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Digital Auto Report 2020

Navigating through a post-pandemic world

This publication has been developed in collaboration between Strategy&, PwC's global strategy consulting business, alongside PwC industry and function experts. Together, we transform organizations by developing actionable strategies that deliver results.

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Digital Auto Report 2020

- ✓ Ninth annual Digital Auto Report, developed by Strategy& and PwC
- ✓ Global consumer survey with a focus on the US, EU and Asia (n = 3,000)
- ✓ Quantitative market outlook until 2035 based on regional structural analysis
- ✓ Interviews and survey with >60 industry executives at OEMs and suppliers, leading academics and industry analysts

Volume 1

Anticipating post-pandemic market dynamics

- Market outlook – penetration of technologies and mobility types
- Technology – shifting gears in connected, electric, automated
- Customers – changing mobility preferences: shared no more?
- Regulation – slowdown or acceleration of key policies?

Volume 2

Rethinking business models and investments

- New business opportunities – hype or reality?
- Economic value – market growth and unit economics
- Investment strategy – OEMs vs. VCs vs. Tech players
- OEM survival guide for a post-crisis market reality

Volume 3

Building a software-enabled automotive company

- Software development cost forecast
- Make, buy, partner strategy decisions
- Organization and culture transformation areas

The mobility ecosystem is transforming into a fragmented future w/different adoption patterns and use cases by region

Executive summary – Volume 1

- With adjusted technology expectations and changing post-pandemic customer preferences, CASE evolves. **Consumers do not expect** fully **automated cars before early 2030s**. **Shared mobility growth is slowing down,** relevance of seamless mobility remains high
- Total **vehicle parc expected to shrink in Europe** (-0.5% p.a.) while **growing in the US** (+1.1% p.a.) **and China** (+3.9% p.a.) until 2035, driven by 1) mobility growth (highest in China), 2) customer preferences for sharing (lowest in US) and 3) vehicle disposal rate
- **Regulatory requirements** are driving **basic connectivity** in **EU** and **US** (>85% penetration of new cars in 2020), while **China is still at 44%**. **Total connected vehicle parc will pass 50% mark in Europe by 2025**; in US as early as 2023 and in China latest by 2029
- **EU and China are leading the e-mobility transformation** with expected new car **BEV share of 17% and 19% by 2025**. **US significantly lower with 5% by 2025** given fewer government incentives and attractive ICE alternative in terms of TCO
- **Automated driving** will emerge in a broad spectrum of use cases with specific requirements that are difficult to scale. While e.g. L4 pilot projects with people movers are running today, **L4 share** of new vehicles is expected to reach **17% by 2035 in EU** (vs. 16% in China)
- Shifts in individual **mobility patterns require a new segmentation** in terms of **private vs. shared** and **active vs. passive driving** – each with multiple use cases at different automation levels. **Shared-active** (e.g. rental, subscription) expected to grow strongest **in EU** (10% of total person kilometers by 2025), while **shared-passive** (e.g. ride-hailing) is expected to grow **significantly more in China** (10% vs. 1-3% in US and EU)
- The **increasing proliferation of use cases and business models** requires many players to **re-evaluate their CASE strategies** with a fact-based view on available technology, value pool sizes and unit economics as well as investment requirements and right to win (→ covered in our next report volume No 2)

Note: Please refer to respective section for detailed assumptions and sources behind stated propositions

Capturing CASE value opportunities requires refocused investment strategy aligned with player's core capabilities

Executive summary – Volume 2

- Expected **market potential of CASE use cases varies** according to our survey of 60+ industry experts in Europe, the US and China:
  - **Connected**: Behind first peak of expectations with **most value expected** in **B2B applications** (e.g. fleet management)
  - **Electric**: While BEV use cases are approaching plateau stage, **fuel cell not yet at peak**
  - **Automated**: **Higher value** expectations **in L4 goods transport** than in private passenger transport
  - **Smart mobility**: **Micro-mobility** with **high value expectation** – on par with ride hailing; view on air taxis not yet converging
- A plethora of well-funded startups are trying to capture this market potential and are putting traditional automotive players under pressure in connected, electric and automated driving. For OEMs and suppliers, specific vehicle-centric business models are the most promising despite strong competition
  - **Connected**: Vehicle-centric and beyond-vehicle B2C services expected to **grow from $8bn to $66bn** in EU/US/China **by 2035**
  - **Electric**: Battery and powertrain market for OEMs expected to **grow from $47bn to $568bn by 2035** – led by China (~$314bn) and EU (~$210bn)
  - **Automated**: ADAS parts market for OEMs (L1-L5) expected to **grow from $22bn to $142bn by 2035** – with China overtaking EU/US in 2030
- Looking at smart mobility, **the line continues to blur between traditional car sales/leasing and alternative ownership** with rental/subscription/ sharing/hailing/on-demand. **Cost per kilometer** ranges between **$0.7 (subscription) and $2.1 (ride hailing) vs. $0.6 (own car)**
- The **market for alternative car ownership** models (subscription, rental, sharing, ride hailing, on-demand) is expected to **grow from $255bn to $1.084bn** in EU/US/China by 2035 – led by Europe with $549bn vs. China $362bn, due to higher consumer prices in mobility and value captured per km in EU
- The pandemic has widened the investment gap between OEMs and VCs and technology players. CASE investments of **Top10 OEMs went from 47 to 16 transactions** in Q1/2 '20 vs. previous year, while **VC invest grew from 36 to 66 transactions** and Top10 **Tech players remained flat** (12 to 11)
- To compete in the long run in this dynamic mobility market, **OEMs need to refocus their investment priorities along specific ways to play** as well as **strengthen their digital capabilities** and technology platform in a well-balanced **build vs. partnership approach** (see Volume 3)

Note: Please refer to respective section for detailed assumptions and sources behind stated propositions

Becoming a software-enabled automotive company will be key to continue capturing value in a transforming market

Executive summary – Volume 3

- **Increased demand** for intelligent and connected functionalities **will significantly change** the Automotive **product** and related **services**
- Software has become the **differentiating factor** for modern vehicles. Software development **cost will almost double –** growing on average **from €181m to €331m per model series** over the next 10 years
- **Autonomous driving functions** will be the **main cost driver** with **45%** of **total software development cost** by 2030
- With a growing spectrum of software components and functions, **innovation leadership** will **not be possible** in all areas. OEMs and suppliers need to carefully **select areas of own value creation**
- **Partnerships** with competitors, suppliers and technology players on an equal footing can **help to master complexity**, the need for talent and to **reduce expenditure by 35-60% per project**
- **Transformation** of mindset from **strategy to decision making** is needed across the company to **adapt to the new paradigm** and to build successful software-enabled products

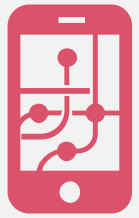
Note: Please refer to respective section for detailed assumptions and sources behind stated propositions

“

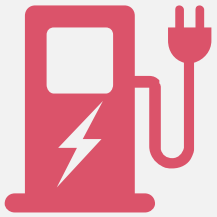
With adjusted technology expectations and changing post-pandemic customer preferences, CASE evolves”

S for Shared becomes Smart (Mobility)*

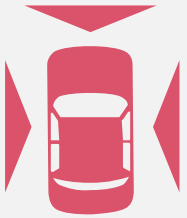
*Smart Mobility describes a transportation ecosystem where stakeholders use data and connectivity to move people and goods sustainably and efficiently.
Shared mobility remains as a sub-segment and an important value pool in this ecosystem focusing on people transport with passenger vehicles.



Connected



Electric



Automated

Smart Mobility

Source: Strategy&

Triggered by the effects of the COVID-19 pandemic, many players will have to reevaluate their CASE strategies

Consumer

COVID-19 postpones consumer spend during lock-downs. Demand recovery expected with preference for EV

Technology

COVID-19 shatters old industries and will lead to market shakeout. Digital and remote tech is on the rise

Regulation

COVID-19 imposes new norms for work environments, consumer interactions and international trade

Economics

COVID-19 cuts topline, accelerating saving needs of OEMs and suppliers as liquidity becomes critical to survive

Connected

COVID-19 digitizes society and increases acceptance and demand for digital – and connected – services

Automated

COVID-19 modifies competition: Big Tech benefits, asset-heavy OEMs struggle to keep up required R&D invest

Smart mobility

COVID-19 reverses preference for mobility modes – own vehicles regain preference against shared

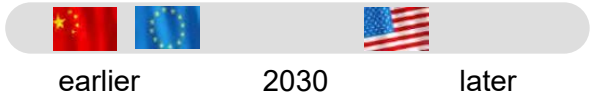
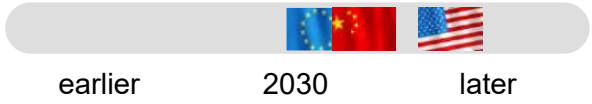
Electric

COVID-19 cools down economies, leads governments to subsidize EVs and increases EV market demand

Source: Strategy&

The acceleration of technology penetration will occur at varying times and speeds globally, as local mobility transforms

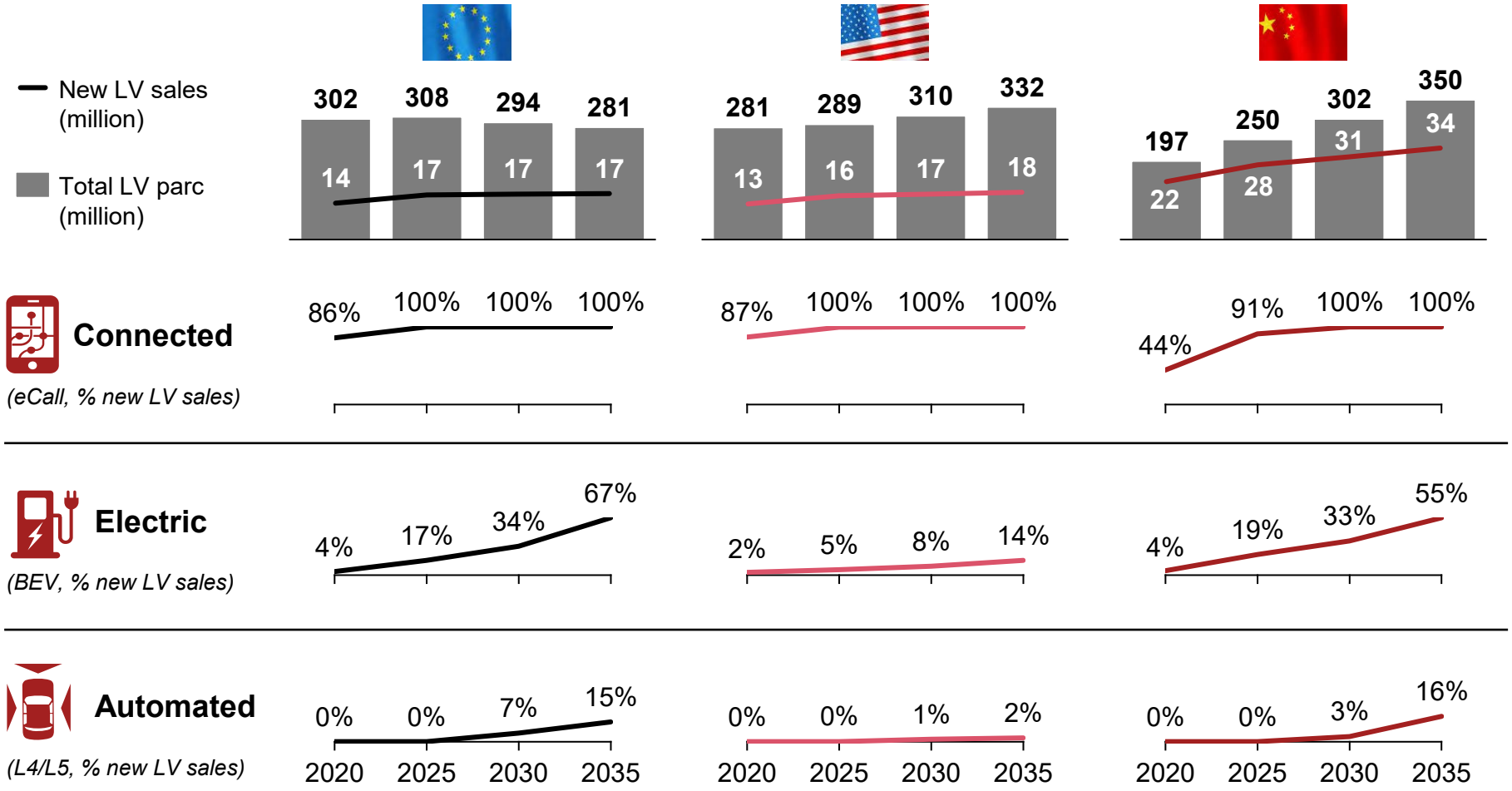
Key considerations to anticipate tipping point of exponential technology adoption

	Technology	Consumer	Regulation	Economics	*Expected tipping points*
Connected	• Connected service **content and UX** • Vehicle **system/EE architecture** • **Network infrastructure**	• **"Digitally savvy" share** of population • **"Freemium" segment** services	• Scope and timing of enforced **connectivity requirements** • Scope of **data privacy restrictions**	• **Indirect value capture** by OEM • **Effective end consumer pricing**	
Electric	• **Battery and powertrain performance** • EV **manufacturability and production capacity** • Charging infrastructure	• **Premium/early adopter** segment size • "**Rational green**" segment size	• **Emission target levels** • **BEV/PHEV incentives** • **Diesel/ICE bans/restrictions** in cities	• Superior **total cost of ownership** (TCO) of BEV vs. ICE in relevant number of segments • **Additional revenues/savings** from V2G/V2X charging	
Automated	• **ADAS** capability by use case • **Data processing** • **Driver UI** • **Network and traffic infrastructure**	• **Premium/early adopter segment** size • **Technology openness**	• Scope and timing of **enforced ADAS safety features** • Geographic **range and quantity of AV test drive/ vehicle approvals**	• **Superior TCO vs. non-AV** in first commercial cases • **Additional value capture** from riders	
Smart Mobility	• **Smartphone penetration** • **Access and fleet availability**	• **Intermodal openness** • People/**traffic density** "**Frequent** user" segment size	• **Private car restrictions**/ taxes • Passenger **transport regulation**	• **Superior TCO** vs. own vehicle • **Dynamic pricing** for opt. use and availability	

ADAS = Advanced Driver Assistance Systems; EE = Electric/electronics, V2G = Vehicle to grid, TCO = Total cost of ownership
Note: A tipping point is defined as the start of exponential growth within a segment of the mobility transformation
Source: Expert interviews, PwC Autofacts®, Strategy&

Total car parc growth strongest in China with high penetration of connected and electric; automation relevant after 2025

Total vehicle parc and technology penetration (in million, %)



Assumptions

- **Total vehicle parc** driven by
  - Growing economic mobility demand after COVID-19
  - Build-up of new mobility fleets with high annual mileage
  - Disposal of outdated vehicles
- **Basic connectivity with high penetration** due to regulation in US/EU; share with over-the-air (OTA) capability significantly lower
- **BEV with strong growth in EU/ China** due to government subsidies and earlier "total cost of ownership" parity (vs. ICE) than in the US
- **Delay of automated vehicle penetration** at L4/L5 due to technical challenges and investment cuts; L3 with first useful applications before 2025

Source: PwC Autofacts®, Strategy&

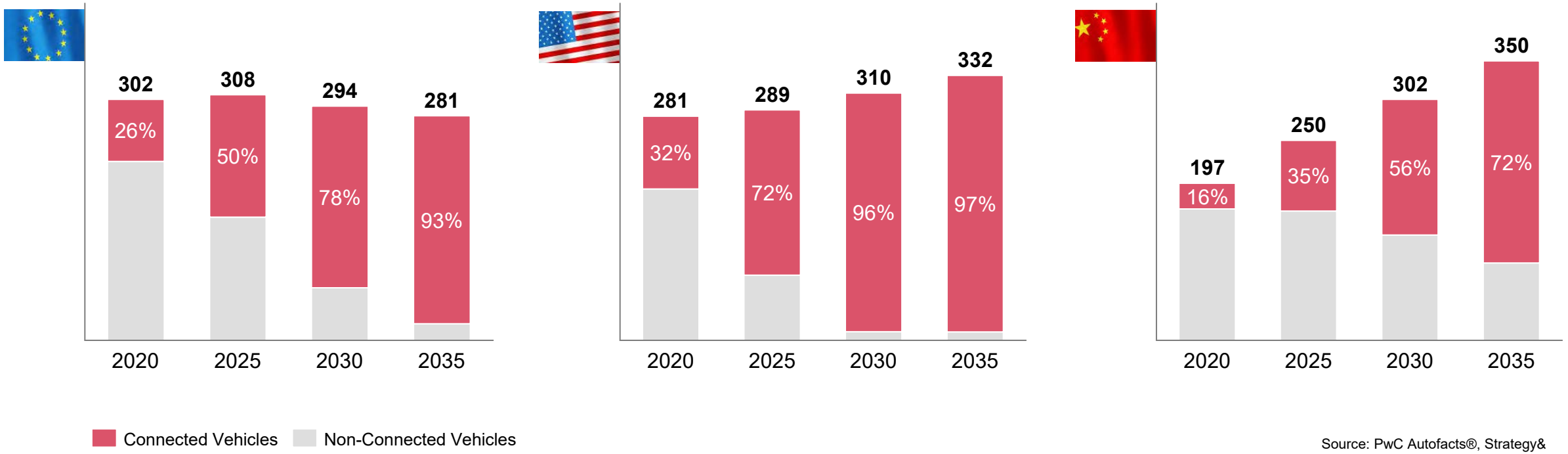
LV = Light vehicles = Cars + light commercial vehicles < 6t GVW

BEV = Battery electric vehicle

ICE = Internal combustion engine

Connectivity will rapidly penetrate total car parc; OEMs need to leverage platforms for scale, while maintaining distinct UX

Total vehicle parc and connected car share (in million, %)

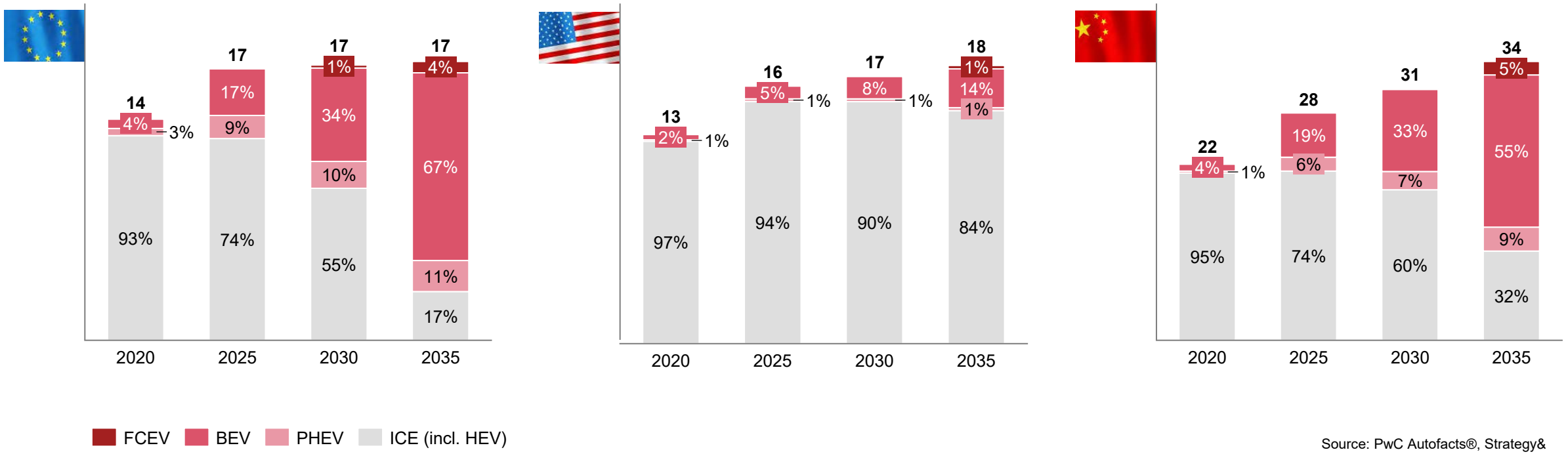


Source: PwC Autofacts®, Strategy&

> “Total vehicle parc expected to shrink in Europe (-0.5% p.a.) while growing in the US (+1.1% p.a.) and China (+3.9% p.a.) until 2035 – connectivity penetration >50% after 2025 in Europe and US.”

The shift from conventional to electric powertrains is under-way; China and Europe head-to-head in market penetration

New vehicle sales by powertrain (in million, %)

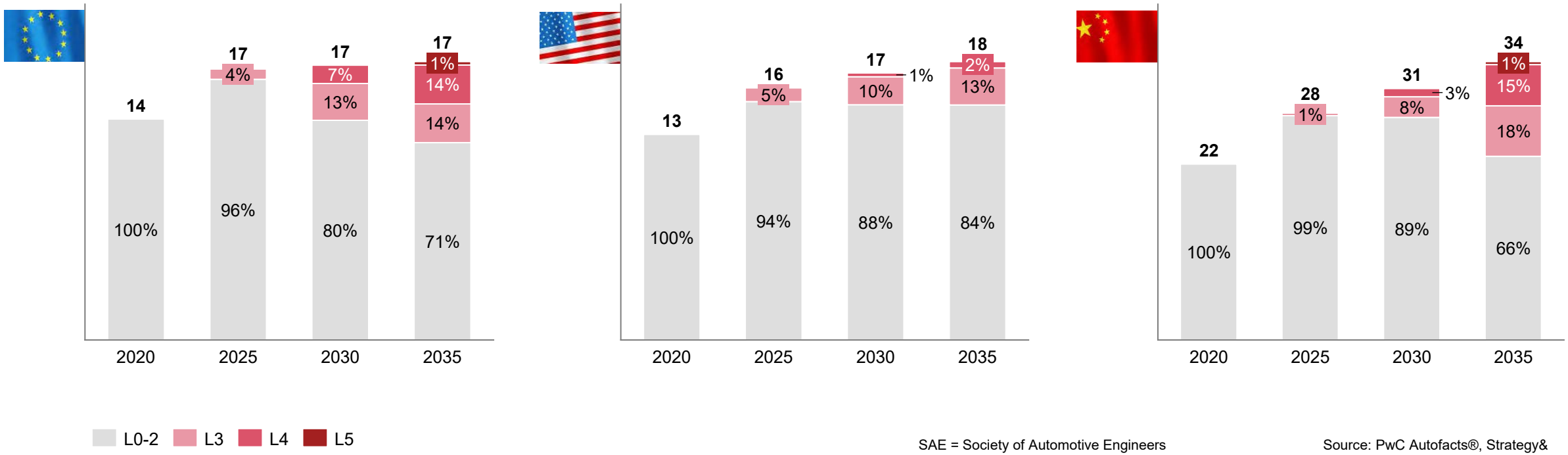


Source: PwC Autofacts®, Strategy&

> "Tightening CO_2 emission targets in the EU and new national guidelines in China accelerate BEV penetration in these regions significantly faster than in the US."

Automated driving will not arrive with a *big bang*: Various useful functions and features will pave the way for L4

New vehicle sales by SAE level (in million, %)



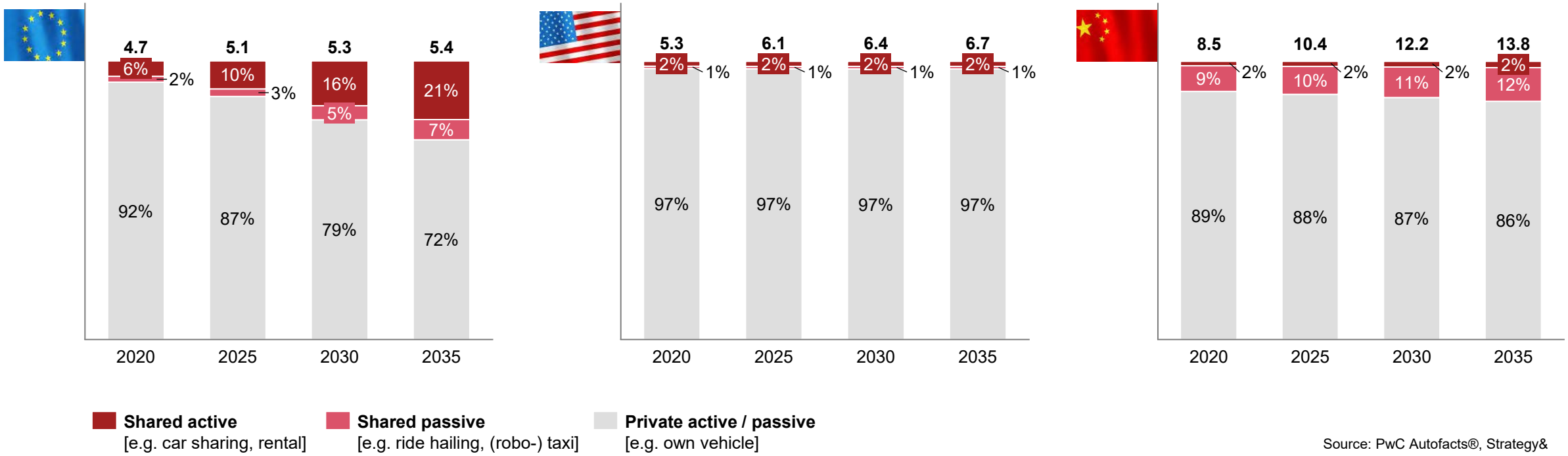
SAE = Society of Automotive Engineers

Source: PwC Autofacts®, Strategy&

> "Before deploying L4 passenger vehicles at scale, players will push the next years for specific automated driving applications in transport / fleets and logistics / industrial areas to recover investments."

Transformation of mobility refocused towards shared active and passive modes due to COVID-19 and slower automation

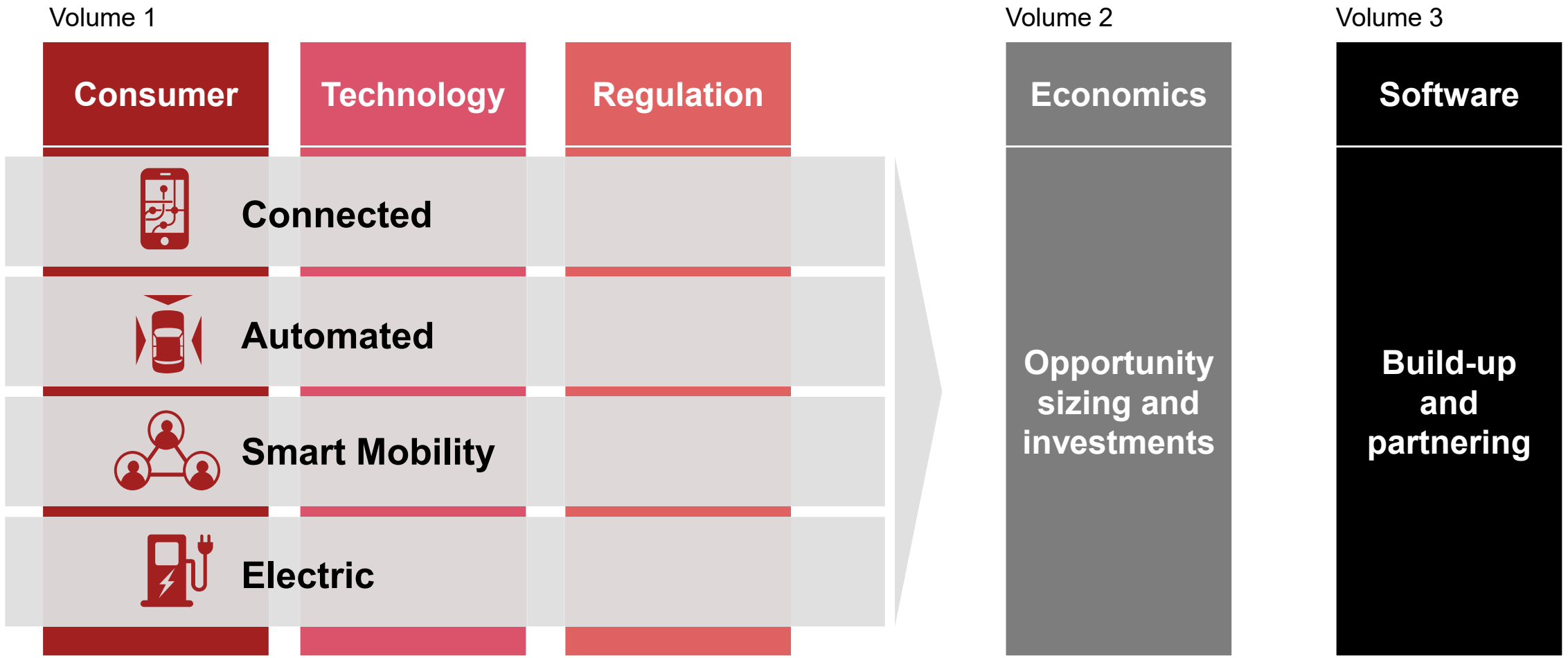
Market penetration by mobility mode (in '000 billion person-kilometer, %)



Source: PwC Autofacts®, Strategy&

"Global market remains difficult to address with one mobility service given high proliferation of different active & passive driving use cases – new players invest in multi-mode transport platforms."

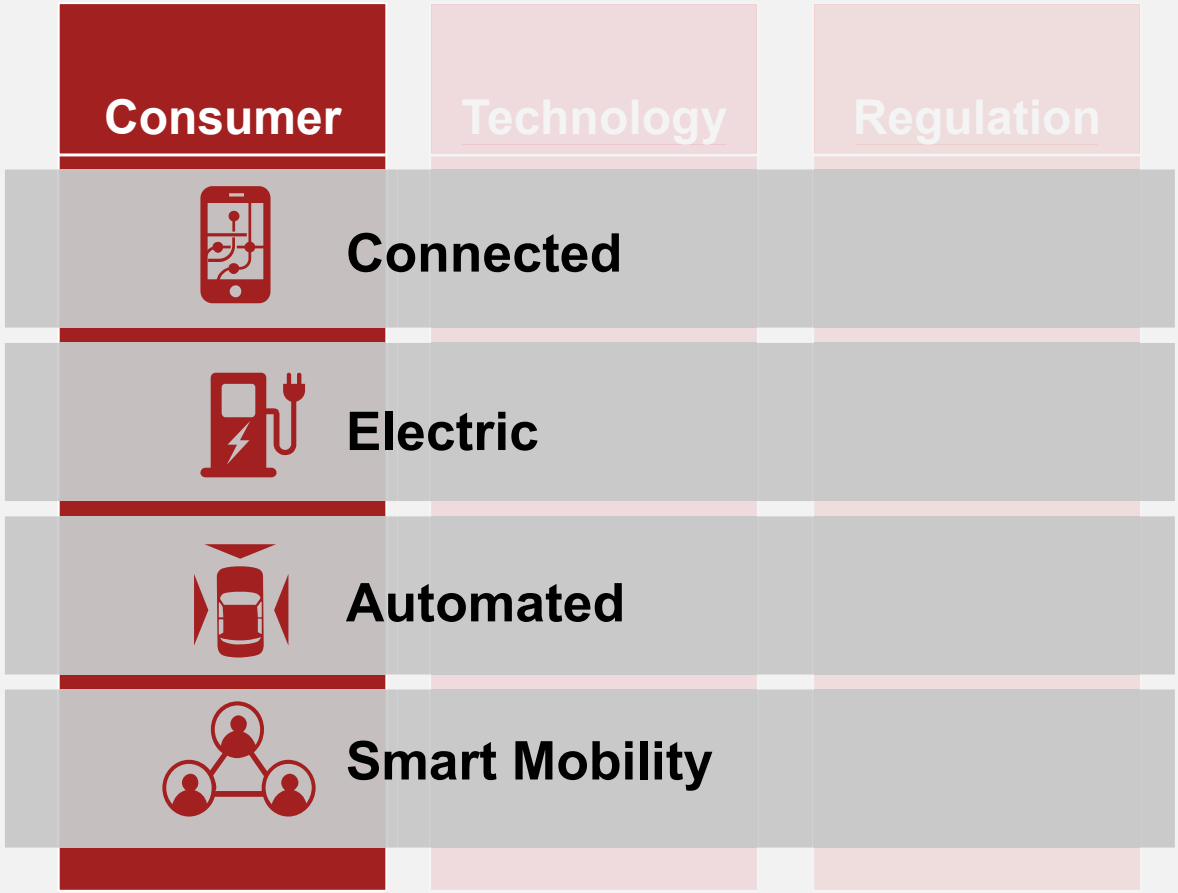
This report series lays out in three volumes 1) CASE drivers, 2) economic opportunities, and 3) capability implications



Volume 1

Anticipating post-pandemic market dynamics

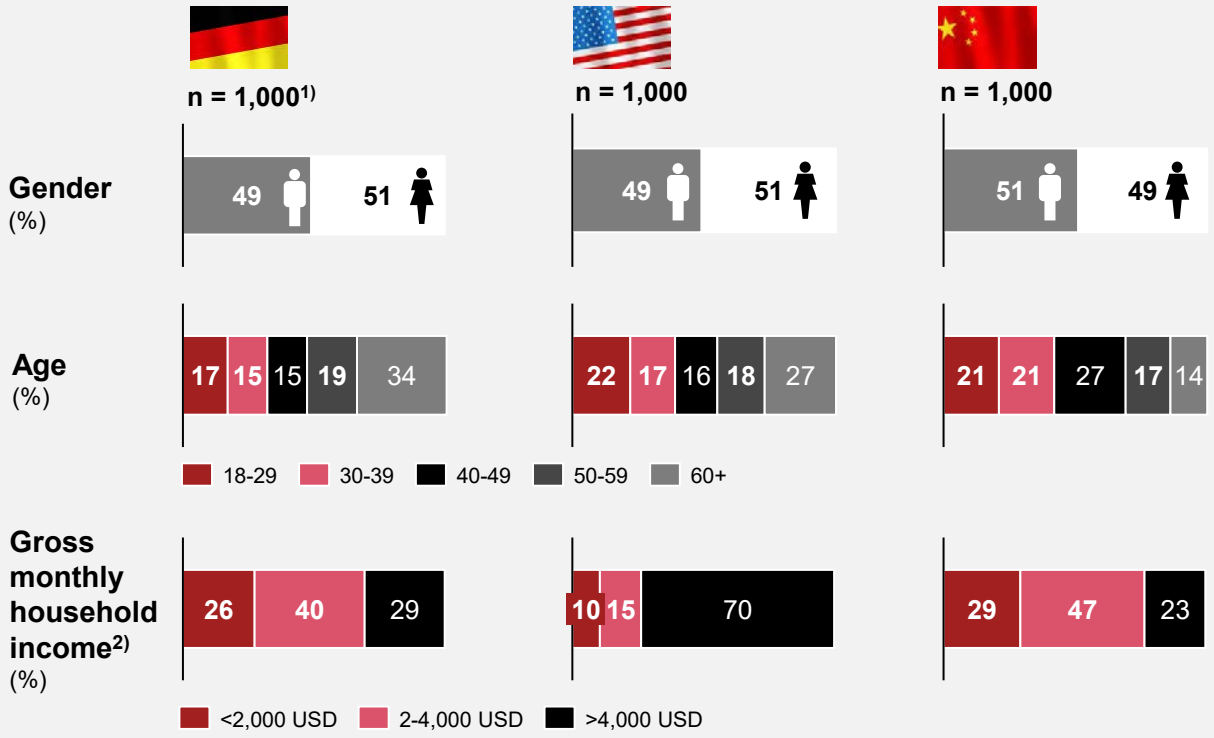
Consumers seek convenient and safe mobility – private transport modes regain importance”



Source: Strategy&

Survey among 3,000 consumers in Germany, the US and China shows latest shifts in consumer mobility preferences

3 regions | **>20** questions | **>3,000** Respondents[1)]



Key results

- Respondents confirm relevance of connected services – **security** & **navigation most important**
- However, **willingness to pay** overall **lower** than most OEMs hoped for

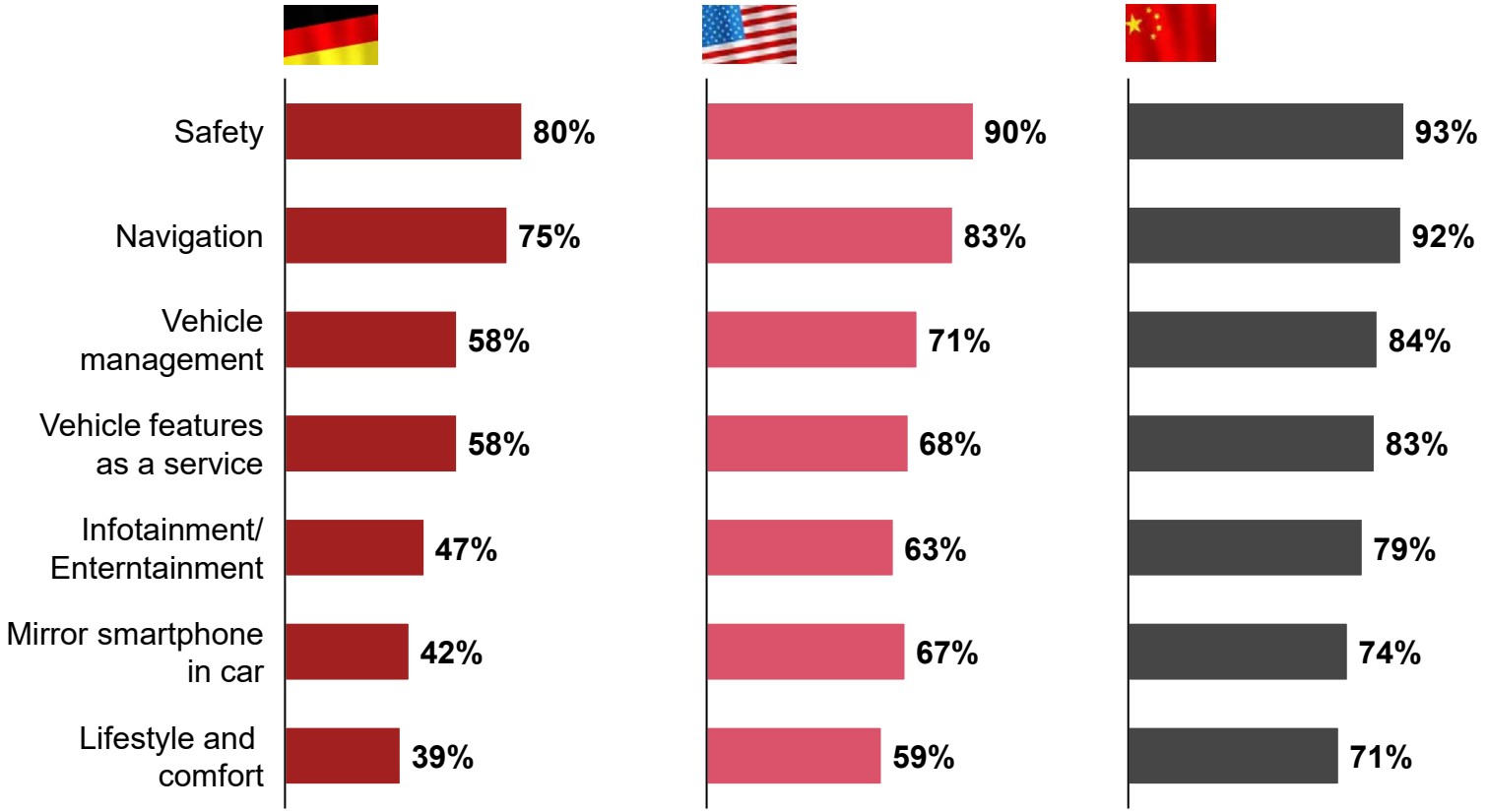
- Consumers expect **AD vehicles** in the early 2030's; first in transportation, later in private cars
- **Two thirds of respondents** would use **automated vehicles**; of those **75% would pay a premium** for an automated driving of **5 – 20%** per ride

- While **new car purchase options lead across regions** pre- and post-pandemic, interest in **car subscription** is growing strongly in China
- **Regular** cleaning / **disinfection** has become most important feature for shared mobility offerings to ensure usage during **COVID-19**

1) Questions on COVID19 effects of mobility behaviour in DE partially n=2,000 2) converted from EUR/CNY (Mid of August 2020) Remaining % up to 100% "not specified"

Respondents highlight the importance of connected services – safety and navigation rated as most important features

Connected services – By importance for consumers[1)]



Question: *"Which connected service categories are particularly important to you?"*

In Germany in particular, **safety** and **navigation rank as most important** services.

Winning consumers in other categories requires **strong USP** and compelling story.

1) Share of respondents, who want to have connected services in their vehicles
Source: PwC Strategy& consumer research 2020; n=3,000 (1,000 DE, 1,000 US, 1,000 CN)

Customers want in-vehicle connected services; however, willingness to pay might be lower than OEMs hope

Connected services – Willingness to pay[1)]

Monthly willingness to pay	vs.	reference prices of other digital & media services			
Fully-fledged connected service offering		Spotify subscription[2]	Mobile voice & data contract	Premium sports stream[3)]	iPhone leasing[4)]
$ 19.5 at 31% willingness		$ 11.9	$ 34.6	$ 14.2	$ 39.5
$ 17.6 at 40% willingness		$ 10.0	$ 43.6	$ 19.9	$ 35.3
$ 4.3 at 58% willingness		n/a	$ 9.8	$ 10.3	$ 33.4

Question: *"Would you like to have Connected Car services integrated in your vehicle and are you willing to pay a surcharge for this? If yes, how much…"*

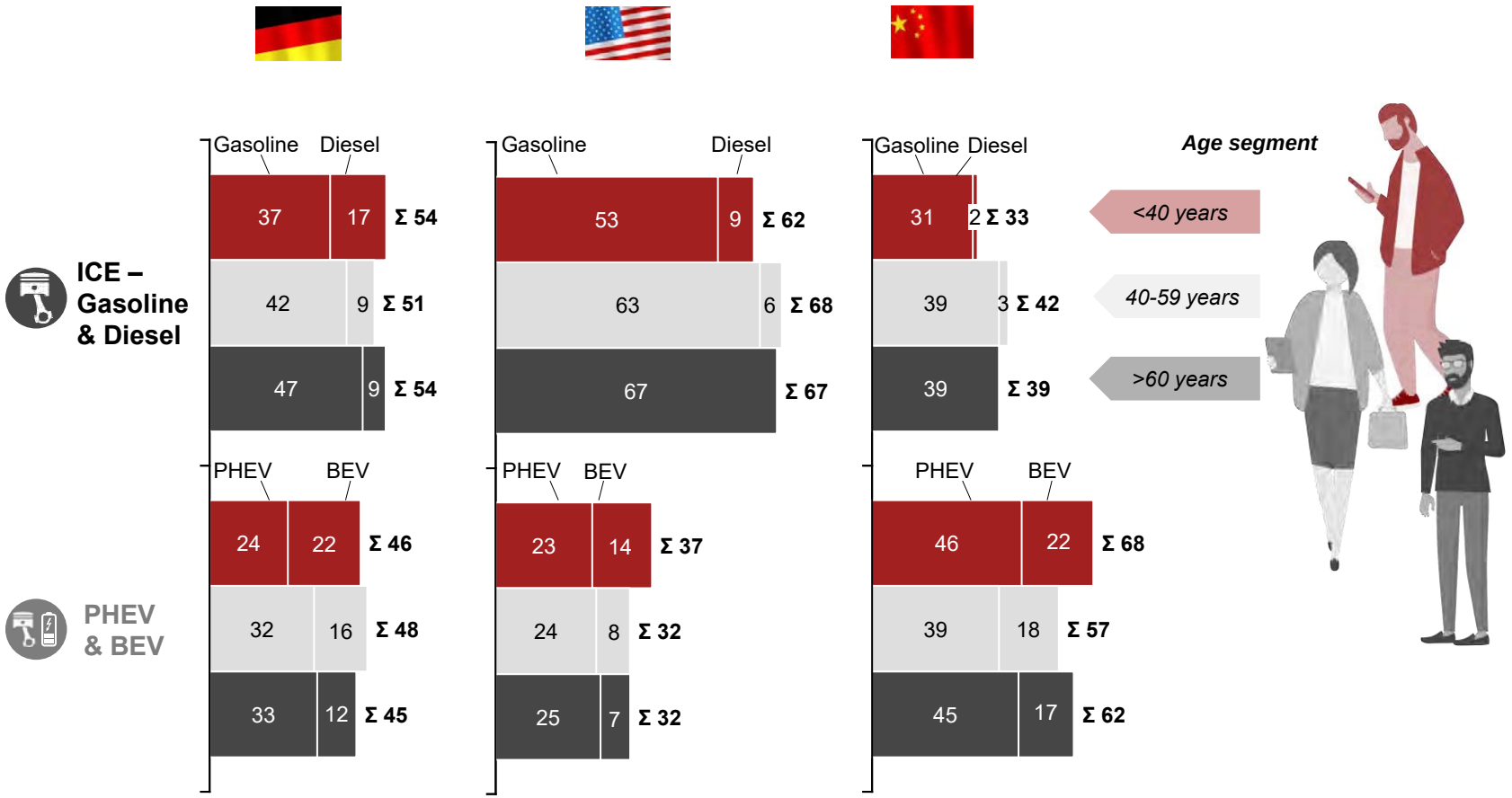
China with **highest share of consumers** (58%) who are **willing to pay an extra** for connected services .

Capturing this value requires providers to compete partially against other digital services.

1) Local currency conversion to USD as of mid of August 2020 2) "Individual" plan 3) DAZN basic package for GER and USA, basic Tencent package in China 4) iPhone 11 64GB, 24 months leasing
Source: PwC Strategy& consumer research 2020; n=3,000 (1,000 DE, 1,000 US, 1,000 CN); International Telecommunication Union 2019

Gasoline still most preferred type of powertrain in Germany and the US; hybrid gains popularity and is most popular in China

Preferred type of powertrain by age (%)



Question: *"Suppose you wanted to buy a car: Leaving aside financial aspects, legal requirements and lack of infrastructure […] – which type of drive do you like best?"*

While **68% of Chinese** consumers below 40 years **prefer electric powertrains** over gasoline, only 46% in Germany and 37% in the US share this preference.

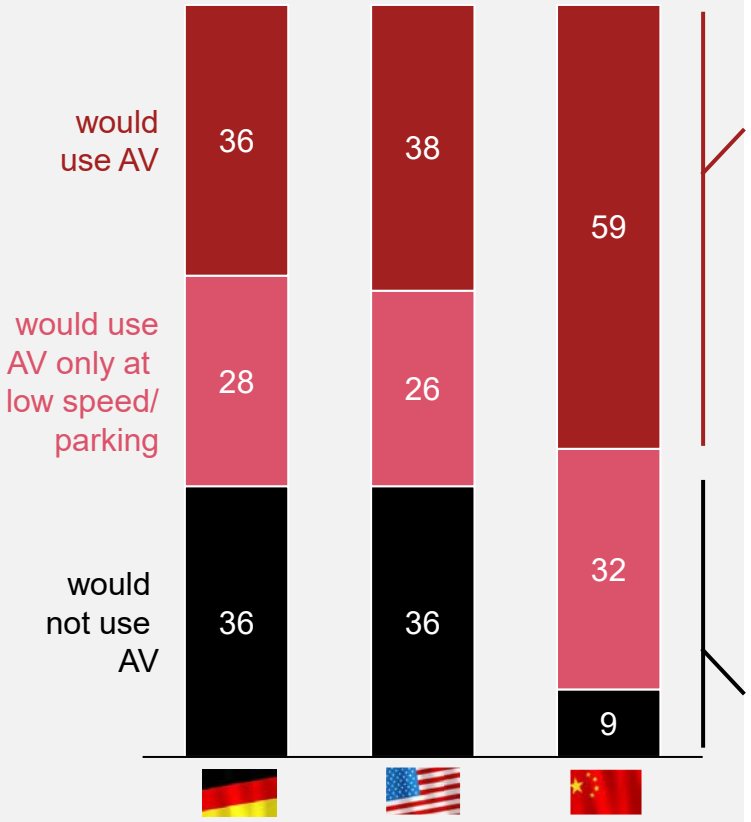
Source: PwC Strategy& consumer research 2020; n=2,000 DE, n=1,000 US, n=1,000 CN

Percentages may not total 100% due to rounding

Two thirds of respondents would use automated vehicles; of those, 75% would pay a premium for an automated driving service

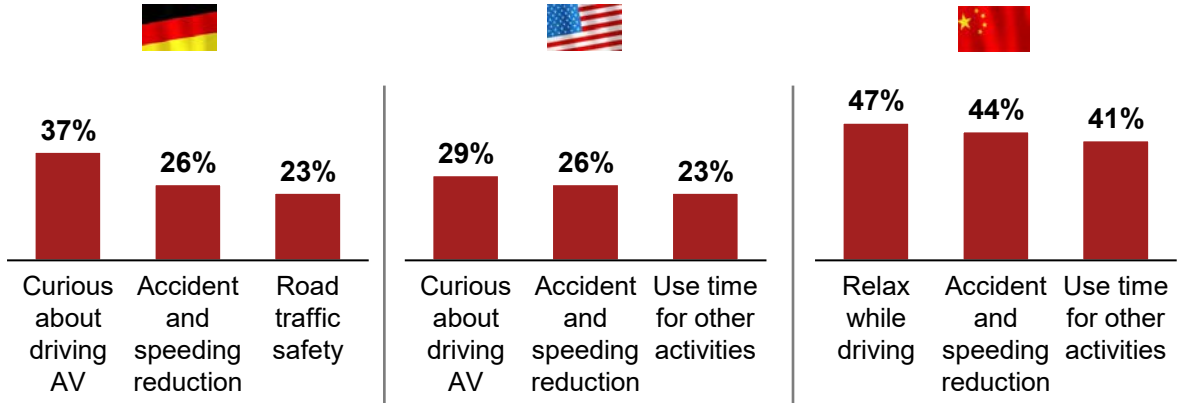
Automated driving – Consumer attitude, impact factors and willingness to pay

Attitude towards AV (%)



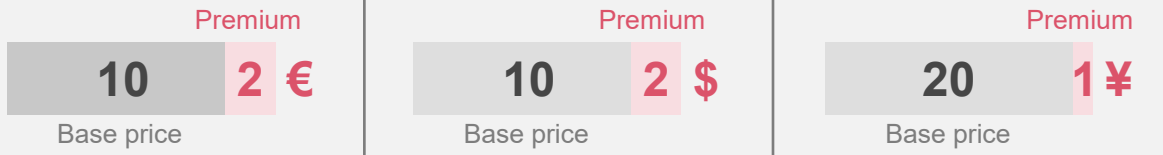
Top 3 Persuasive factors for using AV

(% of respondents)



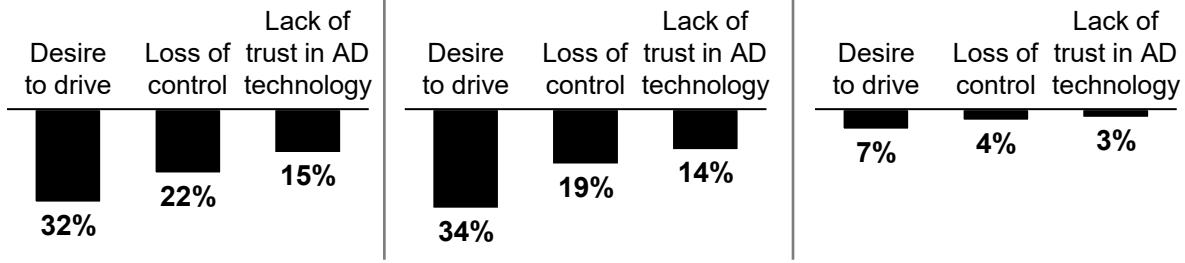
Willingness to Pay

"Would you be willing to pay a premium for an AV (e.g. car sharing, ride hailing)? If yes, how much more would you pay for a 5 km trip with a base price of 10 €/10$/20¥?"



Top 3 Deterrent factors for using AV

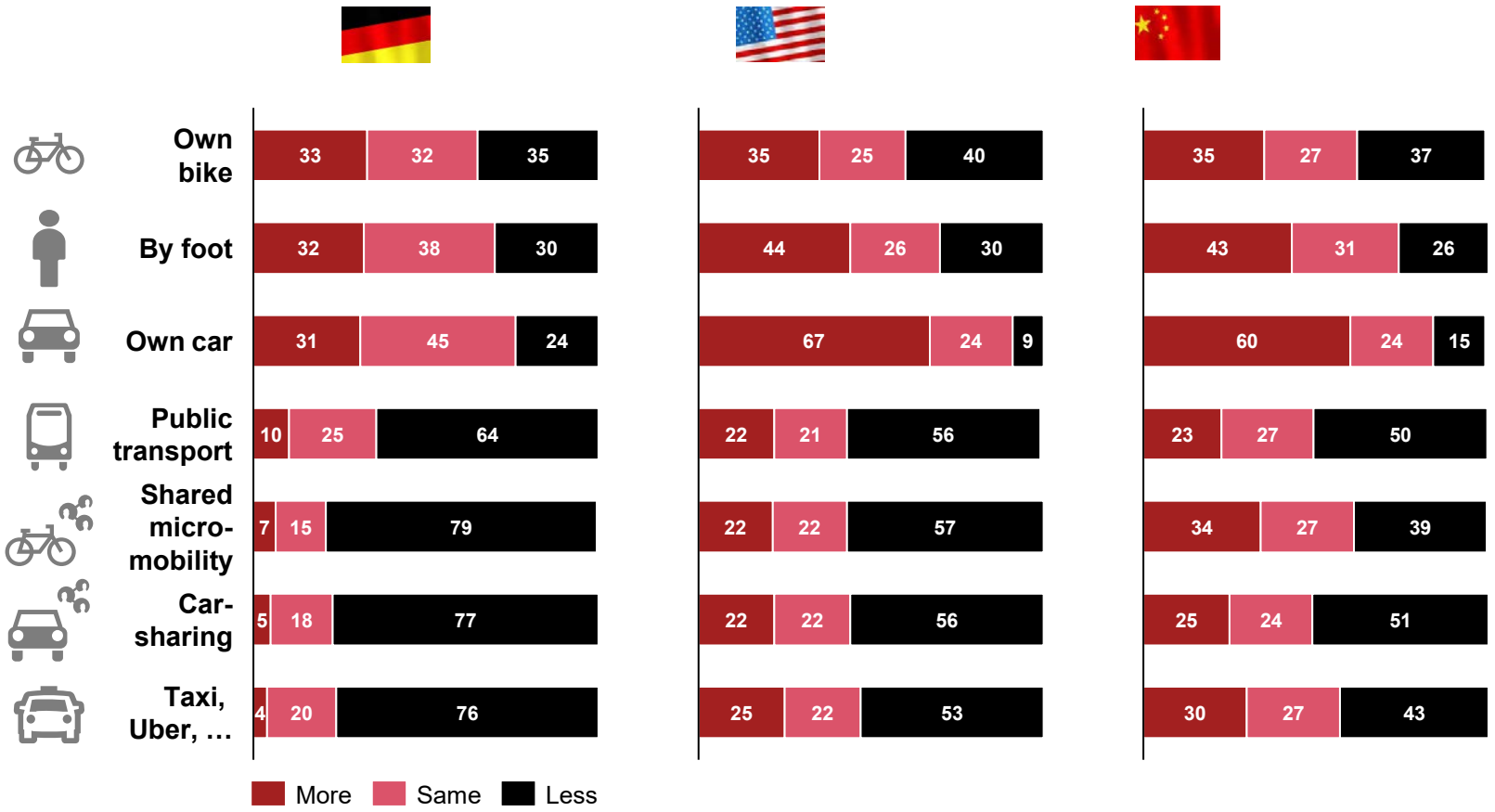
(% of respondents)



Source: PwC Strategy& consumer research 2020; n=3,000 (1,000 DE, 1,000 US, 1,000 CN)
* Average willingness-to-pay a premium for a 5km ride with an automated vehicle instead of having a chauffeur or self-drive

Mobility modes shift due to effects of COVID-19 – use of own vehicle preferred over shared mobility and public transport

Mobility patterns after COVID-19 restrictions (%)[1)]



Question: *"Assuming COVID-19 restrictions are lifted again, how would you use the following mobility modes compared to pre-COVID-19 times?"*

Own car is the clear winner in the US and China. In **Germany**, the **intended increase of car usage is on par with bike and foot**.

At the same time, Germans move away strongly from shared modes.

1) On the example of transportation to/from work
Source: PwC Strategy& consumer research 2020; n=1,259 DE, n=593 US, n=779 CN; Percentage may not total 100% due to rounding

Shared mobility providers win consumers back with clear disinfection concepts rather than with lower prices

Attitude towards shared mobility after COVID-19 lockdown (%)

42	58

1| Regular **cleaning and disinfection** by the provider (28%)
2| Lower/**cheaper** prices (25%)
3| Reliable **availability** (24%)
…
8| Offer of **gloves** and **masks** in the vehicle (15%)
9| **Higher quality/premium** vehicles (11%)

17	83

1| Regular **cleaning and disinfection** by the provider (50%)
2| Lower/**cheaper** prices (40%)
3| **Provision** of **disinfectants** to/in every **vehicle** (39%)
…
8| **Reserved parking** spots (26%)
9| Extensive geographical **coverage** (17%)

2	98

1| Regular **cleaning and disinfection** by the provider (49%)
2| **Provision** of **disinfectants** to/in every **vehicle** (49%)
3| Lower/**cheaper** prices (42%)
…
8| Extensive geographical **coverage** (33%)
9| **Reserved parking** spots (32%)

No usage of shared mobility offerings at all
Open towards usage of shared mobility offerings

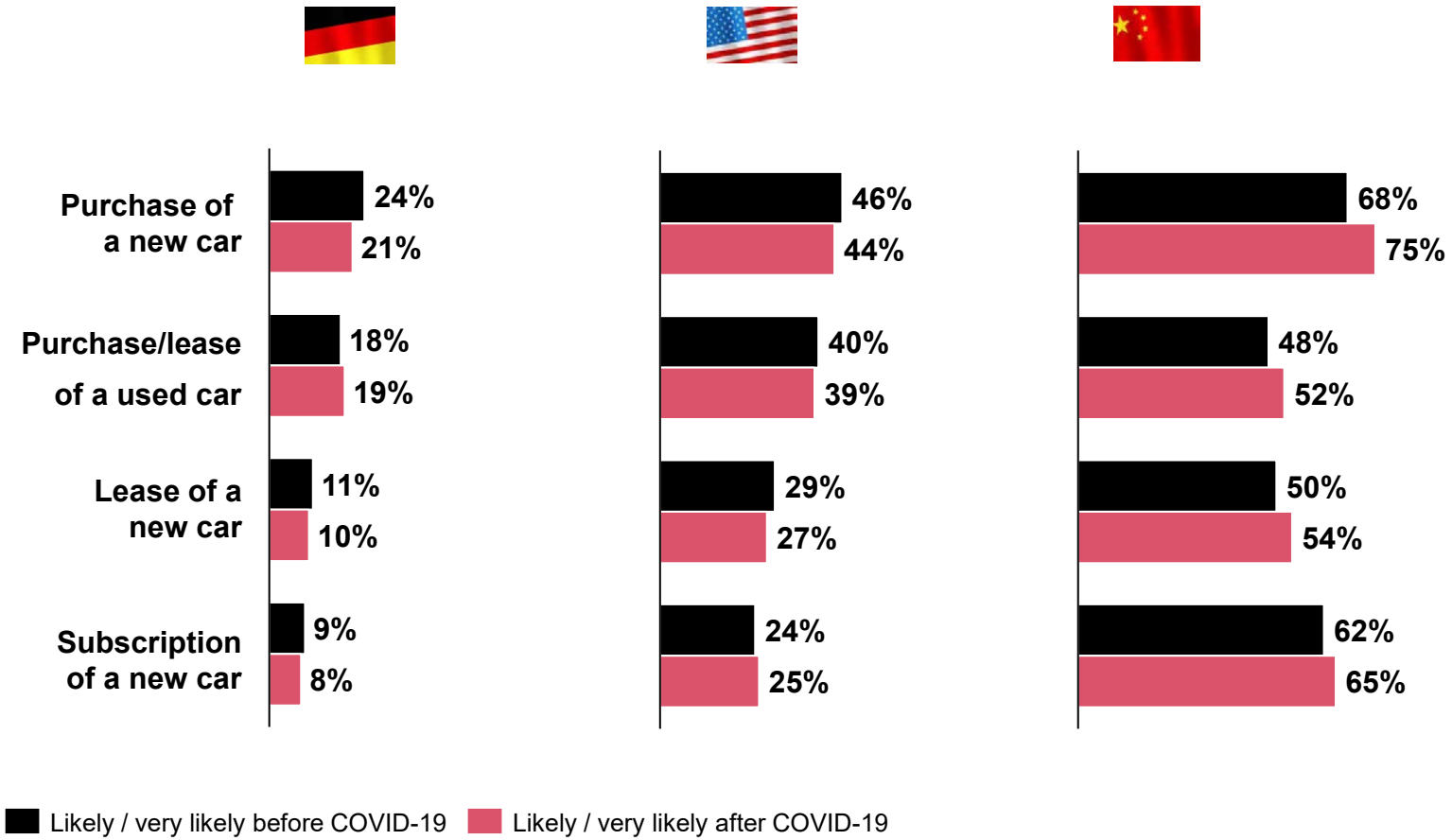
Question: *"Which requirements should providers fulfill to ensure that you would continue using shared mobility offerings after COVID-19 lockdown?*

In Germany, **quality / premium vehicles** seen as **least important** factor to return to shared modes – after cleaning, **price** and **availability are most important**.

Source: PwC Strategy& consumer research 2020; n=2,000 DE, n=1,000 US, n=1,000 CN

Purchasing a new vehicle remains preferred option across regions; China shows strongest increase in subscription intent

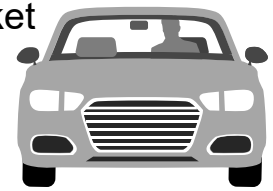
Likelihood to buy/lease/subscribe to a car before/after COVID-19 (%)[1)]



Question: *"Taking the position of pre-COVID-19, how likely was it that your household would buy, lease or subscribe to a new vehicle in 2020/2021? How likely is it now?"*

China, and partly the US, are **open towards subscription models**.

In Germany, further market education needed to win subscription customers.



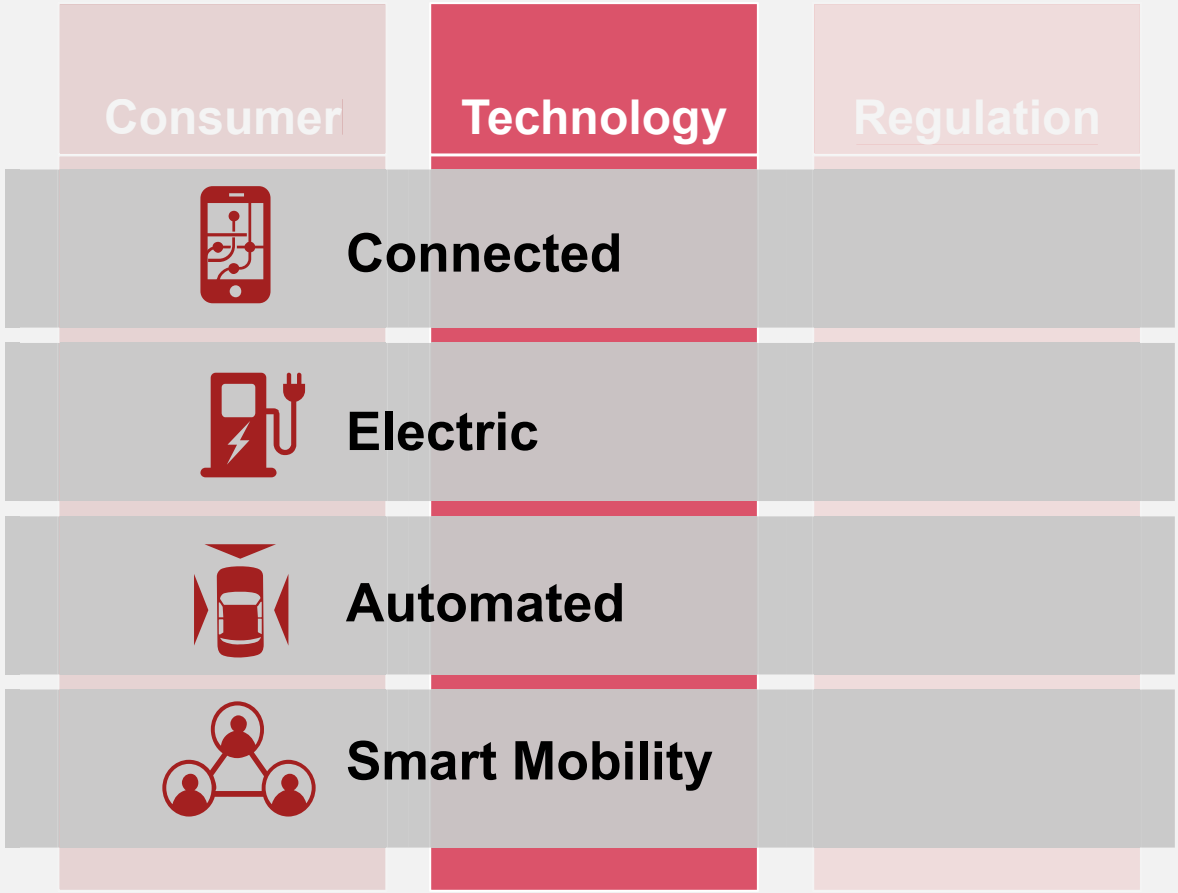
1) Before= 1 year ago, after = within next 1-2 years
Source: PwC Strategy& consumer research 2020; n=2,000 DE, n=1,000 US, n=1,000 CN

Difference to 100%: no/low likelihood to buy/lease/subscribe a car

“

Technology progresses fast – yet complexity of autonomous driving has been underestimated”

Digital Auto Report 2020 – Volume 1



In connected services, OEMs are currently rethinking their "build vs. buy strategy" on key technology components

Connected services components

	Enabler	Hardware	Software	Integration	Content/Service	Sales and CRM
	Plan – Build – Ship – Update – Sunset					
Key value blocks	Cloud infrastructure	Vehicle architecture and ECUs	Automotive security	User interface and controls	Vehicle-based services and apps	Offering bundling and pricing
	Mobile/local network	I/O devices (e.g., sensors, displays)	Vehicle OS, over-the-air-update and cloud platform	System integration	3rd party content and services	User ID and personalization
	Regulation	3rd party hardware (e.g. VR glasses)	Data analytics	Data interfaces and APIs	Cloud/hybrid services incl. vehicles health services	Customer support
Current limitations	• Cloud infrastructure costs • MNO costs • Regional regulations	• Centralized E/E architecture with zonal ECUs • Sensor fusion and virtual sensors	• OTA update functionality • Data processing and intelligent data fusion • Security of data connections	• UI design (e.g. graphical vs. voice only), • Online-first vs. offline-first • Open vs. closed APIs	• 3rd party content and app store integration • Transmission, collection, and analysis of vehicle health data (e.g. based on sensor data)	• Subscription vs. life-time offer model • Customer identification • VIN to UID • Data privacy
Current develop-ments	• Leverage eSIMs for customers and more frequent MNO tenders	• Evaluate sweet spot between complexity reduction and profitability • Enable expendable vehicle architectures	• Define software-value-add strategy Use virtualization to securely separate domains	• Focus on differentiating adaptive user interface • Provide and monetize SDKs and interfaces for 3rd parties	• Leverage smartphone integration for non-connected markets	• Bring user sign-up and log-in journey to perfection • Connect to existing ecosystems (e.g. phone)

Crucial value blocks (own know-how necessary)

CRM = Customer relation management ECU = Electronic control unit HW = Hardware I/O = Input/Output MNO = Mobile network operator
SDK = Software Development Kit SW = Software VR = Virtual reality V2X = Vehicle-to-x communication Source: Strategy&

Technology progress in e-mobility must be evaluated in the context of tech trends across various alternative powertrains

Alternative powertrain developments

ICE

Internal combustion engine

Electrification

- Recuperation and boost as standard features with 12V (budget) or 48V
- Increased electrification of auxiliaries (water/oil pumps, cam phaser, etc.)
- P2 topology avoiding drag torque

Reduction of friction losses

- Coatings and microstructural modifications on cylinder
- Optimization of crankshaft bearings
- Ball bearings for turbocharger

Combustion/emission optimization

- Increasing injection pressures
- Variability in valve trains
- Particle filters for most powertrains including DI gasolines
- Variable compression ratio through variable connection rod

PHEV

***Electric drivetrain** (electric motor, inverter, transmission)*

Efficiency improvement

- Silicon carbide power semi-conductor switches (inverter)
- Bar windings and increased notch filling degree in electric motor

Cost reductions

- Increased integration of inverter and motor

High voltage system and architecture

Architecture

- Integration of power-units (OBC, DCDC, DC charger)
- Top models up to 800 V, standard in volume 400 V

Auxiliaries

- Increasing commoditization of electrified auxiliaries

HV battery system

System design

- Structural integration of housing into vehicle body
- System design incl. recyclability

BEV

Cell innovation

- Increased cell capacity through larger cells
- Cathode cost reduction by minimization of cobalt content and cobalt-free cells
- Increased anode energy density via silicon
- Intrinsic safe cells by application of solid state electrolytes (polymers, inorganics, blends)
- Dry (solvent-free) processing of electrode coatings

FCEV

Fuel cell system

Stack

- Increase of power density
- Optimization of catalyst compositions (reduction of Pt) and nano-scale microstructure
- Optimization of bipolar plate coatings

Balance of plants

- Stack internal humidification and simplified water mgmt.

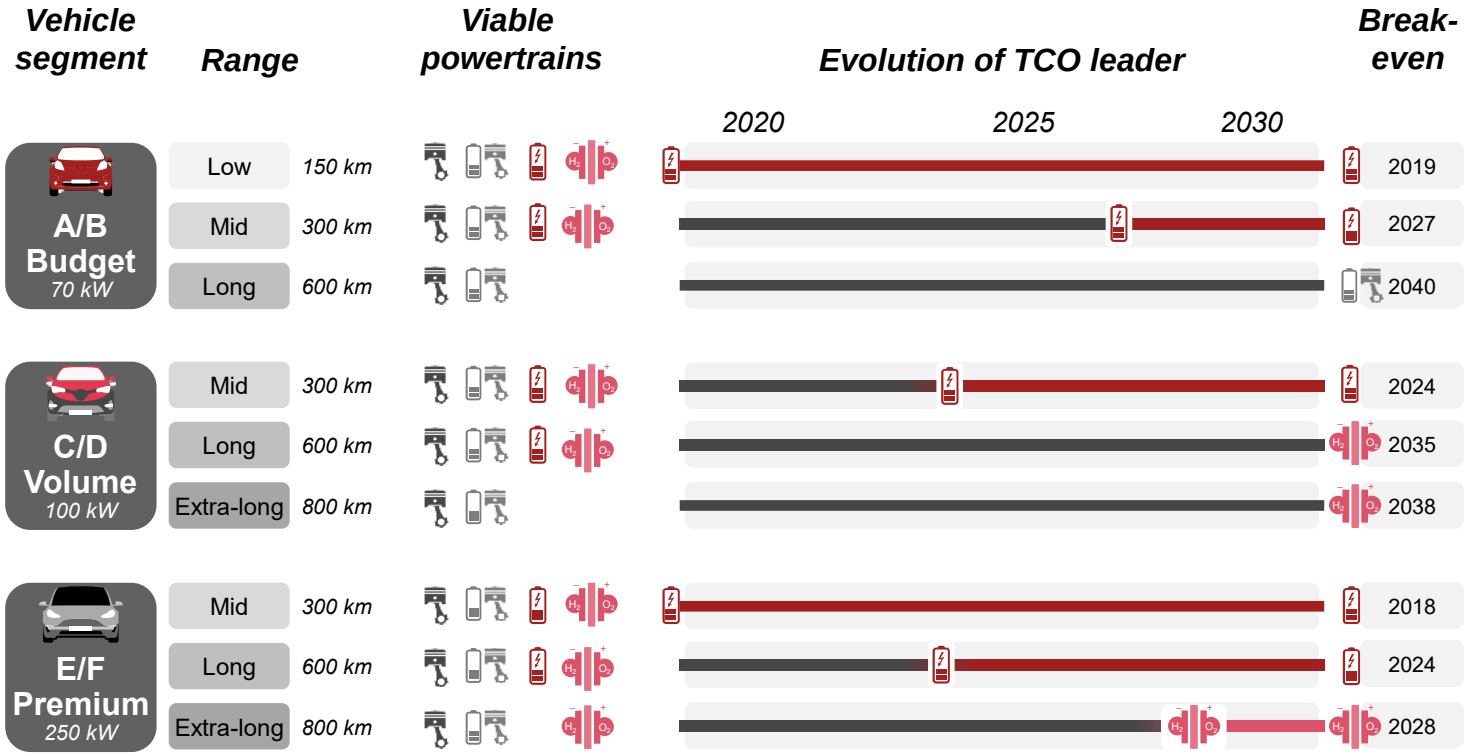
Tank

- Optimization of fiber winding layout and process
- Mixed materials to reduce costs
- Compressed H_2 as standard for passenger vehicles

OBC = Onboard charger DC charger = Direct current charger
Source: Strategy&

BEVs will become economical for several segments – but extended ranges (600 km+) will not be viable with BEVs

Electric powertrain operating cost break-even timeline (vs. ICE)



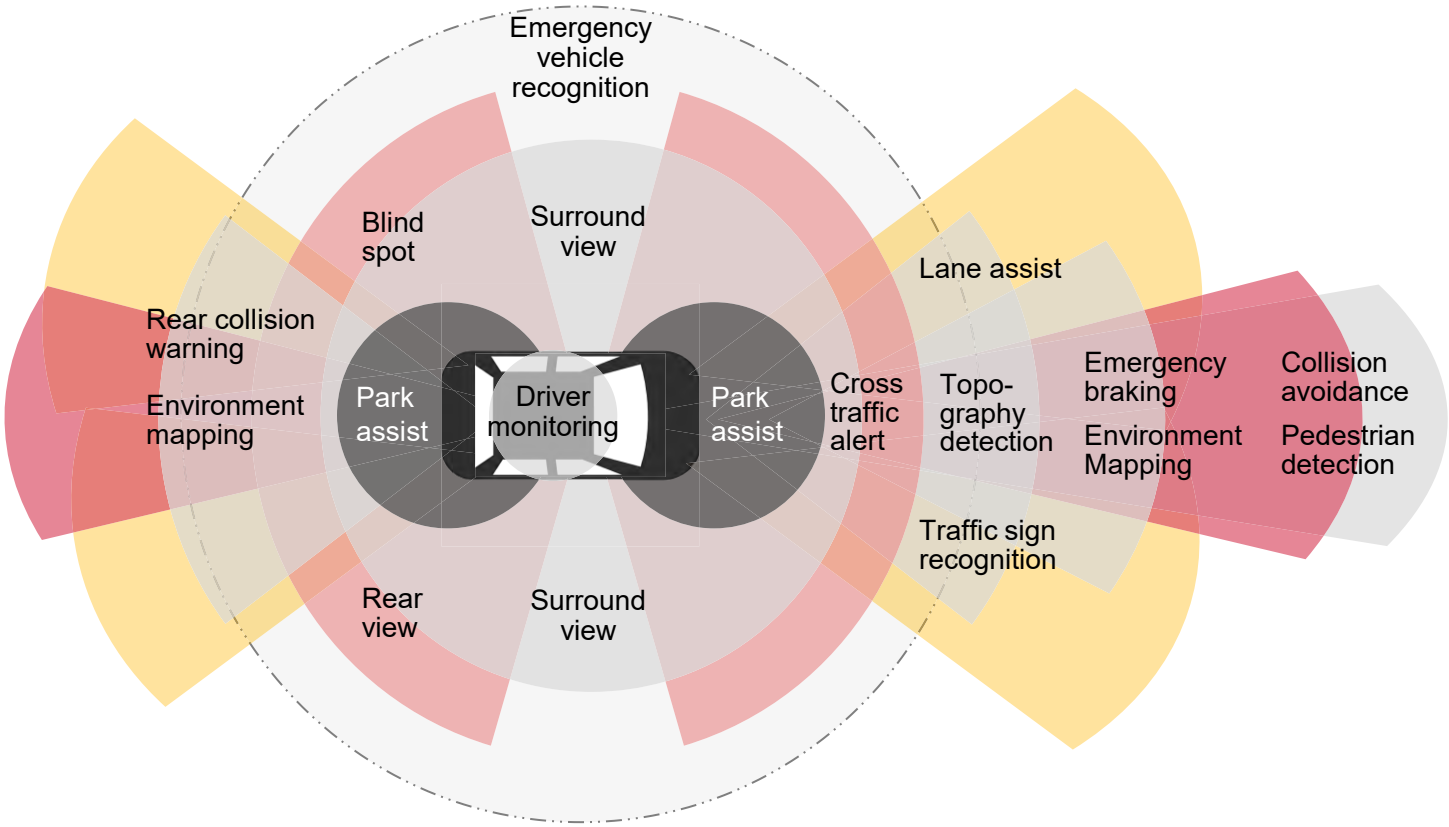
There is **no fixed point** in time **when battery electric vehicles** offer an operating **cost advantage over internal combustion engines** – it depends on factors such as the vehicle segment and range"

Main assumptions: electricity and fuel prices as for Germany 2020; H2 price 5€/kg; PHEV driving modes 40% EV mode/60% ICE mode; FCEV driving modes 40% EV mode/60% FC mode
One-time buying incentives not considered

Source: Strategy&

Hardware, software and infrastructure of automated driving are improving, but overall progress slower than expected

Automated driving technology developments



Current status and limitations

Hardware
e.g. sensors

- **Radar and camera sensors** are developed with a **good cost position**
- **Cheap LiDAR systems** do **not** yet have the necessary **performance**
- **New ADAS computers** based on low power tech are **under development**
- **Different driver assistant systems mandatory** beginning **2022** in **EU**

Software
e.g. smart data usage

- **Test and validation not** yet **mature**
- **Motion prediction** still **not** completely **solved**
- Very **large amounts** of **test data complicate** traditional **analytics**

Infrastructure
e.g. 5G

- So far, there are only a **few test tracks** that are fully developed for automated driving
- **Expansion of 4G** by 2022 for motorways in DE as basis for 5G
- For the time being **only pseudo 5G** based on 4G (non stand-alone)

Source: Strategy&

While L3 enables various attractive use cases, user experience and system complexity breakthrough is happening at L4

Automated driving SAE levels and AD function mapping

HIGH

AUTOMATION

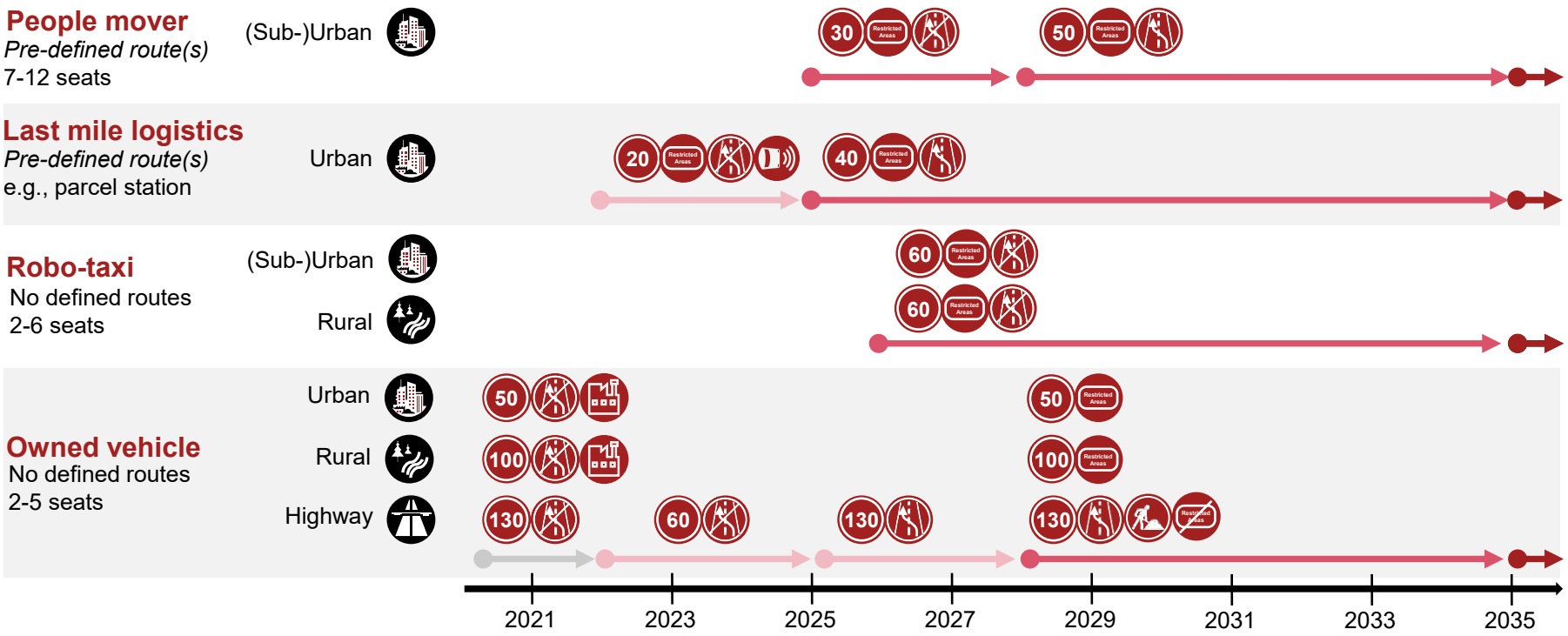
LOW

SAE level	Narrative definition		Vehicle control	Environment monitoring and user interface	Fallback for dynamic driving task	System capability	Exemplary AD functionalities
5 Full automation	The **system performs all aspects of dynamic driving** (driving-mode specific)…	…under **all environmental and road conditions** that can be managed by a human driver	System	System	System	All driving modes	• Universal pilot (full autonomy) • Interactive pilot driving (control via touch/gesture UI) • Robo-taxi and automated people-mover (all conditions)
4 High automation		…even **if a human driver does not respond** appropriately to a request to intervene		Alternative or conventional user interface		Most driving modes	• Urban/rural/highway pilot with multi-lane change • Robo-taxi and automated people-mover • Urban last-mile delivery • Automated valet parking
3 Conditional automation		…**expecting the human driver to respond appropriately** to an intervention request			Human	Some driving modes	• Urban/rural/highway assistant (e.g. hands-off traffic jam, intersection movement, single lane change) • Parking chauffeur • Assisted fleet operations (on-site, off-highway)
2 Partial automation	The **human driver performs remaining aspects** of dynamic driving, **while the system**…	…executes both **steering and acceleration/deceleration** (driving-mode specific)…		Human			• Adaptive cruise control • Remote/key parking assistant • Lane change assistant
1 Driver assistance		…executes **either steering or acceleration/deceleration** (driving-mode specific)	Human and System	Conventional user interface			• Adaptive cruise control • Driver assisted parking assistant • Lane keeping assistant (system steers) • Blind spot monitoring rear/side (system steers)
0 No automation	The **human driver performs all aspects** of dynamic driving, potentially "enhanced" by warning or intervention systems		Human			n/a	• Pre-/forward- collision braking • Front/rear cross-traffic alert with braking

Source: "SAE International Standard J3016", SAE; Strategy&

Commercially viable automated driving applications at L3 and beyond will start becoming available for specific use cases first

Automated driving timeline of commercial road availability



Commercial availability (beyond pilot projects)[1)]

Level 2+ · Level 3 · Level 4 · Level 5

Max. speed · Area restriction · Construction area capable · Automated lane changes · Closed compounds · Vehicle follows user

Urban: *Traffic situations with many traffic interactions and low speeds*
Sub-Urban: *Traffic situations with moderate traffic interactions and moderate speeds*
Rural: *Traffic situations with few traffic interactions and higher speeds*

Current developments

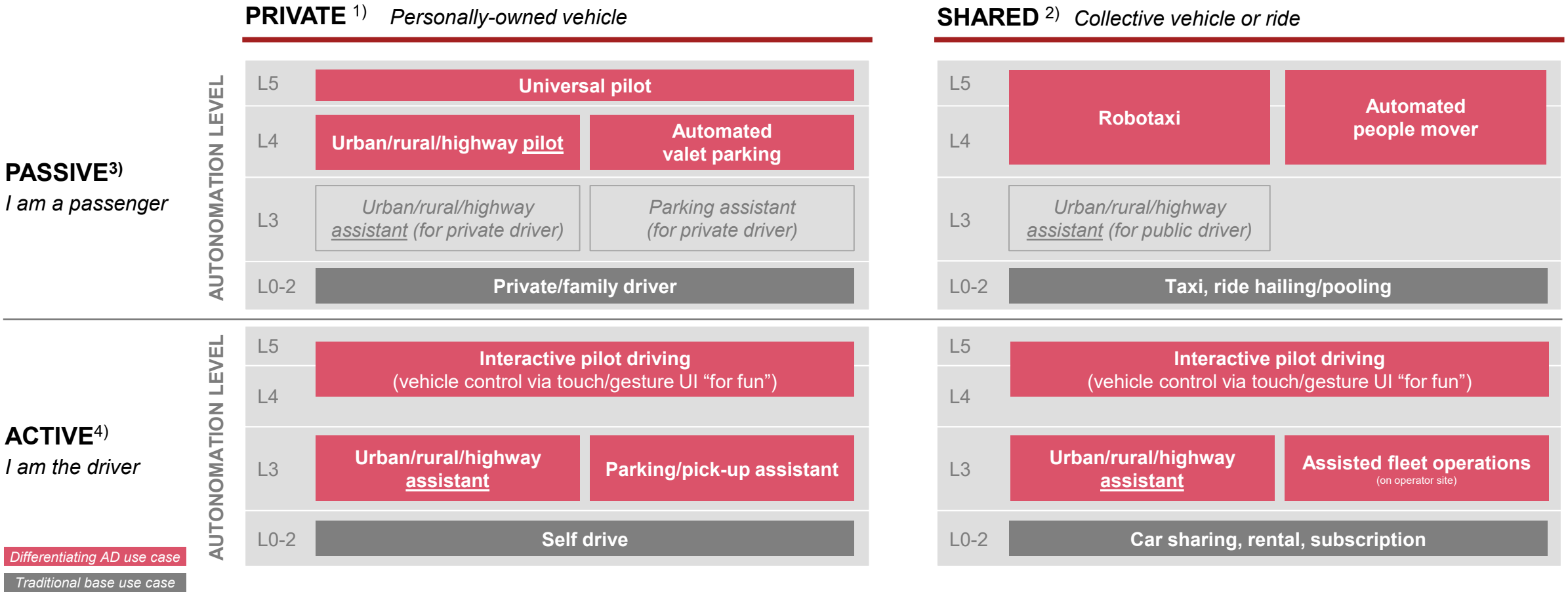
- ADAS technologies require **higher development cost** and efforts than anticipated
- ADAS **sensors** still far **above target cost**, due to small production volumes and sensor fusion/ recognition challenges
- **Regulation** still **uncertain** with the UN/ECE technical framework and national rules not yet fully in place
- While first **L3 vehicles** expected for **2021/22**, first **L4 road applications** beyond pilot projects expected for **~2025**

ADAS = Advanced Driver Assistance Systems UN/ECE = United Nations Economic Commission for Europe
1) Indicating start of availability. Tipping points of significant adoption expected significantly later in certain fields

Source: Strategy&

Individual mobility splits into four modes of private vs. shared and active vs. passive driving, each with increasing automation

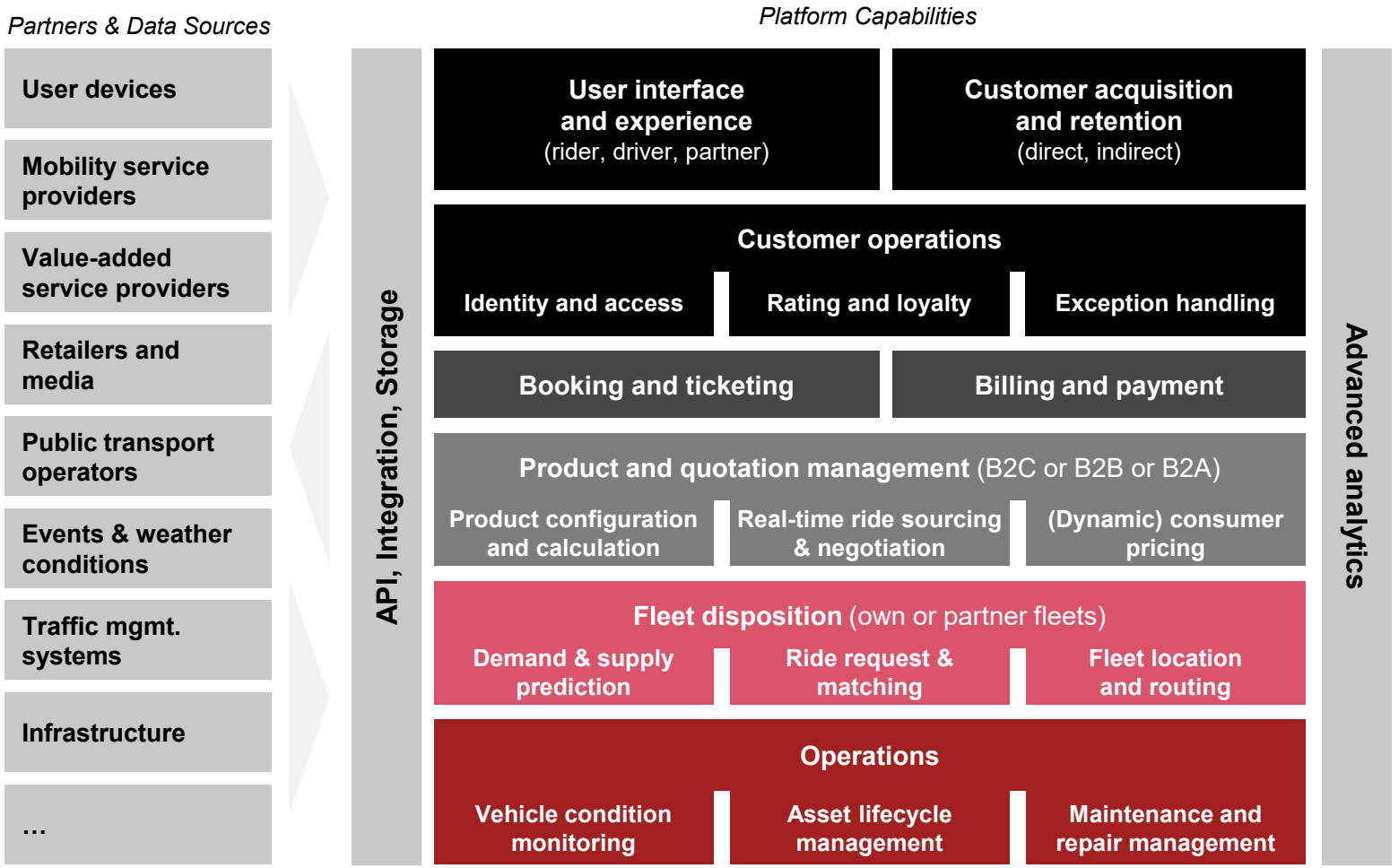
Private/shared mobility modes with selected automated driving use cases



1) Includes self-owned, family-owned, credit-financed, long-term leased, personal company car 2) Includes rental, subscription (up to 1 year), ride-hailing, ride-sharing, car sharing, pool car, car club
3) "Passenger" determines mobility purpose and target, passenger selects means of transport and expected time of arrival, mobility system determines detailed routing and actual time/place of arrival
4) "Driver" determines mobility purpose and target, driver determines means of transport and plans arrival time, driver determines detailed routing and actual time and place of arrival through user interface (UI)
Source: PwC Autofacts®, Strategy&

Seamless smart mobility services require a modular, open API-based technology architecture and platform approach

Smart mobility technology platform building blocks



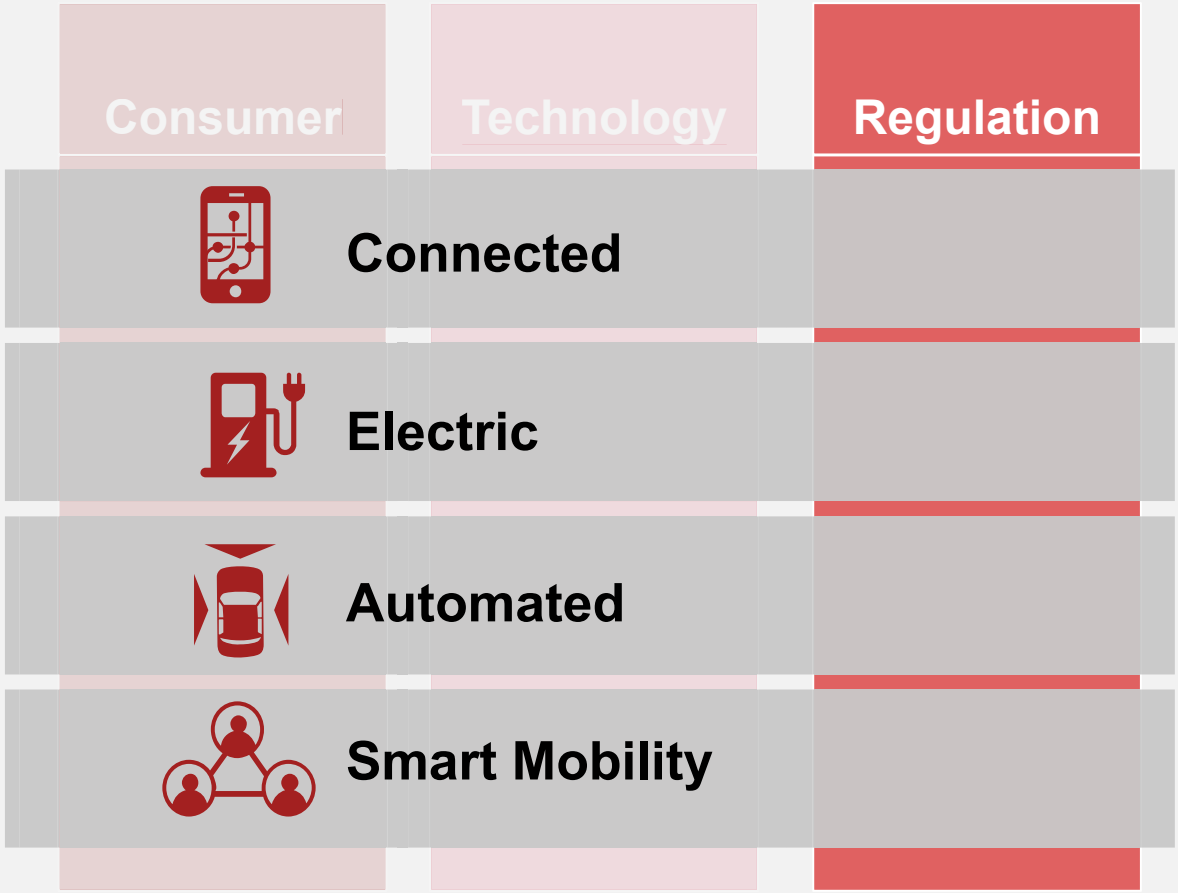
Current developments

In contrast to individual mobility, providing smart mobility requires a **modular technology and system architecture**, capable of **integrating various partners** across the ecosystem with focus on

- **Flexibility to integrate multiple modalities** and mobility service providers (with different brands)
- **Cross-platform customer acquisition** and seamless sign-up/-in
- Region-specific/**local mobility product configuration** and partner management, incl. ride request/ offering brokerage
- **Real-time environment/asset condition-based routing**
- Predictive **maintenance scheduling**
- **Predictive** asset **lifecycle management**

Source: Strategy&

“Regulation aims to accelerate the mobility transformation – but following very different approaches across regions”



Source: Strategy&

Dynamic regulatory discussions shape CASE trends – impacting EV penetration and speed of AV testing rollout in particular

Latest regulatory initiatives and discussions

USA

AUTOMATED Announcement to unify AV policies across 38 federal departments enforcing a consistent regulatory approach (01/2020)

AUTOMATED NHTSA with plan to introduce upgrades to NCAP, involving new safety technologies and test procedures (10/2019)

ELECTRIC Limited national support (i.e. plans to terminate EV subsidies)

Heterogeneous regulatory dynamics; focus on commercial dimension, less on sustainability

GLOBAL

CONNECTED **Internationally harmonized** and **binding UN norms** on **cybersecurity and software requirements** for **OEMs** (06/2020, UNECE's World Forum for Harmonization of Vehicle Regulation, WP.29)

AUTOMATED **First binding global regulation** on **level 3 vehicle automation** with **focus** on **advancing safety** (UNECE's World Forum for Harmonization of Vehicle Regulations)[2)]

AUTOMATED **Updated standards** for **on-road testing of level 3, 4 and 5 prototype ADS promoting a standardized groundwork** for **AV tech** (09/2019)[3)]

Recently introduced **regulations** at UN level with **positive impact** on **CASE adoption**, further **steps** still **required**

EU

CONNECTED **New guidelines** on the **processing** of **personal data** (EDPB, 02/2020)

AUTOMATED Addition of new advanced **test scenarios** to rate **AEB technology** (2020 EU NCAP update)

AUTOMATED **Updated guidelines** to enforce **advanced safety features** (01/2020)

ELECTRIC New **EU CO_2 emission targets**, applying as of 01/2020[1)]

SHARED **New governmental regulations** promoting **shared mobility** (e.g. free parking)

EU states with a **siloed / bottom-up approach** towards **CASE regulation**

China

AUTOMATED **Release** of the **"Strategies for Innovation and Development of Intelligent Vehicles"** with focus on creating an **ecosystem** for **AVs** in **China** (02/2020)

AUTOMATED Plans for **new changes to the NCAP test program** with new **safety additions** (following the Euro model)

ELECTRIC **New national guidelines on safety requirements** and **standards** for **EVs** (coming into force by January 1st 2021)

Top-down approach based on long-term **strategy with positive impact** on **CASE**

Positive expert sentiment **Neutral** expert sentiment **Negative** expert sentiment

Note: (1) the regulation targets a 15% reduction for passenger cars from 2025 onwards and 37.5% reduction from 2030 on. (2) e.g. establishes strict requirements for Automated Lane Keeping Systems. (3) incorporates "lessons-learned based on accumulated field experience in testing prototype ADS-operated vehicles on public roads". (4) general regulatory sentiment derived from various expert opinions across politics and industry, e.g. automotive associations. AEB = Automated Emergency Braking; AV = Automated vehicle; NCAP = New Car Assessment Program; NHTSA = National Highway Traffic Safety Administration; UNECE = United Nations Economic Commission for Europe

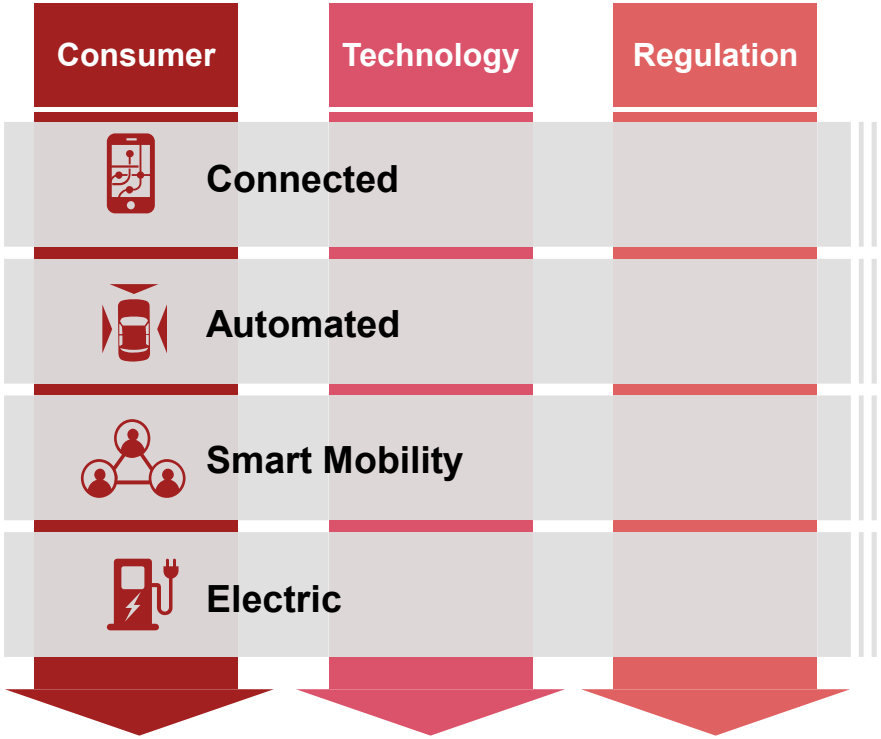
Source: Strategy&

Volume 2

Rethinking business models and investments

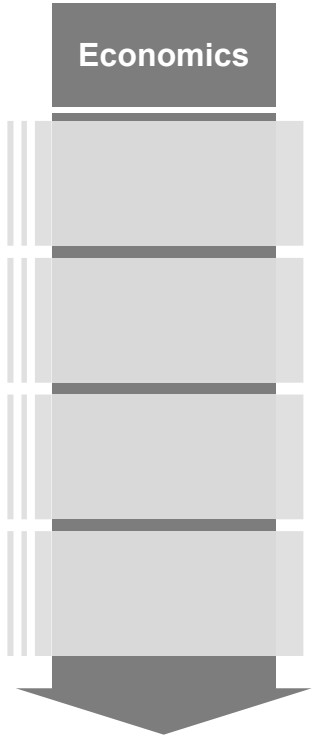
This volume focuses on 1) new business opportunities, 2) market potential and economics and 3) investment trends

Volume 1 – Recap



- **Connected, Electric, and Automated Driving** technologies **evolve** at **different speed** and with a **multitude of use cases** for Smart Mobility
- **Consumers** continue to show a **high level of interest in new technologies**, yet with regional differences and **uncertain willingness to pay**
- **Regulators struggle** to provide **consistent framework** for actively shaping the mobility transformation

Volume 2 – Scope of this document

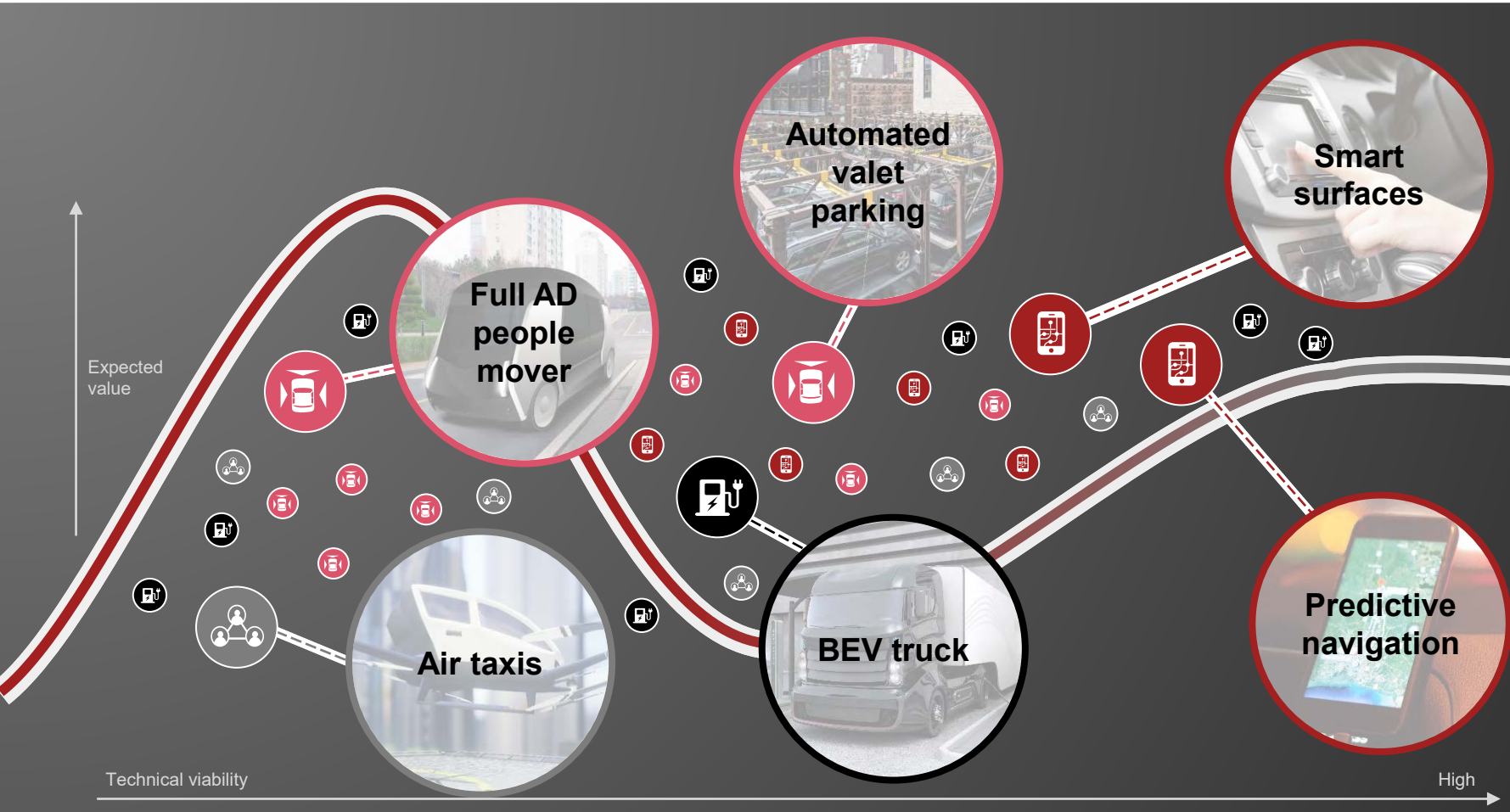


- Capturing **economic value** in a transforming mobility market requires
  1. **Realistic view on CASE** use case potential and maturity, based on broad range of different expert perspectives
  2. **Fact-based assessment** of true **market potential** of individual business models and applications
  3. **Focused investment decisions** to strengthen differentiating capabilities and pursue achievable way to play

Source: Strategy&

60+ industry experts were surveyed to better understand the maturity of emerging CASE technology use cases

Expert survey – CASE use case value and viability



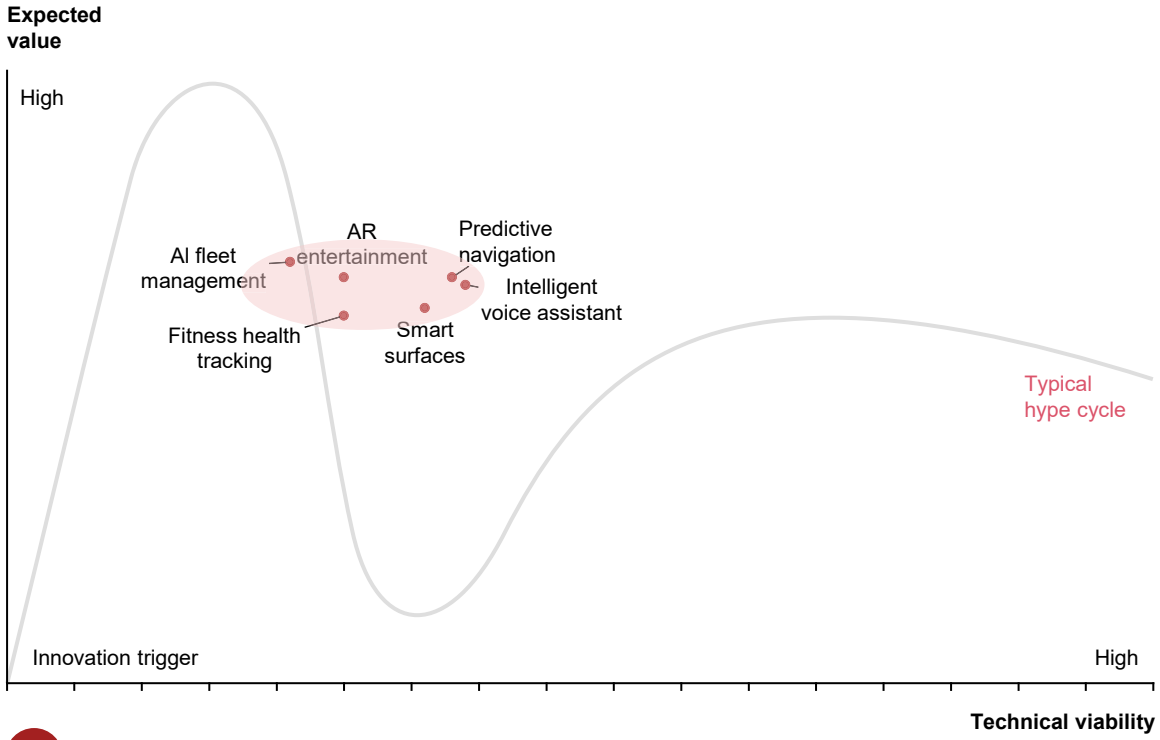
Key takeaways

- 60+ industry experts have been asked to **evaluate** ~30 use cases along **market potential** and technical **viability:**
- **Connected** use cases behind first peak of inflated expectations – most value expected in B2B applications (e.g. fleet management)
- While **BEV use cases start to plateau**, fuel cell possibly not yet at peak
- **Automated driving** use cases with higher value expectations in L4 goods transport than in private passenger transport
- In smart mobility**, micro-mobility with high value expectation** – on par with ride hailing
- **View on air taxis still unclear**, to some extent seen as niche market

Source: Strategy& expert survey in EU/US/CN (n=63)

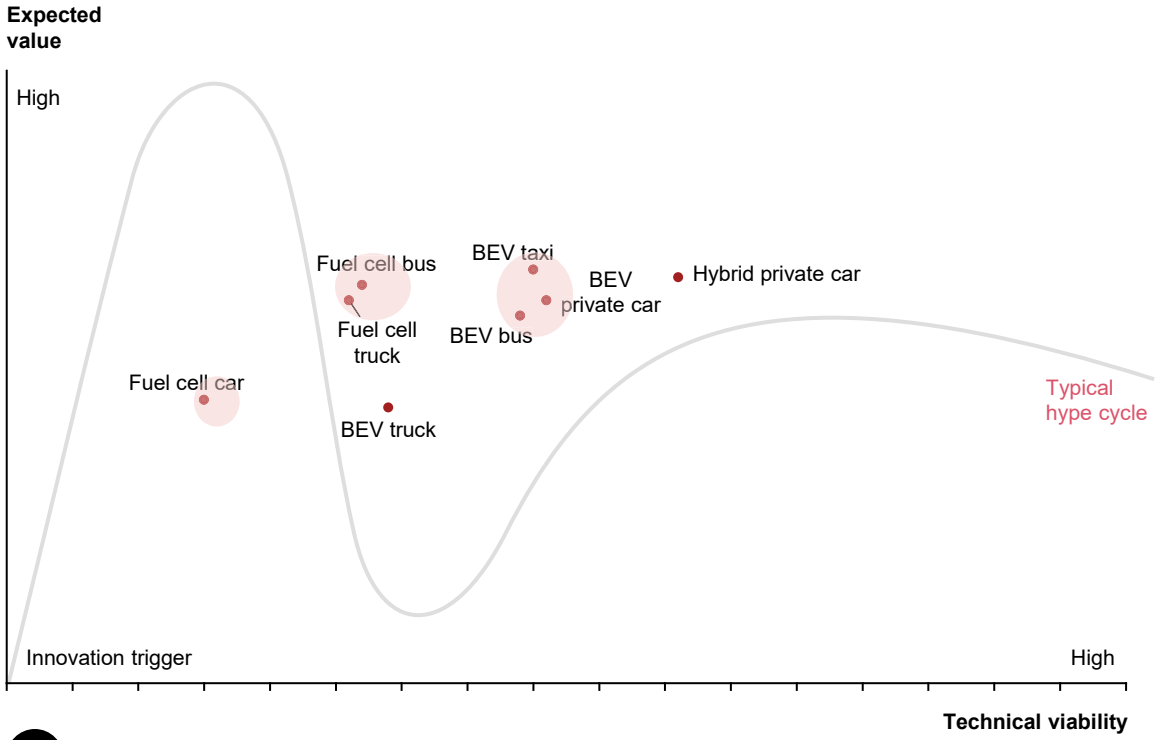
Experts see most connected and electric use cases behind the first expectation peak – fuel cell development still uncertain

Use case evaluation (1/2) – Connected and Electric



Connected

- Overall, **connected** use cases **behind first peak** of inflated expectations
- **No clear winner** – B2B applications (e.g. AI fleet management) with slightly higher expected potential than B2C (e.g. Fitness tracking)



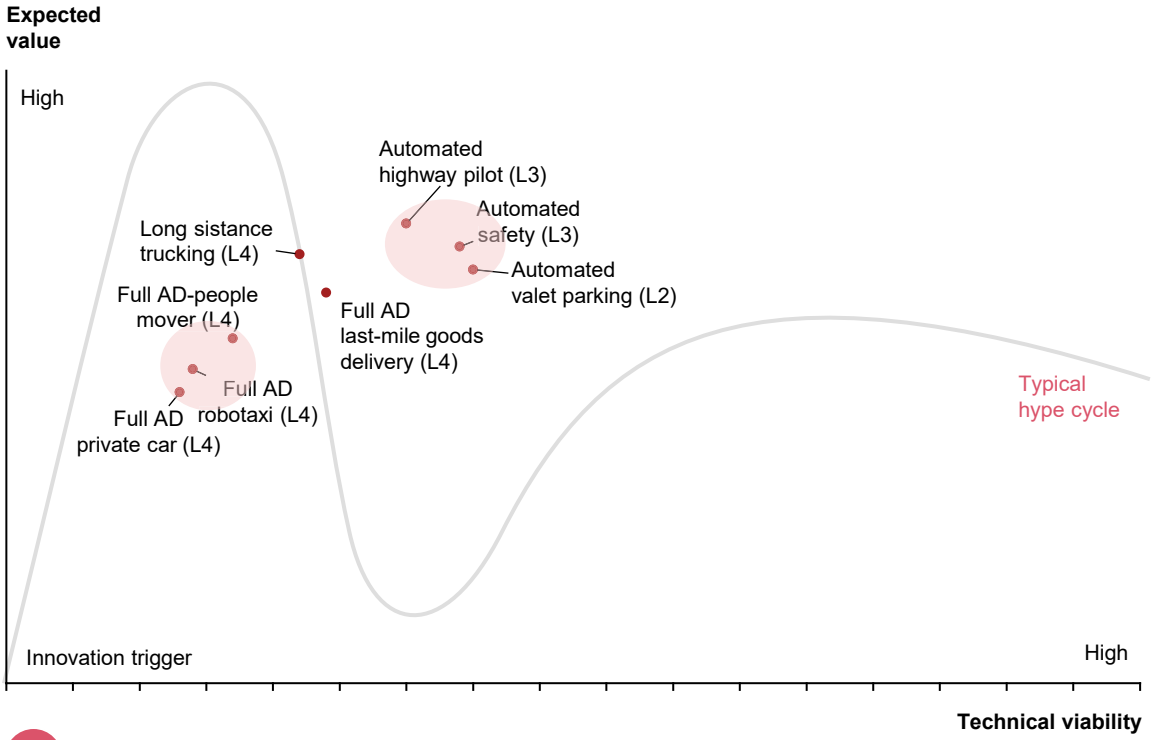
Electric

- While **BEV** use cases **start to plateau**, fuel cell possibly not yet at peak
- **European experts rate fuel cell potential higher** than Chinese respondents – in particular for **commercial vehicles** (bus, truck)

Source: Strategy& expert survey in EU/US/CN (n=63)

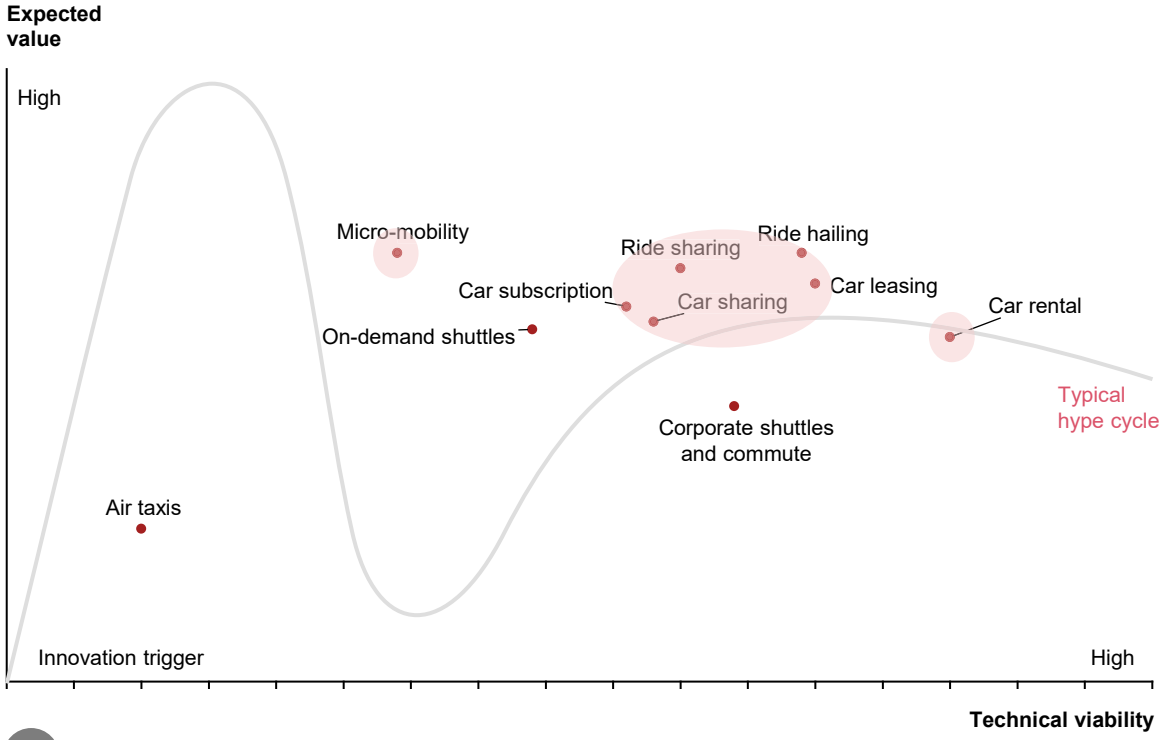
Experts rate L4 market potential and technical viability for goods transport higher than for passenger transport

Use case evaluation (2/2) – Automated and Smart Mobility



Automated

- **L3 use cases** (highway pilot, automated safety) seen to have **relatively high market potential** and viability across regions
- Most **L4 use cases below/after first expectation peak** – commercial use cases (trucking, last-mile) with higher market potential than private use cases



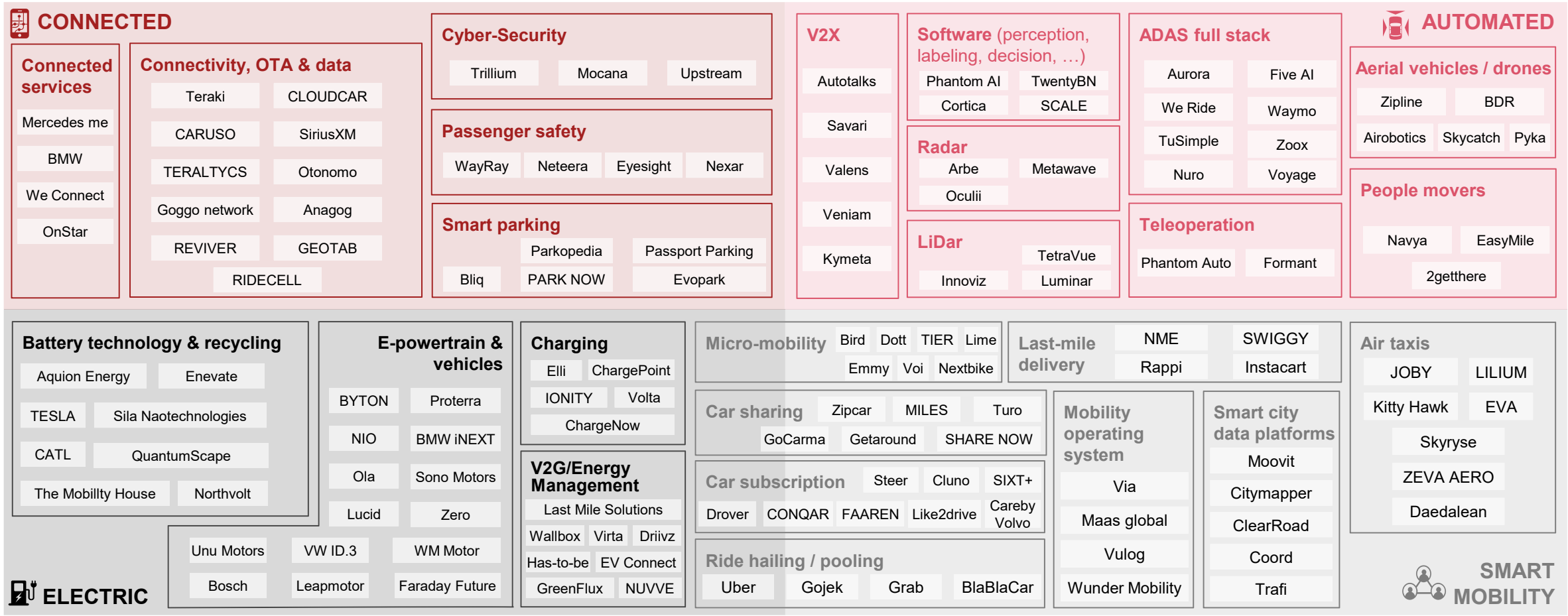
Smart Mobility

- Many smart **mobility use cases** deployed and therefore **at plateau stage**
- **Micro-mobility** with **high value expectation** – **on par with ride hailing**
- View on **air taxis still unclear**, to some extent seen as niche market with low viability

Source: Strategy& expert survey in EU/US/CN (n=63)

Well-funded specialized players and startups put traditional players under pressure across all CASE components

Map of CASE technology players (selection)



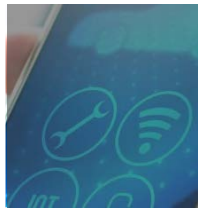
OTA = Over-the-air V2X = Vehicle-to-anything V2G = Vehicle-to-grid
Source: Strategy&

Automotive OEMs' connected service roadmap is evolving with different priorities and ambition levels

Connected services – Examples

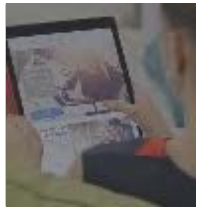
Vehicle features -as-a-Service

- **Light** – BMW high beam assist
- **Access** – Tesla virtual bluetooth keys
- **Camera** – Tesla sentry mode
- **Suspension** – BMW adaptive suspension
- **Pak assistant** – Audi A6 parking assistant*
- **Autonomous driving** – Tesla autopilot upgrade
- **Cruise control** – BMW adaptive cruise control
- **Phone integration** – Daimler MBUX
- **Sound** – BMW e-engine sound pack



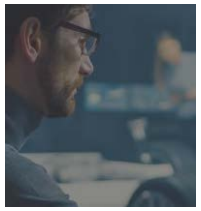
Vehicle-centric services

- **Advanced navigation** – MB live traffic
- **Music streaming** – BMW Spotify
- **Music** – NIO radio
- **Passenger safety** – NIO fatigue warning
- **Vehicle management** – VW we connect
- **Intelligent car assistant** – Alibaba Audi/Volvo/Daimler
- **Loyalty program** – My Chevrolet Rewards
- **Gaming** – Tesla arcade
- **Entertainment** – Tesla caraoke



Beyond-vehicle offering

- **Parking search & pay** – VW we park
- **P2P car / ride sharing** – Sono motors app
- **Smart Home Connection** – BMW IFTTT
- **Last Mile Logistics** – NIO delivery in trunk
- **Personal emergency assistant** – GM OnStar guardian



Data/insights services

- **Fleet mgmt. / diagnostics** – Daimler connect business
- **Car data based insurance** -- BMW CarData
- **Car data marketplace** – Caruso, Otonomo, High M.
- **Driver's log / GPS tracking** – Daimler connect business
- **Predictive maintenance** – BOSCH, Carmen

Degree of innovation

Relatively low → Relatively high

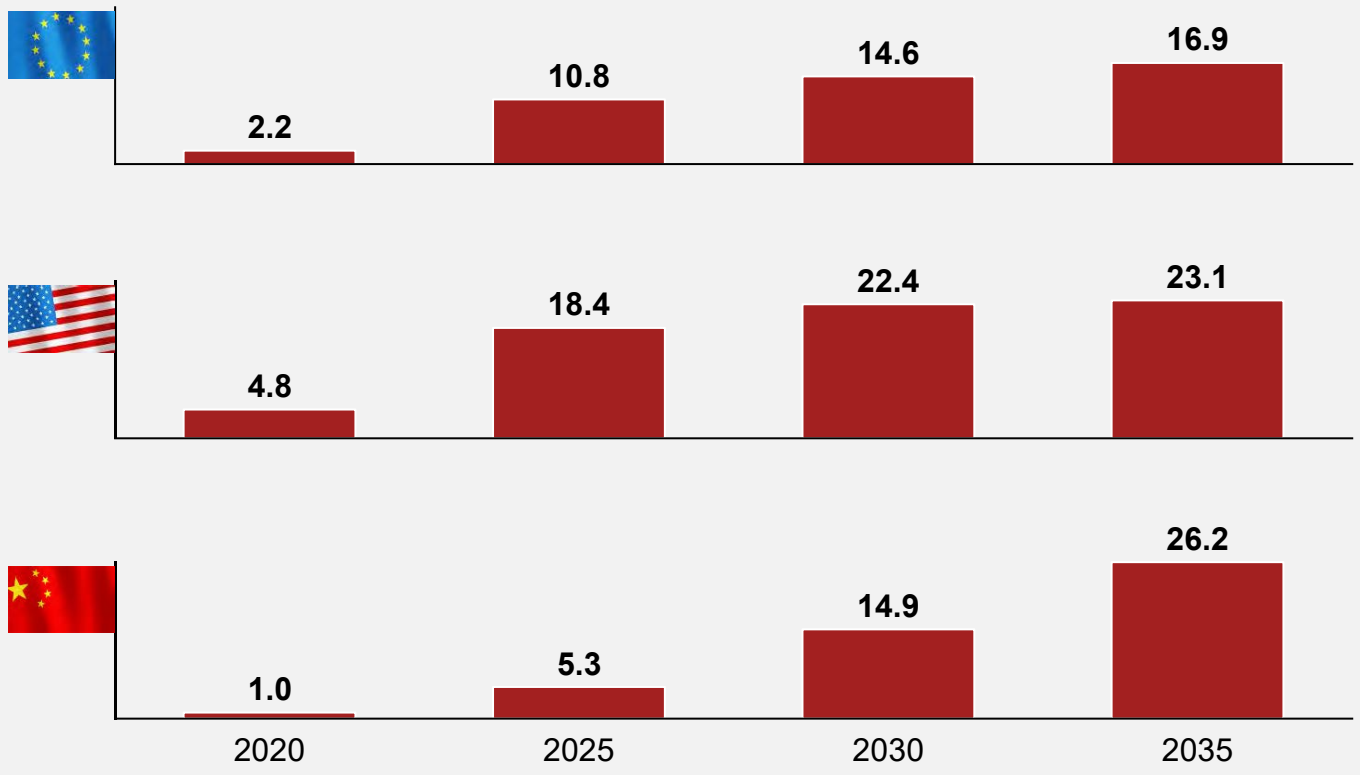
*) Announced by OEM
Source: Strategy&

Established players | New players

Connected service monetization remains challenging – potential for B2C monetization of $66 bn by 2035

Connected services – Market outlook

Revenue potential (B2C) (in USD billions)



Comments

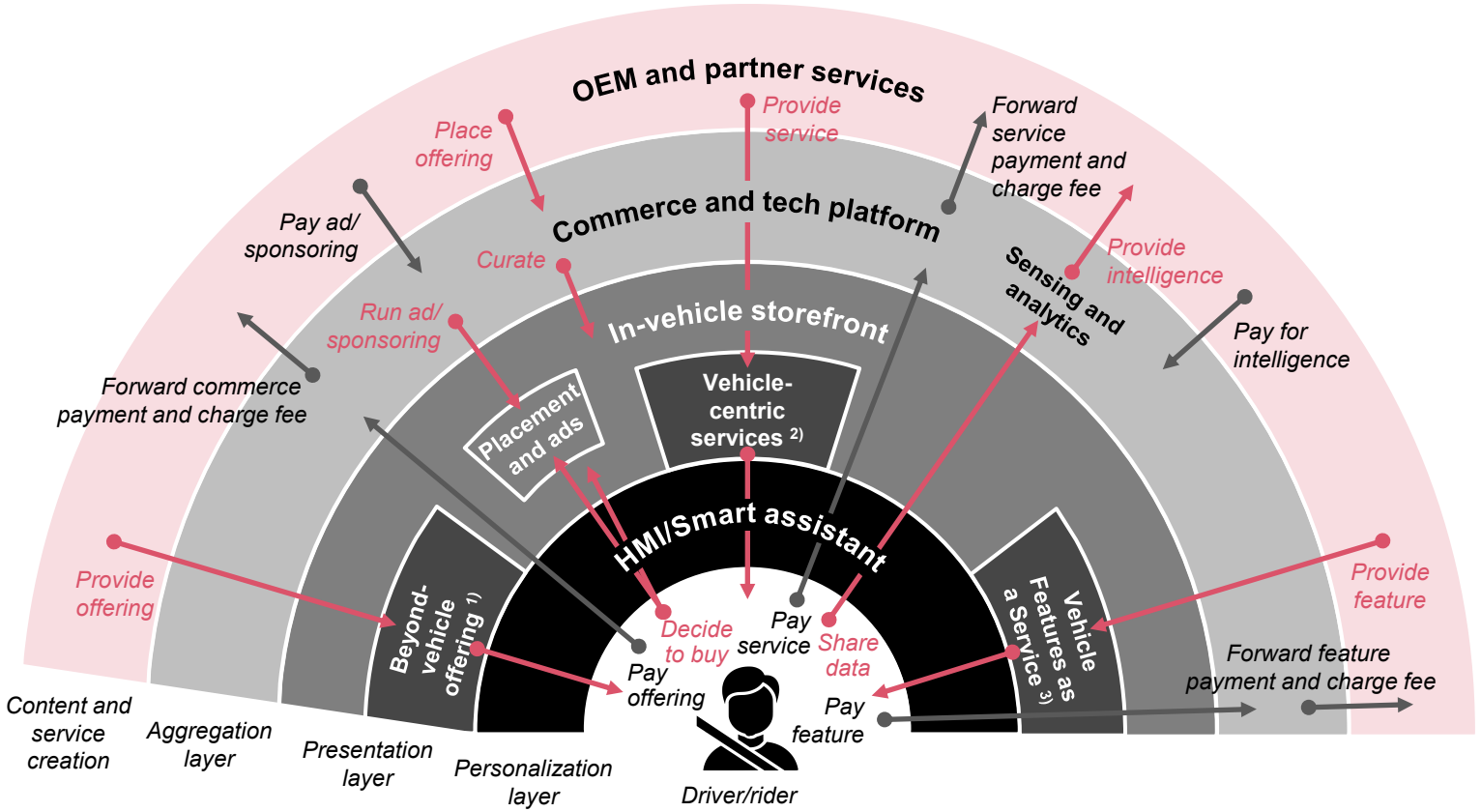
- **Overall revenues** from vehicle-centric connected services (e.g. advanced navigation) are driven by **growing connected car penetration**
- However, **willingness to pay per service quickly erodes** as customers get used to the specific service (commoditization)
- Profitability depends on OEMs' **pricing strategy** and **network operator cost** (data plans)
- As connected services increasingly **contribute to overall customer experience**, OEMs continue to invest in innovative offerings despite limited profitability
- **In-vehicle service marketplaces** accessible via HMI (5th screen) provide additional revenue opportunities, but at **limited margins** due to relatively low commissions for the OEM

General assumption: OEMs launch a portfolio of services with direct monetization intent
Source: Strategy&

HMI: Human machine interface

Connected service marketplaces bring physical and digital content to riders via a central, curated personalization layer

Connected services – Marketplace example



1) Service delivery primarily outside the vehicle (e.g. goods commerce, mobility services, digital life services)
2) Service delivery primarily inside the vehicle (e.g. vehicle management, in-vehicle content)
3) On-demand booking of vehicle hardware/software features (e.g. seat heating or power upgrade on demand)
Source: Strategy&

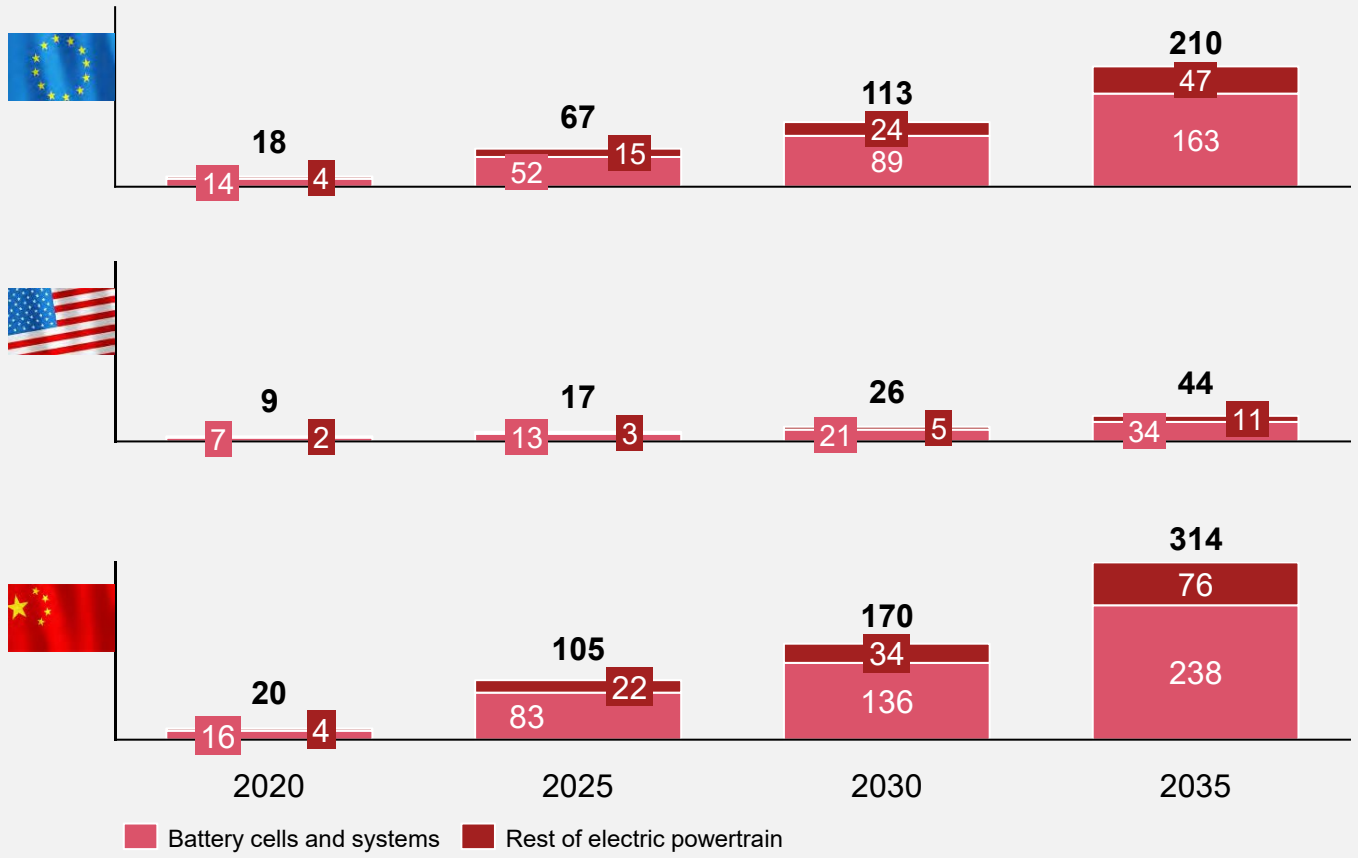
Key findings and implications

- In-vehicle **marketplaces enhance driver and rider experience** by providing a range of features, services and goods (OEM, partners)
- Marketplace operators enable drivers/riders to **experience and consume** OEM and 3rd party **brand environments** with in-vehicle or external fulfillment
- As the key driver/rider touchpoint, in-car smart **assistants remain a battleground** – premium OEMs go captive, others prefer open source
- **Direct B2C/B2B monetization challenging:**
  - Captive (Vehicle FaaS, vehicle-centric services) → **limited willingness to pay**
  - Brokered (Vehicle-centric, beyond-vehicle offering) → **limited transaction volumes**, relatively low commissions
  - Ads/sponsoring → **limited number of eyeballs**

Electric powertrain and battery markets expected to grow strongly, especially in EU and China

Electric powertrain and battery – Market outlook

Revenue potential[1] (in USD billion)



Comments

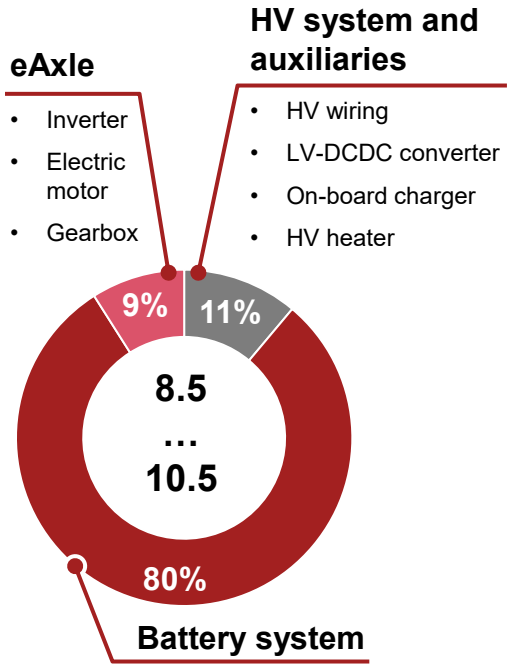
- **Market potential development** driven by **significant increase** in **alternative powertrain penetration**
- Increasing number of **favorable legislations** (e.g. city bans for combustion engines) and **general popular sentiment** are underlying drivers for **global electrification trend**
- **Battery cells and systems** experiencing large drop in costs, but still represent by far the largest cost share in electric powertrains
- Next to battery, second largest cost share of electric powertrain within **e-axle** (covering electric motor, inverter and gear)

1) Revenue on OEM sales price level
Source: Strategy&

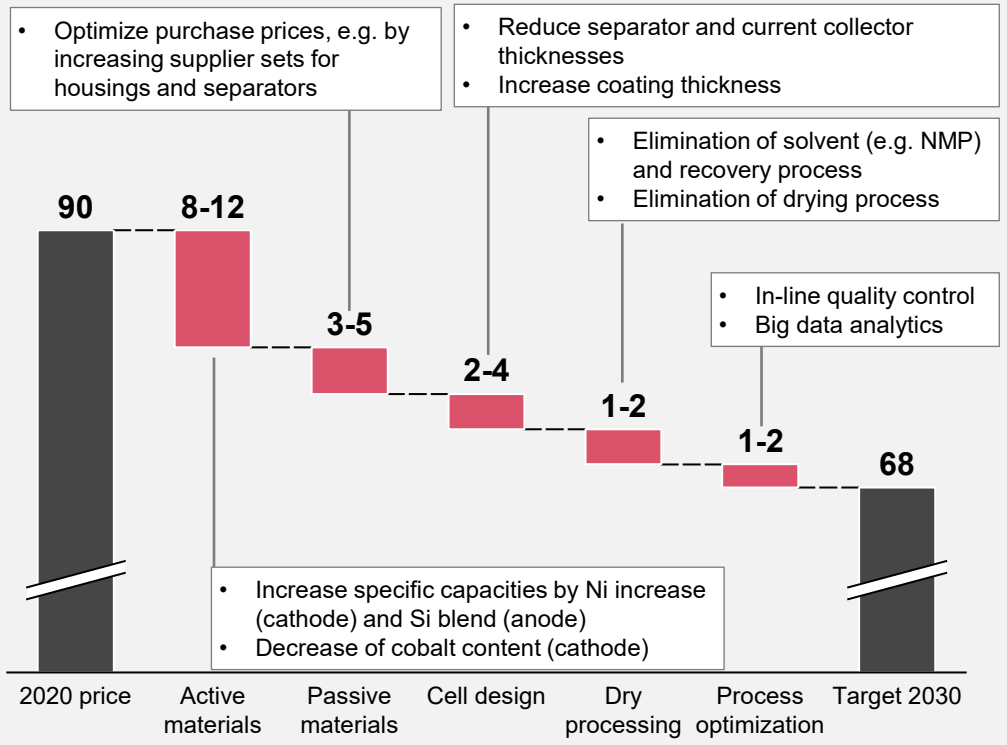
BEV powertrain cost is driven by the battery system (80%); cost reduction of 25% on cell and system level expected by 2030

Electric powertrain and battery – Cost breakdown

Cost breakdown BEV powertrain



Cell prices and selected optimization measures till 2030 (€/kWh)



Large (>70 Ah) automotive cells in large quantities (>10 GWh/p.a.)

Key findings and implications

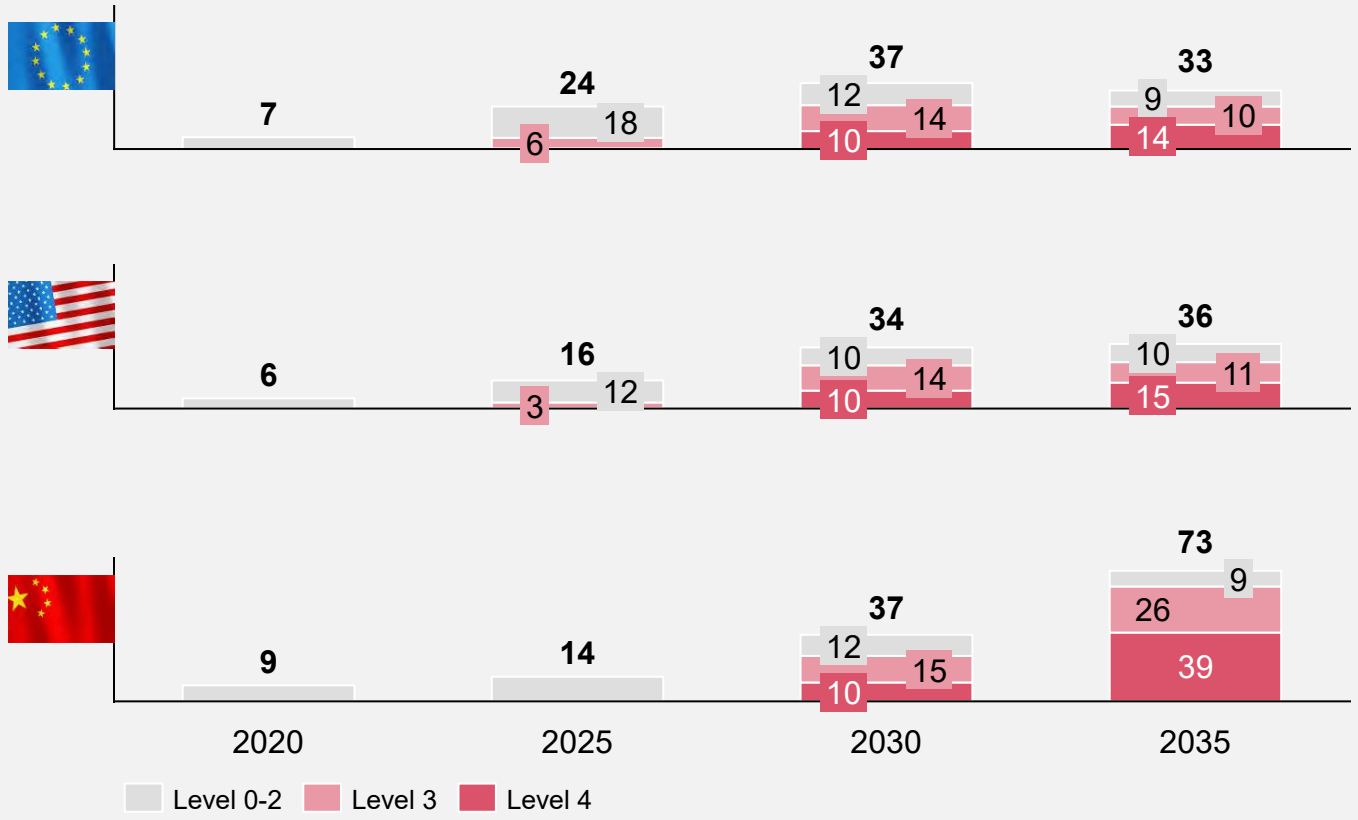
- **Battery system** as the **main cost component** for a **BEV powertrain** (approximately 80%)
- Within **battery system**, **cells** comprise most of the associated **costs,** with optimization of their production process as an important cost lever
- **Optimizing active materials** (e.g. decreasing cobalt content) and **passive materials** (e.g. reducing purchase prices) can help to **substantially decrease cell and battery system costs** by 2030
- **Recycled cell material** with additional **high cost optimization potential**

OEM production costs 2020, 60kWh/100kW, volume class; € thousand; projection based on existing NCM battery technology
Source: Strategy&

OEM revenues allocated to ADAS parts expected to reach $142 bn by 2035 – L4 revenues to quickly outperform L3 once available

Automated driving – Market outlook

Revenue potential[1] (ADAS parts value contribution to total vehicle sales, in bn USD)



Comments

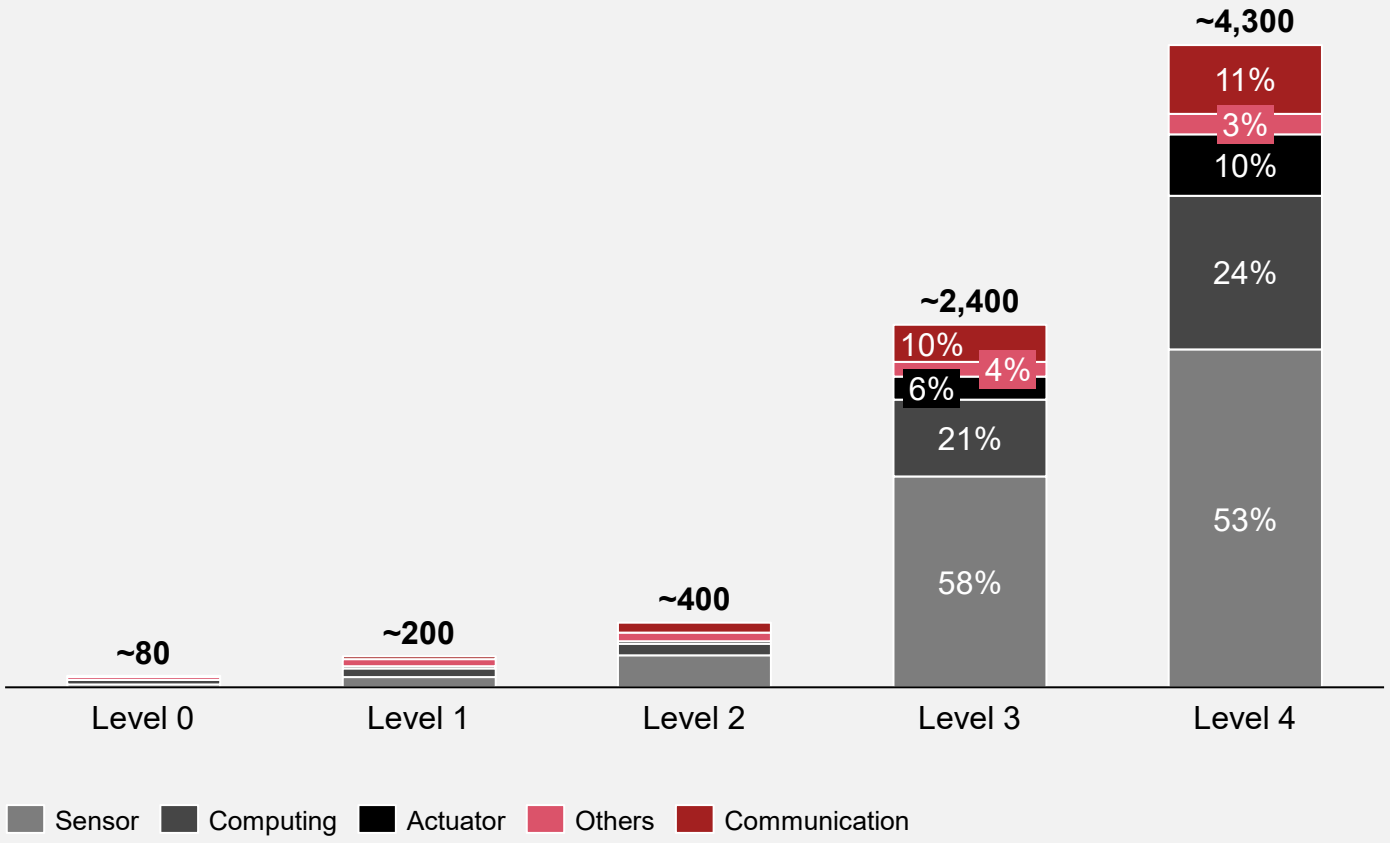
- The forecast reflects **the additional revenues of OEMs** through **new ADAS components** (sensors, actuators, computers, wiring harness, HMI, ...) in the vehicles
- Strong **revenue increase due to EU regulation** from 2022 to 2024, and at the same time **price decrease due to scaling** effects
- Strong **increase of Level 3** applications expected in North America, China and EU, **beginning 2026**
- **Push of Level 4 applications** expected **after 2029** with increased use of **highway pilots** and **valet parking** in China and EU

1) Passenger vehicles and people movers
Source: Strategy&

ADAS cost is driven by sensor prices (>50%); LiDAR sensors / computing expected to drop significantly once volumes grow

Automated Driving – Cost breakdown

ADAS System Material Cost[1] per vehicle (in USD, 2030)



Comments

- Significant **cost reduction expected for LiDAR** sensor and computing unit with rising volumes
- Cost **reduction of cameras and radar** sensors expected **from 2022 to 2024** with new EU regulations due to increase in volumes and scaling effects
- Higher **cost reduction expected for better equipped Level 3 and 4** vehicles due to **new sensor technologies** and rising scaling effects

1) Excluding OEM development and assembly cost
Source: Strategy&

Alternative car ownership models offer new opportunities with increasingly blurred lines between mobility modes

Smart mobility – Subset: Traditional vs. alternative car ownership models

Traditional car ownership → *Alternative ownership*

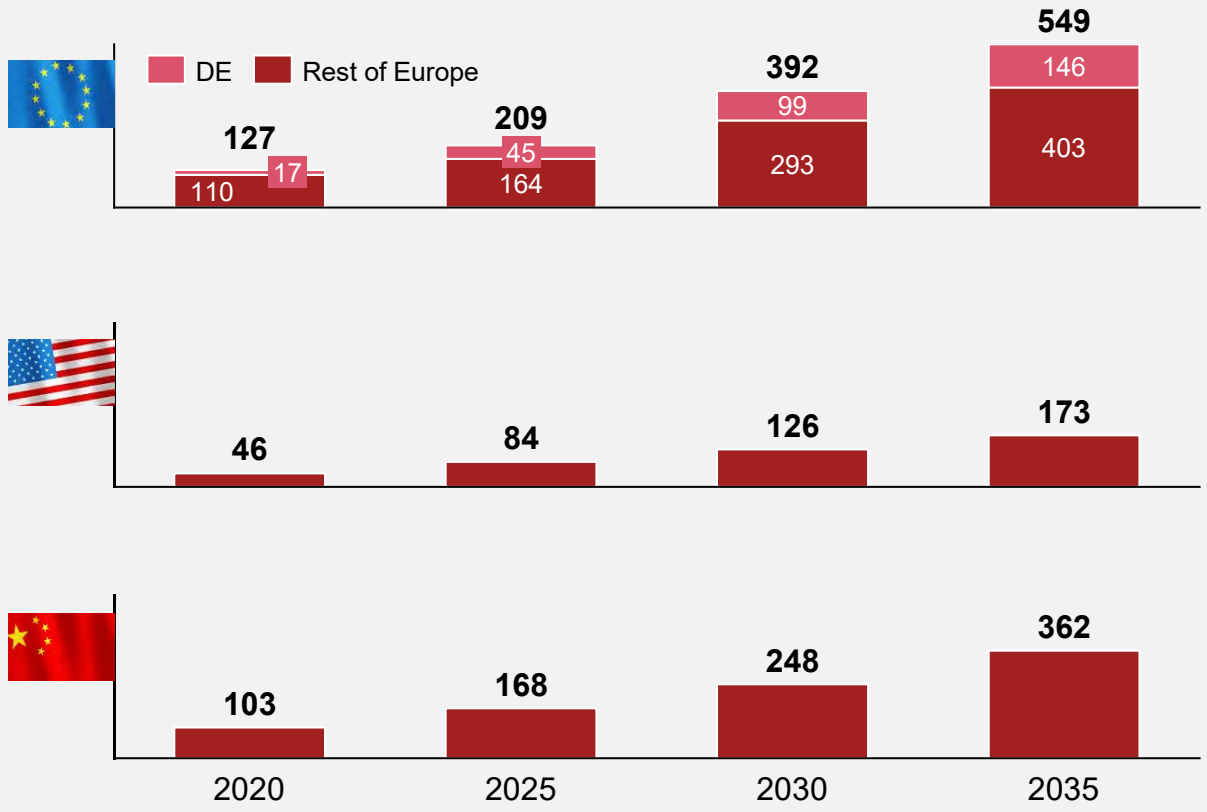
Ownership models	1 Purchase	2 Leasing	3 Subscription	4 Rental	5 Car sharing	6 Ride hailing/ sharing[1)]	7 Automated people mover	8 Micro-mobility
Total cost of mobility (TCM) per km today[2)]	**0.6 $/km**	**0.8 $/km**	**0.7 $/km**	**0.4 $/km**	**1.1 $/km**	**2.1 $/km**	**<1.9 $/km[4)]**	**1.6 $/km**
Driver motivation and distance sweet spot	Control-seeking, all distances	Avoiding upfront investment, all distances	Experience-driven, all distances	Flexibility-driven, intercity medium distances	Spontaneous, short urban distances	Comfort-seeking, short urban distances	Time-sensitive, short urban distances	Time-sensitive, super-short urban distances
Profitability today[3)]	**5-7%**	**10-15%**	**No data available**	**10-15%**	**<5%**	**7-10%**	**Not yet profitable**	**Not yet profitable**

1) Multiple people pooled in one ride 2) TCM = total cost of mobility for end user in Germany incl.: vehicle (mid-sized car), insurance, maintenance, and gas; figures base on typical usage patterns per mode;
3) Estimate based on annual reports, newspapers, expert input
Assumptions: Mode 2: average of leasing offers 15,000km yearly, 24 months, Mode 3: average of current subscription offers, Mode 4: average of rental offers at 250km over 3 days, Mode 5: typical city trip, Mode 6: typical city trip by taxi, Mode 7: typical city trip, Mode 8: average of current micro-mobility offerings (e-scooter)
Source: Strategy& research

Alternative car ownership offers significant market opportunities in Europe, followed by China and the US

Smart Mobility – Subset: Alternative car ownership market outlook

Total revenue potential (in USD billion)



Comments

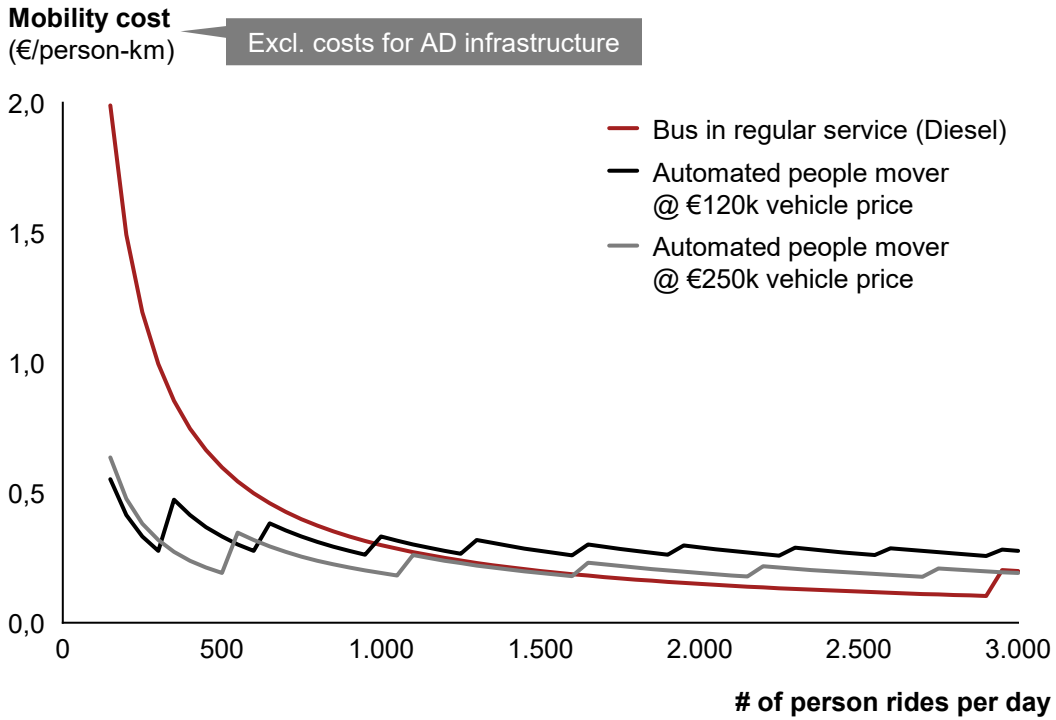
- **Alternative car ownership** sector = **Active shared** (car subscription, rental, sharing) **+ passive shared** (ride hailing, robo-hailing) mobility modes
- **COVID-19** and **delayed L4** technology resulting in more **conservative projections** than previously shown
- **Europe**: **Established active / passive shared mobility** modes plus increasing demand for **subscription** models
- **US**: Moderate market outlook given **strong preference for car ownership** at comparable low cost
- **China**: While kilometers driven in shared passive modes (in particular taxi) are much higher than elsewhere, **per-km prices are 3-4 times lower** resulting in overall **lower market potential than in Europe**
- While automated driving will push shared modes in the long run, it will take >10 years until superior economics are achieved in a broad majority of use cases (beyond urban mobility in larger cities)

Source: Strategy&

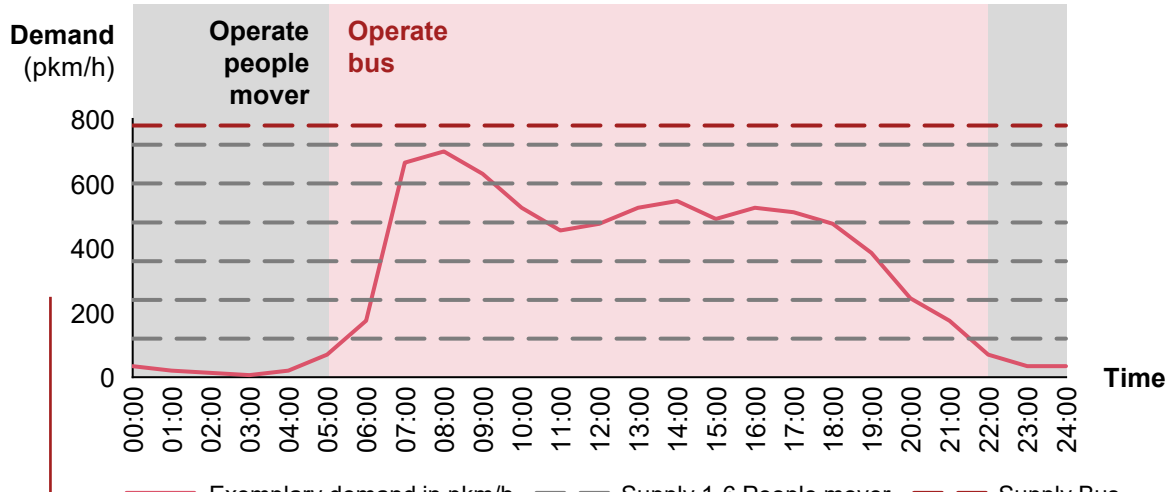
Mode-specific view required to assess cost advantage of new mobility (e.g. people mover) vs. existing modes (e.g. bus)

Smart Mobility – Example: Automated people movers

Cost – Automated people mover vs. bus[1)]



Mobility mix optimization (simulation)



	Drive time[2)]	Total operating costs
Bus only	24h bus/0h people mover	100 (indexed)
People mover only	0h bus/24h people mover	128 (indexed)
Mixed operation	18h bus/6h people mover	82 (indexed)

-18%

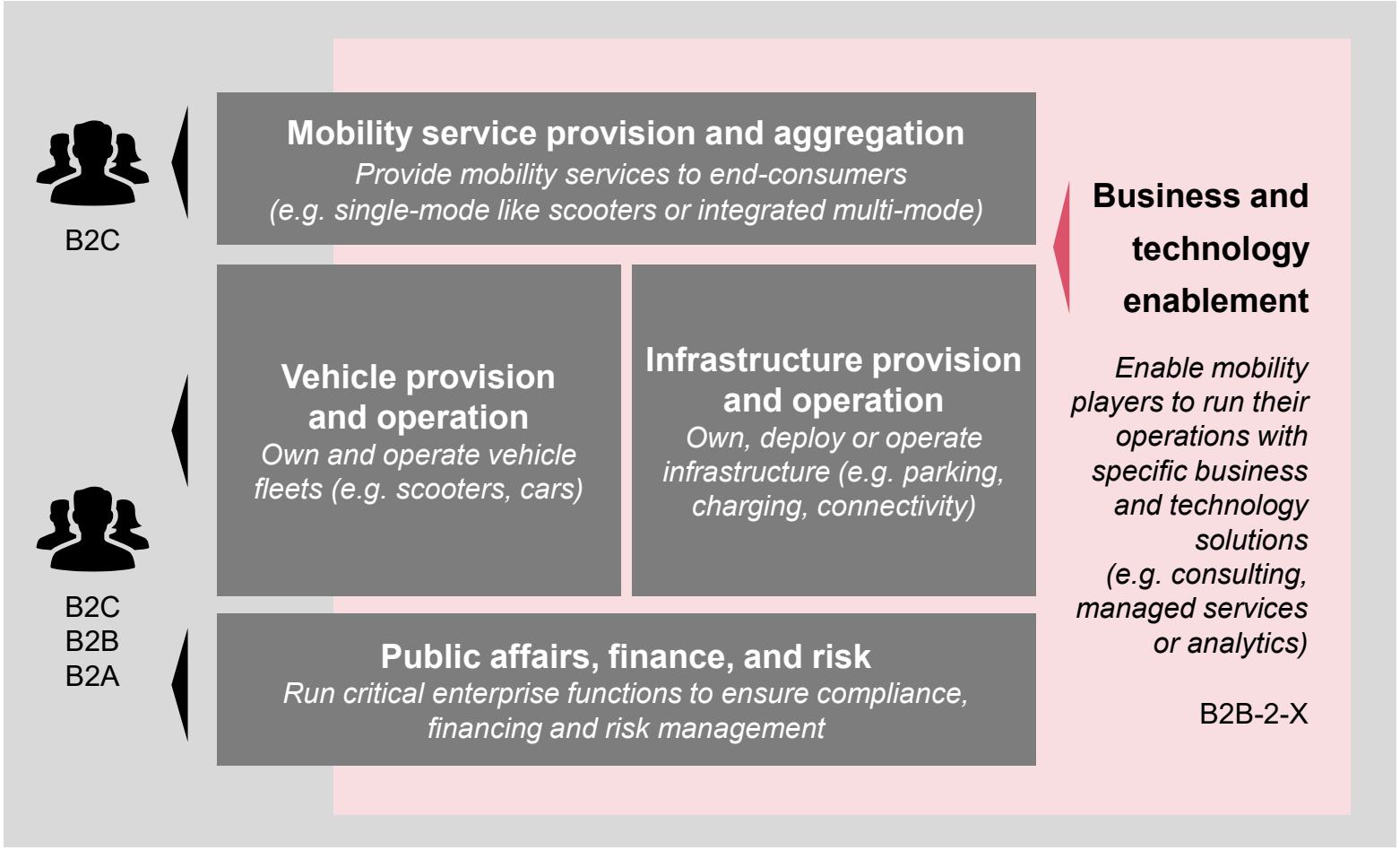
For low demand routes (< 1.000 person rides / day) people movers have a clear cost advantage vs. traditional bus services

Operator cost optimum is achieved by dynamically combining people movers with traditional busses

1) Ø speed bus 13 km/h; Ø speed people mover is 10 km/h; Ø operating hours per day: bus up to 21h, people mover up to 15h; Ø ride distance per person 5 km; Occupancy of vehicles up to max. capacity (bus 60 persons, people mover 12 persons) before another vehicle is used 2) Required charging / driver change time not taken into account
Source: Strategy&

A profitable smart mobility business requires the right selection of value blocks – potentially combining B2C and B2B offerings

Smart mobility – Main value blocks



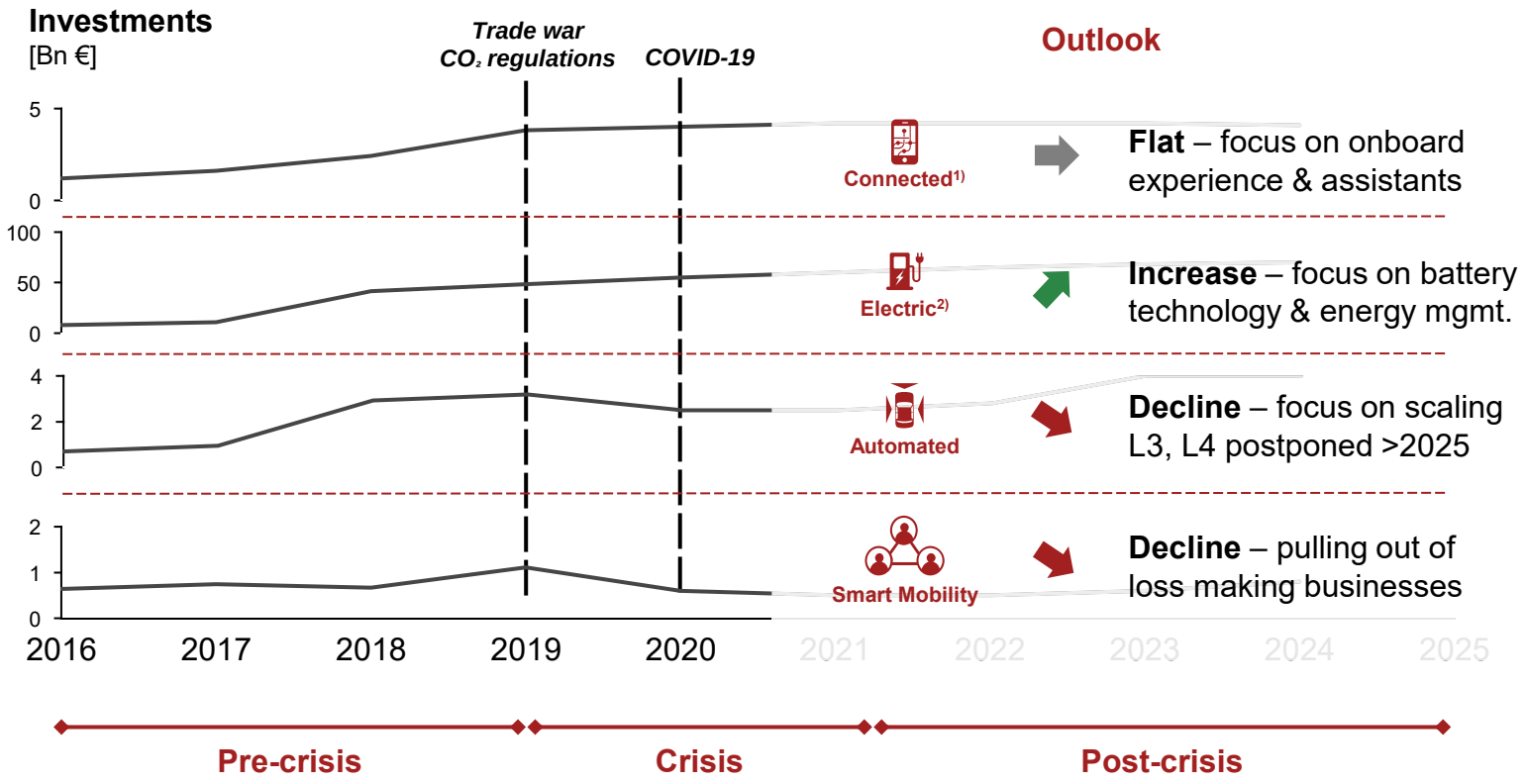
Comments

- Players entering the smart mobility space must evaluate four questions
  - **Where** to play in the mobility ecosystem (which value block / mode)?
  - **What** is the right offering (which degree of business / technology enablement)?
  - **Who** is the customer (B2C, B2B, B2G)?
  - **How** is the offering delivered (which partners) ?
- Identified opportunities should be diligently assessed for attractiveness and individual right to win
- Leading mobility technology players pursue a **dual strategy** combining **B2C** and **B2B** offering to stay close to the consumer while quickly **reaching scale**

Source: Strategy&

Traditional automotive players will need to rethink their investment strategy to capture value in a post-crisis growth era

OEM investment history and outlook



Comments

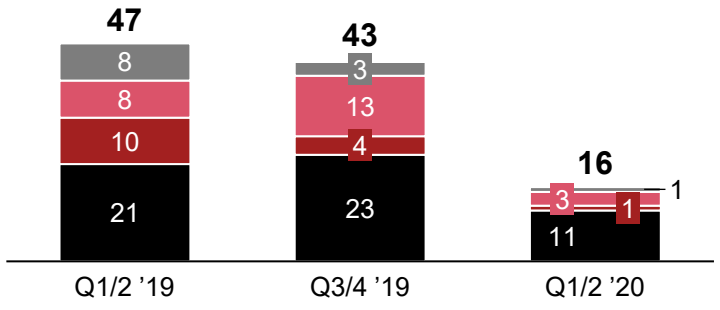
- **With COVID-19 cutting topline** and **regulatory pressure** to adjust vehicle portfolio (CO2 targets), **liquidity became critical** over the 12 months – many investments were put on hold
- Once entering a post-crisis era, **OEMs and suppliers** will need to **refocus their investments** to achieve a **competitive position**
- While a **push on electric mobility is expected**, the outlook on **automated driving** and **smart mobility** is **mixed**
- In automated driving, an **alliance** approach is expected to share development cost
- In smart mobility, **OEM captives** / banks could become the driving force investing in flexible leasing / **subscription models**

1) Incl. software and digital experience 2) Incl. fuel cells
Source: Strategy& research

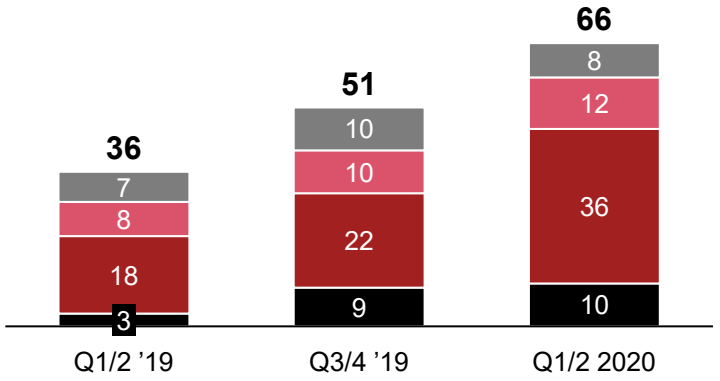
Compared to VCs and Tech Players, OEMs lost ground in connected, automated and smart mobility investments

Investment overview (# of cases 2019/20)

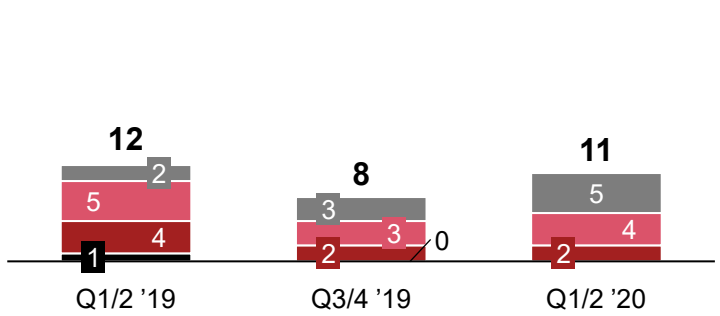
OEMs[1)]



Venture Capitalists[2)]



Tech Players[3)]



OEMs focus on defending core business with investments in alternative / electric powertrain

VC‘s investing in startups building full stack expertise for smart mobility solutions

Tech players accelerate with selective high-volume investments into connected / automated driving

Connected Automated Smart Mobility Electric

Source: Strategy& research, company press announcements, financial statements. Analysis shows total number of single investments (independent of investment amount) 1) Analyzed largest investments of 10 relevant global OEMs incl. Volkswagen Group, Toyota, GM, Hyundai-Kia, Ford, FCA, Nissan / Renault / Mitsubishi, PSA, BMW Group, Daimler; incl. inter-company investments (e.g. into plants) 2) Analyzed largest deals as available, Source: Pitchbook 3) Analyzed relevant investment of 10 global Tech Players incl. Apple, Microsoft, Alphabet/Google/ Waymo, Tencent, Alibaba, Amazon, Uber Technologies, Baidu

VC's invest increasingly in specific software applications with focus on connectivity, security, and platform integration

Investment themes and trends

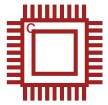
Investment theme		Description	Trend[1)]
Connected	Connectivity & data management	**Technology (software/hardware)** to provide **vehicle connectivity, cloud-based mobility/vehicle data management,** and **analytics services**	↑
	Smart parking	**Software** to locate and **navigate to free parking** space; facilitate **payment** transactions**; enable parking space management**	→
	Cyber-security	**Technology** to protect connected vehicles and smart mobility/IoT providers from **cyber-threats and misuse**	↑
	Passenger safety	**Technology** to improve **driver's safety** (e.g. augmented reality/dash cams) and **monitor driver's health** (e.g. micro sensing/monitoring of vital signs)	↑
Electric	Electric vehicle startups	New **vehicle concepts** with dedicated **platforms, architecture and design** for fully **electric driving** (light vehicles, vans, trucks)	→
	Battery & powertrain technology	**Battery and powertrain technology** to improve charging **time, range, lifetime, performance, cost** and **safety**	↑
	Charging & V2G/energy mgmt.	**Charging infrastructure solutions** to enable convenient charging environment (including routing to charging station, reservation, charging, payment)	↑
Automated	Software (perception, decision, …)	**Machine learning algorithms/software** to enable **visual identification and tracking** of environment and moving objects for automated driving	→
	Radar/LiDar	**Radio/laser wave** sensors/imaging technologies for **automated driving systems** (e.g. measuring distances of surrounding objects)	→
	ADAS full stack	**Integrated technology stack** (software and hardware) providing end-to-end **advanced driver assistance capabilities** (L3/4/5) to vehicles	→
	Teleoperation	**Systems** that enable a **human operator** to **observe/analyze/operate** and **remotely intervene** when **automated vehicles** need assistance	→
	V2X	**Vehicle-to-anything technology** allowing vehicles to **communicate** with their environment (e.g. other cars, traffic systems, charging station, smart home)	→
	People movers	**Technology** to provide an electric, automated vehicle (for 7-12 passengers) navigating on defined routes (separate lanes or mixed traffic)	→
	Aerial vehicles	**Drone technology** (hardware, software) enabling **manned & unmanned vehicles** to operate in the sky (e.g. for **surveillance** or people/goods **transport**)	↑
Smart Mobility	Air taxis	**Air mobility solutions** providing automated guidance, navigation, operation and control of new, small **aircrafts** (mostly electric powered)	→
	Smart city data platform	**Platforms** integrating large amount of data from various stakeholders to connect city operations and optimize urban traffic (tolling, traffic mgmt., routing, …)	↑
	Mobility operating system	**Modular system** of various **software components** to **enable mobility platform operations** (fleet mgmt., asset lifecycle mgmt., booking engine, …)	↑
	Ride hailing/pooling	**Platforms** matching **drivers with riders** to conduct **individual trips** (hailing) or to enable **shared trips** with multiple passengers (pooling)	↓
	Car sharing	**Platforms** matching **cars with customers** for short-term **rent by the minute** (station-based or free floating; professional fleets or private cars/peer-to-peer)	↓
	Car subscription	**Platforms** offering **cars** (single brand or multi-brand) for **short-term lease** with monthly model switch or termination option at a monthly package rate	↑
	Micro-mobility	**Platforms** offering **ultra lightweight vehicles (e-bikes, scooters)** for **short-term rent by the minute** (station-based or free floating)	→
	Last-mile delivery	**Platforms** enabling **urban door-step delivery** of **goods** (e.g. grocery/food/e-commerce) matching riders with merchants/consumers	↑

1) Based on expert opinion (considering recent investor activities, market size/growth, competitive dynamics)
Source: Strategy&

Invest momentum ↑ Accelerating ↓ Slowing down

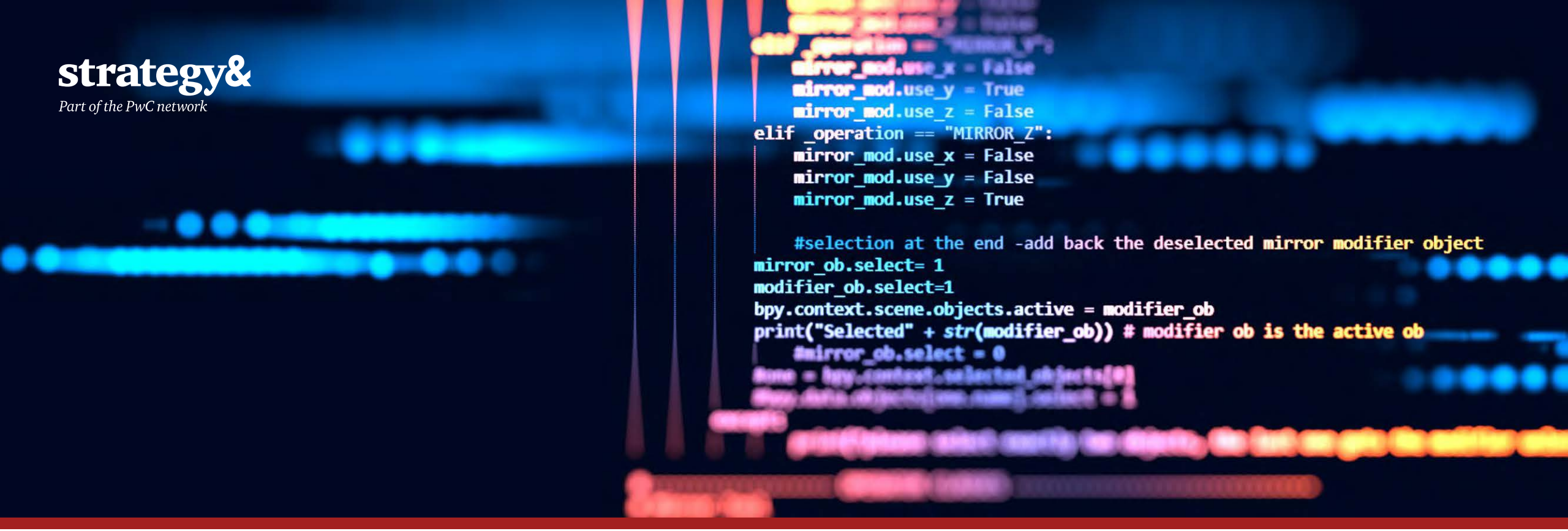
Conclusion: Traditional automotive players need to balance their defensive and attacking games to stay competitive

Key take-aways for traditional players

		Defense	+	Attack
CASE portfolio		**Restructure CASE investment portfolio** Refine investment criteria and strategy; review investments; refine governance; divest assets with unclear profitability outlook		**Double down on ONE way to play** Define 1-3 (max.) growth areas along CASE invest themes; refine own market role; accelerate scale-up via acquisitions
Business model		**Repair core business (vehicle sales)** Stimulate demand after COVID-19 with flexible pricing (discounts, subscriptions); increase direct-to-consumer efforts		**Reimagine platform-based business models** Use momentum in e-mobility to strengthen alliances; expand infrastructure partnerships; test ecosystem monetization options
Operations		**Rebalance efficiency programs** Review and calibrate cost-down targets; enforce ongoing restructuring; selectively invest in process improvements		**Grow differentiating digital capabilities** Reconfirm capability requirements; increase focus on software; ensure sufficient build-up time; engage with partners
Technology		**Consolidate IT transitions** Review IT roadmap; accelerate programs with clear benefit case (cloud transitions); postpone long-term core transitions		**Build open technology platforms** Rethink tech architecture for connected services; invest in cloud-based vehicle architecture; join ADAS software platforms
Organization		**Continue digital enablement programs** Accelerate roll-out of digital workplace agenda; push data-driven mindset and decision making; deploy agile organization		**Strengthen system-based engineering and x-functional work** Introduce new development approaches (from aerospace; tech); invest in dedicated speed-boats; invest in partnerships

Source: Strategy&

strategy&
Part of the PwC network



Volume

3 Building a software-enabled automotive company

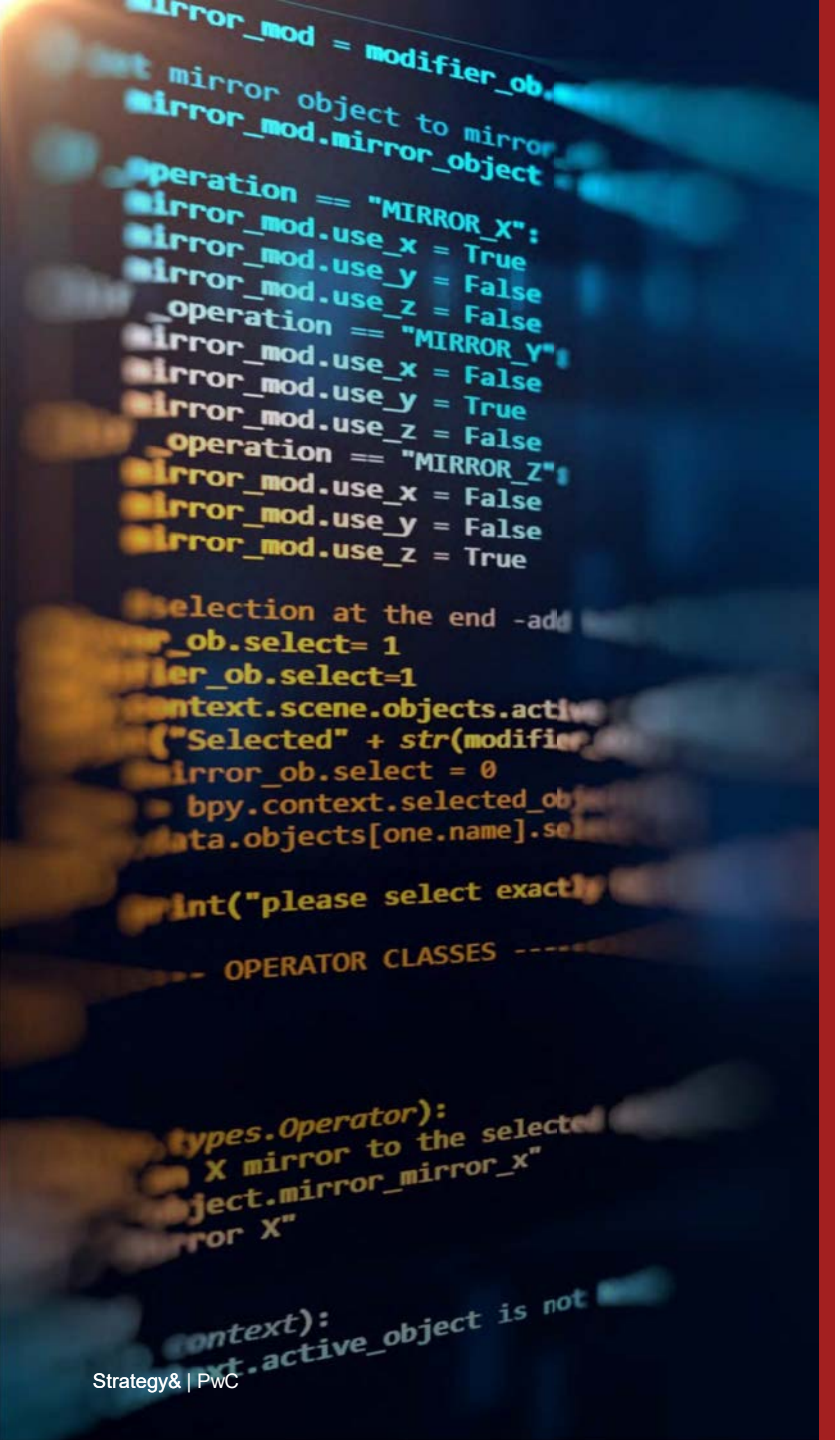
This volume focuses on the key capabilities to become a software-enabled company and how to build them up

Volume 2 – Recap

- Use cases based on **CASE technologies** are at different stages of maturity and vary in **expected market potential**
- Well-funded start-ups trying to capture the CASE market potential put **traditional automotive players under pressure**
- The COVID-19 pandemic has widened the investment gap between OEMs and VCs – Top 10 **OEM investments shrunk 66%**, whereas **VC investments grew 83%**
- To compete in the long run, OEMs need to **refocus their investment priorities** based on specific ways to play, and **strengthen their digital capabilities**

Volume 3 – Scope of this volume

- **Increased demand** for intelligent and connected functionalities **will significantly change** the Automotive **product** and related **services**
- Software has become the **differentiating factor** for modern vehicles. **Development cost will increase** and shift from hardware to software
- OEMs must carefully **select the areas** where and when they will enter the **software competition** themselves
- **Collaborative partnerships** with competitors, suppliers and technology players on an equal footing can help to **master complexity,** the **need for talent** and to **reduce expenditure**
- A **culture change** and **transformation throughout** the company and at all levels are required **to adapt to the new paradigm** and to build successful software-enabled products



Software has become the key differentiating factor for modern cars

Software in Automotive

60%
of vehicle value add

Software will contribute up to **60%** to the **perceived value** of a vehicle in 2030. **Alternative ownership** models could **increase this value** even more

300%
software increase

Connected Vehicles, **Automated Driving, Smart Mobility** and **Electrification** increase the amount of vehicle software by **more than 300%**

3 months
software update cycle

Continuous development and **security patches** will trigger a software update at least every **3 months** in 2030

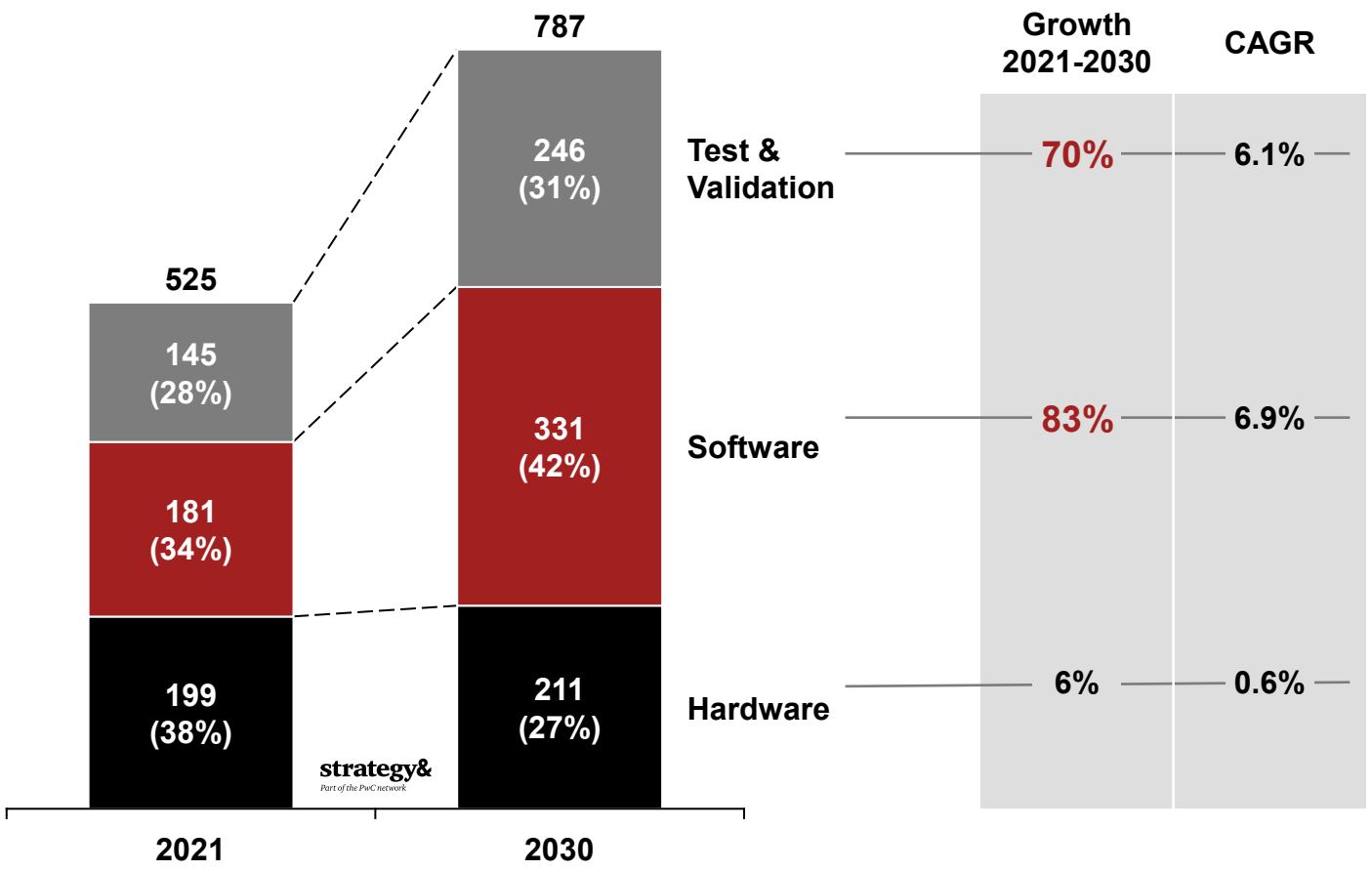
83%
growth in development costs

Software **development cost** per model series will **grow by 83%** within the next decade

Source: Strategy& analysis, Statista, IEEE, Morgan Stanley Research, Market Research Future, IHS

Driven by a change in user expectations and functionality, soft-ware development costs will grow by 83% within the next decade

E/E development cost per model series (€ million)[1]



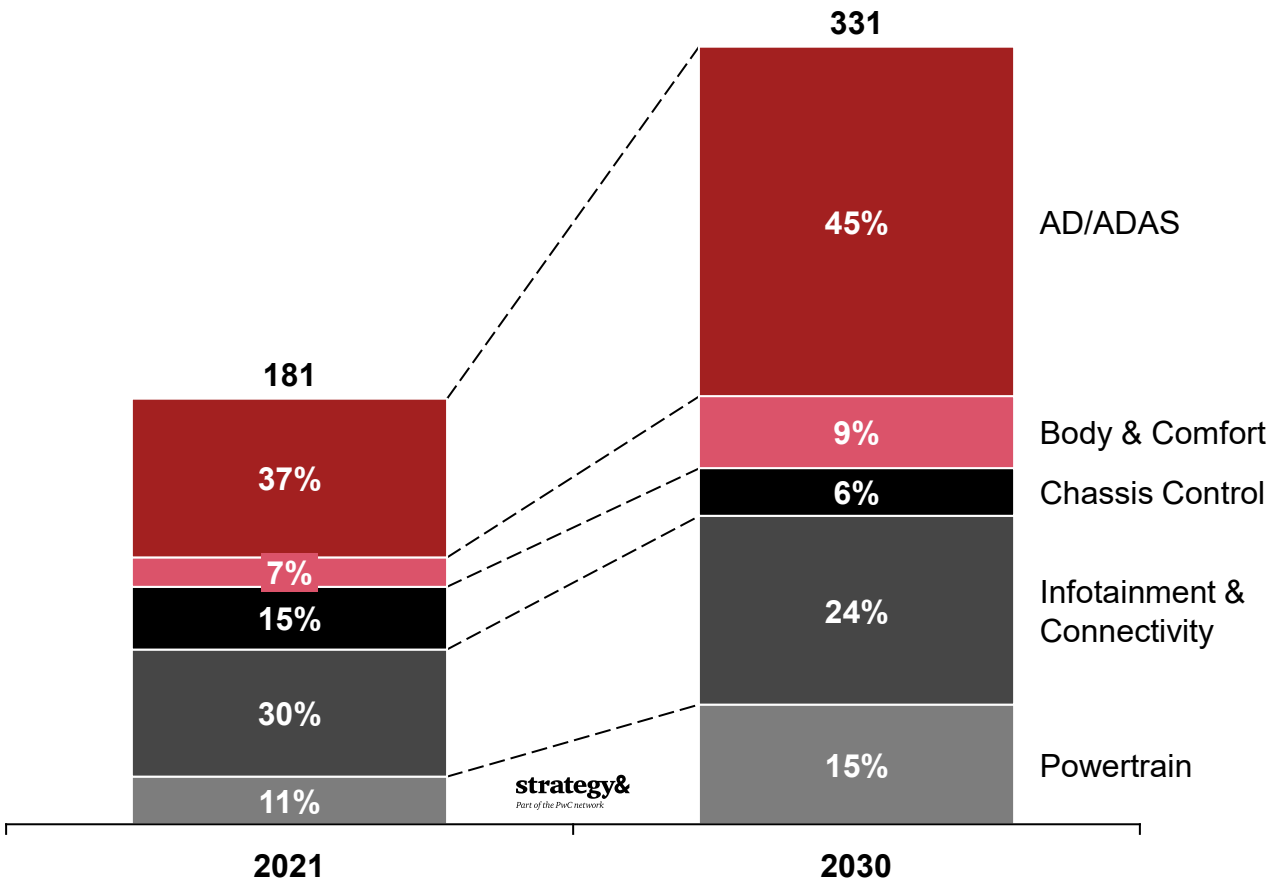
Main drivers for change:

- **Functionality:**
  - Gen Y customers as digital natives will become a substantial vehicle customer segment
  - A growing Chinese market will further increase requirements on digital experience
  - Intelligent and connected functionalities require a software refresh in shorter and shorter cycles
- **Technology and processes:**
  - E/E architecture change from distributed ECUs to centralized controllers will shift development costs from hardware to software
  - Functionality, shorter development cycles, interdependencies and integration efforts will increase software development and testing effort
- **Safety and compliance:**
  - Safety and regulatory requirements, esp. in AD/ADAS will drive up software development and validation cost
  - Requirements for revalidation after adaption to model specific environment drive workload

AD; Automated Driving ADAS: Advanced Driver Assistant Systems CAGR: Compound annual growth rate ECU: Electronic Control Unit 1: Development cost w/o lifecycle support
Source: Strategy& cost analysis based on investments in technologies and functionalities for premium vehicle. New domain controller architecture with shared software development across 7 models

ADAS functionalities as main driver for software cost will grow by 120%, accounting for 45% of the software cost by 2030

SW development cost per model series (€ million)[1]



Main drivers for change (*cf. Volume 1*):

- **AD/ADAS:**
  - Level 2 peak functionality, investments into level 3+ and legal safety requirements will drive up software development cost by 120%
- **Body & comfort:**
  - Smart health will increase development costs for body & comfort functions; relative share stays small compared to most other domains
- **Chassis control:**
  - Development costs decrease due to significant software reuse and decreasing consumer focus
- **Infotainment & connectivity:**
  - Increased consumer requirements are partly offset by software standardization and reuse, development costs will increase by 48%
- **Powertrain:**
  - Optimization of energy efficient driving will drive up development costs significantly

AD; Automated Driving ADAS: Advanced Driver Assistant Systems 1: Software development cost w/o lifecycle support
Source: Strategy& cost analysis based on investments in technologies and functionalities for premium vehicle. New domain controller architecture with shared software development across 7 models

High development cost across the entire technology stack will force OEMs and suppliers to carefully select areas for investment

Automotive digital technology stack

User experience / HMI
Compelling user experience, matching the brand

Functions / applications
Innovative functionality in ADAS, well-being, infotainment and controls

Cloud platform and cloud services
Enrich vehicle data and utilize cloud/edge computing resources

Backhaul connectivity and services
Secure V2X communication and continuous updates

Platforms and analytics
AI-based decision engines analyzing vehicle and environmental data

Vehicle operating system
Secure management of computing resources and SW services

Vehicle computing platform
Enabling current and future SW functionalities on powerful hardware

In-vehicle connectivity and services
Secure communication between domain platform computers

Electronics and power components
Controlled electronic and embedded software components

Security, reliability and compliance
Automotive-grade safety, reliability and compliance as key challenge

Most areas of the technology stack with **high investment need** driven by **technical complexity** and **required innovation**

Being **innovation leader** and **first to market** will **not** be possible **in all areas**. OEMs and suppliers need to **carefully select areas** for investment

Collaboration with **technology players** and **competitors** in **new forms of partnerships** will **scale economies** and **available talent**

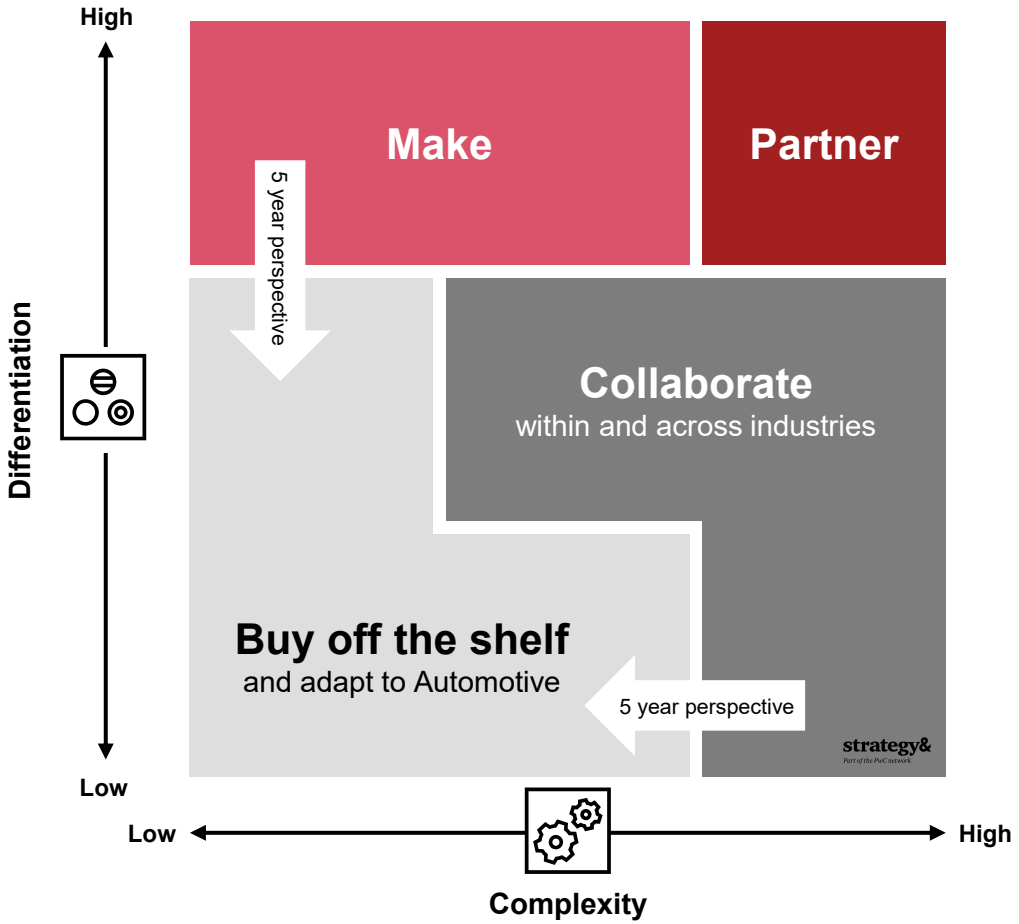
Transforming employees' **mindset** – in particular in **R&D, procurement**, **partner management** and **controlling –** will be key for **software innovation**

Source: Strategy&

ADAS: Advanced Driver Assistance Services HMI: Human-Machine-Interface

Strategic decisions where and when to invest need to focus on three factors: Differentiation, complexity and sustainability

Software sourcing strategy matrix

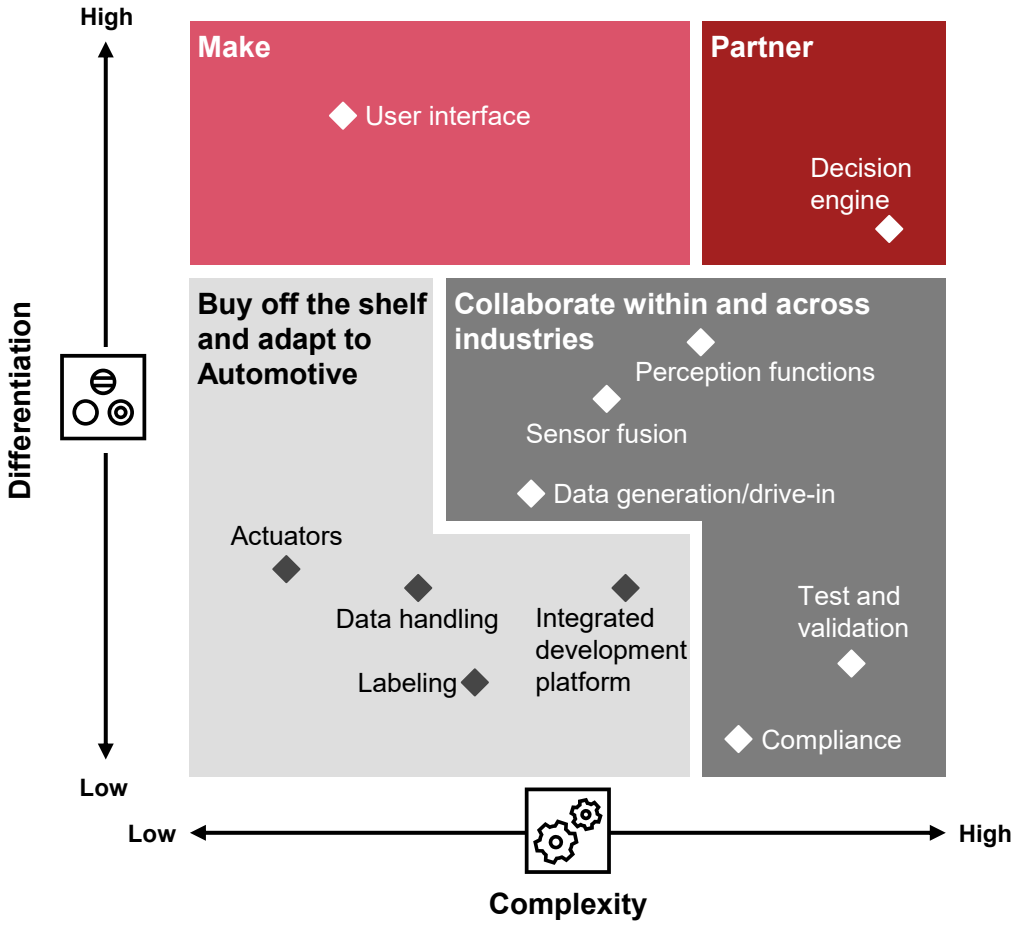


- **OEMs and suppliers** need to **decide where** and **when** they want to compete in the software game since **competing in the full stack** will **not be possible** financially or organizationally
- **Strategic decisions** need to **focus on three factors**:
  - **I.** Targeted **differentiation** matching the brand promise including:
    - Perceived customer value
    - Competitive advantage
    - Monetization potential
    - Product dependencies
  - **II.** Anticipated **complexity** of the product and the technology including:
    - Availability of products / alternatives
    - Maturity of technology and understanding
    - Availability of skilled and experienced resources
    - Forecast expenditure
  - **III. Sustainability** and **timing** of the differentiation including:
    - Today's differentiating assets might become a commodity in 5 years' time
    - Significant reduction of complexity and risk for 2nd mover
- **Collaboration** with **automotive** and **technology players** should be favored to bespoke "Make" in **areas with high complexity**

Source: Strategy&

An exemplary analysis of Automated Driving shows that most functions and components should be developed with partners

Exemplary classification of AD technology functions and components



Example rationale:

- **Make:**
  - **User interface**: Own intuitive user interface and user experience matching to the brand. OEMs should develop own bespoke solutions with limited effort
- **Partner:**
  - **Decision engine**: Level 4+ functionalities with significant complexity. OEMs and suppliers should combine competencies, share risks and achieve licensing revenues in a 2nd wave
- **Collaborate within and across industry:**
  - **Test and validation**: Complex technical challenge with limited market differentiation. Collaboration and sharing of test data and methods and joint tool development and open source will reduce time, cost and risks for all involved parties without sacrificing differentiation
- **Buy off the shelf and adapt to Automotive:**
  - **Integrated development platform**: Sophisticated platforms exist in other industries. Buy off the shelf and adapt to Automotive requirements, supported by specialized technology players

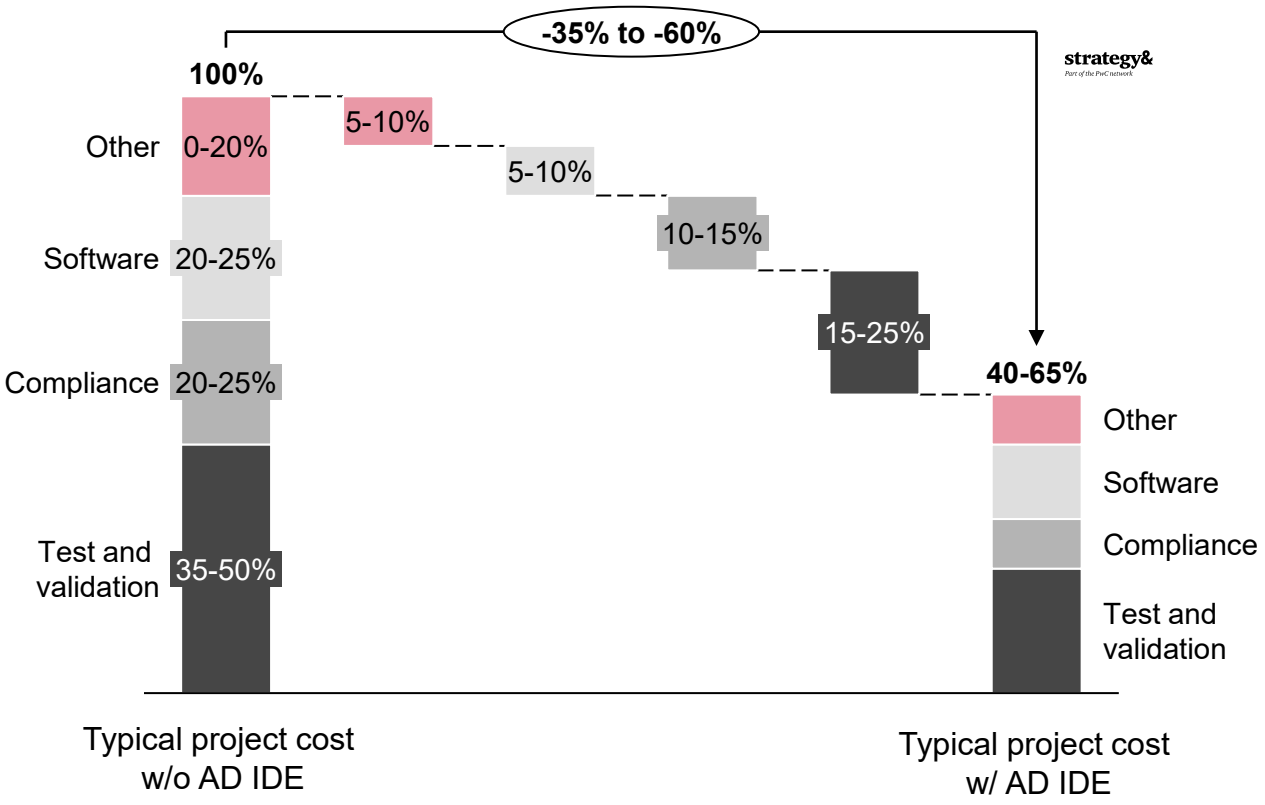
Source: Strategy&

AD: Automated Driving

An integrated development environment built upon cross industry standards will lower project cost by up to 60%

Integrated development environment for Automated Driving

Cost saving potential per project



Collaboration:

- Joint project by **OEM** and **technology player** as platform provider
- OEM provides **automotive expertise** and **use case definitions** for development, testing and compliance
- Tech player provides **first-class software development capabilities**, as well as **global cloud infrastructure**
- Combining **talent** and **knowledge base** resulted **in short realization time** at **high quality**

Key cost reduction levers:

- Fully **automated builds, continuous integration** and **continuous testing**
- Consistent **incident management** across the **toolchain**
- **Integrated test environment** with scaled **virtual testing** in the **cloud**
- **Automated test reports** for AI-based functionality, ISO26262 and SOTIF incl. archiving of software builds and test results
- Automated **project planning**, **tracking** and **reporting,** improved **processes** and **team communication**
- Full **transparency** on **status** between supplier and OEMs, facilitated reporting and problem management

AD: Automated Driving IDE: Integrated Development Environment
Source: Strategy& cost analysis for multiple AD projects with Camera and LiDAR functionality

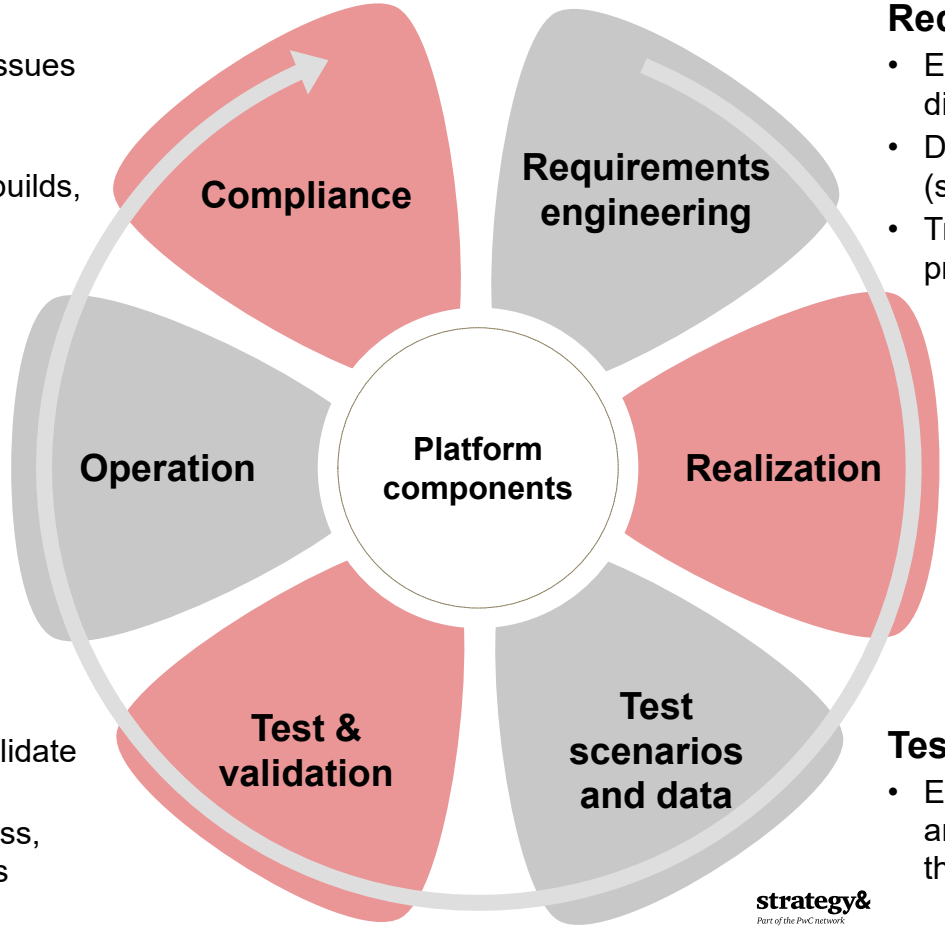
The integrated development environment spans requirements, realization, test & validation, operations and compliance

Integrated development environment for Automated Driving

Compliance
- Environment to document and assess product issues identify root causes and trigger issue resolution
- Compliance conformant documentation of requirements, architectures, designs, software builds, test execution results and data

Operation
- Environment to control, manage, maintain and operate products and related platforms, e.g. conducting (over-the-air) software updates, assessing (live) product usage and performance, operating test platforms and vehicle fleets

Test & validation incl. security
- Environment to design, specify, program and validate tests, document results and assess progress
- X-in-the-loop platforms to execute model, process, software, hardware/mechanics and system tests (incl. smoke, flash and end-of-line tests)



Requirements engineering
- Environment to specify, collaborate, align and discuss product and product validation requirements
- Decomposition of requirements to disciplines (system, HW/mechanics, SW, test & validation)
- Traceability and transparent view on maturity progress across disciplines

Realization
- Environment supporting architecture design, code generation, manual coding, versioning, refactoring, debugging, code analysis and test
- Automated verification of designs and code (documentation, unit and module tests) against company and project standards

Test scenarios and data
- Environment to generate, capture, store, analyze and correct test scenarios, data and configurations that are required for product test and validation

Source: Strategy&

In order to successfully develop and collaborate with partners OEMs will have to undergo a cultural and mindset change

Required mindset change in collaboration

strategy&
Part of the PwC network

	Traditional behavior	New behavior
Strategy	**Everything needs to be done by us, now** dispersing talent across many areas	**Decide on few differentiating areas** for own innovation that match your brand promise
Ambition	**Achieve minimum requirements at best cost** often selecting best cost, not best partner	**Aim for the best partner** being first to market, achieving cost reduction in a 2nd step through scale
Objective	**Detailed and early specification of requirements** often limiting the solution space and innovation	**Clearly define objectives, not the solution** allowing for new and creative approaches
Timeline	**Meticulously planned development schedules** often demanding unrealistic and waterfall developments	**Provide rough timeline of functionalities** utilizing the strength of agile development
Finance	**High financial pressure on supplier** often squeezing out any risk buffers	**Engage in real partnership and share benefits** incentivizing innovation after project award and even after SOP
Collaboration	**Principal-agent-based working model** often lacking communication and team spirit	**Establish one joint team** enabling collaboration of best talent and scale across companies
Decisions	**Management decision in silos** often late decisions with reduced information and accountability	**Give responsibility to the team** enabling decisions that span business, technology and operations

Source: Strategy&

As a consequence OEMs and suppliers need to transform throughout the firm to build up software excellence

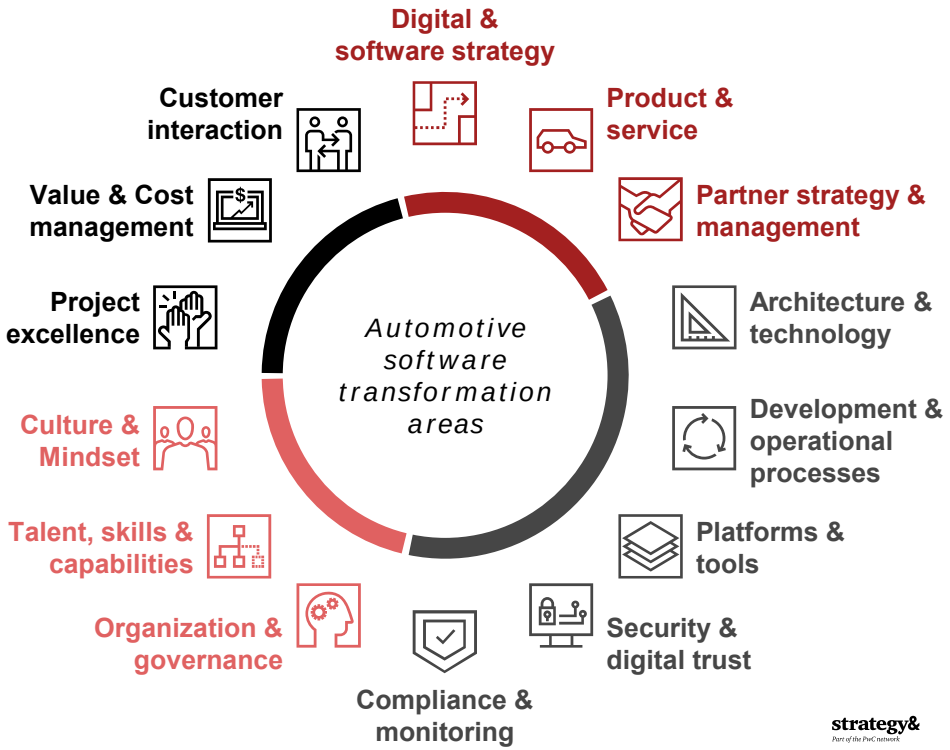
Automotive software transformation areas

Customer, Value & Cost

- Leverage *"**direct end-customer interaction**"* and information about the use of the product
- Drive new sources of revenues by *"**scaling software**"* across models and brands and by using dynamic pricing schemes
- Adapt cost prediction, financial management and project excellence to the *"**new** development, operations and monetization **paradigm**"*

People & Culture

- Establish agile *"**fail fast**"* culture, break hierarchies and *"**enable team decisions**"*
- Strengthen *"**culture of collaboration**"* and open knowledge sharing internally and with partners
- Establish *"**flexible org structures**"* and empowered "cross-functional teams" with business and technology responsibility
- Embed *"**digital at all levels**"* and invest in talent, don't do the transformation half-heartedly



Strategy & Product

- Decide on level of digitization and timeline and own *"**digital brand differentiation**"*
- Invest in *"**a few own differentiators**"*, leverage collaborations for non-differentiating components
- Change from design-build-ship to *"**continuously evolving** **product**"*
- *"**Increase cooperation**"* with competitors, suppliers and technology players on an equal footing

Technology & Processes

- Disruptively *"**rethink the product car**"* and modularize the E/E platform and architecture
- Change from top-down specification to *"**step-wise agile**"* product ideation
- Transform R&D processes to *"**continuous and scaled development**"*
- Establish *"**integrated toolchains**"* to develop and operate cost-efficient, safe, secure, compliant and trusted products and services

Source: Strategy&

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