 3, new domains for autonomous driving and vehicle operating system are now being added to the architecture.

Types of Electronic Systems and Software in Automobiles

Electronic Control Unit

Domain Control Unit

Infotainment/ Content Services

Networking & Communication

Vehicle Control Unit

ADAS/ Autonomous

The migration from internal combustion vehicles to electric vehicles is forcing a fundamental change in the system architecture of automobiles

1. Status of Automotive Software and Electronics

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Vehicle Control Units (VCUs)

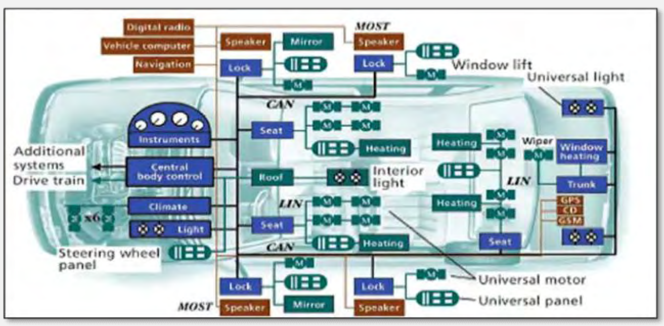
Drive/power train | Environmental | Communication | Peripherals

Integrated Vehicle Control on Prototype 4WD Vehicle with Front and Rear Electric Motors[3]

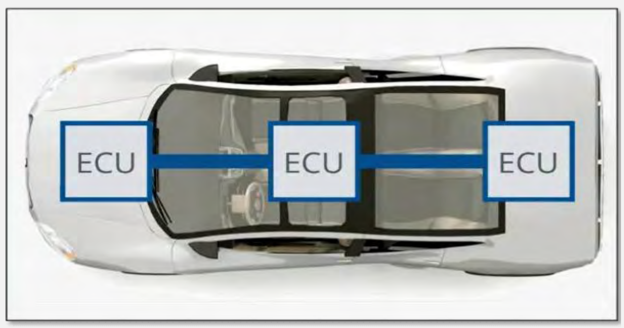
In internal combustion engines (ICE), control systems tend to be local and dedicated to single functions, such as braking and acceleration. In EVs, controls become more centralized with more sophisticated features. The impact of these changes is significant. New designs create opportunities for new suppliers, radically different design approaches, and more substantial capital requirements.

Newer wide bandgap semiconductor technologies such as Silicon Carbide and Gallium Nitride are increasingly able to convert battery-supplied power to higher voltages and currents needed to drive motors and rechargeable batteries. These chips are controlled by embedded processors (MCUs). Associated software completes the system.

Conventional Architecture



Software Centric Approach



The changes in the automobile software architecture are similar in many ways to the changes that occurred in the PC industry starting in the 1980s and in the mobile smartphone industry in the 2000s.

3 Source: Auto Vision News
Note: ECU in this diagram is analogous to VCU (Vehicle Control Unit)

1. Status of Automotive Software and Electronics

It's like 1985 in the Personal Computer Industry

In January 1984, Apple introduced the first Macintosh computer for $2,500, equivalent to a price of $7,000 today. In November 1985, Windows was introduced in the market, allowing many companies to compete in the Personal Computer market, bringing the prices down to mass market and capturing over 90% of the PC Operating System market. The introduction of Windows led to the separation of hardware and software businesses, creating Personal Computer companies including Acer, Dell, Compaq, etc., and application providers such as Lotus, Borland, Microsoft, and a large number of other companies.

The evolution of technology and business models related to microprocessors, operating systems, and applications to connectivity for Desktops followed a similar path as what we are witnessing now for Automobiles.

PC Technology		Auto Technology		Business Model
Technology	Products/ Use Cases	Technology	Products/ Use Cases	
DOS PC	Calculator Word Processing Early Games	Cars with MCUs ECUs	Power Features	Hardware, Software Sale
Mac/Mouse/ Windows	Desktop Publishing Office Desktop	Driver Display	Navigation Infotainment	Hardware, Software Sale
PC Networking. Internet.	Email, Chat Rooms Online Music	Electrification GPS VCU	BMS Powertrain	Hardware, Software Sale Subscription
Browser	World Wide Web	Autonomous, Connected Vehicles	Social	Hardware Software Sale, Subscription, Advertising, eCommerce

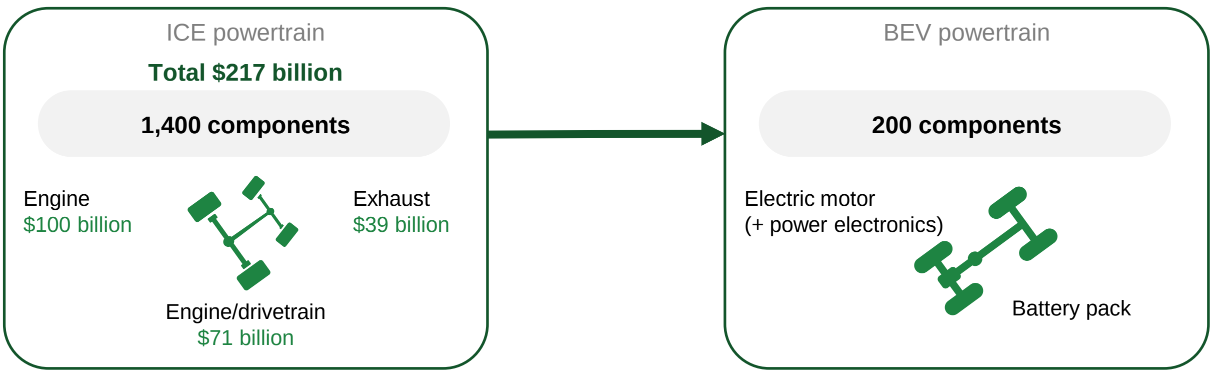
Repeat of PC Operating System Cycle with Smartphones - Emergence of Android

In June 2007, Apple introduced the first iPhone for $499. Within 15 months, Android was introduced in the market, allowing smartphone makers to license the operating system and compete on hardware, price, and applications. Today, Apple iOS has 13% of the smartphone operating system market share, and Android has 87%, similar to the Windows share in the personal computer market.

The Big Disruption - Software Lessons from the PC and Mobile Phone Industries
The move from Internal Combustion Engine (ICE) to Autonomous Connected Electric Shared (ACES) vehicles will have similar hardware and software dynamics as in the PC and mobile phone markets. Apple created premium devices and software in both markets and ended with roughly 10% market share with vertical integration and a closed ecosystem. 90% of the market share is held by open ecosystem players allowing many hardware and software players to compete and bring the costs down.

To see the **scale of the hardware disruption** occurring in the auto industry, let's look at the components that go into an ICE vehicle and an EV:

Change from ICE to BEV Results in global $ 217 billion Powertrain Segment Swapped for BEV Components[4]



The Emergence of Open Vehicle Control Unit or Vehicle Operating System
The evolution of automotive software will reach a stage where independent software / operating system providers, i.e., the equivalents of Windows and Android platforms will emerge, allowing automakers to compete on features without having to themselves master both hardware and software, thereby bringing widely accepted standards, lower costs and new applications to the mass market.

Current Vehicle OS offerings in the global automotive market:
Proprietary OS by automakers - VW, Mercedes Benz, Toyota Arene, Apple, Tesla, Waymo
Open or Third-Party Platforms – Red Hat Linux (IBM), QNX (Blackberry), Android Automotive OS (Google), VxWorks (Wind River/Aptiv), Apex.ai.

According to Blackberry, its software is now embedded in over 215 million vehicles. Most players including IBM, Blackberry, and Google have decided to limit their OS to Infotainment or Digital Cockpit use. Aptiv and Apex.ai include powertrain and autonomous driving.

4 *Source: Dale Cohen*

1.1 Proprietary Design vs. Open Ecosystem EVs

Vertically integrated EV manufacturers will license and customize software in Vehicle Control Units for their own needs resulting in high costs, advanced features, closed ecosystems, and vertically integrated designs. Tesla is following this proprietary product model just as Apple has done with iOS for several decades. It designed its software, building a high-end integrated platform because the software needed was unavailable, and the volumes were too small for independent companies to sell standard products. Like Apple, Tesla was able to build a proprietary product and charge a premium price.

High cost is one of the most significant barriers to EV adoption today. The open ecosystem and lower-cost EVs will be made possible by separating hardware and software, new standards, and shifts in the value chain as OEMs use more off-the-shelf parts and integrate them. This is much like how companies such as Dell became hardware platforms running Windows.

The challenges of building the new ecosystem of EVs and bringing the cost down are not naturally suited for the entrenched auto OEMs to solve. Many new entrants & independent startups will enable the much-needed software infrastructure and offer products that bring down the cost and increase the range of EVs.

Eventually, open ecosystem EVs for the mass market are likely to gain some share as compared to proprietary EV platforms for the reasons of cost-effectiveness and a greater variety of product offerings thus made available.

1.2 State of the Auto Software & Electronics Market – Year 2022 Snapshot

The move to EVs is leading to major shifts in valuations of public companies and private and public sector investments in battery and electrification technologies and is changing the global funding and M&A environment.

There will be significant winners and losers among the existing and new automotive companies, depending on how companies adapt to the move to EVs. Making needed changes too slowly is the main risk for existing automakers, but there is also a risk of not getting the transition to software-defined vehicles right, as illustrated by the recent CEO change at Volkswagen which was caused by its “software unit exceeding its budget, being years behind to launch a new software platform, and mismanaged transition to electrification”.

Categories of Vehicles

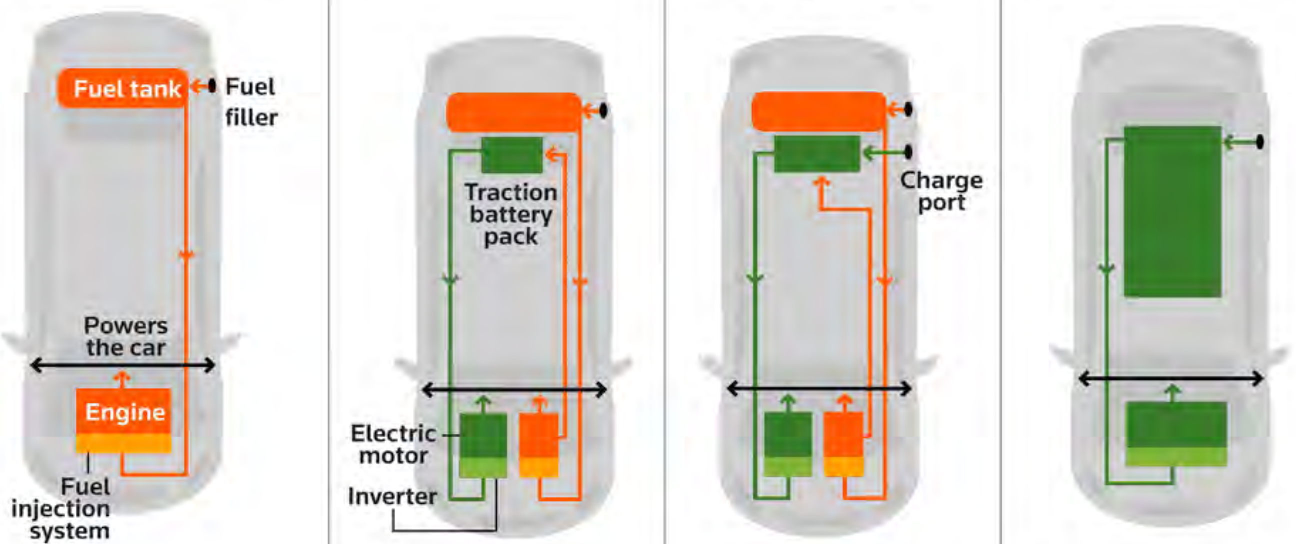
Types of electric vehicles[5]

CONVENTIONAL VEHICLES
Use internal combustion engines. Fuel is injected into the engine, mixing with air before being ignited to start the engine.

HYBRID ELECTRIC VEHICLES
Powered by both engine and electric motor. The battery is charged internally through the engine.

PLUG-IN HYBRID ELECTRIC VEHICLES
Battery can be charged both internally and externally through outlets. Run on electric power before using the engine.

ALL-ELECTRIC VEHICLES
Powered only by electric motor with no engine. Have large traction battery and must be plugged externally to charge.



	Conventional vehicles	Hybrid electric vehicles	Plug-in hybrid electric vehicles	All-electric vehicles
Consumption:	Fuels	Fuels	Fuels and electricity	Electricity
Driven by:	Engines	Engines primarily, motors secondarily	Motors primarily, engines secondarily	Motors
Advantages:	Easy to refuel, long driving range and high speed	Easy to refuel, less fuel consumption, less emissions	Easy to refuel, less fuel consumption, less emissions	Environmentally friendly, low maintenance, government support
Disadvantages:	More emissions, high cost of fuel	Less power, heavier weight of the car	High price, limited models to choose from, heavier weight	Lack of charging stations, short driving range and low speed, heavier weight

5 Source: Thomson Reuters

1. Status of Automotive Software and Electronics

2022 Snapshot - Gasoline, Hybrids, PHEV, EV Cars

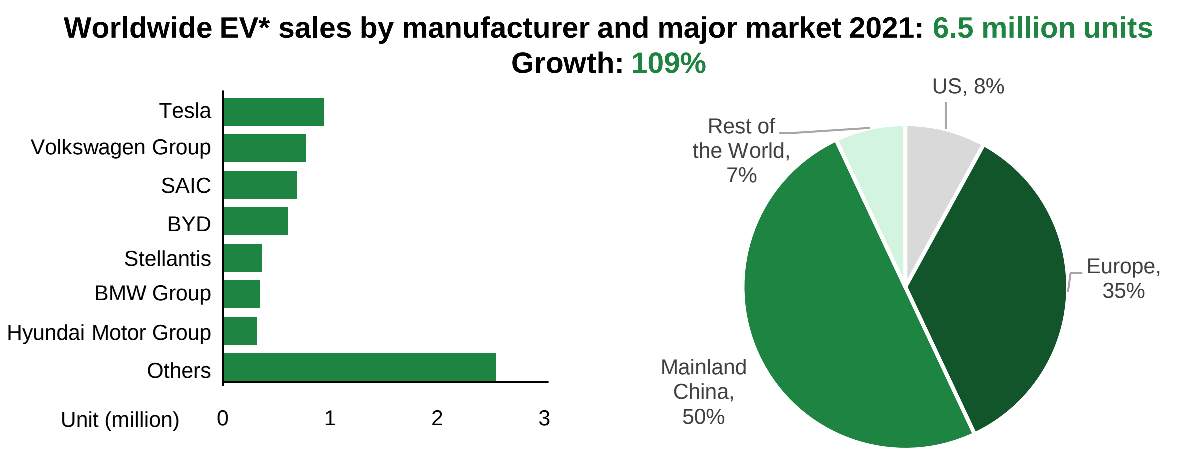
	Internal Combustion Engine		Electrified	
	Gasoline	Hybrids	PHEV	BEV
Starting Cost	$20,000	$1,000 to $3,000 Extra	$43,000	$34,500
Range	400 miles	-	First 20 to 40 miles on Electric.	200 miles on a charge.
Battery	Starter battery	Gas Engine + Electric Motor + Small Battery Pack	Larger Battery	Large Battery Pack.
Charging	N/A	N/A	Level 1 charging (120 volts)	8-10 hours to charge with Level 2 charging (240 volts) fully.
US Car Sales (2021)	15,000,000		608,000 (168,000 PHEV + 440,000 BEV) (4% of total sales)	
Worldwide Car Sales (2021)	72,000,000		6,500,000 (9% of total sales)	
US Federal Tax Incentive	N/A	N/A	Some vehicles eligible for $7,500 incentive	Eligible for $7,500 incentive Not Tesla and GM – Federal incentives expired when they reached 200K vehicles. Re-introduced in 2022.

1.3 Global State of Electrification

The state of electrification is uneven worldwide, and the US is far behind.

In the US, EV adoption in 2021 as a percentage of all car sales (4%) was half the global average (9%). By comparison, the adoption in China and the EU was nearly double the global average (15 and 19%). In 2021, 85% of worldwide EV sales were in China and the EU.

Tesla Leads the EV market, but the US is Far Behind in EV Adoption and Market Share[6]



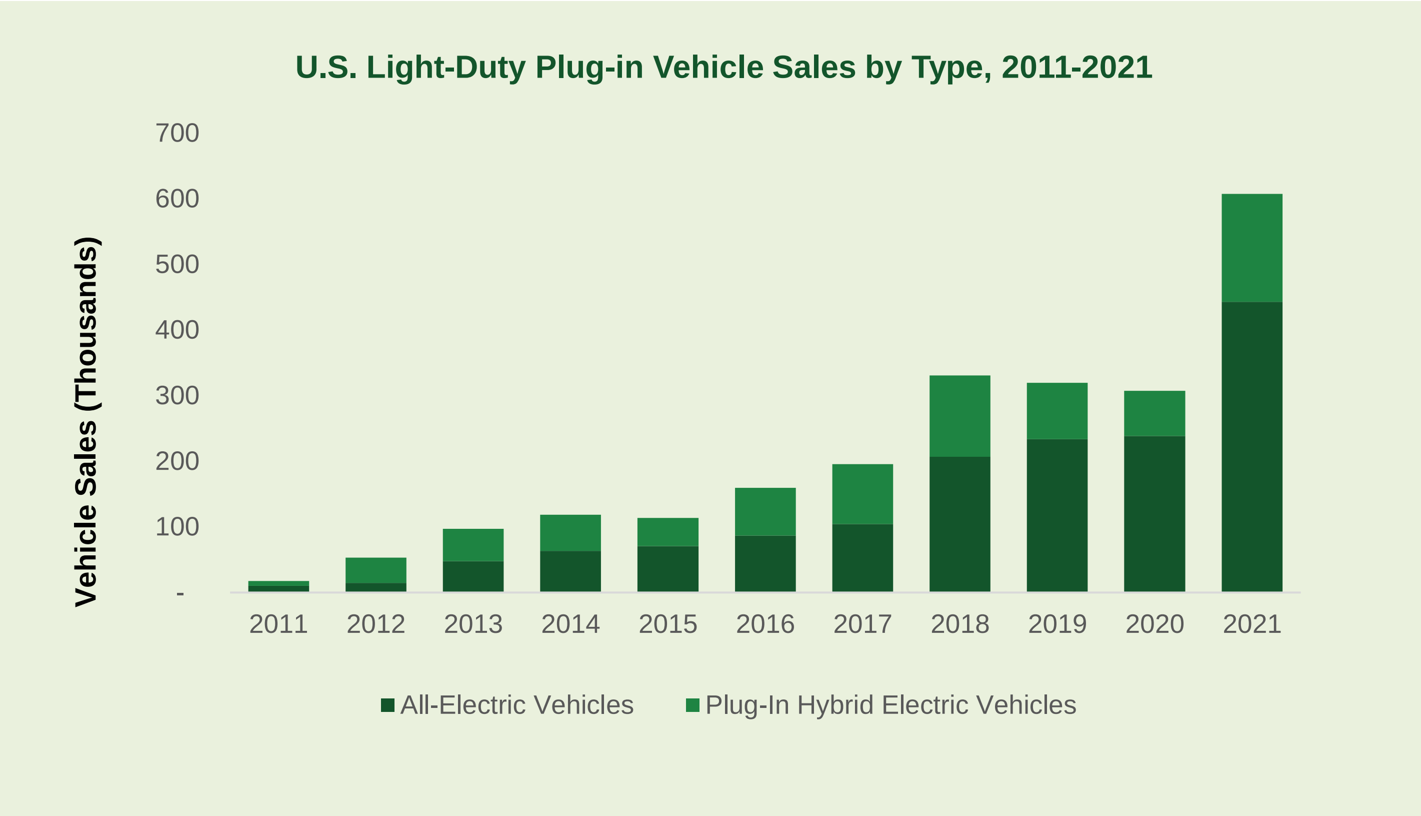
*includes battery and plug-in-hybrid electric vehicles.

One of the key drivers of the success of EVs worldwide (over 100% year-over-year growth) is government subsidies and incentives which reached $30 billion in 2021. In the US both Tesla and GM reached the threshold of 200,000 EVs sold in 2018 triggering a phase-out of a $7,500 federal tax credit over the next 15 months. In 2019, GM discontinued its main EV Chevy Volt citing consumer preference for SUVs and the fact that the company was losing money on each Volt sold. Tesla lowered its prices by $2,000 to reduce the price advantage of other EV-makers. If we exclude Tesla, the EV sales in 2021 in the US were 200,000 electric vehicles, compared to 3,300,000 in China and 2,200,000 in the EU.

In August 2022, there were two events that dramatically changed the EV landscape in the US:

1. US government renewed federal EV subsidies (changing from tax subsidy to point-of-sale credit and expanding to used EVs),
2. California, the largest auto market in the US, announced a ban on sales of gas-powered cars in 2035.

6 Source: Canalys



EV Goals and Investments from Global Automakers

Under the new US EV subsidies law, to qualify for the subsidy, the EV maker must assemble the vehicle in the US and the battery must be powered by materials sourced from the US or its free trade trading partners (meant to exclude China).

US government approved the new EV subsidy renewal law on August 16, 2022. Within two weeks Toyota announced plans to invest $5.2 billion in EV batteries; and Honda and LG Energy announced a $4.4 billion US EV battery factory.

While EV makers in China and the EU were already transitioning to EV's, the new EV landscape in the US will force the US and Japanese automakers to accelerate their EV plans. Nearly all major automakers worldwide have announced their EV goals and list of investments. For example,

- Volvo will only sell electric cars from 2030 onwards
- Ford will only offer electric car sales in Europe from 2030
- General Motors plans to offer only electric Light Duty Vehicles by 2035
- Volkswagen aims for 70% electric car sales in Europe, and 50% in China and the US by 2030; and
- Stellantis aims for 70% of electric car sales in Europe and 35% in the United States.

18 of the 20 Largest OEMs have Committed to Increasing the Sales of EVs

Automaker Announcements Related to Electric Light-duty Vehicles

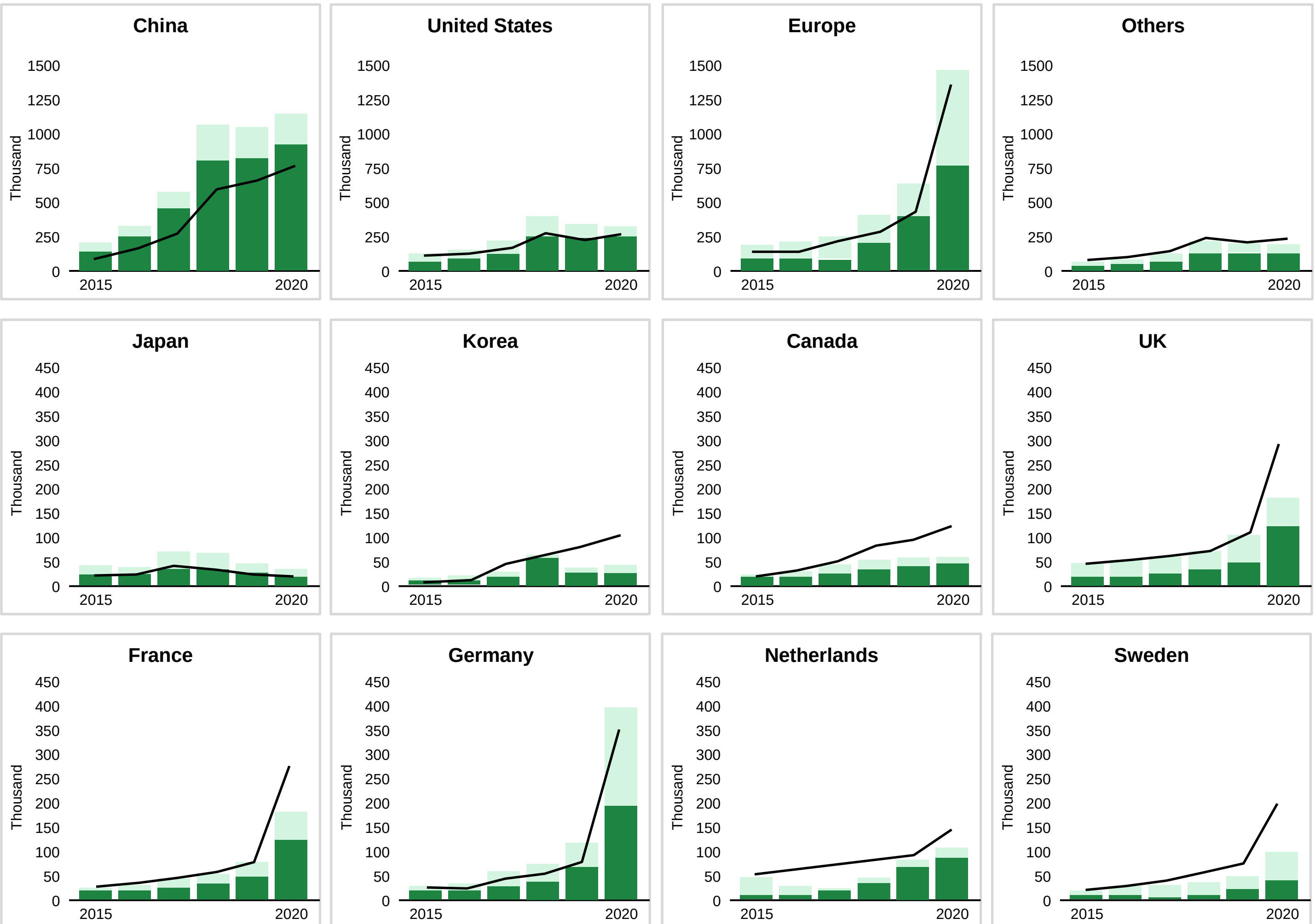
Original equipment manufacturer	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BMW Group			25		15-25%					10
BAIC Group	2				1.3					50%
Changan Automobile (Group)					33					
Daimler		10			25%					50%
Dongfeng Motor Co	1	30%	1		1				1	1
FAW					40%					60%
Ford		40				100%				
GM Group			22		30	1				1
Honda										40%$_T$
Hyundai-Kia					1					
					29					
Mazda		1								5%
Renault-Nissan		20								
		20%								
Maruti Suzuki	1									15
SAIC					30%					30
Stellantis					38%*					70%*
					31%**					35%**
Toyota Group	1				15					>1
Volkswagen					20%					70%
			1		3				26	50%
					75					
Volvo (Geely Group)	1	1	1	1	50%					100%*

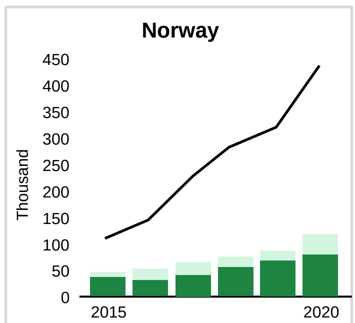
% of sales electric — Annual sales (Million) — New EV models (number) — Cumulative sales (million)

Note: This is based on the authors understanding of OEM announcements and may not be complete. It includes only announcements related to electric light-duty vehicles (PHEVs and BEVs) and it excludes announcements related to hybrid vehicles and those that do not provide a clear indication of the EV share. (Source: International Energy Agency)

Electric Car Registrations Increased Despite Covid in 2021

Electric Car Registrations and Sales Share in Selected Countries and Regions, 2015-2020[7]





Notes: PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle. The selected countries and regions are the largest EV markets and are ordered by size of t total car market in the upper half of the figure and by sales share of electric cars in the lower half. Regional EV registration data can be interactively explored via the Global EV Data Explorer.
Sources: IEA analysis based on country submissions, complemented by ACEA (2021); CAAM (2020); EAFO (2021); EV Volumes (2021) and Marklines (2021)

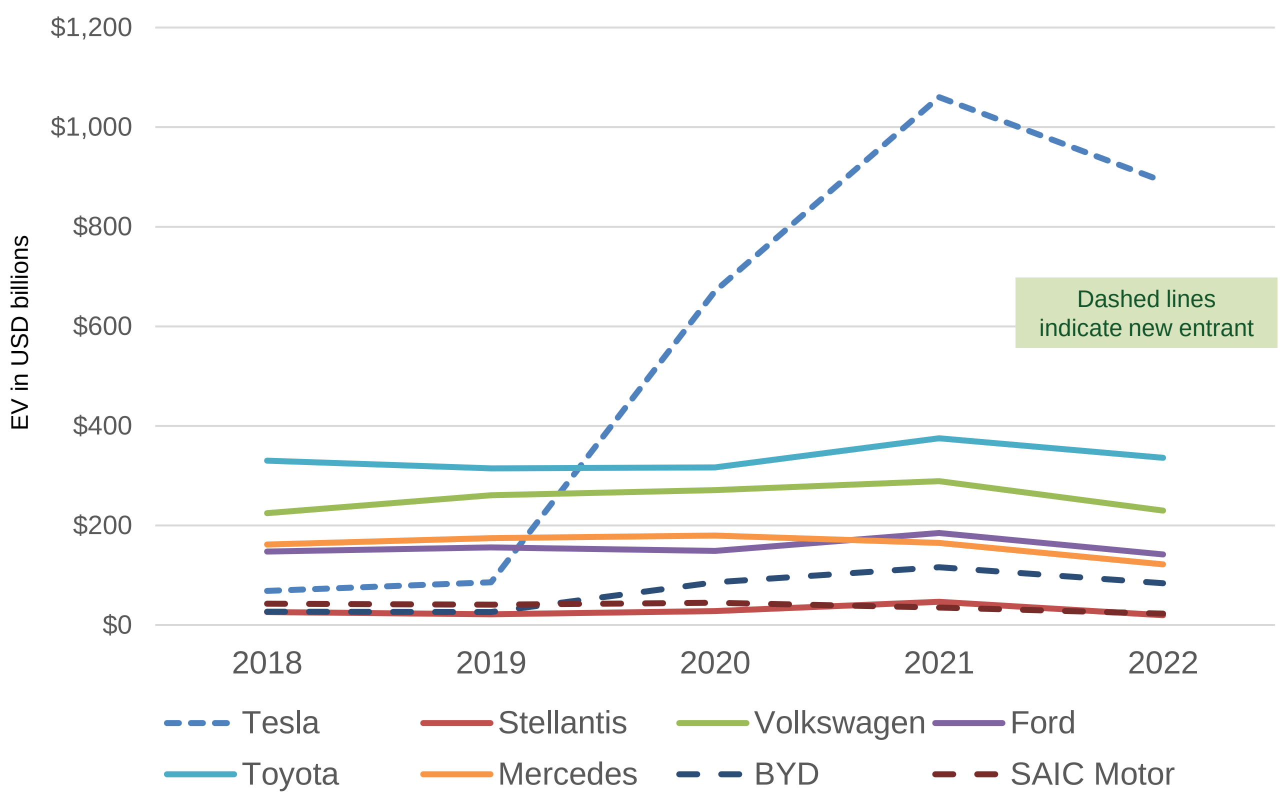
7 *Source: IEA analysis based on country submissions, complemented by ACEA (2021); CAAM (2020); EAFO (2021); EV Volumes (2021) and Marklines (2021)*

Globally in Q1 2022, electric passenger EV shipments exceeded 1.95 million units, with passenger battery electric vehicle (BEV) shipments up 90% year over year, according to Counterpoint Technology Market Research. Counterpoint says EV shipments will go above 10 million units by the end of 2022 and 58 million units by 2030.

1.4 Shift of Vehicle Development Spending and Investments from ICE to ACES

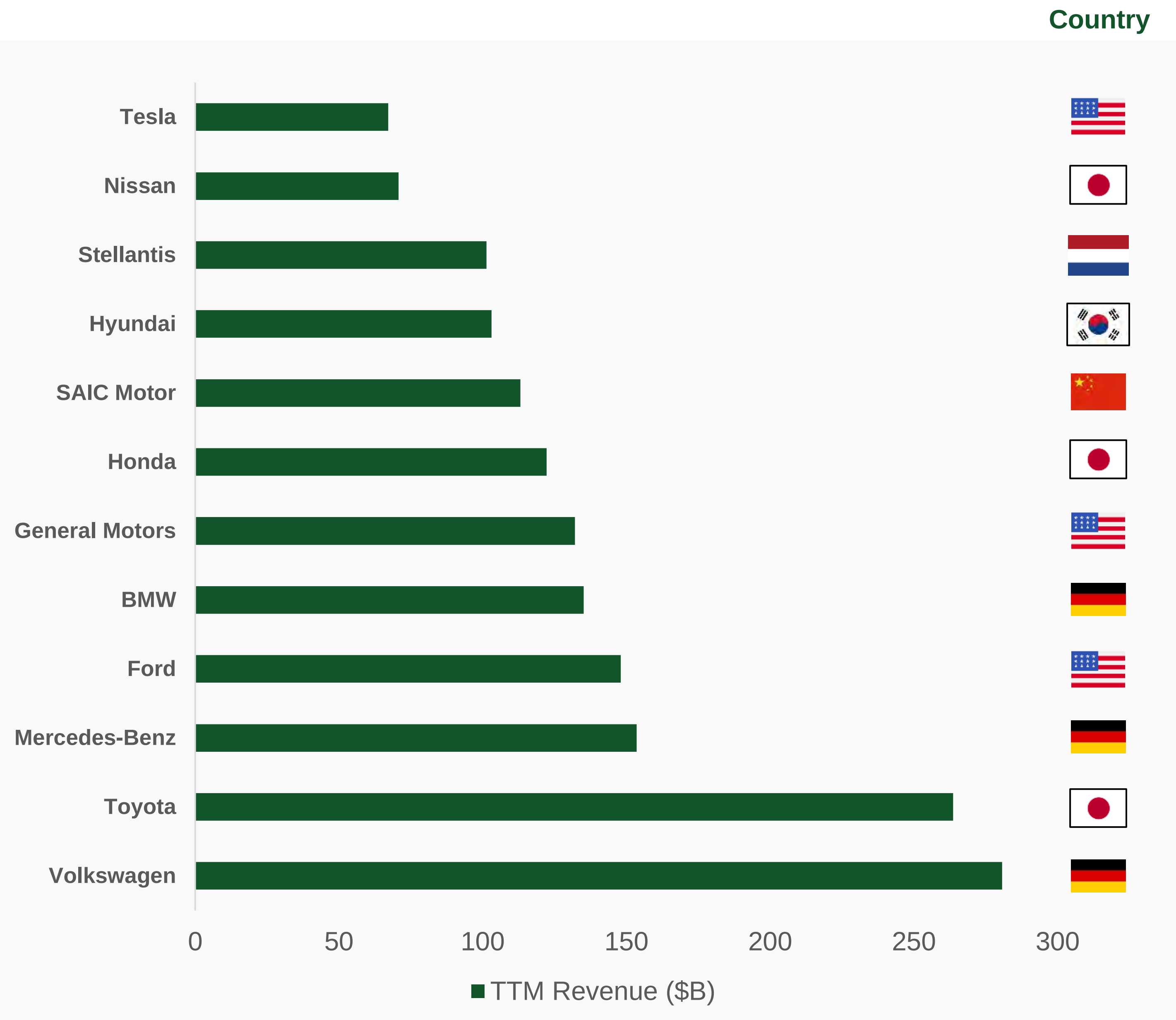
Even though electric vehicles were 9% of all auto sales worldwide in 2021 and are a much smaller percentage of all vehicles on the road, **public and private investment along with corporate R&D has shifted to ACES.**

Enterprise Value of Legacy Automakers and New Entrants[8]



8 Source: Pitchbook

Revenue of Key Global Automakers[9]



9 Source: Pitchbook

2. Move to Electric Vehicles – 2022-2025 Roadmap

The early models of Electric vehicles have been, by necessity, produced by automakers who used **proprietary** and vertically integrated designs. Tesla is the most visible example of this but Porsche, Audi, BMW also offer EVs that fit this description. Hardware and software are fully integrated in these vehicles to provide advanced features. These vehicles are targeted at high-end luxury car buyers and are priced significantly higher than comparable Combustion Engine vehicles.

While the cost of operating EVs compared to Internal Combustion Engine (ICE) vehicles makes them attractive in the current environment of high gasoline prices, the **initial cost is the biggest barrier to the mass adoption of EVs**.

It is hard to over-emphasize the influence of the initial cost on mass adoption. Most people would be surprised to learn that **one-third of cars in the US were electric in 1900**. A Facebook video published by the World Economic Forum shows a fascinating history of the popularity of electric cars before Ford Model T was introduced and cheap oil was discovered in the US (you can watch it **here**). The US Department of Energy has an enlightening history of the Electric Car on its website (you can read about it **here**).

From one out of three cars in the US being electric in 1900, they disappeared completely by 1935. Interest in electric cars didn't return until the 1970's when oil prices increased. Looking at the history of consumer interest in electric vehicles, it is undeniable that cost is the number one determining factor in consumer purchasing decisions.

With high gas prices and climate change worries, the momentum toward electric vehicles has reached critical mass with most major automakers announcing committed numeric goals and timelines for EV production. However, the rate of adoption and timing remain difficult to predict. To understand how quickly the macro-environment, funding, and policies are evolving, it is worth noting that in less than six months that it took to prepare this report, we witnessed three independent events of major significance:

- The war in Ukraine led to high gas prices and strong consumer interest in EVs
- US Infrastructure bill was revived funding EV subsidies and charging infrastructure in the US
- State of California banned gas car sales from 2035.

For automakers and their investors, it is difficult to get the timing right with many external factors and unknowns, including:

1. Initial cost of EVs - how rapidly the cost of EVs can be brought down
2. Charging infrastructure and electricity production investments by public and private sectors
3. Cost and wide availability of EV batteries which are a major cost item in EVs
4. Government subsidies (amounts of subsidies and related policies in major countries)
5. Gasoline prices are volatile and
6. Climate events and the response from governments and consumers.

2. Move to Electric Vehicles – 2022-2025 Roadmap

In a survey taken after the start of the war in Ukraine, 40% of US consumers said that they will consider an EV for their next car purchase. Cost and parity with fossil fuel vehicles is the biggest factor that will determine the timing and the rate of mass adoption of EVs. With consumer switching costs, and funding needed for charging/grid infrastructure in trillions of dollars, it is fair to ask if this time the change will finally happen.

Even if the difficulties of changing consumer habits and the cost of infrastructure slow down the transition, three factors favor the move to EVs this time:

- There is a long-term trend of ***improvements in battery technology*** leading to lower battery cost (up to 30% of vehicle cost) and longer driving range on a single charge; massive new investments have been announced in 2022 by Tesla, Panasonic, Toyota, Honda, LG Energy
- Changing consumer habits and preferences toward EVs, ***shared vehicles*** are driving investments in ride-hailing, last-mile logistics, and micro-mobility; Plug-in Hybrid vehicles will also contribute to increasing mass adoption of EVs
- Significant changes in the way vehicles are designed and manufactured will lead to lower vehicle costs; with the separation of hardware and software and evolving standards, there will be higher use of off-the-shelf components from Tier 2 and Tier 3 suppliers in an ***open ecosystem.***

We will cover the improvements in battery technology in more detail in an upcoming report. In Section 5, we cover shared vehicles with a focus on investments and M&A trends.

In this section, we cover how an open ecosystem is likely to lead to more global price competition and changes in how vehicles are designed and manufactured including a move toward EV platforms (and software updates) will reduce the cost of each new vehicle.

2.1 Search for the Mass-Market EV – Roadmap to Lower Cost EV[10]

In 2015, less than 100 EV models were being sold in the world. By 2021, the number of models being sold was 450 (300 in China, 184 in the EU, and 65 in the US). more choices for EV buyers will lead to lower prices for EVs. More EV models from more EV makers mean more choices and lower prices for EV buyers.

Ford Motor CEO Jim Farley told the Bernstein Strategic Decisions Conference in June 2022 that he expects that automakers will be battling each other for sales of EVs priced around $25,000. “So I believe there will be our industry is definitely heading to a huge price war,” Farley said. It currently costs much more to build an EV than it does one powered by a gas engine, Farley noted. The company’s Mustang Mach-E electric SUV, with a starting price around $44,000 but can run much higher, costs about $25,000 more than a comparable Ford Edge gas SUV, he said.

10 Source: Associated Press

2. Move to Electric Vehicles – 2022-2025 Roadmap

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Timeline of strategic OEM targets for EVs

2020

- **Tesla:** China plant production begins with capacity of **.5m EV's a year**
- **JLR:** To invest **fi1billion** to build electric cars in the UK
- **SAIC/VW:** Invest **$2.33billion** in two separate Chinese electric vehicle players
- **Toyota/BYD: Joint venture** to develop pure EVs
- **BYD and Hino** sign a strategic business alliance agreement for commercial BEVs development

2021

- **BMW:** Electrify European market – **25%** by 2021; **1m** EVs on road by 2021
- **Toyota:** targets **30k** EV sales
- **Mazda:** releases first EV

2022

- **Fiat Chrysler: 30** new battery-powered or hybrid vehicles by 2022 **60%** of cars in Europe to be hybrid or fully electric
- **Renault- Nissan-Mitsubishi: 12 electrified** and **8 pure EVs** in range; **42%** of European sales to be EVs by 2022 (Nissan)
- **Honda:** All European mainstream models to be electrified by 2022 (instead of 2025)
- **Ford: 40 EVs** in 'global portfolio'; To invest **$11.5billion** on EV models by 2022

2023

- **BMW: 25** EVs in range by 2023
- **GM:** 'On track' to meet **20 EV models** target by 2023
- **VW Group: 1m** EV sales

2025

- **VW Group: 25%** global sales to be electric; Up to **3m** BEVs annually by 2025, including **1.5m** by the VW brand
- **Toyota:** Target of **5.5m** total EV sales and **.5m** sales in 2025
- **BMW:** Electrify European market – **33%** by 2025
- **GM: ~1m** global EV sales by 2025
- **Volvo:** Reach **1m** total EV sales by 2025 EV's to represent **50% of global sales**
- **Hyundai:** To invest **$87billion** in vehicle electrification by 2025; EV range to expand to **44** models by 2025; Target of **670k** annual EV sales by 2025

2030

- **BMW:** Electrify European market – **50%** by 2030
- **Mazda:** All models EVs/hybrids by early 2030s
- **Honda: 2/3rd** of **global** sales EVs
- **VW Group: 70 new** electric models by 2028 instead of the 50 previously planned; **40%** global sales to be electric by 2030
- **Daimler:** EV's to make up more than **50% of sales**
- **GM:** Cadillac to be **majority EV**

Key Takeaways

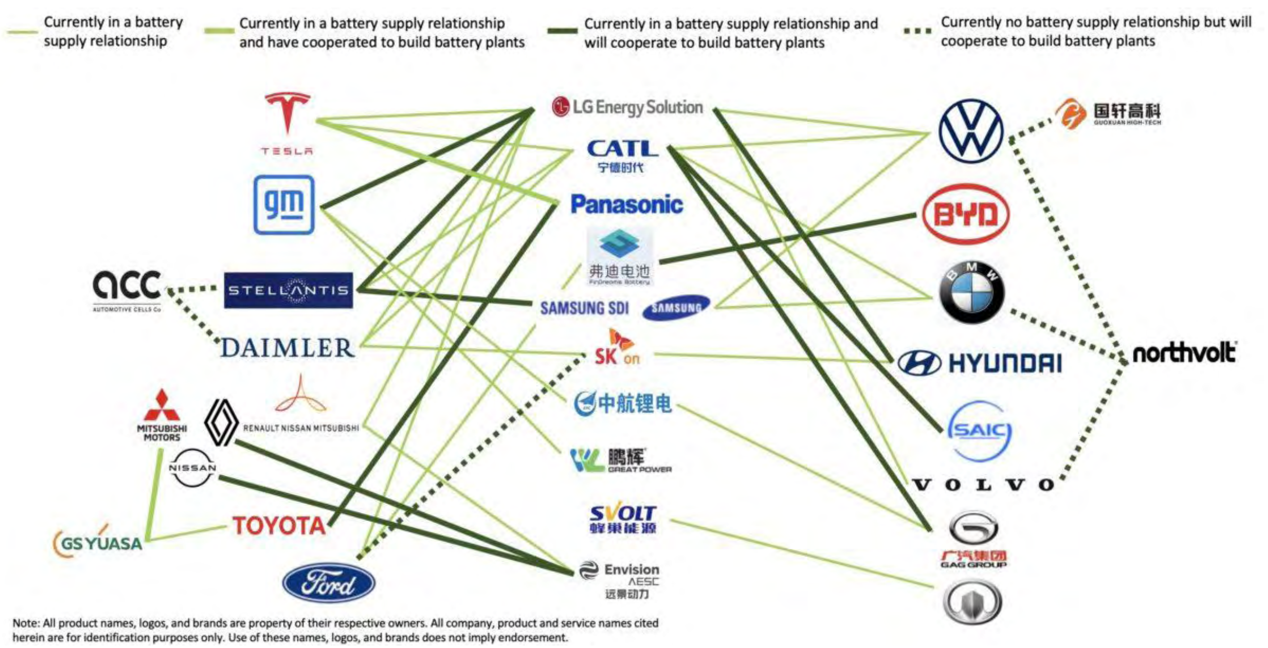
- Unprecedented levels of partnering to defray development overhead, speed new designs
- Pull-ins of release schedules
- Major increase in government subsidies and penalties
- Significant increase in numbers of planned EV models and related investments

2. Battery Partnerships

Batteries are the highest-cost components of EVs and are likely to remain so. Astute automotive OEM executives rightly treat the related supply chain as strategic, sensitive, and mission-critical, and for good reason:

- It takes years to develop, perfect, and commercialize a new battery chemistry;
- The capital cost of an advanced battery manufacturing plant can run into billions of dollars and require two or more years to start producing;
- Competitive forces are very strong – battery capacity, safety, and performance fundamentally drive EV competitiveness.

Strategic Battery Partnerships with Automotive EV OEMs



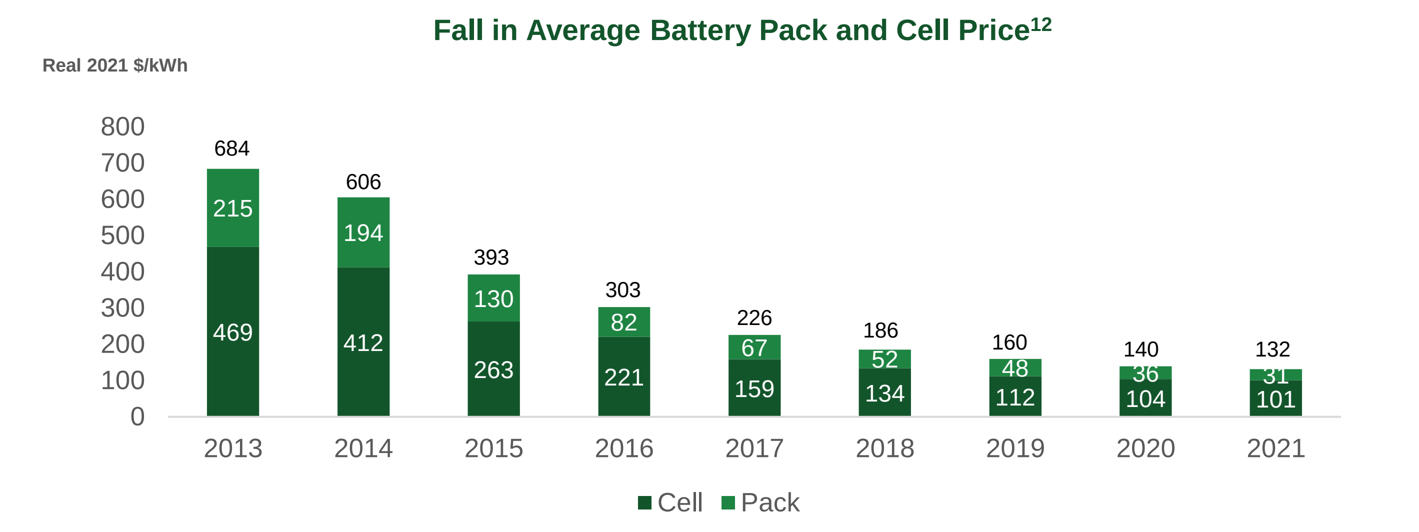
Source: Researcher & Research

Summary of Automotive OEM Battery Partnerships

- American EV OEMs have partnered mostly **with Japanese and South Korean battery suppliers**
- European car makers focused on a battery supply chain in **Europe**
- Most models produced in China by US and European OEMs **utilize Chinese battery suppliers**
- Government subsidies for manufacturing are both **needed and increasingly available**

Decrease in Battery Costs

The chart below shows the fall in battery prices over the last decade. The improvements in EV driving range per charge and the drop in battery prices are likely to accelerate in the next three years with increases in EV sales volumes and the new mega investments from automakers and battery companies in battery R&D and production.



Mass adoption of EVs in the US remains an important milestone for mass adoption of EVs globally. The US is a large auto market, and it is an important player in global standards organizations. With its planned re-entry into semiconductors needed for the auto industry and its software capabilities, the US is likely to play an important role in EVs for the mass market.

As we discuss the paths that lead to lower-cost EVs, it is useful to look at ways in which EV architecture is different from fossil fuel vehicles and ways in which the design and development of vehicles are changing.

12 Source: BloombergNEF

2. Move to Electric Vehicles – 2022-2025 Roadmap

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Key Trends We Expect to See

Item	Before 2018 (Gas/Hybrid)	2022 (EV)	2027 (EV)
New vehicle design cycle	7 years	3 years	2.5 years
Suppliers	85% Tier 1	60% Tier 1	50% Tier 1
Battery cost as % of total	30%	30-40%	25%
Capital cost of a new vehicle platform	$250M	$400M	$500M
Software: total lines of code	500K	1M	2M
Average Driving range	400 miles	200 miles	300 miles
Lithium-ion Battery Cost ($/kWh)	400	115	62

ECUs in an ICE car vs. an EV: A Quick Comparison

While the entire powertrain of an EV is much simpler than that of a typical modern car with an internal combustion engine, the number and sophistication of the ECUs distributed around an EV continue to grow as more functions within the powertrain, chassis systems, driver aids, and automation require computer control. Also, more of them must be certified to safety standards, particularly ISO 26262, which governs electrical and electronic safety in road vehicles.

ECUs in modern EVs have tended to follow similar patterns of functional division to their internal combustion counterparts. However, *those concerned with the powertrain* naturally have to reflect the fundamentally different nature of systems based on batteries, inverters, and electric motor/generator units.

The functional and performance demands on EV ECUs have been multiplying in recent years and are revealing two clear trends:

1. The need to meet the ISO 26262 **functional safety** standard
2. To future-proof architectures, by **enabling ‘by-wire’ control and actuation**

2. Move to Electric Vehicles – 2022-2025 Roadmap

The latter adds **networked smart actuators and sensors** needed for tight closed-loop control that are coordinated via advanced networks from a more powerful and centralized computer. In effect, the car becomes a data center on wheels.

The Engine Control Unit versus a Domain or Vehicle Control Unit: A different philosophy applies to EVs compared to IC engines in control terms. An engine ECU directly controls all the parameters that need controlling through direct connections to sensors and actuators, whereas a VCU for an EV acts as a central control and coordination hub for many subsystems' ECUs. This change creates standardized hardware platforms on which multiple layers of new software can run.

Cautionary note: Some automotive OEMs (particularly BMW) label DCUs as ECUs. For the purpose of this publication, DCUs relate to true domain control/multi-function compute engines and ECUs relate to single-function modules.

Vehicle Control Systems

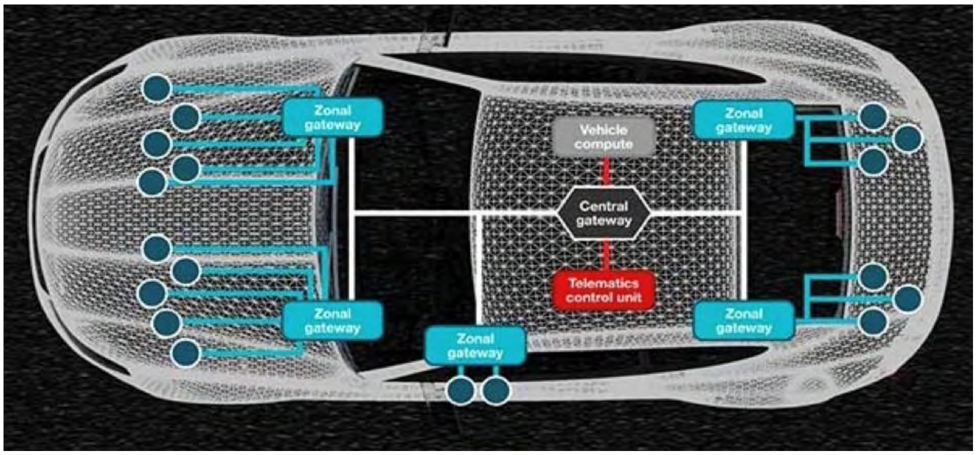
- Historically proprietary to automotive companies, but Tier 1 suppliers are growing these capabilities
- Tier 1 automotive suppliers such as Bosch produce embedded modules and subsystems
  - As a powertrain domain controller, the vehicle control unit (VCU) can provide torque coordination, operation and gearshift strategies, high-voltage and 48V coordination, charging control, onboard diagnosis, monitoring, thermal management and much more for electrified and
- The VCU also ensures fail-operational function for highly automated driving (HAD) solutions
- Other than these drive-related functions, higher-level versions also support interconnected functions like predictive and automated longitudinal guidance, Advanced Driver Assistance System (ADAS) connection, and body controller functions.

Vehicle Development

Vehicle designs are seeing sweeping changes. We expect more shifts in architecture, supply chain, design processes, and additional features in the next five years than we have seen in the last fifty. For automotive OEMs, multiple challenges have come to bear:

1. Competitive development cycles have shrunk to 3 years from 7
2. The number of components per EV is about 20% of an ICE, while control and network systems in an EV are far higher
3. The capital cost of a new EV platform has increased beyond the means of even the largest OEMs
4. The infrastructure for recharging batteries is woefully inadequate, and there is little evidence that traditional petrochemical energy companies or electric utilities will respond. New business models that employ mobile-first services, renewable generation, and stationary storage may win the day.

1. Technological breakthroughs in semiconductors, networking, batteries, and software are coming fast and furiously - making it challenging to keep up and take advantage
2. Standards and interoperability schemes are complex and numerous, especially for safety
3. Shared vehicle services are likely to decrease total unit demand for new vehicles while increasing the distance driven per day by each vehicle.



Changes in Vehicle Design[13]

1. Shorter design cycles fundamentally change design processes. The relationship between OEMs and suppliers has become more collaborative. Opportunities for new suppliers with decreased time to revenue. More experimentation and more design iterations.
2. Vehicles become platforms. Hardware and software become less coupled, where hardware is standardized and cost-driven, and software is feature-rich, mission-critical, and value-driven. Recurring revenue and remote upgrades become essential revenue sources.
3. Server-class computing and connectivity. The amount of data and information is growing exponentially (10s of Gbps) while latency requirements become more stringent (10s of ns).
4. Artificial intelligence (AI) and software-based services have become an every-vehicle phenomenon.

Existing domain vehicle architectures cannot meet performance requirements, are too complex to maintain, and inefficient - driving a need for new architectural approaches. Advancements in Processing capabilities and High-Speed Vehicle Networking drive transition to more effective Central Computing and low latency Zonal Vehicle Architectures.

This change in system architecture both enables and drives sweeping changes in software architecture. It starts with a modern operating system such as Blackberry's QNX, which claims to have won designs in 24 out of the top 25 EVs and shipped into over 215 million vehicles.

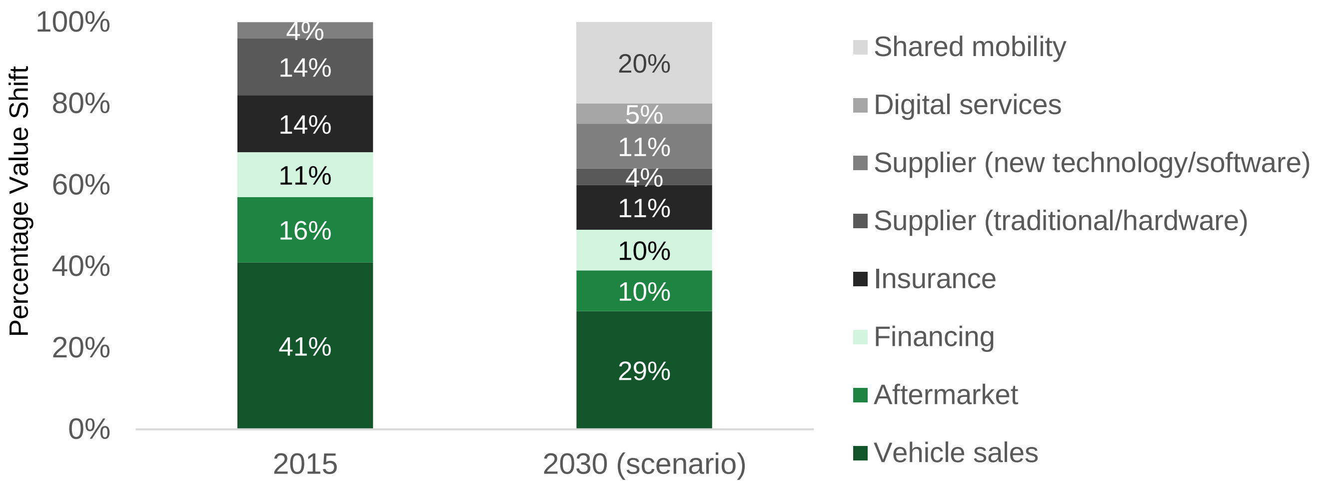
13 Source: Blackberry

Tesla had the advantage of starting fresh. Its architecture is a centralized control unit (VCU-equivalent), with most patches and upgrades from over-the-air updates. This approach lays the groundwork for incremental improvements, safety fixes, and recurring revenue generation. Strapped with legacy architectures, most other automotive OEMs are moving to this architecture gradually. They all require advanced features such as ADAS and infotainment that are poorly suited for hardware with embedded software. And the automotive OEM needs to "own" its platforms to ensure incremental revenue and effective systems software management.

The Drivers Centralized Architecture Include:

- Safety
- Security
- Reliability supported by system redundancy
- Efficient power management and distribution
- Ability to interface with and make use of hundreds of sensors
- Rapid time to market
- Management and control of every vehicle function
- Hypervisors and independent modules or containers that do not interfere with each other
- Cloud connectivity with over-the-air updates
- ADAS
- Self-driving

Figure 2. Projected Value Shift in the Auto Industry



(Source: KPMG)

Key Signs of Value Chain Disruption

Already committed to a wholesale shift to EVs, Automotive OEMs recognize that consumers will not purchase vehicles at significantly higher prices. As a result, more astute companies embrace changes to the supply chain and contributors to value. Well-handled, they will be able to manage costs to ensure profitability. If poorly handled, even larger OEMs may find their businesses severely compromised.

The OEM-Supplier Equation is Changing

The old world of OEMs specifying component and subsystem requirements to suppliers has given way to collaborative development, where suppliers frequently bring new technologies and product ideas to the table. Many OEMs have begun to view hardware as the platform and software as the differentiator - opening up the field to suppliers, both new and innovative incumbents. Nimbler forms of engineering management are increasingly being applied across the development landscape.

New Skills Required for OEMs' Engineering Teams

OEMs find themselves having to repurpose their engineering teams. Most thermal engineers for ICE may have to adapt to EV problem-solving (such as thermal management of battery packs). On the other hand, developing or evaluating battery chemistries or designing battery packs requires significantly new learning. Once focused on tightly-coupled embedded systems, software engineers must expand their capabilities farther up the stack, employ agile development methods, and apply faster, more efficient testing methods. These changes drive more engineering to the supplier level and require standards-based approaches to most problems.

The 'Asset-light' OEM

Where incumbent automotive OEMs possess their own manufacturing facilities, the idea of contract manufacturing and related design services has firmly taken hold, as evidenced by the creation of the MIH ("Mobility in Harmony" Consortium[14] by Taiwanese multinational electronics contract manufacturer, Foxconn, which aims to bring together strategic partners such as OEMs, Tier-1 suppliers and electronic service providers (ESPs) to build and standardize next generation EV technology, including autonomous driving and mobility services. A recent announcement[15] adds India's Tata Group to the 2,417*-member consortium of software, hardware, and other service providers. (*as on July 30, 2022)

Key Finding

The industry is rapidly changing from vertical integration to horizontal, much like the computer industry changed in the 1980s and 1990s.

14 Source: MIH
15 Source: Just auto

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An App-store for vehicles?

The disruption of the value chain extends beyond the vehicle and into the cloud and into apps. The analogy of mobile phones as platforms and app stores for users to purchase desired functionalities is not that far away. Forward-looking automotive OEMs see themselves as platform providers, setting standards for application compatibility, look, and feel while cultivating an ecosystem of certified app makers. It is easy to imagine Tesla Cloud or Toyota Cloud which allow consumers to download apps and content, pay for services and share vehicle maintenance data with the automakers.

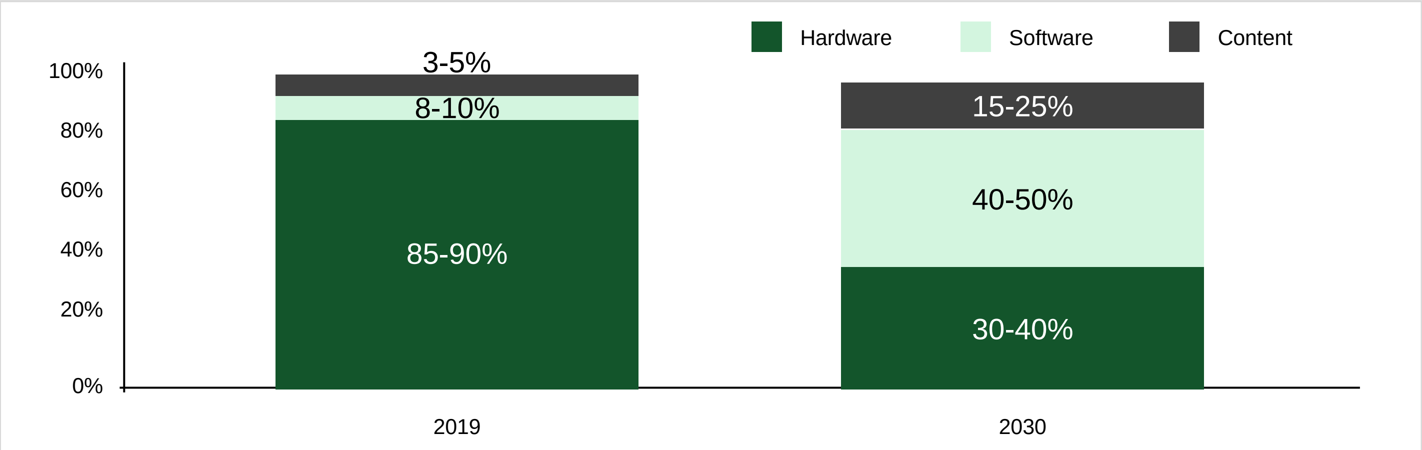
Summary: AI Value Creation in Autonomous Vehicles

Currently, vehicle hardware accounts for around 85–90% value of the vehicle. The remaining value of the vehicle is generated by software and content. In the next 5-8 years, 95 to 98% of the new vehicle is expected to have some or other form of AI-powered technology, making software-based service offerings a much larger value driver than the hardware, possibly approaching 40–50% of the vehicle's value.

Imagine a vehicle where the owner can upgrade driver assistance functions, infotainment content, or suspension characteristics via a simple software subscription request. This need has forced automotive OEMs to look at hardware architectures that support reliable and much higher bandwidth for foolproof connectivity, processing and security implementations.

AI has become a core technology underlying almost all of these developments requiring vastly different engineering capabilities at automotive OEMs and their suppliers.

Summary: AI Value Creation in Autonomous Vehicles[16]



16 Source: FutureBridge Analysis and Insights (Note: Hardware includes ICs and electronics)

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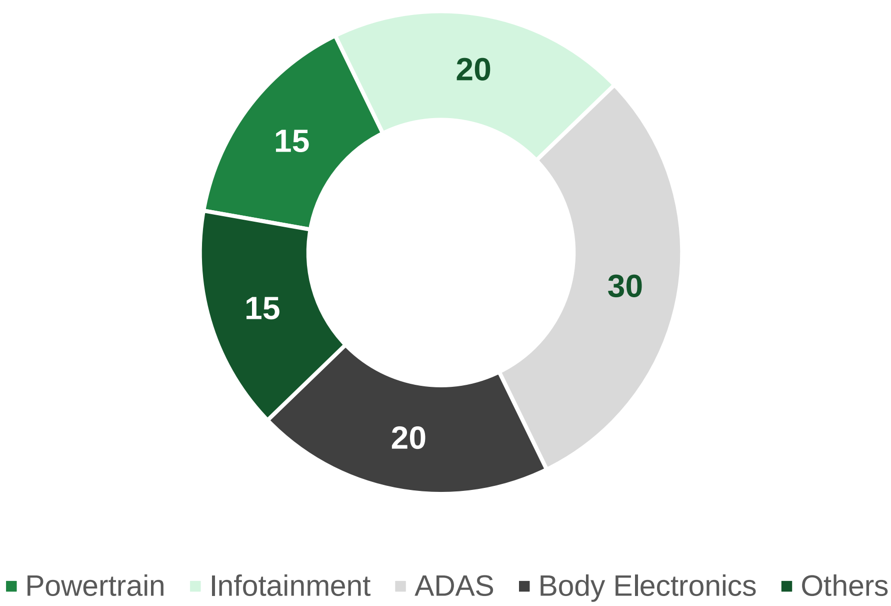
Key Takeaway

One wrong move could take your company down. If you view your company as only an automobile company or automotive supplier, think again - you are in the mobility industry where user experience has become primary.

Money Trail and M&A Activity

Global Automotive ECU Market Share, By Application



The global automotive electronic control unit (ECU)[17] market is projected to grow from $58.31 billion in 2022 to $94.58 billion by 2029, exhibiting a CAGR of 7.2% during the forecast period 2022-2029.

According to McKinsey, the convergence of Electronic control units will open up a new market for domain controllers, ECUs, and DCUs with a market potential of $156 billion in 2030

17 Source: Fortunebusinessinsight

2. The Move to Electric Vehicles and 2022 - 2025 Roadmap

Financing Deals	Deal Count (2021 and 2022)	Capital Invested ($B, Median)	Pre-Money Valuation ($M, Median)
Autonomous	343	20.5	145.4
Connected	576	17.0	71.8
Electric	215	13.5	58.2
Shared	69	15.8	47.5

Key Investors

Autonomous	Connected	Electric	Shared
MOTUS GI	andreessen horowitz	COATUE	Alumni Ventures
NVIDIA	intel capital	IDG Capital	FIRSTMARK
SINOVATION VENTURES	MANIV MOBILITY	V CAPITAL 創新投資	Keyframe
顺为 SHUNWEI	Qualcomm ventures	Fidelity INVESTMENTS	PreSeed Ventures
TRUCKS	SAMSUNG SAMSUNG VENTURE INVESTMENT	tandem	Shell Ventures

18 Source: Pitchbook

2. The Move to Electric Vehicles and 2022 - 2025 Roadmap

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M&A Deals	Deal Count (2021 and 2022)	Pre-Money Valuation ($M, Median)
Autonomous	40	1,600.0
Connected	61	955.0
Electric	89	852.1
Shared	15	178.0

Active Strategic Buyers

Autonomous	Connected	Electric	Shared
intel	APTIV	blink	BlaBlaCar
MAGNA	Brookfield	BOSCH	DiDi
NVIDIA	Qualcomm	Ford Smart Mobility	PSA Groupe
TOYOTA	ublox	gm	TURO
woven planet	Verisk	TESLA	Uber
ZF Group			

19 Source: Pitchbook

2. The Move to Electric Vehicles and 2022 - 2025 Roadmap

Financial Overview of Selected Publicly-Traded Companies[20]

Company	Ticker	Stock Price	Ent Value	Revenue NTM	Gross Profit LTM	LTM EBITDA	LTM Gross Margin	EBITDA Margin	NTM Rev Growth	EV/NTM Rev
Kudan	4425	$19.3	$153	-	$1	($20)	45.8%	(810.4%)	-	-
Ambarella	AMBA	$75.6	$2,692	$353	$221	($14)	62.8%	(3.9%)	0.1%	7.6x
Autoliv	ALV	$83.5	$8,698	$9,615	$1,283	$913	15.7%	11.2%	17.7%	0.9x
BYD Company	002594	$47.8	$125,461	$63,148	$4,867	$893	12.9%	2.4%	67.7%	2.0x
Ford	F	$12.8	$147,469	$154,831	$20,199	$22,120	15.0%	16.4%	15.0%	1.0x
General Motors	GM	$34.5	$138,855	$157,161	$17,498	$24,293	13.4%	18.6%	20.4%	0.9x
Nissan Motor	7201	$3.8	$62,190	$77,849	$12,053	$9,508	16.1%	12.7%	3.8%	0.8x
Tesla	TSLA	$805.3	$830,160	$107,779	$18,201	$14,241	27.1%	21.2%	60.5%	7.7x
Toyota Motor	7203	$15.9	$371,925	$265,458	$53,156	$53,430	19.0%	19.1%	(5.0%)	1.4x
Volkswagen	VOW3	$135.3	$226,100	$283,910	$54,478	$61,073	18.7%	21.0%	(2.4%)	0.8x
Schneider Electric	SU	$126.8	$83,122	$33,342	$14,002	$6,742	41.0%	19.7%	(2.4%)	2.5x
Mitsubishi Electric	6503	$10.8	$20,085	$35,763	$11,256	$4,249	28.2%	10.7%	(10.3%)	0.6x
Sensata Technologies	ST	$44.0	$9,538	$4,308	$1,290	$815	33.5%	21.2%	11.8%	2.2x
Aptiv	APTV	$97.9	$28,780	$19,595	$2,298	$1,621	14.6%	10.3%	24.2%	1.5x
Deere	DE	$323.0	$143,116	$51,150	$13,282	$9,395	29.3%	20.7%	12.8%	2.8x
Nidec	6594	$66.9	$41,955	$16,460	$3,590	$1,693	21.0%	9.9%	(3.6%)	2.5x
ACV Auctions	ACVA	$7.0	$600	$519	$166	($79)	42.2%	(20.2%)	32.3%	1.2x
DoorDash	DASH	$71.8	$22,032	$7,013	$2,729	($335)	51.8%	(6.4%)	33.2%	3.1x
Qualcomm	QCOM	$153.3	$175,774	$47,971	$22,972	$14,969	58.5%	38.1%	22.2%	3.7x

20 *Source: Pitchbook*

2. The Move to Electric Vehicles and 2022 - 2025 Roadmap

Top ECU Manufacturers

Name	EV	NTM Revenue	NTM EBITDA	EV/NTM Revenue	EV/NTM EBITDA
ZF Friedrichshafen AG	-	-	-	-	-
Continental AG	$18,965.4	$40,264.6	$4,617.0	0.5x	4.1x
Denso Corporation	$44,468.9	$48,113.4	$2,705.0	0.9x	16.4x
Hyundai Mobis	$9,709.8	$39,080.2	$2,561.6	0.2x	3.8x
Autoliv	$8,721.6	$9,631.4	$1,180.7	0.9x	7.4x
Bosch GmbH	-	-	-	-	-
Valeo Inc.	$9,738.3	$21,170.2	$2,474.0	0.5x	3.9x
NXP Semiconductors	$55,270.1	$13,597.7	$4,690.4	4.1x	11.8x
Embitel	-	-	-	-	-
Texas instruments	$160,784.2	$19,826.2	$11,043.5	8.1x	14.6x
STMicroelectronics	$33,614.5	$16,626.0	$5,555.2	2.0x	6.1x
Rimac Automobili	-	-	-	-	-
Delphi (Aptiv)	$31,643.7	$19,595.0	$2,927.8	1.6x	10.8x
Pektron	-	-	-	-	-
Hitachi Automotive	-	-	-	-	-
Hyundai Mobis Co. Ltd.	$9,709.8	$39,080.2	$2,561.6	0.2x	3.8x
Panasonic Corporation	$24,702.8	$59,072.3	$5,611.7	0.4x	4.4x
Lear Corporation	$11,090.5	$22,557.5	$1,821.7	0.5x	6.1x

Top VCU Manufacturers

The global VCU market is dominated by major players[21]

Name	EV	NTM Revenue	NTM EBITDA	EV/NTM Revenue	EV/NTM EBITDA
Robert Bosch	-	-	-	-	-
Continental AG	$18,965.4	$40,264.6	$4,617.0	$18,965.4	$40,264.6
Texas Instruments	$160,784.2	$19,826.2	$11,043.5	$160,784.2	$19,826.2
Mitsubishi Electric Corporation	$19,262.8	$35,636.5	$3,703.1	$19,262.8	$35,636.5
STMicroelectronics	$33,614.5	$16,626.0	$5,555.2	$33,614.5	$16,626.0
Electra EV	-	-	-	-	-
Continental	$18,965.4	$40,264.6	$4,617.0	$18,965.4	$40,264.6
Sensor-Technik Wiedemann	-	-	-	-	-
Magna	$22,125.4	$39,847.4	$3,887.8	$22,125.4	$39,847.4
Denso	$44,468.9	$48,113.4	$2,705.0	$44,468.9	$48,113.4
BASF	$65,239.0	$86,130.9	$10,814.7	$65,239.0	$86,130.9
ZF Friedrichshafen AG	-	-	-	-	-
Sonatus	-	-	-	-	-

21 Source: Pitchbook

VOLKSWAGEN AG - COMPANY PROFILE

Founded	Market Cap:	Revenue:	P/E:
1937	$86 billion	€250.2 billion (2021)	3.7
Employees	Enterprise Value:	Growth Rate:	EV/Revenue:
672,800	$214 billion	5%	0.81

Data effective September 2, 2022, except where noted

Outlook:

- Migrating from a classic OEM to a vertically integrated mobility company
- Electrification led via Scalable Systems Platform (SSP) – aiming for 70% minimum BEV share in EU by 2030; 50% in China and USA
- Software led via in-house CARIAD team - software stack 2.0 (E^3 2.0) will include a unified operating system for vehicles from all Group brands
- Battery & Charging: Six giga factories in Europe with a total production capacity of 240 GWh by 2030 will help to secure battery supply.
- Mobility Solutions: autonomous driving will be a game changer; development of a self-driving system for autonomous shuttles with its strategic partner ARGO AI
- Key alliances are with Ford, Mahindra & Mahindra, Northvolt, plus others to further accelerate New Auto

Business Description:

Founded in 1937,Volkswagen AG is one of the world's largest automakers with 8.6 million units sold in 2021 across all of its Brands (e.g, VW, Audi, Porsche, Seat, Skoda, etc.). VW does business globally and has several joint ventures in China, its largest market. VW has recently embarked on a Group strategy "NEW AUTO – Mobility for Generations to Come", which is a significant driver of VW's transformation and accelerates its realignment from vehicle manufacturer to tech company. VW has earmarked €73 billion for future technologies from 2021 - 2025, representing 50% of total investments

Notable Transactions

Target	Deal Size	Date	Type	Description
Northvolt	$1.1B	Jul 2022	Late VC	Energy Storage
TKI Automotive	Undisclosed	Mar 2021	M&A	Connected Parts
Hella Aglaia Mobile Vision	Undisclosed	Feb 2021	M&A	Software

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Founded	**Market Cap:**	**Revenue:**	**P/E:**
1937	$195 billion	JPY 31.38 Trillion (FY 2021)	10.02
Employees	**Enterprise Value:**	**Growth Rate:**	**EV/Revenue:**
372,817	$333 billion	4%	0.01

Data effective September 23, 2022, except where noted

Outlook:

- Migrating from a classic OEM to a vertically integrated mobility company
- With an objective to have over 3.5 million EVs by 2030, TMC will increase new investment to 2 trillion yen, aiming for more-advanced, high-quality, and affordable batteries.
- Recently announced $5.6 billion investment in Japan and US battery production to increase its combined battery production capacity in Japan and the United States by up to 40 GWh
- Products will be developed using TNGA 'platform' approach
- Software led via in-house development team – focusing on connected vehicles
- Mobility Solutions: autonomous driving will be a game changer; development of a self-driving system for autonomous shuttles with its strategic partnerships with Grab, Uber, and internal partners
- Toyota has invested in "Woven City", a prototype city where people, buildings, and vehicles are connected through data and sensors.
- Key alliances are with Suzuki, Mazda, BMW, Panasonic, and others

Business Description:

Founded in 1937,Toyota Motor Corporation (TMC) is one of the world's largest automakers with more than 9 million units sold in 2021 across all of its Brands (e.g, Toyota, Lexus, Daihatsu, Hino, etc.). TMC's global vision is to lead the future mobility society, enriching lives around the world with the safest and most responsible ways of moving people. Toyota has most recently adopted a more aggressive EV strategy, while it continues to be a pioneer is the usage of Hydrogen as a source fuel.

Notable Transactions

Target	Deal Size	Date	Type	Description
Momenta	$500.0M	Sep 2021	Late VC	Autonomous Driving
E-Mobility Power	$182.9M	Apr 2021	M&A	E-Mobility Charging
United Fuel Cell	$1.1B	Jun 2020	Joint Venture	Fuel Cell Systems

3. Electrification and Charging Infrastructure

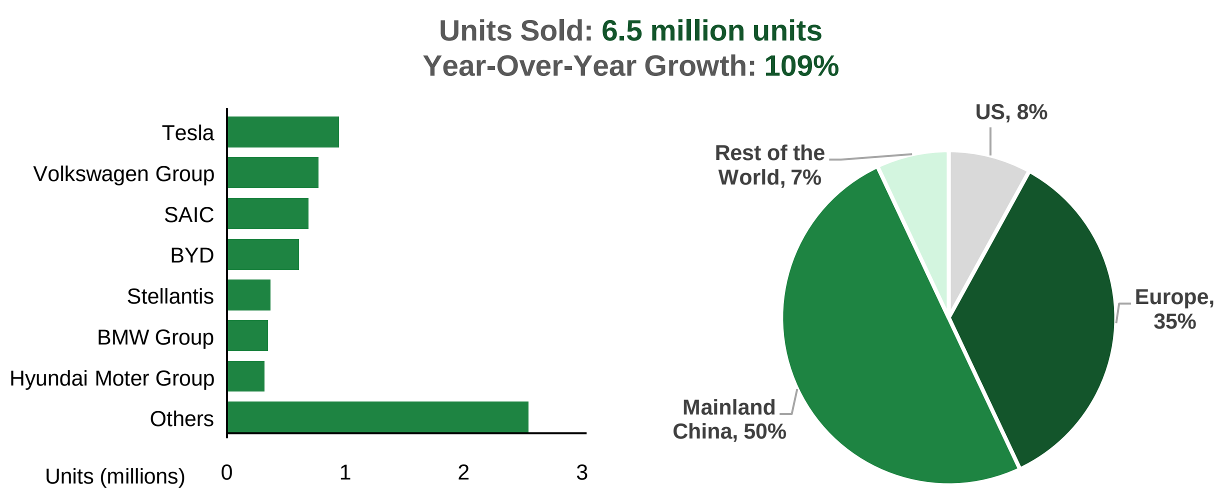
In our lifetimes, internal combustion engines have consistently generated more than enough electricity as a byproduct. Loss of power existed when a dead battery prevented the engine from starting. Once the engine started, the vehicle did not need the battery anymore - the alternator could take over to generate electricity from the internal combustion engine. It produced enough mechanical energy to move the vehicle, sufficient thermal energy to provide heat, and enough electricity to power lights, windows, wipers, electronics, and recharge the battery.

Today's electric vehicles face an entirely different problem. All the power comes from batteries, and they must propel the vehicle while providing heat, air conditioning, and a rapidly increasing array of functions such as automatic doors, entertainment systems, and vehicle-to-road and vehicle-to-vehicle communication. As a result, there is a limited amount of energy for every function, from motive power to safety, communication, entertainment, and navigation. These higher demands increase the need for higher energy capacities, faster battery charge/discharge rates, and more sophisticated electronic controls to ensure vehicle safety and performance. It is a complex systems problem that goes beyond the vehicle to include charging infrastructure, wireless networking, and the electric grid.

3.1 China and EU are Leading in Adoption and Market Share with the US and Japan Lagging

Both US and Japan are lagging in electrification and adoption of EVs. The list of top seven EV manufacturers worldwide includes three companies with their headquarters in Asia and three companies with headquarters in the EU.

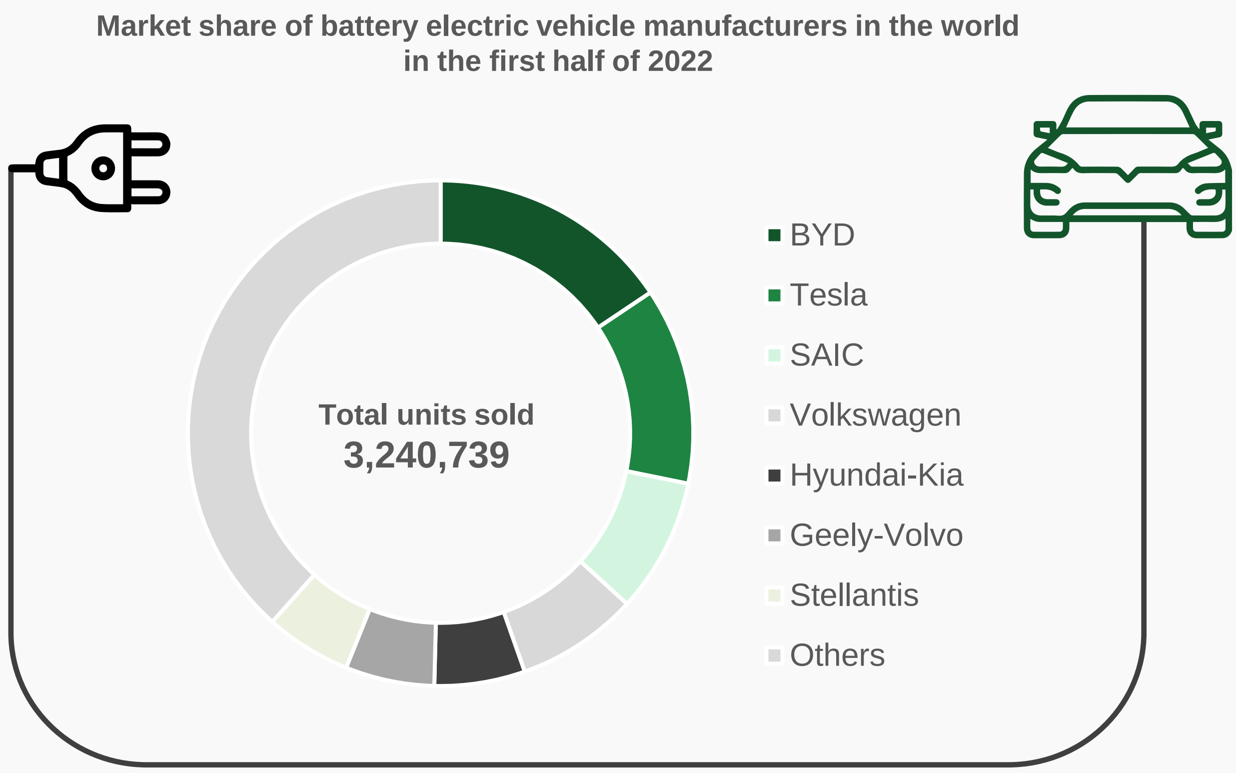
Worldwide 2021 EV Sales by Manufacturer and Major Market



Competition for Market Share is Fierce[22]

We are in the early innings of this epic battle. Because of the stakes involved, growth companies with the highest capitalizations are winning. And the race in China, led by BYD, is the largest of all.

Tesla Likely to Lose Top Place as Biggest BEV Producer in 2022



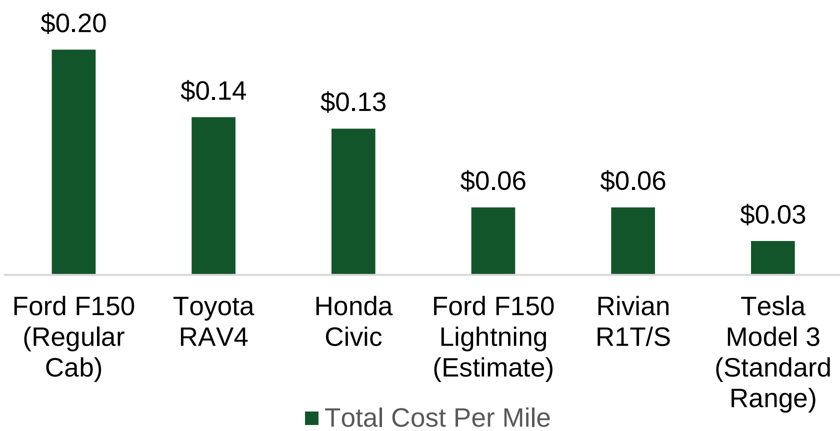
3.2 Open-Source Movement in EV

We have discussed this aspect in some detail in Section 1. Even though they rely on technological innovation to win, both Tesla and Toyota have announced that they will not mount a legal defense of their advanced patent portfolios. In making their patent portfolios publicly available, Tesla and Toyota hope to drive faster industry growth and stimulate innovation from others. This approach is analogous to the Open-Source Movement in computing and cloud, where the open-source Linux operating system is the most deployed in datacenters and embedded systems.

22 Source: Statista, CleanTechnica
*Note: * January 1 to May 31, ** including SAIC-GM_Wuling*

3.3 Key Drivers and Obstacles for Electrification across the globe[23]

The most significant growth obstacle for EVs is the initial cost of purchase. While most consumers care about the environment, few are willing to pay a premium for transportation. However, the operating cost of an electric car in the US is already far below equivalent gas prices, as shown below.



In markets like China and India that are at the vanguard of electrification globally, especially in the two- and three-wheeler categories, key drivers have been the following:

The Regulatory Framework: A decisive policy push (by State and Central governments) in terms of demand incentives to electric two-wheeler (e2W) buyers

Total cost of ownership: Rising fuel prices that impact the working- and middle-class consumer more than others, making the total cost of ownership (TCO) of an e2W significantly lesser than that of an Internal Combustion Engine (ICE) 2W

The Demand side: Significant focus on moving to EV fleets by e-commerce, food delivery and shared mobility companies leading to greater demand pull for e2W market

The Supply side

While the need for engineering expertise in aspects like battery design, drivetrain hardware and software, and charging infrastructure for Electric 2-Wheelers is significant, it is smaller than that of cars, trucks, and other high-voltage battery-operated vehicles. This has enabled the entry of a larger number of players in the Electric 2-Wheeler market in several geographies.

23 Source: Electrek and Zeta

Total Cost of Ownership of EVs is Compelling[24]

The Total Cost of Ownership includes purchase, maintenance, and insurance minus government subsidies. EVs enjoy maintenance costs of 30% less than their gas equivalents and are projected to have a longer operating life. After all, EVs have about one-third or less of the number of components. Considering all relevant factors and government incentives, the lifetime ownership cost of most EVs are already lower than ICE. While these differences are compelling, the purchase price of new EVs still exceeds their gas equivalents. Electric vehicle prices are moving in the right direction, though, decreasing 10%, on average, from April 2020 to April 2021.

3.4 Crossing the Tipping Point

If consumers are economically rational, why are EV sales still so small? Higher purchase prices lead to “sticker shock.”

All EV drivers, at one time or another, develop “range anxiety” - that sinking feeling that they do not have enough charge to get to their next destination. There is even the notion of “deadhead miles” - how long drivers have to go just to find a charging station instead of their final destination. Consequently, there is a great deal of investment in charging systems and stations. Chevrolet, for example, will pay for a Level Two charging outlet in a Bolt EV buyer’s home in partnership with Qmerit. Later in this section, we will discuss EV charging infrastructure.

Range anxiety is starting to wane due to improvements in single-charge mileage and the buildout of charging stations. But most experts agree that purchase price parity is needed for consumers to become “EV first” in vehicle purchase decisions.

Key Finding

Most consumer surveys show that purchase price and range anxiety are the two most important limiters of EV purchases.

24 Source: Money Magazine

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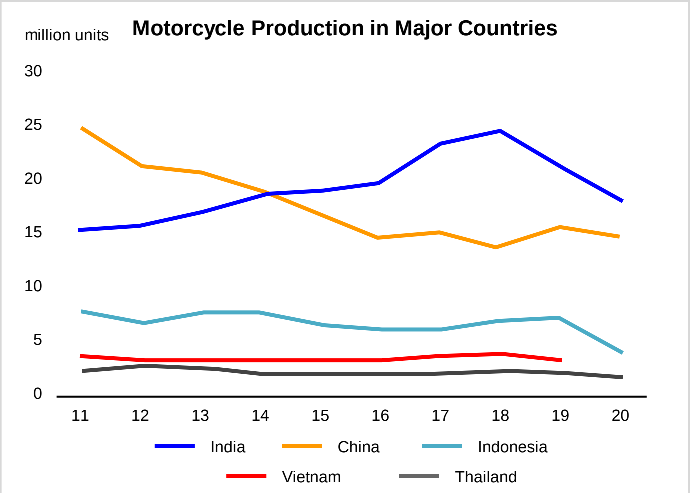
3.5 The Global Perspective: Electric Two-Wheelers (e2W), Three-Wheelers (e3W) and eBikes

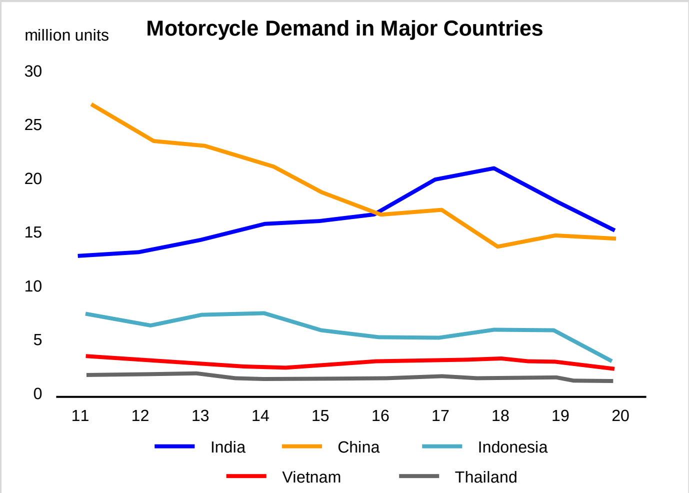
3.5.1 Two-wheelers (comprising e-bikes, kick scooters, mopeds, scooters, and motorcycles) are among the fastest-growing transport mode in many emerging economies. In the next twenty years, the global fleet of motorcycles & scooters is projected at over 400 million vehicles, as compared to about 270 million today. While Asia has the lion's share of the global two-wheeler fleet, with India, China, and Indonesia being the top three markets - in India, for instance, two-wheelers account for 70% of the 200 million-plus registered vehicles[25] on the roads - growth rates in many African countries are among the highest in the world.

The global two-wheeler market size[26] (including Motorcycles, Scooters, and Mopeds) was valued at $90 Billion in 2016 and is expected to reach $154 Billion by 2024, growing at a CAGR of 6.9%.

Global 2W Production & Demand[27]: Asia is one of the major motorcycle and scooter production centers in the world.

- The total number of motorcycles & scooters produced in the world's major countries in 2020 is estimated to be 49 Million units. India's production of two-wheelers for the financial year ended March 2022 fell 3.4% y-o-y to 17.7 Million units due to Covid
- Global demand for motorcycles in 2020 fell 17% year-over-year to 44 Million units (source: Yamaha). Asia was down 20% to 34 Million units, accounting for about 80% of total demand.





25 Source: imrenew
26 Source: goldsteinresearch
27 Source: Goldstein Research
India Production and Sales statistics: SIAM
Marklines
Unep.org

3.5.2 Three-wheelers (3W) are generally used as commercial vehicles to transport passengers and cargo. These vehicles are equivalent to *pickup trucks* or *small delivery vans* in use in developed markets. Three-wheeler mobility is driven by the easy maneuverability, affordability, and door-to-door transport capabilities of these vehicles, especially in congested cities and smaller towns. As many developing countries in Asia-Pacific and LAMEA require faster and cheaper options for public and goods transport, three-wheelers suit the requirements best.

(Image Source: Altigreen Propulsion Labs)

The three-wheeler market was valued at $8.4 billion in 2020 and is projected to reach $15.5 billion by 2028, registering a CAGR of 10.3% from 2021 to 2028[28]. The Asia Pacific is expected to remain the largest market with high demographic growth, a larger middle-class income population, and an increasing inclination towards the electrification of vehicles.

Burgeoning demand for e-commerce in several developing economies is a huge factor in the rise in demand for these vehicles, as they are predominantly used for last-mile transport, in addition to passenger mobility. India is the largest producer of these types of vehicles globally, selling about 1.2 to 1.4 million three-wheelers annually, and currently has around 7.2 million registered three-wheelers on the roads today[29].

Why electrify two- and three-wheelers?

- Internal combustion engine (ICE)-based two and three-wheelers can be highly polluting, emitting substantial amounts of particulate matter (PM) and black carbon (BC), a potent short-lived pollutant. A two-stroke scooter, for example, produces more particle emissions than a passenger car. Experts agree that two and three-wheelers are a high priority in moving to electric mobility. Scenario calculations using the UN Environment eMob calculator show that assuming a steep and global shift to 90% battery electric motorcycle sales by 2030 could result in CO2 emissions reductions of about 11 billion tons between now and 2050.
- At the same time, overall monetary savings stemming from lower fuel and maintenance costs could amount to about $350 Billion by 2050, even after considering a higher purchase price of electric motorcycles.

28 Source: Allied Market Research
29 Source: Vahan

The shift in the electrification of two and three-wheelers is being led by Asia, which is also the largest market for these types of vehicles. China is the world's largest e2W market, with 33.9 million electric two-wheelers (including e-bikes, e-mopeds, electric scooters, and motorcycles) produced in 2020.

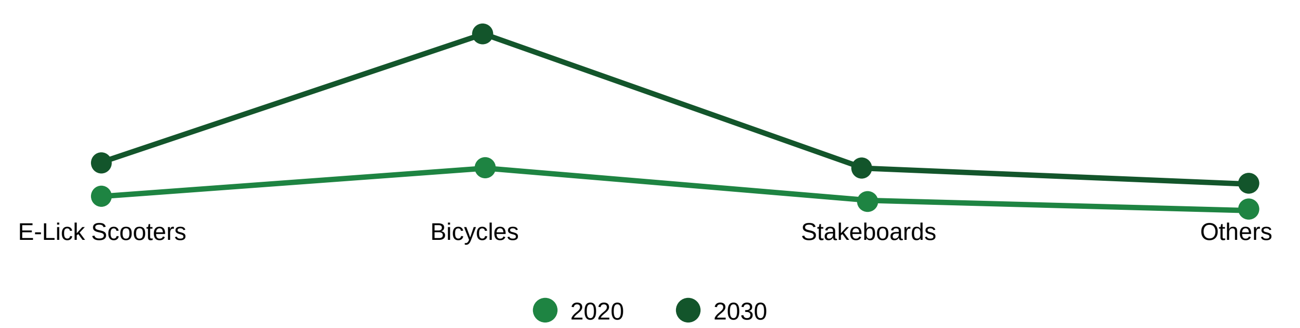
In the month of June 2022, nearly 45% of all three-wheelers sold in India – mostly comprising rickshaws used in public shared mobility – were electric. Further, electric two-wheelers formed nearly 54% of all EVs sold in the fiscal year that ended in March 2022, which were approximately 429,000.

3.5.3 eBikes and Micro-mobility

E-Bikes refer to a range of small, lightweight vehicles operating at a speed of not more than 25 km/h (15 miles/h) and considered *ideal for commuting within a 10 km range, i.e. for Micro-mobility*. These vehicles include e-bicycles (e-Bikes), e-kickscooters, skateboards and others. These vehicles do not require the rider to be licensed or insured and are uniquely adaptable to urban and rural usage. In congested and slow city traffic, they use less space on the roads and when parked, and are well-suited for shared mobility.

Given the growing number of brands and models in electric kick scooters and electric bicycles as well as rental and sharing services using these vehicles, the global micro-mobility market size is expected to surpass around $198.03 Billion by 2030, growing at a CAGR of 17% from 2021 to 2030 (Source: Global Newswire[31])

Micro-mobility Market by Vehicle Type[32]



30 Source: Global electric 2W Market, May 2022
China's electric two-wheeler market, Sep 2021
CEEW-CEF
Ostara Insights

31 Source: Global Newswire

32 Source: CB Insights

Given the post-pandemic trend towards more personal mobility, many customers prefer owning electric bikes and scooters instead of using shared mobility programs. In Europe, for instance, Direct-to-consumer (D2C) e-bike sales are set to reach 17M units annually by 2030, up from 3.7M in 2019. Electric bike sales in the US, meanwhile, grew 145% between 2019 and 2020, according to NPD Group.

3.6 The Battery Pack and the Battery Management System (BMS)

A battery pack in the EV consists of hundreds or even thousands of Lithium-ion (Li-ion) cells packed into modules. Every cell must be monitored for safe and efficient operation, which requires a specially dedicated system called the Battery Management System (BMS).

Standard Lithium-Ion batteries can fail catastrophically unless carefully controlled by limiting their discharge rates. That involves circuits and control systems that limit how fast these batteries charge and discharge and mechanical systems to keep them cool. If it’s too fast, the batteries overheat and explode, often in a chain reaction. Thermal runaway occurs when a cell, or an area within the cell, achieves elevated temperatures due to thermal failure, mechanical failure, internal/external short-circuiting, and electrochemical abuse. Conditions like these can harm the lifespan or the capacity of the battery. As a result, a deeply engineered and safety-hardened BMS is critical to EV safety and performance.

Next-Generation Battery Technologies

U.S. companies are already developing next-generation battery technologies, including Ionic Materials, QuantumScape, Sila Nanotechnologies, Sion Power, and Sionic Energy. Most are still nascent technologies, and the path to commercialization involves many testing cycles, design improvements, and further testing.

Many, including QuantumScape, with a strategic partnership with Volkswagen, are developing solid-state batteries, where the electrolyte between anode and cathode is no longer a liquid or gel. Solid electrolytes are safer than non-solid electrolytes which are more prone to a battery catching fire or exploding and other failures.

Battery cost, density, and performance breakthroughs are primary drivers in EV growth. Tesla has developed and patented a newer battery cell: the 4680. These cells have five times more energy with six times the power, enabling a 16% range increase and faster acceleration. At the battery-pack level, the form-factor improvements alone result in a 14% reduction in cost per kWh. Other automotive OEMs, notably BMW and VW, are investing heavily in battery technology.

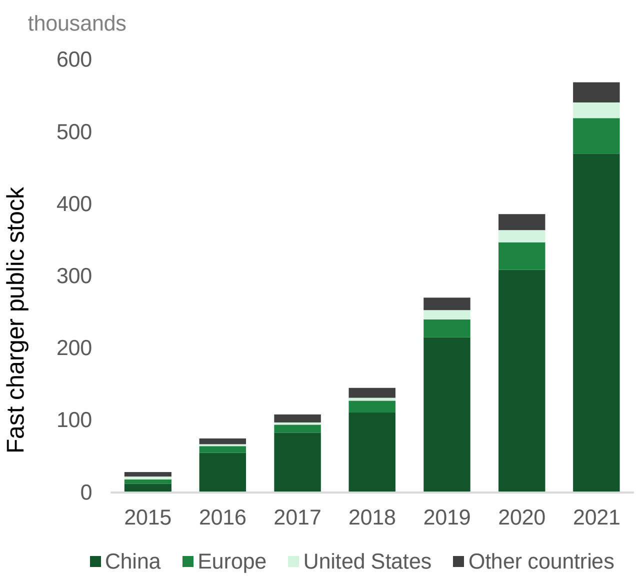
3.7 Public Charging Infrastructure[33]

Grocery stores, restaurants, offices, and shopping malls are convenient public charging locations. It's an increasingly important employee benefit for companies that have returned to the office post-pandemic. Public charging infrastructure is sorely needed to increase EV adoption. Until gas stations existed everywhere, ICE vehicles did not ramp up either. Standard Oil built gas stations, priced fuel below market prices, and forced local competitors out of business. While unfair competition laws prevent that practice today, there is still a "land grab" for charging. We predict that breakout business models, not just sheer buildout for scale, will likely win the day in public vehicle charging.

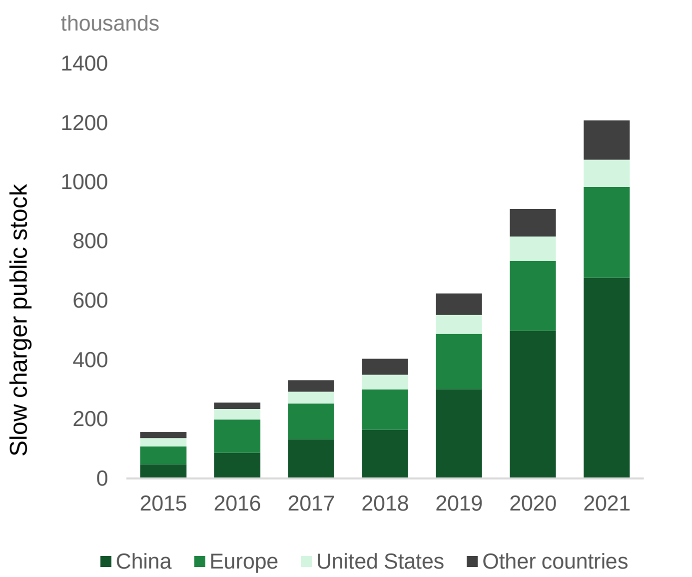
China has installed more publicly available charging stations than all other countries combined. Unsurprisingly, China is far and away the largest market for EVs. While the governments of other countries (especially the US) claim that EV charging infrastructure is a priority, their execution lags China considerably. For example, EV owners who live in apartment complexes and low-income communities typically lack charging options at home since they cannot make structural changes to their homes. Winners in multi-unit housing will find a way to reward drivers, property owners, property managers, renewable energy developers, and utility companies. It's not easy, but notable examples of a new business model exist. Consider how the San Francisco-based environmental organization Carbon Lighthouse rewards property owners, tenants, maintenance companies, and utilities via sharing cost savings and then apply its model to EV charging.

Publicly accessible chargers worldwide approached 1.8 million charging points in 2021, of which a third were fast chargers. Nearly 500,000 chargers were installed in 2021, more than the total number of public chargers available in 2017.

Fast Publicly Available Chargers



Slow Publicly Available Chargers



33 *Source: International Energy Agency, Global EV Outlook 2022*

3.7.1 Markets and Opportunities for EV Charging Infrastructure[34]

Widely available EV charging infrastructure can clearly help drive consumer acceptance of EVs. Publicly available EV charging infrastructure is as critical as advanced EVs. Without it, consumers will not buy EVs. Who owns that infrastructure and how it is financed and deployed varies from country to country. Especially in the US, opportunities for business model innovation exist. At one extreme, Tesla has chosen vertical integration and, impressively, has installed over 70,000 charging stations worldwide. The company plans to triple the size of its Supercharger network within two years. The new Model 3 uses all 250 kW of power, can charge 75 miles in only 5 minutes, and a theoretical 1,000 miles in an hour. Models S and X only support peaks of 200kW, which means that we could see a slash of 50% in charging times compared with older versions of the Supercharger.

For a new Supercharger installation in a commercial or retail area, Tesla covers all the capital cost, does the set-up itself, and pays whatever electricity the Superchargers draw from the local utility. And all they ask is some prime real estate, ideally located, for at least five years. While this is an impressive plan, there are significant challenges, especially in areas with limited real estate and energy grid capacity. At 250kW per station, that's a lot of power.

Consider the installation underway along Interstate 5 in Coalinga, California, mid-way between the Bay Area and Los Angeles. It's the largest Tesla Supercharger installation worldwide, with 98 stations. An installation of this size would not be possible without significant utility power capacity. Undoubtedly, Tesla made the site selection relying on Pacific Gas and Electric's upgrade to its nearby Gates substation would provide sufficient power. Post-upgrade, Tesla's usage would be only about 3% of the substation's 800-megawatt capacity – leaving plenty of spare capacity for other customers. This capacity would not be possible without the proximity of an existing primary north-south high-voltage transmission line. Few sites feature ample land, heavy interstate Tesla EV traffic, a comfortable retail environment, and sufficient utility capacity. The business model of collaboration between retailers and Tesla makes sense. Tesla brings EV customers and makes money selling electricity, enabling the retailer to justify the land allocation for increased customer revenue. Tesla using its proprietary solution is building out charging infrastructure aggressively to stay ahead of the competition.

34 Source: Electrek

3.7.2 Business model innovation

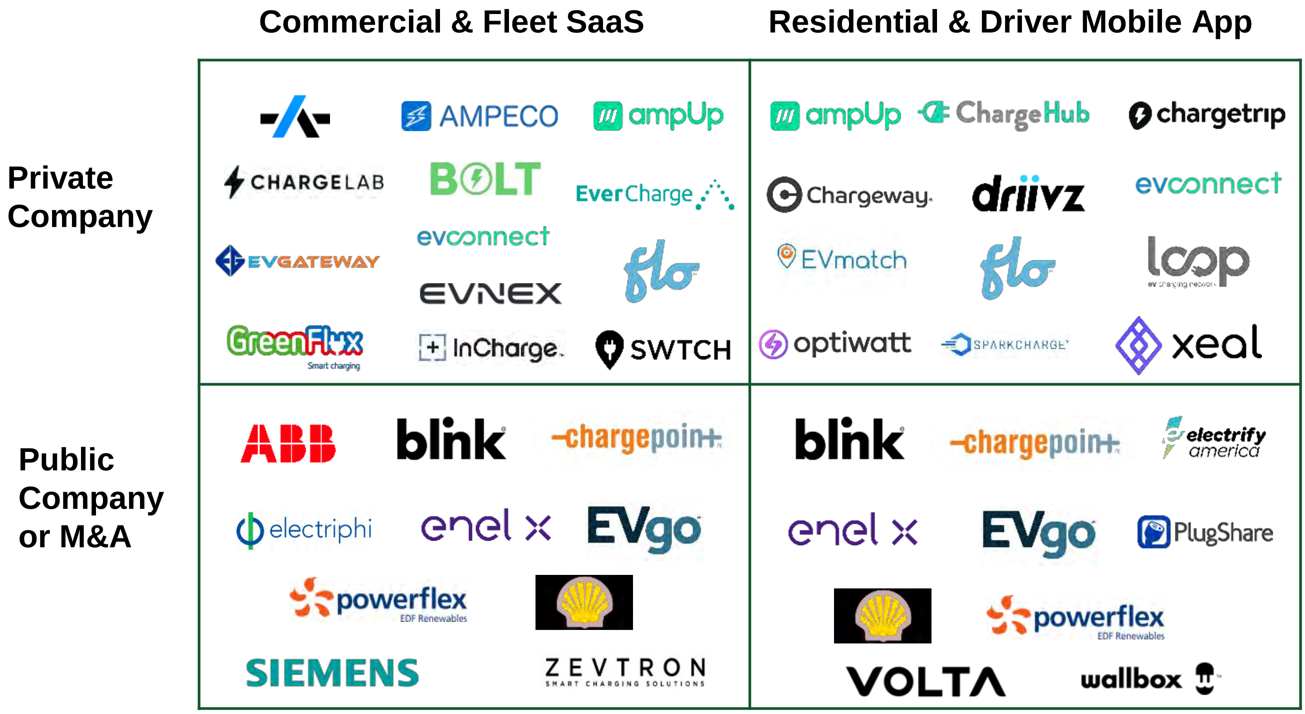
Here is a rough calculation of Tesla's financial outlook for the Coalinga, California site with 98 charging stations, assuming no solar and no stationary storage:

Parameter	Low	Average	High
Capacity per vehicle (kWh)	100	100	100
Average recharge energy/vehicle (kWh)	30	50	70
Supercharger power (kW)	200	225	250
Time to recharge (minutes)	9	13	17
Customer price ($/kWh)	$0.250	$0.250	$0.250
Cost of electricity to Tesla ($/kWh)	$0.175	$0.150	$0.125
Tesla revenue per charge	$7.50	$12.50	$17.50
Tesla profit per charge	$5.25	$7.50	$8.75
Tesla profit per minute	$0.58	$0.56	$0.52
Number of charging stations	98	98	98
Average usage level (%)	3%	5%	8%
Tesla total profit per minute ($)	$1.72	$2.76	$4.08
Tesla total profit per year ($)	$901,404	$1,448,685	$2,146,200
Capital cost of installation ($)	$1,700,000	$1,500,000	$1,300,000
Payback period (years)	1.89	1.04	0.61

This is only one example of a business model. There are many examples of startups, commercial real estate developers, retailers, and independent operators who can drive extraordinary returns from EV charging installations and operations. The amount of M&A in this space is more than in any other category of 139 emerging spaces tracked by Pitchbook with 1,100 deals.

A key question that can be best answered through experimentation is how will consumers want to have charging delivered? Gas stations in their current form are not likely to work. While Superchargers help with wait times, charging takes longer than refilling a gas tank. Instead of a gas station, what if Starbucks started adding charging stations and bundled services and user experience together? How about a new type of convenience store that has great WiFi, work areas, and conversation zones?

EV Charging System Market Map



It is still the “Wild West” for EV charging as an industry. Who will be the operators? Will they own and operate EV charging fleets or build a franchised network of local operators? Will non-transportation retailers such as coffee shops or fast-food restaurants emerge? What industries will view EV charging as core? It could include electric utilities, petrochemical companies, commercial operators, renewable energy producers, government-owned rest stops, or newly formed businesses. The chart above lists only a representative group of companies, with business model categories that include:

- EV charger systems producers
- Stationary energy storage systems
- EV charging operators
- Apps and enabling software
- Industrial controls and equipment makers

We anticipate continued fragmentation that is agitated by government incentives before things settle down. After all, it took decades for gas stations as we know them today to emerge, and they evolved over time to include integrated convenience stores. We can imagine a business model that expands the convenience store into a consumer experience that looks and feels like a coffee retailer or remote office. There is incremental revenue available from drivers waiting for their EVs to recharge, but their interests and willingness to wait for charging are still very much in question. Importantly, supercharging may reduce the wait time to approximate the refill of a gas tank – in which case EV charging will be a visit to a gas station.

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Riso Capital

3. Electrification and Charging Infrastructure

Notable M&A Transactions (2021 & 2022)

Acquiror	Target
ROMEO POWER TECHNOLOGY	NIKOLA
Schneider Electric	evconnect
blink	SemaConnect
VONTIER	driivz
MER Group	elmtronics
bp	AMPLY FLEET CHARGING SIMPLIFIED
BEDEO	PROTEAN
TURNTIDE	AVID
Ford	electriphi
EATON	greenmotion car and van rental
VOLVO	cellcentric

Battery Producers

EV batteries are not currently produced by US companies. The industry is dominated by Asian companies, many of whom are expanding manufacturing capacity in the US to take advantage of government incentives, both federal and state. While many startups develop advanced batteries, few can scale to volume manufacturing. They are limited by capital (a volume battery manufacturing plant starts at several hundred million US dollars), and an even bigger factor is time to commercialization. Because safety is paramount, there is no easy way to bypass qualification and certification steps. For example, the failure to qualify results in a development restart that can take years. Mature companies such as LG, Panasonic, and Samsung SDI have been at it long enough that they can "copy exact" when constructing a new manufacturing plant. And there are numerous partnerships and collaborations, some of which include automakers – VW and QuantumScape, for example. While it is not clear who the ultimate winners will be, we anticipate that changes in market share will occur slowly because of how long it takes to reach volume.

Battery Producers by Market Share

Rank	Company	2021 Market Share	Country
#1	CATL	32.5%	China
#2	LG Energy Solution	21.5%	Korea
#3	Panasonic	14.7%	Japan
#4	BYD	6.9%	China
#5	Samsung SDI	5.4%	Korea
#6	SK Innovation	5.1%	Korea
#7	CALB	2.7%	China
#8	AESC	2.0%	Japan
#9	Guoxuan	2.0%	China
#10	PEVE	1.3%	Japan
n/a	Other	6.1%	ROW

3. Electrification and Charging Infrastructure

Selected M&A Transactions (Battery Technology)

Date	Target	Acquiror	Target Business Description	Transaction Value ($M)	Revenue ($M)	EV/ Revenue
Aug 22	Romeo Power	Nikola	Designer and manufacturer of lithium-ion battery modules and packs for commercial electric vehicles.	$144.00	$32.10	4.5x
Jun 22	Willison Motors	-	Operator of a vehicle garage and service centre	-	-	-
Jun 22	Tianhai Electric	Angstrom USA	Manufacturer of battery cables and wire harness assemblies	-	-	-
May 22	Johnson Matthey	Nano One Materials	Manufacturer of sustainable battery materials	$8.00	-	-
May 22	Kratzer Automation	National Instruments	Provider of vehicle testing systems and software services	-	$123.60	-
Sep 21	Spiers	Cox Automotive	Developer of advanced battery packs designed to be used in hybrid and electric vehicles	-	-	-
Aug 21	OXIS Energy	Johnson Matthey	Manufacturer of battery systems	-	-	-
May 21	Springpower	Tesla	Develops and commercializes graphene and silicon nanomaterials for lithium-ion batteries	$3.00	-	-
Mar 21	Cuberg	Northvolt	Developer of lithium-ion batteries intended to supply sustainable, high-quality battery cells and systems.	-	-	-
Mar 21	Cellentric	Volvo Group	Manufacturer of hydrogen fuel cell systems intended to offer climate-neutral and sustainable transportation to the world.	$725.70	$40.10	18.1x

Key Takeaways

- Significant SPAC activity in 2021, now dormant
- Average SPAC-based company’s market cap is down over 60% YoY
- Matching battery technology to the right acquirer involves chemistry and process compatibility
- Startup space has become crowded – only a few clear winners have emerged
- Time to revenue for new battery chemistries is more than 3 years

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MOTOVOLT E-BIKES – COMPANY PROFILE

Founded	**Total raised:**	**Last financing:**	**Investors:**
2019 Kolkata, India	$5M	$3.5M (Pre-series A)	Founding family of Himadri Specialty Chemicals
Employees	**Last financing valuation:**	**Close date:**	
110	N/A	Oct 2022	

Outlook:

- Motovolt solves for **lack of affordable short-range personal mobility** options in a huge and fast-growing market, given that over 90% of India uses manual bicycles or public transport for short commutes, which form the vast majority of all commutes in India.
- We expect that these e-bikes that retail in the $400-500 price range will fill a critical gap for rural and semi-urban customers in developing countries looking for motorised personal mobility vehicles, to upgrade their daily commute from buses and shared rickshaws.
- Motovolt targets the Aspirers and the Next Billion, forming 66% of Indian households.* This can form a potential Serviceable Obtainable Market (SOM) of $5.5bn and 13.7 million households that the Motovolt product can reach. Customers in these segments are looking for sub-$500 2-wheeler options as well as to upgrade from bicycles for personal mobility.

Business Description:

India’s first mass-market e-bike. The Company has designed and launched a range of smart e-bikes made for aspiring Indians in semi-urban, rural and urban areas. Founded in 2019, the company has created an e-bike powertrain and technology platform, which enables it to design and launch a wide range of smart connected e-bikes for micro-mobility applications.

4. Connected Vehicles

This section covers Internal Communication (Local Area Network, Communication Bus) and External Connectivity (Internet/Cellular/Satellite Data) elements of Connected Vehicles. Auto OEMs are ramping up their infrastructure networks and teams to prepare for Autonomous vehicles and content services.

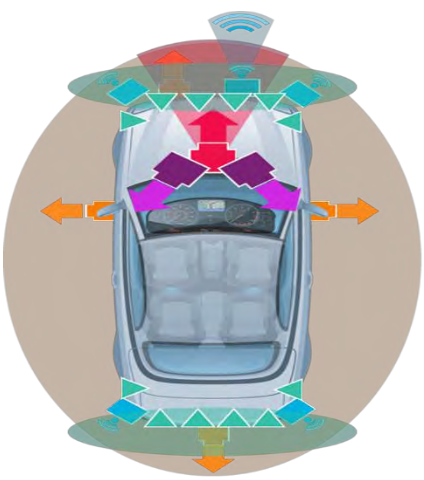
Key Finding

Internal vehicle networking is experiencing rapid technological advancements from Controller Area Network (CAN) to Flexible Data-rate CAN and Automotive Ethernet.

Improvements in external connectivity in vehicles are mostly stalled for technology and business model reasons. With external networking, EVs become platforms capable of offering network services and generating recurring revenues from consumers who become subscribers. While there is clear need for cellular data and WiFi in vehicles, auto OEMs currently face significant challenges and obstacles before designing cellular or satellite Internet into their vehicles and offering subscription services. Consumers now expect their mobile phones and apps to be their primary source of data and content services in the vehicle.

The need for visually-oriented sensing drives both internal and external networking advancements. Not too long-ago internet speeds were too slow to support Netflix or other video streaming services. Modern networking technologies changed all of that. A similar trend exists in EVs. The primary drivers involve sensing for driver and vehicle safety.

Intelligent Vision/Sensing Distribution in Vehicle[35]



360 Surround View	Back-up Camera Automatic Parking Object Detection
Front Camera Mono or Dual	Adaptive Cruise Automatic Braking Smart Lighting Object Recognition
Interior Cockpit Camera	Drowsy Driver Occupant Detection Facial Recognition
Long-range Radar	Collision Warning Object Detection Adaptive Cruise
Mid-range Radar	Cross traffic warning Object Detection
Ultrasonic Sensors	Parking Assist Blind spot detection

35 *Source: Vamshi Kandalla*

4.1 Internal Networking

The revolution in internal networking for Autonomous and Connected EVs will not be televised. It will be live-streamed on large screens in self-driving vehicles. The changes in user experience from the driver with eyes on the road to a mobile office and media center drive visible changes to the networks inside of vehicles. But this change is less significant compared to the communication required for advanced control systems and the data they need to exchange with each other.

Although there is little agreement on how much data a connected EV could generate, some estimates have put the upper limit at 32 terabytes of data per day. And with millions of EVs expected to be on the road over the next decade, that will give literal meaning to "highways of data." (Source: Macropolo[36])

The classical high-speed Controller Area Network (CAN) bus is standard based and supports bit rates from 40 kbit/s to 1 Mbit/s. The second generation of CAN is called CAN FD (CAN with Flexible Data-rate) and is 5 to 8 times faster. Even this increase is not nearly enough for the high bandwidth requirements of ADAS (Advanced Driver Assistance Systems), infotainment systems, cameras, and DCU-to-DCU communication.

Automotive ethernet offers much higher data transfer rates vs. CANbus but lacks some of the safety/performance features of Classical CAN and CAN FD. The coming years will see automotive ethernet, CAN FD, and CAN XL being used - many times in the same vehicle design.

We anticipate that the advent of "sensor fusion," where most or all sensors connect with a central computing engine, will drive much of the required bandwidth. Gone are the days of individual Electronic Control Units (ECUs) - small devices in a vehicle's body responsible for controlling specific functions such as airbags, power windows, seats, and keyless entry. Replacing them are Domain Control Units (DCUs) that connect directly to sensors and do the work of up to 100 ECUs per vehicle that they replace. It's the move to DCUs that will help to enable Software Defined Vehicles. So, what's the networking part?

It starts with the augmentation of a shared bus architecture (CAN bus) with a switched and routed architecture (Ethernet). CAN bus has guaranteed delivery, but garden variety Ethernet does not. Yes, this is the same Ethernet that connects computers to servers, storage, and the internet. In the case of vehicles, however, Ethernet has to be engineered with high reliability and, in some cases, redundancy. When you are surfing the web, and the network drops a packet, it simply re-tries, and your page gets served up. A dropped packet could make the difference between life and death in a moving vehicle. As a result, the entire internal network is being re-engineered to provide:

- Far higher bandwidth without blocking
- Security

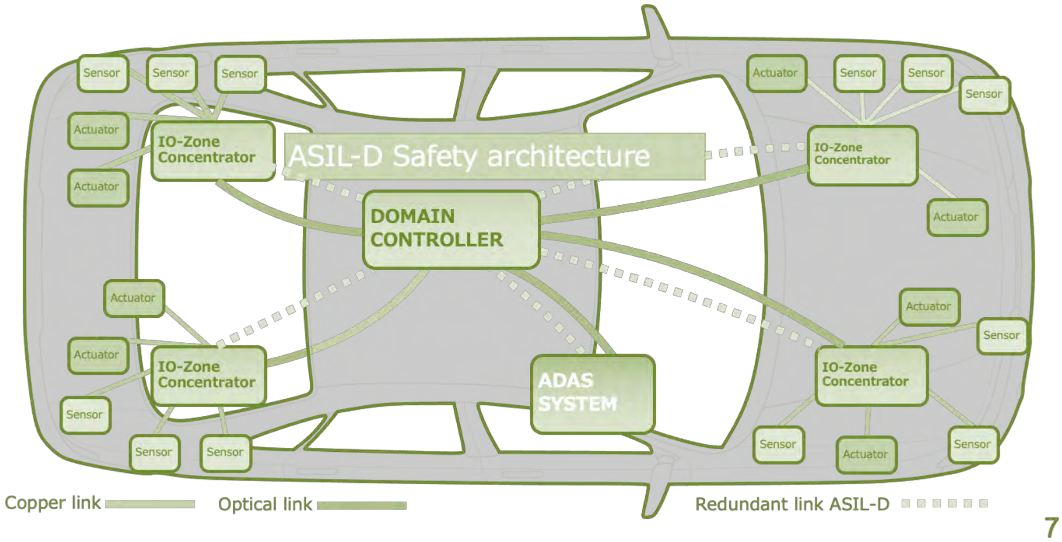
36 Source: Macropolo

- Large amounts of image data
- Guaranteed delivery of data

The architectural upgrade in newer vehicles - especially EVs - opens opportunities for new suppliers and drives a fundamental change in design responsibility between automotive OEMs and their suppliers. Where ECUs come with hardware and software tightly coupled and proprietary, DCUs and their networks increasingly rely on standards - making the vehicle a standard hardware platform on which multiple software layers can run.

Semiconductor companies offer switches and physical interfaces that provide data security and safety features beyond Ethernet. For example, Marvell Semiconductor's third-generation BrightLane™ switches have two redundant processors on the chip, advanced security features, and wiring interfaces. Weight and cost are primary considerations; automotive wiring is simpler and lighter compared to data centers.

New automotive architecture based on Physical Zones of the vehicle[37]



Internal Networking Challenges

In their current design cycles, automotive OEMs face difficult questions:

1. How to integrate multiple network protocols, including CANbus, Ethernet, and permutations of each?
2. What medium to use - multiple forms of copper, optical fiber, or wireless? What are the related weight, cost, and complexity considerations?
3. How to cope with the impact of DCU and VCU architectures and mounting pressures on bandwidth?

37 Source: Vamshi Kandalla

While answers to these questions vary from one OEM to another, the degree of change is so significant that the automotive supply chain is being disrupted. For this reason, many semiconductor manufacturers have either started or expanded their automotive product lines.

While companies such as Navitas are bullish regarding future revenues, newer suppliers must overcome a high bar to penetrate automotive OEMs and Tier 1 automotive suppliers. They benefit from today's much shorter automotive design cycles - typically three years, compared to historical seven-year cycles. However, supply chain management teams scrutinize the financial strength of every new supplier and often require risk mitigation that can be costly to the new supplier. For example, many require that designs and core IP be placed in a third-party repository that the OEM can access if adverse new supplier conditions materialize. The combined burden of these barriers to entry and at least three years to production revenue dissuades all but the best-funded startups. Some startups use the strategy of attracting corporate VC (CVC) investment with an assurance of supply guarantee from the CVC's parent company.

4.2 External Connectivity

A survey of over 1,100 Automotive Executives in 13 countries conducted by KPMG reports that 84% agree that a vehicle subscription would be a competitive offering. So, automakers should be motivated to offer the best possible solution as consumer demand clearly exists. The same KPMG survey reports that 67% of the executives surveyed think that automakers and auto dealers are best positioned to succeed in offering vehicle subscriptions.

Ford Motor CEO Jim Farley has stated publicly that he expects connected vehicle services to become a major source of revenue for Ford and its dealers, and the company's future depends not on selling cars but on selling car owners a continuous stream of services, from hands-free driving technology to the latest touchscreen infotainment apps. Ford predicted at a Bank of America Auto Summit event that the company will have 32 million Over-The-Air (OTA) capable vehicles on the road by 2028. (source: Ford Authority[38])

There are many connected vehicle services that consumers want, and automakers will provide, but most services are not-chargeable. Consumers expect most of the services to come free with the vehicle purchase without a monthly fee.

38 Source: Ford Authority

4.2.1 Connected Vehicle Subscription

Automakers are caught between consumers who want connected services from WiFi connectivity to infotainment and content services on the one hand, and the high cost of providing these services on the other. Mobile carriers and satellite Internet service providers have to invest in building out the 5G infrastructure and cannot bring the cost down for several years.

There is no general agreement on who should provide the service and who should pay for it. There have been well-publicized attempts that have not gone well for automakers, the most famous being BMW charging an $18 monthly fee for Heated Seats with some models. (Source: Bloomberg[39])

Ford expects that connected vehicle revenues will come from commercial business and ADAS subscriptions and will reach $20 billion per year by 2030. (Source: Ford Authority[40])

4.2.2 Connected Vehicle Infrastructure – Cost of 5G and Bandwidth Demand from ADAS

Progress in external connectivity for vehicles will be slow and difficult because of several factors coming to play at the same time:

a) Huge volume of data generated by Autonomous vehicles
b) Power of mobile carriers
c) Lack of 5G and satellite network infrastructure
d) Slow consumer acceptance of vehicle subscription.

Volume of Data

Autonomous and connected vehicles generate huge amounts of data. According to estimates from Intel, an autonomous vehicle generates 4 terabytes (TB) of data in an hour and a half of driving. Current test drives of ADAS R&D vehicles are generating 20 TB of data per vehicle per day. Even with all the advances in AI and compression, the amount of data generated remains a major obstacle as ADAS requirements include low latency.

Power of Mobile Carriers

Mobile carriers are using their power to force Automakers to purchase expensive data with exclusive long-term (10 years or life of the vehicle) contracts, even for 4G and LTE speeds. 5G roll-out will help, but the business model and economics are not yet in place. Even though eSIM technology is ready, dominant mobile carriers have used the GSM standards process to block making SIMs interoperable. Auto OEMs must design one mobile carrier into the vehicle and build different models for different regions worldwide.

39 Source: Bloomberg
40 Source: Ford Authority

Lack of 5G and Satellite Network Infrastructure

With so much demand for 5G without autonomous vehicles, mobile carriers have no reason or incentive to make deals with automakers.

Satellite Internet is a good answer for Over-The-Air software updates, but not for real-time ADAS use because of longer latency and high cost. Satellites provide wide coverage but do not deal with everyday indoor obstacles such as parking garages. According to Iridium Communications CEO Matt Desch, “It’s a big race called Space 3.0. The last thing a car manufacturer really wants is to pick badly.”

Slow Consumer Acceptance of Vehicle Subscription

A viable Vehicle ISP Subscription/Advertising model is yet to emerge. For now, consumers have to rely on their smartphones and apps to do simple things that need data in the vehicle, such as content services (for example search for a charging station nearby).

4.2.3 Connected Vehicle Revenues for Automakers

Connected vehicle services will generate large amounts of revenue for automakers from commercial fleets and ADAS services. Consumers and automakers will also benefit from predictive maintenance and the ease of ordering parts and services when automakers have access to more data from vehicles. The infrastructure challenges will eventually be solved for fleet and ADAS needs with a combination of 5G and satellite network services.

Consumers will bring their mobile phones and home/office Internet connection subscriptions into the vehicle and use apps and devices to access infotainment features without paying for an additional monthly subscription.

For both ADAS and infotainment costs, the business model of paying for software and network may look different in vehicles than it does at home or office. Consumers seem more willing to pay $5,000 or $10,000 as part of the vehicle cost than pay a monthly subscription fee, although that may change over time.

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Notable M&A Transactions (2021 & 2022)

Acquiror	Target
Connected Vehicles	
nexar	VENIAM
Qualcomm	Arriver
Applied Intuition	
HYUNDAI	AirPlug
QUESTAR Driving Knowledge	SAFERIDE Vehicle Insights. AI Driven.
Connectivity	
Sensata Technologies	SMARTWITNESS
goPuff	rideOS
WAYMO	trustworthy ai
HARMAN	SAVARI
GENTEX CORPORATION	GUARDIAN optical technologies
Software and Connectivity Expertise	
STELLANTIS	MobileDrive
CACI	SA Photonics
JUNGHEINRICH	ARCULUS
knowit	swedspot
HEXAGON	IMMERSAL

Selected M&A Transactions (Connected Vehicles)

Month	Target	Acquiror	Target Business Description	Transaction Value ($M)	Revenue ($M)	EV/ Revenue
Jun 2022	EV Connect	Schneider Electric	Developer of a cloud-based software	-	$1.5	-
Jun 2022	HotSpot	IBI Group	Developer of parking payment application	-	-	-
May 2022	Numocity	ABB E-Mobility	Developer of EV charging stations	-	-	-
Apr 2022	Zeelo	Swvl	Operator of a B2B bus sharing platform	$100.0	$5.4	18.5x
Feb 2022	Drivably	ACV Auctions	Developer of AI-driven tools	-	-	-
Feb 2022	EGK	Carota	Developer of domestic car networking system	-	-	-
Jan 2022	Visionful	Cloudastructure	Developer of a monitoring and management system	-	-	-
Jan 2022	Greenplan	-	Developer of route planning software	-	-	-
Jan 2022	Innogy eMobility Solutions	Compleo Charging Solutions	Developer of a cloud-based eMobility platform	$62.4	$23.8	2.6x
Dec 2021	YOLOBus	EaseMyTrip	Developer of mobility platform	-	-	-

5.1 Autonomous and Shared Vehicles – State of the Market

Autonomous vehicle technologies and shared vehicle ecosystems are attracting significant pieces of auto tech investments. The two segments are very different in the timing of mass market adoption and therefore they attract different types of investors.

M&A and Funding by Sector in 2021-2022	Autonomous Hardware	Autonomous Software	Ride Hailing
Number of Deals	69	70	27
Private Equity	-	$2.92 Billion	$1.6 Billion
Venture Capital	$3.85 billion	$7.25 Billion	$5.2 Billion
Corp/Strategic M&A	$9.91 billion	$1.41 Billion	$773 Million
IPO	$309 million	$1.49 Billion	$4.44 Billion
Total Amount Raised	$13.3 billion	$13.07 Billion	$11.99 Billion
Total Capital Invested	$24 billion	$57.37 Billion	$171.36 Billion (*)

(*): Uber and Lyft funding and IPOs occurred in 2016 and 2019.

Top luxury brands such as Tesla, Mercedes Benz, BMW, Audi, and Cadillac are introducing new autonomous technologies in luxury cars. The autonomous car’s target customers are high-end buyers who are paying extra for safety and convenience. The automakers see these as long-term investments in their core customers to protect market share. Even if there are very high levels of investments needed and no return for the next five years, the large market opportunity justifies the investment by luxury car makers.

Other than luxury car makers, investments in autonomous hardware and software have come from venture capital funds investing in startups that will supply the technology for autonomous and ADAS use cases.

Shared vehicle services offer investors an immediate mass market, ready cash flow, and profits. With the financial benefit of not owning a vehicle and being able to move a large upfront cost to very small on-demand payments, shared vehicle services are a very scalable business. As a result, the shared mobility sector attracts late-stage venture capital and private equity funds, SPACs and IPOs.

The number one ride-hailing company Uber reported 6.3 billion trips, gross bookings of $90 billion and revenues of $17.4 billion in 2021, its eleventh full year of existence.

Autonomous technologies and shared mobility reinforce each other – they are related in ways that impact the patterns of use. While autonomous vehicles have the disadvantage of increased cost for consumers, shared vehicles have higher utilization, so can justify higher one-time acquisition costs. It is easy to see that shared mobility can subsidize the higher costs associated with autonomous technologies that are significant.

> *"The increasing penetration of autonomous vehicles will have a very positive impact on sharing concepts"*
>
> *"Urban areas are destined to see the widespread proliferation of shared and electric vehicles."*
>
> *Source: PwC report on Auto Industry Trends*

5.2 Levels of Autonomy[41]

The Society of Automotive Engineers (SAE) defines six Vehicle Automation Levels as:

0	1	2	3	4	5
No Automation	**Driver Assistance**	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Zero autonomy, the driver performa all driving test	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times	Driver is a necessity, but it is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

41 Source: PwC report on Auto Industry Trends

5.3 Adoption of Autonomous Vehicles – 2022 Snapshot

We are in the early stages (Level 2) of automation of the driving function with a lot of innovation that is yet to reach the public in the coming years. Currently, a handful of Autonomous Level 2 systems are being sold with luxury vehicles at a cost of between $2,500 and $12,000 as self-driving options.

At Autonomous Driving Assistance Systems (ADAS) Level 2, the vehicle can control both steering and accelerating/decelerating. Level 2 systems provide support in areas such as speed and distance control, steering and lane changes. The automation is not self-driving because a human sits in the driver's seat and can take control of the car at any time.

In December 2021, Mercedes-Benz was the first automotive manufacturer worldwide to secure internationally valid system approval for conditionally automated driving (SAE Level 3). In May 2022, Mercedes started taking orders for Drive Pilot Autonomous First “Drive”.

Commercial ADAS Products in 2022	Autonomous Driving Level	Cost
Tesla Enhanced AutoPilot	Level 2	$6,000
Tesla Full Self Driving	Level 2	$12,000
Cadillac (GM) Super Cruise	Level 2	$2,500
Mercedes Benz Distronic	Level 2	$2,600
Mercedes Benz (S-Class and EQS) Drive Pilot	Level 3	$10,500

BMW, Audi, Lexus, Toyota, Honda and Ford are also providing and working on self-driving features in their high-end cars.

Witnessing a Waymo vehicle on the road with no driver or seeing a driver in the next lane reading a newspaper while sipping coffee will certainly get your attention, but many practical and economic considerations will drive the adoption of Autonomous technologies in the next five to ten years.

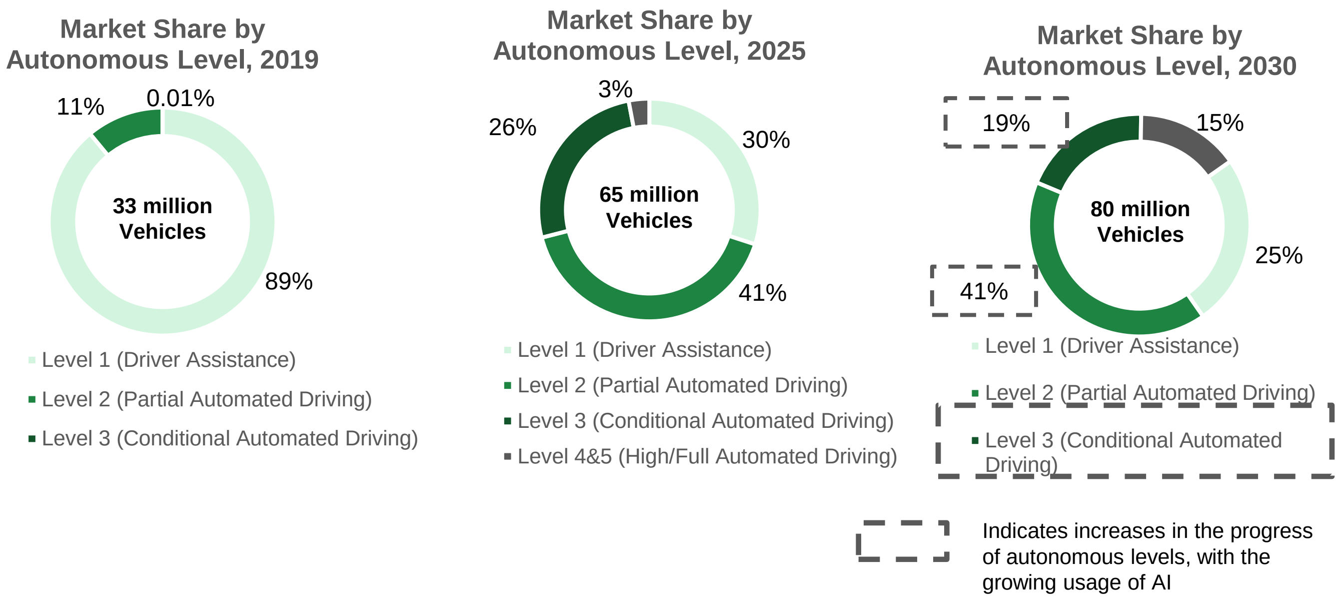
In addition to the significant technical challenges, there are many factors that will slow the pace of adoption of Level 3, 4, and 5 Autonomous driving, including vehicle and infrastructure costs, inertia in changing people’s habits, state of standards and regulation, insurance, and liability.

5.4 Autonomous Technologies in Trucks

Compared to passenger vehicles, Autonomous technologies will be adopted quicker in Trucks because these commercial applications have fewer technological challenges as they operate in more controlled environments. A truck going between a factory and a warehouse can employ Level 4 and Level 5 Autonomy levels much easier than a passenger car downtown with people walking around and biking nearby.

In addition, the benefits of adopting Autonomy for Trucks are bigger because of the large distances and the corresponding use of fossil fuels.

Projected Timeline of Autonomous Levels 1 to 5[42]



In this report, we do not take a deep dive into autonomous technologies but focus primarily on investments and M&A activity since 2021. Past research reports from Woodside Capital Partners on Autonomy and related topics include:

- Computer Vision Report (May 2016)
- Beyond the Headlights: ADAS and Autonomous Sensing (September 2016)
- The Automotive LIDAR Market (April 2018)
- Autonomous Vehicles (November 2018).

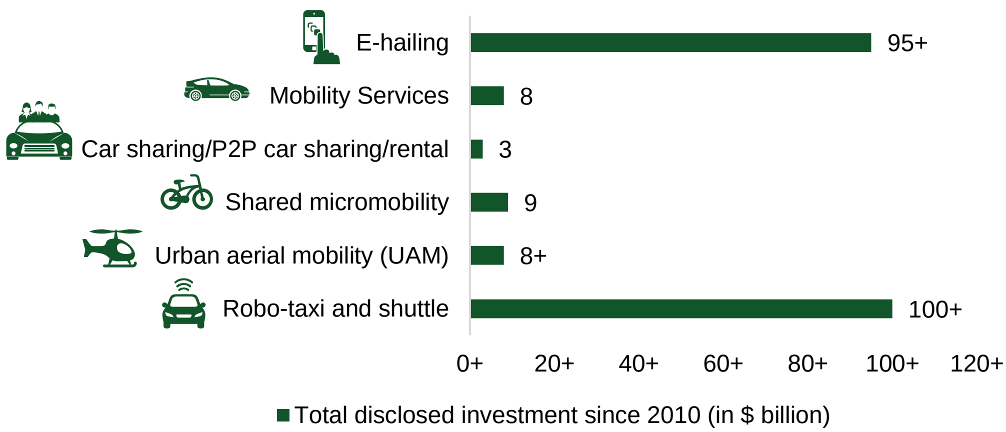
42 Source: FutureBridge Analysis and Insights

5.5 Shared Vehicles Services

More than $100 Billion has been invested in non-autonomous shared-mobility companies, mainly by venture capital and private equity players. Following the success of Uber and Lyft in the US, similar companies in China (Didi), India (Ola), Indonesia (Gojek), and Grab (South-East Asia) have all reached valuations from $5 Billion to $30 Billion.

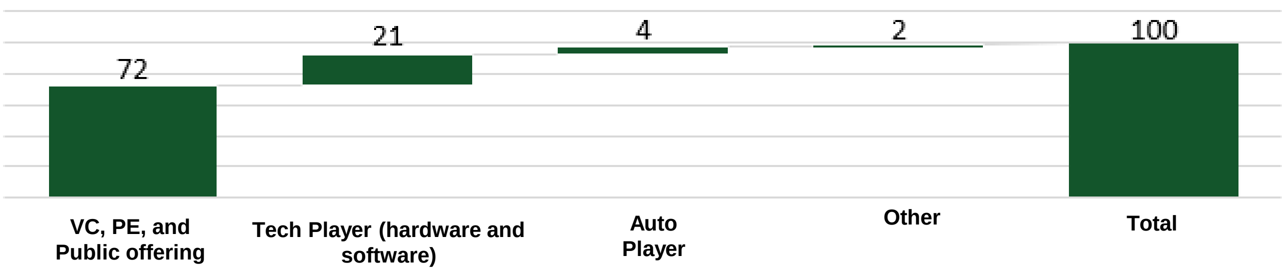
Ride-hailing companies are using their strong market positions and cash from IPOs to expand into Last Mile Delivery and Logistics pushing their growth rates and valuations even higher.

Total Disclosed Investment Since 2010 (in $ billion)



Number of companies
109
97
116
120
50+
400+

Total Disclosed Investment Amount Since 2010 by Investor Type. Percent of Total[3]



Total Disclosed investment amount since 2010 by investor type. Percent of total[3]

1. Total Disclosed investment amount since 2010 by investor type. Percent of total[3]
2. Includes ride-pooling, mobility-as-a-service players, etc.
3. Figures may not sum to 100%, because of rounding.
4. Venture Capital: Private Equity.

5.6 Autonomous Vehicles have a Positive Impact on Shared Mobility

If we combine the two trends of shared and autonomous, we get four types of mobility:

1) private/personal and self-driven
2) shared and self-driven
3) private/personal and autonomous
4) shared and autonomous.

The most popular kind of transport today is the private self-driven car. However, as we noted above, the shared and self-driven mobility segment is growing rapidly and has attracted large amounts of investments and M&A activity.

With the intersection of Autonomous and Shared Vehicles trends, the overall stock of autos on the road can decline while the overall passenger miles are still going up.

An autonomous vehicle at the airport or train station, an eBike, or a 3-wheeler downtown can work on-demand 24 hours a day and cover a lot of passenger miles. As the proportion of shared mileage increases, vehicle mileage will be a lot higher than personal mileage because of the pooling effect. Fortunately for automakers, vehicles will need to be replaced faster so new vehicle sales will be slower to be affected than the overall stock of vehicles.

In addition to personal mobility, shared vehicles are also used in public mobility and micro mobility.

Adoption of EVs in Ride Hailing Fleets, Rental Cars and Taxis

Despite the significant energy and maintenance savings potential of EVs, the adoption of EVs in Ride-hailing fleets has been slow due to the high initial cost of EVs. Ride-hailing services, similar to rental cars and taxis also need long range per charge, seat capacity, large trunk space, and minimum downtime while charging.

With all the challenges listed above, the EV adoption rate among ride-hailing services is under 1%. Ride-hailing companies typically have limited influence on the purchase of vehicles by drivers.

On the positive side, ride-hailing services, rental cars, and taxis have a much higher utilization rate so the impact on air pollution is much higher than on private vehicles. Consumer preference for EVs along with subsidies from governments, congested cities with high pollution, and ride-hailing companies will certainly lead to a higher adoption rate of EVs over time.

Investments in Shared Vehicle Services in 2021 and 2022

Financing	Amount Invested (in $M)	Number of Deals 2021 and 2022
Ride Hailing	10,671	92
Car Sharing	727	33
Bike and eScooter Sharing	1,023	24
Micromobility	2,210	36

Selected M&A Transactions (Ride Sharing)

Month	Target	Acquiror	Target Business Description	Transaction Value ($M)	Revenue ($M)	EV/ Revenue
Jul 2022	Urbvan	Swvl	Developer of a daily commute smart transportation system	$82.0	-	-
May 2022	Citymobil	People&People	Operator of an online cab booking portal	-	-	-
Apr 2022	Zeelo	Swvl	Operator of a B2B bus sharing platform	$100.0	$5.4	18.5x
Apr 2022	Viapool	Swvl	Developer of a private transport platform	$100.0	$4.5	22.2x
Mar 2022	Holmi	Taxi 31300	Operator of an online platform	-	-	-
Mar 2022	Car Club	Tribecar	Developer of a car-sharing platform	-	-	-
Mar 2022	Spin	TIER	Provider of dock less mobility systems	-	-	-
Nov 2021	Taxifirst	Take Me	Provider of taxi services	-	-	-
Oct 2021	Moov Digital Transportation Solutions	Getir	Developer of flexible ride-sharing platform	$23.0	-	-
Oct 2021	BlueSG	Goldbell Group	Provider of an online ride renting service	$18.5	$3.9	4.7x

6. Response from Incumbent OEMs and the Path Forward

To understand the path forward for the new automotive world, it is very useful to note the response from the incumbent automakers in the US, the EU, and Japan to three major changes – the success of Tesla, China's lead in EV adoption, and the entry of Google, Apple, Amazon, and Uber into parts of the auto industry. Incumbent automakers need to adapt to these changes which play to their weaknesses. They must move from a world of five-to-seven-year product design cycles, vertically integrated supply chains, and unionized factories to a new world of cars getting over-the-air software updates from the cloud and adding new features.

The year 2022 can be called the year of "Incumbent Automakers Meet Silicon Valley, China, and Big Tech" or "The Old Auto World Meet the New Auto World." It is the year when GM and Ford finally became serious about EVs, partially because the US government brought back subsidies and California announced a ban on fossil fuel vehicle sales from 2035. Even Toyota and Honda had to change direction in 2022, announcing massive new investments in batteries and accelerating EV plans.

1. Tesla's Success. The first shock for the incumbent automakers has been the stunning success of Tesla over the last five years. In 2021, Tesla had over 70% market share of the EV market in the US, with around $27 billion in sales. It is safe to say that the first response from the leading automakers in the US was to ignore Tesla and the EV segment. In the US, there have been a very small number of EV models available for consumers, and even those relying partly on subsidies and tax incentives.

2. Emergence of China. When the auto industry and the government in the US have been slow to move on electrification, China has taken a big lead in EV sales (especially mass-market EVs), EV batteries, and charging infrastructure, allowing several Chinese automakers to become major players in the global EV market. The China EV market in 2021 was more than three times larger than the US - worth $124 billion (source: Mordor Intelligence[43]); the top five EV makers in China were Tesla and four domestic companies: BYD, SGMW (SAIC-GM-Wuling), Chery, and GAC.

3. Entry of Big Tech into the Auto Industry. The change toward software-defined vehicles requires the incumbent automakers to bring in new technology suppliers and access new capabilities like software development and cloud deployment, which are not their traditional strengths. As the software and electronics content of automobiles goes up from less than 5% to more than 50%, their share of vehicle sales and ongoing revenues will decrease. Consumers in 2022 care as much about the user experience, data, digital cockpit, entertainment, and content services as they do about horsepower. Companies like Google and Apple (and even Facebook/Meta) are competing with their browsers, voice assistants, and content services to enter the auto industry value chain.

43 Source: Mordor Intelligence

6. Response from Incumbent OEMs and the Path Forward

Traditionally, most automakers did not have sufficient software and cloud skills to adapt to the new EV world. In addition to going through The Big Disruption, they must compete with the new breed of pure-EV competitors starting with Tesla. We note three kinds of responses from incumbent automakers to their urgent need to incorporate software:

1. Building software engineering capabilities and teams
2. Partnering with software, semiconductor companies and service providers
3. Making strategic acquisitions of companies with automotive software IP and expertise.

6.1 Building Software Engineering Capabilities and Teams

Some OEMs, most notably Volkswagen and Toyota, have invested heavily in building software engineering teams and expertise. Just a few months before filing for its IPO, Porsche announced the removal of its CEO Herbert Diess whose master plan for beating Tesla was to hire 10,000 software engineers (source: Bloomberg). According to Reuters: "Diess' ousting was also linked to his troubles leading the carmaker's software unit Cariad, a source with knowledge of the matter said, set up on his watch but far exceeding its budget and years behind on goals to launch a new software platform." In his farewell dinner speech, Diess stated: "Where we are struggling through," Diess said, "that will be the same for everybody else." (source: Automotive News Europe[44])

The recruiting environment for automakers is not favorable because they must compete with other industries (for example financial services) that are also going through digital transformation. The more modern software stack at many companies from Amazon and Facebook to Tesla makes them much more attractive to software engineers, compared to older, more legacy software and waterfall methodologies at automakers. The five to seven-year design cycle at a traditional automaker cannot compare with DevOps environment at Facebook which allows a new release several times a week. While an automaker is changing components in each vehicle, Tesla can fix problems and deliver new features with Over-The-Air software updates from the cloud.

To understand the recruiting challenges that automakers are facing and how they are responding, we spoke to Richard Surridge, Managing Director of AVANT, a global mobility talent acquisition based in Southampton, UK for this report. AVANT is helping its clients fill Vehicle Engineering, e-Powertrain, and ADAS jobs.

44 Source: Automotive News Europe

On Engineering Recruiting by Automotive OEMs

By Richard Surridge, Managing Director, AVANT[45], a Mobility Talent Acquisition company

Automotive companies have long sought the panacea of hiring engineering talent with 5-10 years of experience within one very specific component or system, and this has always been a challenge. However, this skills shortage has not prevented automotive OEMs from launching new technology because the components and systems have remained unchanged for 100 years. The skills existed already; you just had to attract new talent and retrain existing staff within one of the four traditional pillars of mechanical, structural, electrical or electronic engineering).

But what happens when an industry faces such fundamental change that the needed skills simply didn't exist 5 years ago or don't exist today? The automotive industry, or as it is becoming referred to – the future of mobility, needs software engineers, scientists, and chemical engineers – in the thousands.

Software engineers are needed for the rapidly increasing prevalence of sensors and semiconductors required to deliver both ADAS and full self-driving capability, all the advancements in AI, ML/CV which come with it – and the effort required to move data processing to the edge. Silicon Valley is now at the forefront of advancements in autonomous driving technology. As vehicles transition to an internet-enabled, e-commerce platform on wheels, with the ability to digitally communicate with 'everything' (V2X), the number of semiconductors and embedded software required rises exponentially.

The automotive industry is also changing the vehicle's propulsion system. Scientists and engineers are needed to develop electric powertrains, in the form of either batteries or hydrogen fuel cells, to replace the internal combustion engine, a system engineered over the last 100 years. And to run the Gigafactories to manufacture (battery) cells and assemble packs and modules. In many cases, the industry is trying to attract skills that simply don't exist within a traditional automotive environment.

Consequently, OEMs must open new technical centers away from their traditional vehicle engineering heartland to attract talent with specific 'future mobility' focused skill sets. It's more prudent to hire talent from software-led, tangential industries with an 'agile' approach (gaming, AI/ML, computer vision, semiconductor, big data, social media) than it is to retrain an existing workforce to learn and undertake complex software engineering challenges associated with autonomous driving and vehicle connectivity.

Global OEMs are establishing US west-coast tech centers to take advantage of existing skills from transferrable industries for software-focused development, or in the specific example of JLR, creating software tech centers in Manchester (UK), the Republic of Ireland, and the US (Portland). Indeed, in some instances, OEMs have recognized the best way to expediently develop software-led EVs is the creation of entirely new companies, unencumbered by the legacy business. For example:

- VW created CARIAD to develop all aspects of Group-wide software, including a VW OS
- Toyota's subsidiary Woven Planet is tasked with creating a proprietary Toyota OS
- Ford has split its business in two, with Ford Blue focused on legacy ICE vehicles, whereas Ford Model E is tasked with developing EVs.

45 Source: LinkedIn

6.2 Partnering with Software, Semiconductor Companies

Automakers are partnering with software companies from Blackberry, NVIDIA, Red Hat, to Synopsys; and semiconductor companies such as Marvell, ST Micro, and Intel.

The biggest automakers will build their own software and cloud capabilities, but many automakers will have to use off-the-shelf software and solutions for reasons including cost, compatibility with industry standards, and because they cannot invest in R&D in certain areas.

There is some likelihood that new major suppliers of automotive operating systems will emerge, like iOS and Android. Apple and Google (not including Waymo) are heavily engaged in R&D in software to be designed into cars, but they are staying away from safety and autonomy features, focusing only on infotainment. Several companies such as Apex.ai are working on an operating system for software-defined vehicles.

Red Hat, now part of IBM, is notable for its open-source offerings because automakers do not want to be locked into platforms that they do not own or control.

We interviewed Francis Chow, Vice President and General Manager of In-Vehicle OS and Edge at Red Hat (IBM) for this report. Mukesh Ahuja, George Jones, and Sri Purisai conducted the interview with Francis to talk about Linux, Vehicle OS, and the role of open source in software development for the automotive industry. Below are the excerpts from the interview.

The Role of Linux and Open Source in the Auto Industry

Interview with Francis Chow, VP and GM of In-Vehicle OS and Edge at Red Hat (IBM)

Sri: Please tell us about your role at Red Hat.

Francis: I am responsible for the Edge business at Red Hat. Within that umbrella, we are building a new Linux-based in-vehicle operating system for the automotive industry, along with modernized toolchains, to help accelerate the automotive industry's transformation.

George: How do Red Hat position itself and Linux for the auto industry?

Francis: What is happening in the auto industry is analogous to what happened to data centers in the early 2000s and telcos in the early 2010s. All these industries have moved, or are moving from a purpose-built, vertically integrated system approach to a scalable, horizontal platform approach. Data centers adopted Linux and open source. And today, open source is foundational to e-commerce, social media, video, and many other services. We are seeing telcos adopting open-source platforms.

Automakers have the opportunity to leverage open source to drive faster innovation and reduce time-to-market and development costs. We have a history and track record of supporting mission-critical applications for long life cycles, and we want to enable automakers to build software platforms using Linux and open-source methodologies, which would allow them to focus on delivering inventive new features and value-added services to consumers.

Vehicle OS

Mukesh: Where are we with Vehicle OS and the most significant software applications in the vehicle?

Francis: Today most cars use proprietary operating systems. One of the reasons is that there has been no Linux distribution certified for functional safety, which is the ISO 26262 standard. There are 4 safety levels - ASIL (Automotive Safety Integrity Level) A, B, C, and D, D being the highest. Our current plan is to certify our in-vehicle operating system to ASIL-B, which would be adequate for most of the complex software applications in the vehicle, including advanced driver assistance systems (ADAS), infotainment, digital cockpit, body control, and connectivity.

Assisted driving or autonomous driving would be one of the key software applications in software-defined vehicles. I think the timing of true Autonomous Vehicles levels 4 and 5 is not soon. There are a lot of legal and ethics issues to be sorted out. Our OS can support automakers for their overall safety concept supporting up to level 3 which would be the bulk of the market near term.

Then comes **Infotainment**, including Digital Cockpit which connects to the personal ecosystem - phone, home, TV. Young people are pushing the industry in this direction. My favorite example is kids watching a movie: as they started the movie from the house, it should be seamless for them to continue watching in the car. The technologies to support this are all here today. I can see that a marketplace for apps for cars could thrive.

George: After infotainment, what is next in line?

Francis: The industry is working on connectivity and how data is drawn from the car and used externally. Estimates are that 15 Terabytes of data can be generated per car per day. You can take data out, but the data is not structured and it's very large in size. Many innovations will come related to what you take from the car and what you don't, and how best to utilize the data to enhance safety and support new use cases.

Cameras and sensors generate a lot of data and in the next decade companies will figure out how to monetize all this. For example, driver monitoring data can help arbitrage who is responsible for accidents. Car makers can also sell the data to insurance companies to better optimize premiums. Data can also be used for predictive maintenance.

Sri: Who will own the Vehicle OS?

Francis: I assume you are referring to the software stack, not just the Linux operating system here. Some OEMs are going to do their own. Some will continue to leverage the current ecosystem and their tier-1 suppliers. Some will partner with new entrants like Red Hat or Google to build out the technology. Some might choose not to cede control of their data to companies like Apple or Google.

But many automakers tried to develop their own OS and stacks and failed. It is a very complex effort that requires diverse expertise and skills on each layer of the technology stack.

George: Will Google come out with its own OS? Or on top of Red Hat?

Francis: Android Automotive OS is already in the market today. There are a couple of architectural options on how Google and Red Hat can work together to address different use cases and challenges. We can sit side by side on hypervisors to support different applications, or Android can also run on top of our OS to support their application services. Our value-add is safety certification which allows both safety and non-safety applications to be run on the same host OS.

Connectivity and Vehicle Subscription

George: Who will get the Connectivity and Vehicle Subscription revenue?

Francis: The traditional model will likely change. I think vehicles could become platforms and automakers can develop applications that run on the platform themselves, or rely on automotive ISVs to create these apps, or both. Over time, the APIs will be well-defined, some standardization will occur, which will be followed by faster innovation. Companies will be able to develop once and sell to many automakers. The subscription revenue could be shared between the platform owners and the app developers in some fashion.

Sri: It looks like most OEMs will not build 5G into the cars but will sell after-market and then see how the market develops. Like with Apple CarPlay, you instantly have 5G. What other apps can be deployed?

Francis: Certainly, V2X and autonomous driving are on the list.

George: How much time is devoted to internal vs external communication and architecture? Will we see Kubernetes in cars?

Francis: We are focusing on how to enable this paradigm change. We will not prescribe networking specs or connectivity standards, but provide the software infrastructure, toolchains, and tool flow to support these over time.

Kubernetes is designed for clusters of servers with dynamic workloads and unknown apps. In a car, you should know for the most part what is going to run on them. Yes, you do want containers, but not Kubernetes necessarily - full Kubernetes orchestration is too heavyweight. We have technologies that support lightweight container runtimes, in addition to lightweight Kubernetes, designed for certain future non-timing critical workloads that can run distributedly from the cloud to the edge to the cars.

Why Open Source and Why Linux

George: Why would Automakers and Tier 1 suppliers use open source now?

Francis: First, there is so much innovation you can leverage with open source. 28,000 people contributed to open source projects last year, and few companies have that many engineers. The industry is starting to understand how open source can help them. Second, it avoids the fear of being locked in. With open source, you won't be locked in due to some proprietary interfaces. And for us, we won't be competing on the upper layer stacks or trying to monetize the vehicle data.

Software talent is an issue. Some automakers are kicking the tires on open source because they cannot hire enough good software developers without it. The amount of talent you can find in open ecosystems is 10x to 100 times more than proprietary ecosystems. Red Hat's goal is to provide not only support for open source based products, but also to help automakers transform the way they design software with open source.

At many traditional car makers, most subsystem design is bespoke, with limited reuse across models or generations. Typical software compilation flow is compile-from-source and takes hours to iterate and debug one issue. An open source Linux platform with modernized toolchains allows for easy design reuse, and can dramatically reduce development time and cost. For instance, you can fix a bug and recompile in minutes. When you cut your development time, it does translate into significant cost savings.

As OEMs navigate the architectural change from 100s of ECUs to a few, say 3 to 5 high performance compute platforms, they must deal with development cost, availability of talent, and time to market. Red Hat is proud to collaborate with GM to help them address these challenges. You can watch a YouTube video on the collaboration here.

Mukesh: Who is the likely leader with an **Autonomous Driving** software platform?

Francis: No clear leader has emerged. We are going to see a lot of innovation in this space and there will be consolidation over time. What I am quite sure is that open source will play a role in this.

George: How does Red Hat enable safety certification?

Francis: Our current target is ISO 26262 ASIL-B. We believe this would allow us to address the most complex applications and add the most value. Systems like anti-lock brakes and airbags are ASIL-D and they are better served in small, purpose-built subsystems. We are working closely with our partner Exida on the safety certification. We are also pioneering a new approach called Continuous Safety Certification. The idea is that we can incorporate safety artifacts in our CICD flow and make subsequent re-certification much faster compared to traditional approaches.

6.3 Making Strategic Acquisitions for Software IP and Expertise

Several automotive companies have made acquisitions with the goal of acquiring software and domain expertise in new areas of innovation. Below we include some examples of acquisitions made by automakers in the Connectivity, Autonomous and Shared Vehicles.

Notable Software and Connectivity Expertise Transactions

Acquirer	Target
Stellantis	Mobile Drive
CACI International	SA Photonics
Jungheinrich	arculus
Knowit	Swedspot
Hexagon	Immersal

Notable Autonomous and Shared Vehicles Expertise Transactions

Acquirer	Target
Robert Bosch	Five (Automotive)
Waymo	RobotWits
Harman International	Apostera
Xiaomi	DeepMotion China
WeRide	MoonX (China)
CARIAD (Volkswagen)	Hella Aglaia Mobile Vision
Nuro	Ike Robotics
Magna International	Optimus Ride

Glossary[46]

ACES Autonomous driving, connected vehicles, electrification of the powertrain, shared mobility
AD Autonomous driving
ADAS Advanced driver assistance systems
ASP Average selling price
AV Autonomous vehicle
BEV Battery electric vehicle
BJB Battery junction box
BMS Battery management system
CAGR Compound annual growth rate
CMC Cell management controller
DC/DC Direct current to direct current
DCU Domain control unit
E/E Electrical and electronic
ECU Electronic control unit
EMS Electronics manufacturing services
EV Electric vehicle
HEV Hybrid electric vehicle
HV High voltage
HW Hardware
ICE Internal combustion engine
I/O Input/output
LiDAR Light detection and ranging
LV Low voltage
MCFM McKinsey Center for Future Mobility
OEM Original equipment manufacturer
OS Operating system
PHEV Plug-in hybrid electric vehicle
SOP Start of production
SW Software
VCU Vehicle Control Unit

46 Source: McKinsey

References

PitchBook. (n.d.). *Venture Capital, Private Equity and M&A Database*. Retrieved September 30, 2022, from https://pitchbook.com